A RAND NOTE

Spectrum Management and Electromagnetic Compatibility Issues in the Department of Defense

G. E. Parnell, C. M. Crain, A. L. Hiebert

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Prepared for the
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PREFACE

This Note is a survey of the history and current status of some of the more significant spectrum management and electromagnetic compatibility (EMC) issues facing the Department of Defense. The field is one of rapid change and growing attention, and this Note reflects the state of affairs as of March 1991.

Increased reliance on technology as a force multiplier necessitates greater understanding of the concerns intrinsic to using that technology. These concerns are both technical and administrative in the case of EMC. Intended for a broad audience, this Note addresses both areas but requires little or no previous knowledge of either. It may be useful to those involved in any manner with military electronics in Government and private industry and to those having interests in spectrum usage.

Much of the content regarding current matters is derived from papers presented and issues discussed at a special panel on electromagnetic compatibility considerations at the 1990 Military Communications (MILCOM '90) Conference. The conference was sponsored jointly by the Department of Defense, the Institute of Electrical and Electronics Engineers, Inc. (IEEE), the IEEE Communications Society, and the Armed Forces Communications and Electronics Association (AFCEA), and it was held in Monterey, California, September 30–October 1, 1990.

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SUMMARY

As devices of an electronic and electromagnetic nature grow in complexity, so too do the intricacies surrounding their use. If they are to operate predictably and reliably, they must be able "to operate in their intended operational environments without suffering or causing unacceptable degradation because of electromagnetic radiation or response."[1] That ability is known as electromagnetic compatibility (EMC), and its already profound importance will inevitably grow as we rely more and more upon technology. For civil systems, inadequate EMC results in inefficient spectral utilization and economic loss. For military systems, the consequences can be disastrous. Hence, assurance of EMC of military systems is imperative. In this Note, we survey both technical and administrative issues of EMC and use of the electromagnetic spectrum, especially as pertaining to the Department of Defense (DoD), from the past through the present.

EMC and the related issue of spectrum usage have recently been pushed to the forefront of attention. A number of factors have synergistically contributed to this. The electromagnetic spectrum is already crowded, and the past ability to accommodate new uses with virgin spectrum exists no more. Meanwhile, we are living in an era of unprecedented and growing technological advancement that will place even greater demands on this resource. The International Telecommunications Union (ITU) reports that the number of applications for spectrum in the past decade have exceeded that for the previous eight decades, while the number of applications for spectrum use was greater in 1989 than in the previous ten years combined. A key to handling this demand will be to provide for EMC of devices. The increasing identification of national strength with economic well-being has engendered the move within Congress to "liberate" spectrum from use by the U.S. Government for use by emerging technologies expected to provide a national economic advantage. This is happening at a time when the military services, traditionally reliant upon their technology and use of the spectrum as a force multiplier (e.g., electronic warfare), are being reduced by an austere budget. In addition to these factors, the military services have recently had experiences with the consequences of EMC problems that have received a fair amount of media and Congressional attention.

EMC may be addressed in two realms: intrasystem EMC and intersystem EMC. Intrasystem EMC is concerned with the compatibility of a system consisting of electrically

[1]From the definition of electromagnetic compatibility found in the *Department of Defense Dictionary of Military and Associated Terms*. See Bibliography.

interconnected equipments and/or equipments in proximity within a describable geometry. Examples are a single aircraft or a spacecraft. Intersystem EMC is concerned with the interactions among distinct systems and their electromagnetic environment. The process of assuring EMC by applying sound engineering principles to the resource that is the electromagnetic spectrum is known as spectrum engineering, the technical component of spectrum management.

Because EMC considerations extend beyond political borders and among all users of the spectrum, channels of cooperation and administration have historically been established. The spectrum is a shared resource that is nondepletable but limited at any given time. Whatever time it is not used is lost forever. Hence, its use must be carefully managed. Herein lie many of the administrative concerns of EMC.

Internationally, EMC considerations sprang into being with the telegraph and then later with the "wireless." The international body governing these matters today is the International Telecommunications Union (ITU), housing the International Radio Consultative Committee (CCIR), the International Telegraph and Telephone Consultative Committee (CCITT), and the International Frequency Registration Board (IFRB), as well as a General Secretariat. The ITU is a specialized agency of the United Nations, and member nations negotiate and adhere to its decisions.

Within the United States, a unique structure for governing spectrum use exists. The National Telecommunications Information Administration (NTIA) within the Executive branch governs spectrum matters for all U.S. Government agencies. It is assisted by the Interdepartment Radio Advisory Committee, a body consisting of representatives from 21 Government agencies. All non-Government use of the spectrum is administered by the Federal Communications Commission (FCC), an independent regulatory agency. The FCC and the NTIA generally act independently, but they maintain formal channels for cooperation. For international projection of official U.S. positions, the two agencies confer, and dissemination is conducted through the Department of State.

Within the Department of Defense, provisions for the EMC Program are provided in the new DoD Directive 3222.3, effective August 20, 1990. Areas covered by the program include database and analysis capability; standards and specifications; measurement techniques and instrumentation; education for EMC; design, doctrine, tactics, techniques, and procedures; operational problems; and test and validation. Generally, the military services are jointly responsible for these program areas with the Air Force acting as the management agency for the Electromagnetic Compatibility Analysis Center (ECAC) in Annapolis, Maryland, which maintains the DoD EMC database and analysis capabilities.

For a Departm .nt of Defense system to be acquired and operated, it must receive spectrum support. That process begins with the request and approval of spectrum to be allocated for the desired purpose(s). This is done through a process known as the *J-12 process*, and approval is gained through the Military Communications Electronics Board (MCEB) and the NTIA. The system must then be certified to be in compliance with the allocation, and finally, a frequency is assigned. The process can be arduous and long, especially with some technologies pushing back frontiers, such as the Joint Tactical Information Distribution System.

A number of EMC-related activities are currently being pursued within the DoD, many of which capitalize on the emergence of new computer capabilities. Among those is the Technology Transfer Program (TTP) of the ECAC, designed to provide periodic releases of the ECAC's analysis capabilities adapted for personal computer and minicomputer use in field applications. Recent experiences with some of these have been most encouraging. Also, there are the plans for the next generation of the Frequency Record Resource System of DoD frequency assignments to be a distributed information system. In addition, there are ongoing contingency support efforts provided by such agencies as the ECAC and the Joint Electronic Warfare Center (JEWC) in San Antonio, Texas.

Recognizing the cross-service nature of many operations, the DoD recently chartered the Joint Electromagnetic Interference Joint Test and Evaluation (JEMI-JT&E), headquartered at Eglin Air Force Base, Florida, for a period of three years; its task is to examine EMC matters of joint operations. A spin-off of that effort has been work toward a Joint Spectrum Management System (JSMS) as a computerized umbrella system to coordinate among existing and planned methods for providing for EMC in operations.

A potential problem for the DoD is the fragmentation of efforts. Although the EMC and electronic warfare communities represent different facets of the same problem, for example, they are unnecessarily segregated.

Beyond the DoD, there are a number of activities regarding spectrum use and EMC having direct bearing on the DoD. Recently, the NTIA undertook a study to be used in developing policy for use of the spectrum into the next century, which has just been issued as of this writing. Also, on the national level, legislation is pending before Congress to transfer on the order of 200 MHz of spectrum from use by the U.S. Government to private hands to accommodate emerging technologies. It is likely that success of this legislation would encourage further such efforts. On the international level, the ITU will be convening a World Administrative Radio Conference in 1992 for the purpose of forging international agreements concerning use of specified portions of the spectrum, some of which are vital to DoD interests.

Generally, the field of EMC is one of much present activity and is of critical concern to the DoD. It is fated to gain greater attention as demand for spectrum grows, with competition likely to be fierce. Users and uses will be scrutinized as never before. Present users of the spectrum will increasingly be challenged to actively defend their share by prospective users representing new technologies, uses, and interests. An effective defense will require nothing less than ongoing, comprehensive understanding of a highly charged, complex, and dynamic technical and political environment. The DoD, as a major user of spectrum, faces a serious challenge for the future.

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ACRONYMS

ADP	Automated Data Processor
AFC	Area Frequency Coordinators
AFCC	U.S. Air Force Frequency Management Center
AFCEA	Armed Forces Communications and Electronics Association
AFES	Army Frequency Engineering Software
AFEWC	Air Force Electronic Warfare Center
AGAFES	Air-Ground-Air Frequency System
AIEEE	American Institute of Electrical and Electronics Engineers
ATC	Air Traffic Control
ATCRBS	Air Traffic Control Radar Beacon Systems
ATFES	Army Tactical Frequency Engineering System
BER	Bit Error Rate
C^2	Command and Control
C^3I	Command, Control, Communications, and Intelligence
CCIR	International Radio Consultative Committee
CCITT	International Telegraph and Telephone Consultative Committee
CEAC	Committee for European Airspace Coordination
CECOM	Communications-Electronics Command (Army)
CENTCOM	Central Command
CEPT	Committee, European Post and Telecommunications
CFRS	CENTCOM Frequency Resource System
CINC	Commander in Chief
CINCEUR	Commander in Chief, Europe
CINCLANT	Commander in Chief, Atlantic
CINCPAC	Commander in Chief, Pacific
CNI	Communications, Navigation, Information
CNO	Chief of Naval Operations
COE	Concept of Employment
COM NAV	Communications and Aeronautical Navigation Aids (Working Group on)
CONUS	Continental US
CSPM	Continuous Phase Shift Modulation
CTEIP	Central Test and Evaluation Investment Program

DCA	Defense Communications Agency
DDN	Defense Data Network
DDR&E(T&E)	Defense Research and Engineering (Test and Evaluation)
DEC	Digital Equipment Corporation
DME	Distance Measuring Equipment
DME/N	Distance Measuring Equipment/Normal
DME/P	Distance Measuring Equipment/Precision
DoD	Department of Defense
DOE	Department of Energy
DVAL	Datalink Vulnerability Analysis
ECAC	Electromagnetic Compatibility Analysis Center
ECM	Electronic Countermeasures
EIA	Electronics Industries Association
EMC	Electromagnetic Compatibility
EMCAS	EMC Analysis System
EMCP	Electromagnetic Compatibility Program
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EPG	Electronics Proving Grounds
EW	Electronic Warfare
EWVA	Electronic Warfare Vulnerability Analysis
FAA	Federal Aviation Administration
FACTS	Frequency Assignment Computer Terminal System
FAS	Frequency Assignment Subcommittee
FAS-HF	Frequency Assignment System—High Frequency
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FMAC	Frequency Management Advisory Council
FP	Frequency Panel
FRRS	Frequency Resource System
FY	Fiscal Year
GSA	General Services Administration
HF	High Frequency (3MHz-30MHz)
HHS	Health and Human Services
ICNI	Integrated Communications, Navigation, and Identification

IEEE	Institute of Electrical and Electronics Engineers, Inc.
IEMCAP	Intrasystem Electromagnetic Compatibility Analysis Program
IFF	Identification—Friend or Foe
IFRB	International Frequency Registration Board
IRAC	Interdepartment Radio Advisory Committee
IRE	Institute of Radio Engineers
ISYSCON	Integrated Systems Control
ITACS	Integrated Tactical Air Control System
ITNS	Integrated Air Navigation System
ITU	International Telecommunications Union
JCS	Joint Chiefs of Staff
JEMI	Joint Electromagnetic Interference
JEWC	Joint Electronic Warfare Center
JRFL	Joint Restricted Frequency List
JSMS	Joint Spectrum Management System
JT&E	Joint Test and Evaluation
JTAC	Joint Technical Advisory Council
JTF	Joint Test Force
JTIDS	Joint Tactical Information Distribution System
LEO	Low earth-orbit
LOS	Line-of-sight
LV	Low Volume
MCEB	Military Communications Electronics Board
MIDS	Multifunctional Information Distribution System
MIJI	Meaconing, Intrusion, Jamming, and Interference
MILCOM	Military Communications (Conference)
MOE	Measure of Effectiveness
NASA	National Aeronautics and Space Administration
NSA	National Security Agency
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
OTM	Office of Telecommunications Management
OTP	Office Telecommunications Policy

PACAF	Pacific Air Forces
PLRACTA	Position, Location, Reporting, and Control of Tactical Aircraft
PMP	Program Management Plan
PMTC	Pacific Missile Test Center
RF	Radio Frequency
RFCP	Radio Frequency Compatibility Program
RFI	Radio Frequency Interference
RMA	Radio Manufacturers Association
RVAN	Radio Vulnerability Assessment
SAE	Society of Automotive Engineers
SAF/AQ	Secretary of the Air Force/Acquisition
SAIS	Secretary of the Army for Information Systems
SEMCAP	Specification and Electromagnetic Compatibility Analysis Program
SFAF	Standard Frequency Action Format
SHAPE	Supreme Headquarters, Allied Powers Europe
SPEED	Spectrum Planning, Engineering, and Evaluation Device
SPS WG-1	Spectrum Planning Subcommittee Working Group 1
SSR	Secondary Surveillance Radar
STC	SHAPE Technical Centre
TACAN	Tactical Air Navigation
TCAS	Traffic Alert and Collision Avoidance System
TEC	Test and Evaluation Committee
TFRMS	Tactical Frequency Record Management System
TTP	Technology Transfer Program
USA	U.S. Army
USAF	United States Air Force
USAFTAWC	USAF Tactical Air Warfare Center
USCG	U.S. Coast Guard
USCINC	U.S. Commander in Chief
USMC	U.S. Marine Corps
USPS	U.S. Postal Service
UV	Ultraviolet
VA	Veterans Administration
WARC	World Administrative Radio Conference

I. INTRODUCTION

The ability of equipments of the U.S. military to function reliably and predictably is essential; electronics and electromagnetic systems are no exception. They are, however, exceptional in that, unlike most military hardware elements, they cannot be tested and assessed independently. They must work in a complex electromagnetic environment created in part by difficult-to-predict sources, including themselves, other friendly military systems, enemy systems, and nonmilitary spectrum users. This fact of nature renders independent testing and evaluation inadequate. Beyond the independent, single-system approach lies the approach of evaluating systems within an interdependent framework of multiple systems, using modelling and testing as the keys. Even with the best databases that can be developed and the application of scenarios deemed most likely, these two components of evaluation of systems are no more than complementary, with neither alone completely satisfactory for answering the fundamental question for each of our electromagnetic systems and subsystems: "Will it work when and where we need it?" A growing recognition of the gravity of this question is the motivation for this Note, wherein we will examine the inextricably intertwined issues of spectrum use and electromagnetic *compatibility* (EMC)[1] for answers.

We shall provide a perspective on the state of these issues while giving an overview of several timely topics, many of which were presented during a special panel on EMC issues at the recent Military Communications Conference (MILCOM '90), sponsored jointly by the Department of Defense (DoD), the Institute of Electrical and Electronics Engineers, Inc. (IEEE), the IEEE Communications Society, and the Armed Forces Communications and Electronics Association (AFCEA). Among these are developments of methodologies and plans for assessing electronic warfare vulnerability and for testing of systems in a joint environment. Also, we shall examine a case history of the hurdles to be jumped along the path to ensuring EMC for a complex communications-electronics system. In addition, this Note will discuss MIJI (meaconing, intrusion, jamming, and interference) reports, their uses, and deconfliction, as well as a case study of the laborious route toward fielding of systems. Finally, from a broader view, we shall examine the role of the DoD as a sharer of the resource for electromagnetic devices, the spectrum, along with other Government[2] agencies,

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[1]Detailed definitions of terms and usages specific to this field are given following the introduction and throughout the Note as they arise.

[2]The capitalized term *Government* is used throughout to indicate only the federal government of the United States. In cases where ambiguity might arise, those levels of government involved will be explicitly stated.

the private sector, and the international sector as it prepares its positions for the World Administrative Radio Conference (WARC '92) on international agreements for radio spectrum allocation.

II. CAUSES FOR IMMEDIATE CONCERN

For electronic and electromagnetic systems to operate predictably and reliably, they must operate as intended within and as a contributor to an unpredictable electromagnetic environment—an environment that can be hostile, depending upon the contributions, intentional as well as unintentional, from other systems, friendly as well as unfriendly. Our growing military reliance on electromagnetic devices, whether they be those things traditionally brought to mind as transmitters or receivers (e.g., radios and radars) or those finding new utility in military applications (e.g., computers and microchips), demands close attention to their interactions with their environment. Whereas the DoD has long recognized this need, never has it had greater immediacy than at the present, and the difficulties can only worsen. A convergence of several circumstances has brought us to this juncture; we discuss them below.

HEIGHTENED AWARENESS OF ELECTROMAGNETIC EFFECTS ON MILITARY OPERATIONS

Recent experiences of compromised effectiveness of systems that might be attributable to avoidable electromagnetic interference (EMI) from friendly systems have thrust this topic into the limelight. Some of these have received substantial and potentially embarrassing public notice and, notably, congressional interest. An example of the type and possible magnitude of such problems is the loss of HMS Sheffield in the British-Argentine conflict in the Falkland Islands, anecdotally attributed to electromagnetic compatibility problems. In that incident, many lives were lost—perhaps avoidably.

In 1989, in response to concerns raised about the topic of electromagnetic interference in general and its role in the Libyan air raid of April 1986 in particular, the House Armed Services Committee conducted an inquiry into the general mechanisms used by the armed forces for avoiding potential electromagnetic interference between systems (i.e., assuring their mutual EMC). A result of this and other attentions has been a heightened awareness of the critical nature and unexpectedly broad scope of the topic. Historically, concern for EMC between systems has been largely confined to those systems installed on a single platform. Occasionally, integrators of these systems "investigated interplatform EMC with peripheral systems on other platforms for limited operational scenarios. But until recently, interplatform EMC responsibility was limited to intraservice consideration" (Hooton, 1990). Clearly, this approach does not ensure success for joint operations. On a grander scale, however, even interservice considerations are insufficient to ensure the success of joint operations such as Operation Desert Shield/Storm, for they do not necessarily factor in the questions of compatibility with allies, other Government agencies, and commercial enterprises, or operability within a specific country or countries, or—of special importance—susceptibility to performance degradation due to friendly electronic warfare.

ACCELERATED RATE OF EMERGING TECHNOLOGIES

In the post–World War II era, the West has relied on a technical edge as a force multiplier to gain military superiority over the numerically greater Eastern Bloc forces. Much research and development have been expended to ensure that this edge was maintained. Innovative technology as the prescription for existing problems, however, does not always come without side effects, many often unforeseeable and most usually undesirable. Serendipitous spin-off applications of seemingly unrelated research are no different. A caveat common to all electromagnetic devices is that they are intrinsically potentially susceptible to the vagaries of their electromagnetic environment. Thus this explosion of technologies affecting command, communications, control, and intelligence (C^3I) has thrust upon us an unprecedented need for vigilance against problems yet to be determined.

INCREASING COMPETITION FOR THE ELECTROMAGNETIC RESOURCE: THE SPECTRUM

Closely related to the emerging technology issue is the demand for spectrum. New technologies have invited new uses for the spectrum, and although it is an undepletable natural resource, it is nonetheless limited by practical considerations. Historically, competition for spectrum was avoided simply because there was virgin spectrum for new products. That fortunate circumstance no longer exists. Commercial uses for spectrum are growing daily, as are questions about the validity of the Government's need for its share of the spectrum. In fact, legislation is presently pending in Congress that proposes to reallocate some of the most valuable spectrum from Government to non-Government use. The potential benefits of using scarce spectrum as a form of capital investment in emerging technology that could position the United States favorably in international competition and of designating that spectrum's use as a generator of revenue may prove to be undeniably attractive incentives to lawmakers. This pending legislation marks the first attempt by Congress to involve itself in the specifics of radio spectrum allocation, but it is unlikely to be the last. Enactment of such legislation would be make the military's current electromagnetic compatibility difficulties even harder to solve. Clearly, the Government and the DoD will be compelled to make strong cases for their utilization of the spectrum.

GROWING PROMINENCE OF ELECTRONIC WARFARE

Any system that relies on electromagnetic components, given the appropriate stressful electromagnetic environment, can suffer degradation of performance, regardless of the source of that stressful component of the electromagnetic environment. Hence, friendly electronic warfare (EW) systems, just as other nonfriendly EW systems, can cause unintended electromagnetic interference. The present compartmentalization of electronic warfare and EMC is a convenient taxonomy founded on intended uses, but nonetheless it is an artificial one in the laws of physics. The growing prominence of electronic warfare techniques for denying enemy advantage must be accompanied by the requisites of EMC with friendly systems.

AN AUSTERE BUDGET

An austere budget invites exploration for sources of income and scrutiny of expenditures. Consequently, the issues of spectrum management and electromagnetic compatibility attain new importance. The spectrum is a resource for commercial growth and concommitant revenue. Its careful cultivation (management) is vital. An austere budget also demands increased value for the dollar. Hence, electromagnetic compatibility of acquired systems among themselves and the systems of allies, with (friendly) EW systems, in likely scenarios, etc., acquires new prominence.

FORCE RESTRUCTURING

In addition to budgetary constraints, the changing and complex world political climate is forcing examination and restructuring of the military services. Long-standing notions are subject to revision. The instruments of command, control, communications, and intelligence are likely to grow in importance. At the forefront of those is the military use of spectrum, and the infrastructure for managing that use is the subject of discussions for improvement.

Not all of the above issues are new, but their urgency is. And there is every reason to believe that the urgency will only escalate—possibly, even in spite of our best efforts, and inevitably without them.

III. BACKGROUND DEFINITIONS AND CONVENTIONS

The field of EMC is broadly based. A natural consequence of this is a richness of terminology; definitions abound. Often, different terms convey almost the same meanings but with different emphasis. On the other hand, the same term may have different meanings in different contexts. Although we wish to avoid dwelling on semantics, below we offer definitions for some critical terms along with insights into the ramifications of these definitions. Unless otherwise stated, the definitions used throughout this article are from the *Department of Defense Dictionary of Military and Associated Terms.*[1]

Electromagnetic compatibility is defined as "the ability of telecommunications equipment, subsystems, and systems to operate in their intended operational environments without suffering or causing unacceptable degradation because of electromagnetic radiation or response." Telecommunication is said to be "any transmission, emission or reception of signs, signals, writings, images, sounds, or information of any nature by wire, radio, visual, or other electromagnetic systems." Assimilating these two definitions concurrently invites a number of significant questions, reflecting the breadth of the issues. Some examples are: What constitutes unacceptable degradation? What exactly is the intended operational environment, and how flexibly and inclusively is it defined? What is the role of electronic warfare (EW) systems, both friendly and unfriendly, in EMC?

Electromagnetic interference[2] could be roughly termed the state that exists in the absence of EMC. More exactly, electromagnetic interference is "any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics/electrical equipment. It can be induced intentionally, as in some forms of electronic warfare, or unintentionally, as a result of spurious emissions and responses, intermodulation products, and the like." Interestingly, the reference to electronic warfare contained in this definition would seem to imply that all interference caused as a consequence of electronic warfare is intentional, but that is not necessarily the case.

Electromagnetic environment is the "resulting product of the power and time distribution, in various frequency ranges, of the radiated or conducted electromagnetic emission levels that may be encountered by a military force, system, or platform when performing its assigned mission in its intended operational environment." The definition

[1]See Bibliography.
[2]A term used as frequently is Radio Frequency Interference (RFI).

continues by listing specific contributors to the electromagnetic environm nt, but the list is no means exhaustive.

The *electromagnetic spectrum* is defined as the "range of frequencies of electromagnetic radiation from zero to infinity."

Reflection upon these definitions will reveal a discipline that is at once an extremely broad technical field and a labyrinthine administrative arena. The expansiveness of EMC issues necessarily limits our discussion. This Note will for the most part limit discussions of technical issues to radio frequency (RF) interference modes, with no more than passing mention of other electromagnetic radiation such as electromagnetic pulse (EMP), lightning, static charging, laser optic communications, and ultraviolet rays (UV).

IV. HISTORIC PERSPECTIVE OF SPECTRUM MANAGEMENT AND ENGINEERING AND OF ELECTROMAGNETIC COMPATIBILITY

Among the reasons listed as causes for our immediate concern in the areas of spectrum management and EMC, one of the strongest forces in the evolution of institutions and methods to address these issues has been the rapid emergence of technologies. Literally, invention has often been the mother of necessity, with each advance necessitating new institutions to administer use and methods for assessing that use. In this section, we provide a brief, by no means exhaustive, overview of the development of those institutions and elaborate on their present structures having special pertinence to DoD concerns. Additionally, we will trace the growth of spectrum engineering[1] as a discipline.

INTERNATIONAL DEVELOPMENTS

The history of these institutions begins with the telegraph. As it grew beyond national borders as a means of communication, it became apparent that an international organ for developing and negotiating standards and procedures was required. In 1865, the International Telegraph Union was founded in Paris by the members of the first International Telegraph Convention.

On the heels of the telegraph requiring wires and cables came the "wireless telegraph," the radiotelegraph. As the only means for maritime communication, its use was of paramount importance to maritime states. Consequently, the first International Radiotelegraph Convention was signed in Berlin in 1906, with 26 maritime states in attendance. Twenty-one years later, in Washington, D.C., the International Radiotelegraph Conference implemented the Table of Frequency Allocations, a milestone in the growth of radio.

In 1932, the communities of these complementary forms of telecommunications combined with the meeting of their respective plenipotentiary conferences in Madrid. Their conventions were merged, and the International Telegraph Union became the International Telecommunications Union (ITU). By 1947, the ITU had become a specialized agency of the UN, with headquarters in Geneva.

Within the ITU are a number of permanent organizations and various conferences. The permanent organizations are the International Frequency Registration Board (IFRB), the International Radio Consultative Committee (CCIR), the International Telegraph and

[1] Loosely, the technical component of spectrum management.

Telephone Consultative Committee (CCITT), and the General Secretariat. Among the conferences are the Plenipotentiary Conference, the supreme organ of the ITU, and various administrative conferences. The Plenipotentiary Conference meets at intervals of five to six years. Elected from the Plenipotentiary Conference are the 41 members of the Administrative Council, who, among other administrative duties, arrange for the convening of conferences to address arising matters. An example of such conferences is the World Administrative Radio Conference, to be convened in Spain in 1992 to address issues of reallocations of spectrum in some bands having direct impact on the DoD. As explained in greater detail below, the United States participates in and abides by the decisions of the ITU.

U.S. NATIONAL DEVELOPMENTS

Concurrent with the international developments, the federal government of the United States began instituting its own structures for management of electrically transmitted communications. In 1922, the Interdepartment Radio Advisory Committee (IRAC) was formed by various Government agencies to coordinate their telecommunications activities. Twelve years later, the Communications Act of 1934 was enacted to provide for the regulation of telecommunications in foreign and interstate commerce. The structure to evolve out of this act is unusual in the community of nations; the United States has one agency regulating non-Government communications and another agency regulating communications of all Government agencies. Those supervisory agencies are, respectively, the Federal Communications Commission (FCC), an independent regulatory agency, and the National Telecommunications and Information Administration (NTIA), housed in the executive branch of the Government.

The IRAC, still in existence,[2] assists the Administrator of the NTIA in an advisory capacity.[3] The IRAC, however, is "a group of users. As such, it has been severely limited in its capacities as a policy-forming body. The practices and priorities it has generated have always been restricted to those by which a group of users with equal rights could get along" (President's Communications Policy Board, 1951). Consequently, an additional advisory body, the Frequency Management Advisory Council (FMAC), was established in 1965 to

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[2]Membership consists of representatives appointed by each of the following member departments and agencies: Agriculture, Air Force (USAF), Army (USA), Coast Guard (USCG), Commerce, Energy (DOE), Federal Aviation Administration (FAA), Federal Emergency Management Agency (FEMA), General Services Administration (GSA), Health and Human Services (HHS), Interior, Justice, National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), Navy (USN), State, Treasury, U.S. Information Agency (USIA), U.S. Postal Service (USPS), and Veterans Administration (VA).

[3]Pursuant to Executive Order 12046 of March 27, 1978.

supplement the IRAC's recommendations and provide the essential balance for Government and industry in spectrum management issues. Its 15 members,[4] selected by the Administrator of the NTIA, are recognized authorities drawn from academia and industry.

Originally, the powers now associated with the NTIA resided in the Executive Office of the President.[5] In 1978, in a move to streamline and reorganize that office, these powers were transferred to the Secretary of Commerce, who in turn passed them to the Assistant Secretary of Commerce for Communications and Information as the Administrator of the NTIA.

For the most part, the two agencies of the United States regulating communications operate independently. They do coordinate their spectrum activities closely, however, with the FCC having a representative, nonmember liaison to the IRAC to express its interests and the NTIA participating in the rulemaking processes of the FCC with the advice of the IRAC. Mutual accommodation between these agencies has been the rule, but it is not mandated by any legal provisions. This poses a predicament that was stated forcefully in 1951 in the final report issued by the President's Communications Policy Board, a body appointed for a one-year term to "study the present and potential use of wire and radio communications by governmental and non-governmental agencies" and to "make recommendations in the national interest concerning policies for the most effective use of radio frequencies." In that report was this statement:

> The President need not turn to the [Federal Communications] Commission for any sort of prior consultation or advice before exercising his powers under the [Communications] Act [of 1934]. Furthermore, Section 305 of the Act specifically gives the President the power to assign radio frequencies to Government stations, and specifically exempts Government stations from the licensing and other regulatory powers of the Commission when they are operating as such. The Act on the one hand provides no standards to guide the President in assigning frequencies to Government stations; his determination is final. On the other hand, the Act places the Commission under no duty to respect the President's assignments; either the Commission or the President could start a radio war by assigning a frequency already in use to an interfering user.

Fortunately, such drastic confrontations have not occurred, but it is remarkable that cooperation is voluntary.

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[4]One of the authors, C.M. Crain, served on the Council from 1965–1987.

[5]Among other names given to the bodies having these powers while in the Executive Office are: Office of Telecommunications Management (OTM) and Office of Telecommunications Policy (OTP).

This bifurcated structure presents an additional layer of complexity in projecting U.S. positions into the international arena. In matters of coordinating frequencies bilaterally with foreign administrations, the FCC usually represents U.S. Government agencies acting in accordance with the rules and regulations of the ITU. In matters of disseminating official Government policies internationally, the Department of State acts to represent the combined interests of the FCC and the NTIA based upon their individual recommendations. They each follow their own individual procedures for arriving at these recommendations. The positions of the NTIA usually originate in and/or are executed by the IRAC. Specifically, the IRAC:

- Prepares Government positions to international radio conferences.
- Formulates telecommunications policy advice for the Government to be released internationally by the Department of State.
- Provides guidance for implementing U.S. telecommunications treaty obligations concerning Government operations.
- Advises and assists in international coordination matters not handled by the FCC.

Once the proposals by the IRAC are reviewed and approved by the NTIA, they are coordinated with the FCC. The Department of State then develops the official U.S. positions based upon these combined views.

TECHNICAL DEVELOPMENTS AND THE DOD

While the administrative institutions for spectrum management were evolving, the demand grew for commensurate development of technical expertise for incorporation into administrative processes. The emergence of spectrum engineering, the technical component of spectrum management, is rooted in the military, for it was here that the increased demands on the spectrum and the compactness of some military forces first led to serious problems with EMC.

Beginning in the early 1950s, crowding of the electromagnetic spectrum began receiving serious assessment when RAND embarked on a survey of the signal density of surface-deployed radars in the post–WWII, radar-rich environments of Europe and of the United States. Having established the nature and magnitude of the problem, the next step was to determine methods for reducing mutual interference by identifying candidate processes and evaluating them for their reduction effectiveness, their counter-countermeasure capability, and their performance and economic costs. Thus, the foundation was laid for the discipline of spectrum engineering having as its cornerstone analysis techniques for achieving EMC.

As a result of those studies, the military reached the conclusion that EMC among its users of the spectrum could not be achieved by a simple, prestructured procedure for frequency assignments prevalent at that time. Fortunately, also resulting from those studies were concepts and methods which could be applied to and ameliorate the problems. In June 1960, the DoD responded by instituting its Radio Frequency Compatibility Program (RFCP). This program[6] provided for a number of significant firsts:

- Establishment of the Electromagnetic Compatibility Analysis Center (ECAC) in Annapolis, Maryland, the first facility ever dedicated to achieving operational, (intersystem[7]) EMC through analysis.
- Creation of two databases to be continually updated, one as a library of spectrum signatures of existing and proposed military equipments, the other dedicated to "information regarding the planned specific operational environment of electrical equipments and systems."
- Inclusion of EMC requirements in engineering standards, regulations, and specifications.
- Requirement for test capabilities to ensure that the standards for EMC are met, leading to the establishment of test facilities by the individual services.
- Establishment of a training program in EMC issues.
- Instructions for the Military Communications-Electronics Board of the Joint Chiefs of Staff to review and revise the frequency allocation and assignment procedures used within the DoD.

Following the allocation of emergency funds for the services to implement the RFCP requirements for gathering spectrum signature data and for the start-up of the Electromagnetic Compatibility Analysis Center, the center began operations in 1961, providing the capability for the present practice of conducting analysis prior to the

[6]Technical components and analysis techniques of the RFCP were based upon work done at RAND, and establishment of the Electromagnetic Compatibility Analysis Center was conducted with the assistance of RAND staff.

[7]*Intersystem* EMC is concerned with the compatibility of a weapon system used with another in the same tactical geographical area. More generally, it is the compatibility of a system with its environment. *Intrasystem* EMC is concerned with the compatibility within a system having electrically interconnected equipments and/or equipments in proximity located within a describable geometry as, say, those in a single aircraft, spacecraft, or ground station.

assignment of frequencies for systems to be acquired as well as operational support for systems already deployed.

On July 5, 1967, the RFCP was formalized and amplified by DoD Directive 3222.3 as the DoD Electromagnetic Compatibility Program (EMCP), with the responsibility of its oversight conferred on the Assistant Secretary of Defense (Telecommunications)[8] and the Chairman, JCS, or their designees. Subsequent changes have been made to this directive, with the latest[9] being signed on August 20, 1990.

The decisions by the military to include EMC as a requirement in systems standards had significant repercussions. The armed forces, each responsible for its own acquired systems, formed their individual research and development laboratories to economically preempt design flaws before systems became operational. Industry was compelled to develop its technical expertise in order to address the issues raised by EMC and comply with these new standards. Professional and industrial organizations such as the Institute of Electrical and Electronics Engineers (IEEE), the Electronics Industries Association (EIA), and the Society of Automotive Engineers (SAE) responded with renewed attention to the field.

Following the lead of the military, in December 1963, the acting Special Assistant to the President for Telecommunications, on behalf of the two Government agencies regulating spectrum use, turned to a special agency, the Joint Technical Advisory Council (JTAC),[10] for assistance in addressing the "need for consolidation and clarification of the technical programs leading to the enhancement of EMC, and for leadership in developing national policy and adequate official recognition and support of this work in the United States."[11] The JTAC had been created in 1948 by the Institute of Radio Engineers, Inc., (IRE)[12] and the Radio Manufacturers Association (RMA)[13] as a body to "obtain and evaluate information of a technical or engineering nature relating to the radio art for the purpose of advising Government bodies and other professional and industrial groups." In response to this request, the JTAC undertook a massive study lasting four years and spanning the breadth of the issues of EMC, culminating in a final report titled *Spectrum Engineering—The Key to Progress*. This tome, released in March 1968 and representing the collective wisdom of some of the most distinguished leaders in science and engineering, was the definitive work

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[8]Now the Assistant Secretary of Defense (Command, Control, Communications, and Intelligence) (ASD/C^3I).

[9]Development of this updated directive was a portion of the authors' efforts in support of the Office of the Assistant Secretary of Defense (C^3I).

[10]Called the Joint Technical Advisory *Committee* at that time.

[11]From the statement of objective of the Charter for the JTAC.

[12]Merged with the American Institute of Electrical Engineers (AIEE) in 1963 to form the Institute of Electrical and Electronics Engineers, Inc., (IEEE).

[13]Now the Electronic Industries Association (EIA).

depicting the state of spectrum engineering and EMC at that time. More important, its observations and projections provided direction in the field for years to come.

Beginning in the 1960s and 1970s, a number of technologies matured sufficiently to contribute synergistically to both new problems and opportunities for the DoD. Solid-state devices, with their advantage of compactness, afforded increasingly sophisticated and complex systems. Fitting a multitude of them in close proximity constituted a new engineering challenge, however. Whereas the ECAC had been dedicated to the problems of intersystem EMC, the responsibility for intrasystem EMC of a system fell under the purview of the individual military branches and their laboratories developing that system. Fortunately, that same advance of solid-state circuitry that facilitated building increasingly complex systems also produced newly enhanced computing capabilities. Computer assisted modelling and analysis of intrasystem EMC and vulnerability[14] soon became practicable with the result of avoiding costly retrofits and unnecessarily waiving EMC requirements. Among those early programs were the Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP)[15] and the Specification and Electromagnetic Compatibility Analysis Program (SEMCAP),[16] both of which are continually updated and are still in use today.

Advanced composite materials gained prominence in the design of structures with desired properties, such as strength with light weight. A side effect, however, was that electromagnetic properties previously known or taken for granted, such as electromagnetic conductivity and shielding, were no longer a given. EMC analysis and protective measures would be required to accommodate the unusual nature of these advanced composite materials and structures. This mandated commensurate changes in existing DoD specifications for EMC. Work began in the early 1970s to determine the necessary ingredients for incorporating these changes. Once the principal electromagnetic parameters were established, the primary electromagnetic hazards and vulnerabilities and the methods for protection against them were assessed and the specifications were modified accordingly.

The use of space by NASA, followed by the DoD and others, spawned the seemingly surprising result of orbital space congestion by vehicles and debris. Not unconnected to that was the crowding of the spectrum used in operating the vehicles. Analytical techniques for minimizing orbital and spectral congestion were required to keep apace with demands. The

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[14]These programs also examined sources not previously treated, such as lightning, electromagnetic shielding, static charging, and electromagnetic pulse (EMP).

[15]Based upon work done at RAND and developed by the Rome Air Development Center of Utica, New York and McDonnell Aircraft Company in St. Louis, Missouri. Distribution, updating, and maintenance are performed by Kaman Sciences Corporation of Utica, New York.

[16]Developed at TRW.

ECAC was called upon to establish a space spectrum database and provide needed analysis for military space systems.

V. RECENT AND CURRENT EMC ACTIVITIES OF THE DOD

From the preceding, it is clear that the DoD has a history of innovation and leadership in the arena of EMC. That attention to the issues of EMC, by necessity, remains the status quo today. In the following, we will survey some current challenges and resulting activities within the DoD. We begin by outlining the provisions of the new DoD Directive (DoDD) 3222.3 establishing the department's Electromagnetic Compatibility Program, and then we survey other DoD activities, most of which were presented during a special panel discussion of EMC issues[1] at MILCOM '90. Those activities are discussed as they apply to either the phase of conceptualization, research, and development or the phase of operations.

THE DOD ELECTROMAGNETIC COMPATIBILITY PROGRAM AS ESTABLISHED BY THE NEW DOD DIRECTIVE 3222.3

As stated previously, the Radio Frequency Compatibility Program (RFCP), established in 1960, was formalized as the Electromagnetic Compatibility Program (EMCP) by DoD Directive 3222.3 in 1967. On August 20, 1990, a new DoDD 3222.3 was issued to reflect needed adaptations to evolutions in the EMC arena and as part of a response to streamline the DoD directives system by merging DoDD's 3222.3 and 5160.57, "Electromagnetic Compatibility Analysis Center (ECAC)." As its predecessor did, the directive provides for guidance in making policy and for specific responsibilities in the EMCP. Some of the more significant new features, explored below, deal with increased accessibility of the ECAC to provide analysis and with new assignments of responsibilities.

In general, the new directive provides that the ASD/C^3I and the Chairman, JCS, are jointly responsible for oversight of the EMCP and for policy guidance and direction to the ECAC, while issues of joint operations fall under the purview of the Chairman, JCS. The areas of the EMCP delineated by the directive are:

- Database and analysis capability,
- Standards and specifications,
- Measurement techniques and instrumentation,
- Education for EMC,
- Design,

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[1]These will be cited individually by author(s), with the full article title in the Bibliography. Only selected highlights of these are presented here. For more complete treatments of the topics, please see the original papers, to be published in the classified proceedings of MILCOM '90.

- Doctrine, tactics, techniques, and procedures,
- Operational problems, and
- Test and validation.

Previously, responsibilities for developing and maintaining a coordinated plan in support of some of these areas for the entire DoD were assigned to individual military services. Specifically, the Navy had the responsibility for standards, the Army was tasked for measurement techniques and instrumentation as well as test and validation, and the Air Force, in addition to being appointed management agency of the ECAC, was responsible for EMC database and analysis capabilities. With the new directive, the individual services are jointly responsible for these and the remainder of the program areas, while the Air Force remains the administrative agency for the ECAC, providing its program, budget, and financing. In matters involving signals intelligence (SIGINT), the Director, National Security Agency (NSA) is assigned responsibilities pursuant to DoDD C-3222.5, "Electromagnetic Compatibility (EMC) Management Program for SIGINT Sites (U)."

A key feature of the new directive is the provision that the ECAC have, beyond its DoD joint EMC analysis functions, a sponsored program to provide analysis on a reimbursable basis—in addition to that provided to DoD components—to other departments of the U.S. Government and others (industry), as authorized by ASD/C^{3}I. In order to facilitate this broadened role of the ECAC, a special note is found in the directive authorizing the ECAC to communicate directly with those requiring this sponsored work.

APPLICATIONS OF EMC IN SYSTEMS CONCEPT, RESEARCH, AND DEVELOPMENT

It must be borne in mind that the passage of a system from concept through procurement and operation is seldom linear, and iterations throughout are likely. At any given time, various aspects of a complex communications-electronics system will be in different phases. The need for EMC of systems invites, and often requires, innovation to avoid potential pitfalls throughout all these phases. In what follows, we outline the potentially treacherous route toward acquiring the spectrum support necessary for operating a communications-electronics device. Then we turn to a case study of the progress of a complex electronics-communications system along this path. The case study is intended to serve as a paradigm for the success achievable when considering EMC at each step of a system's development and, perhaps, for its likely doom without such prudence. Finally, we will relate a proposed methodology for assessing potential vulnerabilities.

Background: Acquiring Spectrum Support

With the presumption that forethought is likely to be less costly than hindsight, consideration of the EMC of a given system should begin at the earliest stages. Accordingly, at a minimum, each of the DoD components is to demonstrate that radio frequency support will be available[2] for any communications-electronics system that will radiate electromagnetic energy in a particular band prior to entering into contractual obligations for its full-scale development, production, or procurement. This demonstration of spectrum availability falls under the heading of spectrum allocation. It is but one of three steps required of a communications-electronics system prior to its actual operation:

- *Allocation* for spectrum must be requested and approved.
- *Certification* (by the NTIA) must be made that the equipment conforms to the provisions of the allocation.
- *Assignment* of specific frequency bands for operation must be issued.

Confusion arises about the terms allocation and assignment. *Allocation*, as used in spectrum management, refers to an entry made in the ITU's Table of Frequency Allocations designating that that band may be used for prearranged applications under specified conditions. *Assignment* conveys the meaning of authorization by an administrative agency to actually radiate electromagnetic energy in a given band subject to established guidelines.

The process of gaining spectrum allocation is the first step toward maturing a system. It is initiated by receiving EMC guidance from the Military Communications Electronics Board (MCEB) via a request (DoD Form 1494, "Application for Equipment Frequency Allocation") and by completing FCC Form 130 (for ITU registration). Approval of the allocation request is in the form of a Joint Chiefs of Staff (JCS) Frequency Guidance Memorandum (called a *J/F 12* paper). This approval is based upon recommendations from various parties affected. Specifically, allocation is granted based upon:

- A review by those military agencies[3] potentially affected that have requested through their major command to receive the periodical distribution of new J-12s.

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[2]Mandated by the Office of Management and Budget (OMB) Circular No. A-11 (May 1986) and implemented within the DoD by DoD Directive 4650.1, "Management and Use of the Radio Frequency Spectrum."

[3]These agencies are usually referred to as the *J-12 holders*.

- Comments from the Commander in Chief (CINC) of each of the military command areas.[4]
- Comments from host nations in which the equipment is to be used.
- An EMC assessment conducted by the ECAC.

In addition to this, there must be NTIA assurance of spectrum support based upon:

- A review conducted by the Spectrum Planning Subcommittee of the IRAC.
- An assessment of EMC by the NTIA.
- Compliance of the DoD component with international requirements.

After receiving allocation of spectrum, a system may enter into the full development stage. As the system is developed and matures, equipments will require certification before they proceed to the step of receiving frequency assignments. The frequency assignments are granted specifically for times and locations. The authority for assigning frequencies for military equipment depends upon where the equipment is to be operated. If it is to be used:

- Within the United States and its possessions outside of a CINC area, the appropriate assigning authority is the Frequency Assignment Subcommittee (FAS) of the NTIA.
- Outside the United States and its possessions (or if it is space equipment having no links to the United States or its possessions), the appropriate authority is the Frequency Panel (FP) of the Military Communications Electronics Board.
- Inside the United States and its possessions within a CINC area (or if it is space assets having links to the United States and its possessions), the Frequency Panel and the Frequency Assignment Subcommittee jointly assign frequencies.

All frequency assignments are approved only after consultation and coordination with the frequency managers of existing users, test ranges, and the unified commands; with host nations and treaty organizations; with the FAA (at the national level but usually initiated at the local level); and with the Area Frequency Coordinators (AFC) of the military services. For use of the spectrum in non-Government bands, coordination with the FCC is required.

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[4]Sometimes referred to as a *CINC area*.

Spread Spectrum Applications: A Case Study for EMC Issues

Current trends in spread spectrum technology promise a particularly arduous route toward achieving EMC. In such instances, success depends critically on early and sustained attention to the details of EMC throughout all phases of concept formulation, research, and development. The case history[5] of the Joint Tactical Information Distribution (JTIDS) serves to illustrate this.

The JTIDS mission is to supply tactical users in the battlefield with various communications, navigation, and identification (CNI) services by integrating them into a single system that is both jam-resistant and secure and can accommodate the constraints imposed for use with many tactical platforms. The term *terminal* is used to refer to each JTIDS unit. Different terminals are continually being developed, with the first being the "Class 1" terminal used on airborne and ground-based command and control (C^2) platforms, followed by the lighter and smaller "Class 2" terminal. Another terminal being developed cooperatively for NATO uses by the United States, France, Germany, Italy, and Spain is the NATO Multifunctional Information Distribution System (MIDS) Low Volume (LV) terminal. The coverage between platforms with JTIDS terminals is primarily line-of-sight (LOS) up to 500 n-mi. Those users requiring information from a source not within the line-of-sight are accommodated by the feature allowing the network of terminals[6] (hence the term *Distributed*) to act as relays between the information source and the inquirer, with no apparent performance penalty to the relayers.

The JTIDS program is rooted in concurrent pursuits of the Air Force and Navy. The MITRE Corporation, in the 1960s, under contract with the U.S. Air Force Systems Command, had been working on development of two separate systems: the Integrated Communications, Navigation, and Identification (ICNI) system and the Position, Location, Reporting, and Control of Tactical Aircraft (PLRACTA) system. These efforts were combined in 1973 under the heading SEEK BUS. Meanwhile, the Naval Air Development Center had been developing the Integrated Tactical Air Control System (ITACS) and the Integrated Air Navigation System (ITNS). The endeavors of the Navy were merged with those of the Air Force in 1975 to form the present JTIDS program.

From the outset, it was clear that the spatial, temporal, and frequency separation methods of conventional spectrum management would be insufficient for application to JTIDS. Consequently, a comprehensive battery of tests and analyses would be required to

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[5]Our treatment closely follows that of Carvin (1990).
[6]*Terminal*, as used with JTIDS, refers to a JTIDS unit.

assure that JTIDS operated compatibly with other systems operating within the frequency band to be allocated.

In 1976, the first request was made for a frequency allocation for JTIDS. This initial request was limited, not allowing for the full potential of the system. Owing to the technical challenges of the system, the Office of Telecommunications Policy[7] agreed to treat the request with special consideration. A steering committee, later to become the Spectrum Planning Subcommittee (of the IRAC) Working Group 1 (SPS WG-1), was formed to investigate the issues. This group launched a study to determine the appropriate frequency band. The frequencies considered ranged from 225 MHz to 4990 MHz. Below this range, bandwidth was inadequate. Above this range, the free-space propagation losses would require power generation beyond the technology available at that time for devices satisfying the size and weight constraints. The study concluded that no single band could easily accommodate the requirements for JTIDS. Nonetheless, a principal candidate was identified: the 960–1215 MHz band, dedicated to both government and nongovernment aeronautical radionavigation worldwide. Among the criteria favoring this band were two synergistically useful facts: this band was used globally for the same applications, and those applications were well-defined and developed. Together, these facts provided specific and universal guidelines for developing JTIDS.

The in-band services potentially affected by JTIDS fell into three categories:

- Distance Measuring Equipment (DME). This includes DME/Normal (DME/N), used to calculate distances between aircraft and surface beacons, TACAN, the military's DME/N with the added ability to determine bearing to the beacon, and Precision DME (DME/P), developed along with microwave landing systems and allowing greater accuracy in airport approaches.
- Secondary Surveillance Radar (SSR). This includes Air Traffic Control Radar Beacon Systems (ATCRBS), employing ground-based radar and airborne transponders, Identification Friend or Foe (IFF), the military ATCRBS with the ability for encryption of identity codes, and Mode S, an improvement of the ATCRBS permitting the address of specific aircraft.
- Traffic Alert and Collision Avoidance Systems (TCAS), being developed as a means for avoiding midair collisions.

[7]Predecessor to the NTIA.

The pertinent characteristics of these services were identified and analyzed. Establishing EMC with these systems, it was decided, would require adjusting three parameters of the waveform of JTIDS:

- Pulse modulation,
- Pulse shape, and
- Carrier frequency selection.

The chosen pulse modulation was continuous phase-shift modulation (CPSM), which produces lower spectral sidebands than previously used methods, thereby minimizing the impact of JTIDS on adjacent channels. Pulse shape was chosen to further enhance the sideband power. There are 51 carrier frequencies for JTIDS. These were chosen over the 960–1215 MHz band, with two gaps: one around 1030 MHz, and the other around 1090 MHz. This was, again, to minimize the impact of JTIDS operation on ATCRBS, Mode S, and TCAS. Additionally, consecutive pulsed frequency-hopping carriers were chosen with minimum time and frequency separations to render them distinguishable from pulse pairs of the TACAN/DME.

Obviously, there were a great many considerations and even more analysis, testing, and validation necessary in designing a system such as JTIDS. When these were accomplished, the Office of Telecommunications Policy approved this initial limited request for spectrum allocation for JTIDS. This was done, it should be noted, with reservations expressed on behalf of the Federal Aviation Administration (FAA). After conducting public hearings, the FCC finally allowed the allocation three years after the initial request had been made (March 15, 1979), and the appropriate footnotes were entered into the ITU Table of Frequency Allocations.[8]

The allocation of spectrum for JTIDS was done with particular stringency. The technical conditions for peacetime operation required JTIDS terminals to monitor strictly for deviations in the uniformity of carrier frequency distribution, pulse width, operating time, and power of emission relative to the 1030 and 1090 MHz neighboring[9] bands. If such deviations were detected, operations were to cease at once. Any equipments not specifically tested for EMC would not be allowed to operate. In addition to the technical provisions in

[8]Each nation abides by the general provisions of the ITU's Table of Frequency Allocations but administers the specifics of spectrum management as footnotes to these general provisions. Indeed, as is germane in later parts of this Note, it is probably true that one can arrive at a multitude of different (apparently conflicting) statistics, depending upon one's use and understanding of these footnotes.

[9]Within 7 MHz.

the allocation approval, the DoD was subject to administrative requirements. Among these were the requirement to maintain a log of instances when this self-monitoring capability had been called upon and also when it had failed. In addition, the equipment was subject to periodic confirmation that it was operating correctly. Moreover, the DoD was required to consult with civil authorities on the issues of collocating JTIDS and radionavigation equipment on aircraft, and locating ground-based JTIDS terminals near radionavigation sites. The DoD was also required to assist in ensuring that new radionavigation equipments would be electromagnetically compatible with JTIDS.

Once allocation for spectrum had been approved, the next step was to certify equipment as being in compliance with the provisions of that allocation. Because JTIDS terminals are developed to meet the specifications mandated by different platforms and because they are subject to refinement, certification of different terminals falls at differing times. The first terminal to receive certification was the Class 1 terminal in 1982. The next-generation Class 2 terminal was certified in 1989. Neither was certified, however, without first acceding to design changes.

In order to actually use the equipment, a frequency assignment must be secured. That assignment is given only for specific times and locations. Usually, this is easily acquired if the request conforms to the provisions of the frequency allocation. But for missions requiring deviations from these provisions, coordination with the FAA is required. In cases where EMC tests were unavailable for FAA perusal, the FAA has required that the operations take place during the early morning hours.

By the early 1980s, it became evident that the initial allocation of spectrum for JTIDS was insufficient for routine, peacetime training operations. Consequently, the DoD submitted a request for an extended allocation. By 1984, the test and evaluation phase was begun. The Spectrum Planning Subcommittee Working Group 1 (SPS-WG 1) of the NTIA, which had overseen tests for the initial limited allocation request, was assigned a similar responsibility for this allocation request. By this time the complexity of the task had grown, owing to the facts that there were more operational deployments to consider and that the capabilities of JTIDS had expanded. Accordingly, the SPS-WG 1 appointed sub-working groups to address the issues of designing tests, charting EMC guidelines for the terminals, and proposing coordination procedures between the DoD and the FAA. The test issues are still being resolved.

Internationally, the tale of securing spectrum support for JTIDS follows a similar vein. It had been apparent from the early stages that because JTIDS terminals were to be installed on NATO owned E-3s and at NATO ground facilities, spectrum support would be required in the appropriate nations as well as multinational coordination. A request for these, similar in nature to the original request for domestic spectrum allocation, was made to the Committee for European Airspace Coordination (CEAC). Using results from the American tests in addition to tests obtained from the United Kingdom and the Federal Republic of Germany, the SHAPE Technical Centre (STC) performed the required analysis. The Working Group on Communications and Aeronautical Navigation Aids (COM NAV) evaluated the results and, in 1982, recommended to member nations approval of that allocation. The expanded allocation alluded to earlier was recommended by the COM NAV in 1984 based upon further tests. Some NATO nations have implemented this later recommendation and others have not.

Clearly, the path toward fielding a complex communications-electronics system can be long, with many potential roadblocks. Equally clear is that JTIDS would not be as far along as it is today had it not been for vigilant attention to EMC from the start.

Electronic Warfare Vulnerability Analysis (EWVA): A Development Tool

The DoD has long been aware of the potential for fielded electronics systems to be electromagnetically vulnerable in a combat environment. Consequently, beginning in 1978 the DoD launched an effort[10] to appraise those vulnerabilities, which evolved to spawn the ambitious, present-day project known as the Electronic Warfare Vulnerability Analysis (EWVA). EWVA is intended as a DoD-wide methodological program to assist in the acquisition, test, development, and use of weapons systems. In what follows, we survey this evolution from its genesis through the present, and we outline some of the key issues and considerations for this new project.

In 1978, the Office of the Secretary of Defense (OSD) set up the Datalink Vulnerability Analysis (DVAL) Joint Test Force (JTF); its mission was to develop and validate a methodology to ensure that datalinks operated effectively in an electronic combat environment. That mission reached fruition, after five years of effort, with a four-module approach to assessing vulnerabilities, each module concentrating on a different aspect of the problem:

- *Interceptibility*. Can the enemy intercept signals emitted by the system?
- *Susceptibility*. Is the system susceptible to (intentional or unintentional) EMI at a given frequency?

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[10]Our treatment closely follows that of Flock (1990).

- *Accessibility*. If the system is susceptible to EMI at a given frequency, can access to that EMI mode be gained and exploited by the enemy?
- *Feasibility*. If the system is both susceptible and accessible to EMI, is it feasible that it will occur?

These questions, of course, must be tailored to the particular system being evaluated. Each of the modules consisted of four phases: pretest analysis, test design, test execution, and post-test design. With a nod to this approach, in June 1983 the Office of the Undersecretary of Defense, Research and Engineering, directed the services to implement the methodology as an approved procedure for testing and evaluating electromagnetically dependent systems. That mandate was soon broadened beyond datalinks to encompass all electromagnetically dependent systems. The charter for the DVAL JTF was extended for a year to assist the services as they implemented the required methodology.

Over the next several years, the individual services initiated various actions to come into compliance—for example, by designating implementing agencies to set up a program and executive agencies for managing it when in place. Nonetheless, implementation was not uniform, and in no case was it complete, a situation that persists today.

By the end of 1988, interest in the issues of assessing system vulnerabilities to an electronic combat environment was spurred when the DoD Test and Evaluation Committee (TEC) resolved that a (more uniform) pan-service program could be established by one of the services using start-up funds from the Central Test and Evaluation Investment Program (CTEIP). Following that establishment, fiscal responsibilities for the program would then pass to the individual military services. The program chosen was to be called Radio Combat Vulnerability Assessment (RVAN). In an April 1989 memo, the Chair of the TEC designated the Air Force (SAF/AQ) as the lead agency in establishing the program. The mission of conceiving and executing a Program Management Plan (PMP) was given to the Air Force Electronic Security Command. By May 1989, the name of the program had been changed to Electronic Warfare Vulnerability Analysis to correspond more closely with the terminology used in DoD Directive 4600.3 "Electronic Counter-Countermeasures Policy." At the present time, there is a rigorous schedule defined for EWVA to achieve its goals.

In a May 31, 1989, draft of the PMP, RVAN (EWVA) is envisaged as an "ordered process of assessing electromagnetic-dependent systems' vulnerabilities to electronic combat, exploitation, disruption, destruction, and deception by present, mid-term, and far-term threat capabilities, and to evaluate fratricide from friendly systems." Again, according to the same PMP draft, EWVA is expected to build upon the foundation laid by DVAL by expanding it to cover the entire spectrum for the full life-cycle of the system. Further, it is expected to be applied to each system judiciously, weighing the depth of analysis and allocation of limited resources against the expected benefit.

The challenge in creating EWVA is immense, but the project holds many opportunities for fulfilling important needs. Presently, the processes for assessing vulnerabilities among and even within the services vary widely. There is limited sharing of information and resources (databases and facilities). In addition, there is no vehicle for closer coordination among the services to minimize duplication (or possible omission) of efforts. Here is a clear opportunity for an EWVA program to perform a valuable task as an "umbrella" organization directing vulnerability assessments by identifying functional domains and appropriate supporting databases, and by either finding or developing necessary interfaces.

Whatever form EWVA takes, there are several key elements to enhance its likelihood for success. It must have the characteristics of uniformity and commonality across and within the individual services, maximizing interoperability. This should include consistency in its applications of analysis, modelling, testing, and choice of scenarios, with correlatable databases and reproducible results. But while striving for a degree of standardization, it must also be adaptable to the systems being evaluated, to the limitations of resources available for the vulnerability assessment, and to the changing nature of threats, all the while maintaining rigid configuration control. The EWVA process must be documentable. It must also be timely in its responses. Finally, it must be relevant, with measures of effectiveness (MOEs) relatable to actual operating needs and yielding pertinent information for decision makers, developers, testers, users, and system maintainers.

APPLICATIONS OF EMC IN SYSTEMS OPERATIONS

Whereas the preceding has examined efforts to preempt the necessity for costly EMC changes to systems prior to employing them in operations, even the most careful and thorough preparations cannot anticipate all eventualities. EMC is a factor that must be addressed during operations as well. Indeed, as systems become increasingly sophisticated and their interrelations grow more complex, EMC challenges in operations take on new prominence. In the following, we discuss recent and ongoing DoD activities aimed at ensuring EMC of systems during operations. We will explore innovations in EMC tools to enhance responsiveness to the dynamic demands of peacetime and wartime operations and a methodology for testing of systems used in joint operations.

The Need for Improved Spectrum Management of Operations

The advancement of technology has brought unprecedented capabilities for operations, and it has also increased the burden on the EMC community to cope with its concomitant technical and administrative pressures. Uniquely positioned to provide information on the extent of problems experienced is the Joint Electromagnetic Warfare Center (JEWC) at Kelly Air Force Base in San Antonio, Texas. There, a database is maintained of all reported instances of unusual electromagnetic incidents experienced by DoD entities. With the assumption that all such incidents (called MIJI incidents for reasons explained below) are potentially the manifestation of foreign probing of U.S. capabilities and techniques, it is required[11] that they be reported to JEWC for careful analysis to evaluate, among other things, whether they are intentional or unintentional and to find technical or operational solutions.

Unusual electromagnetic incidents in navigations and communications are often referred to as *MIJI* incidents as a consequence of the fact that they generally may be categorized as being caused by either *Meaconing, Intrusion, Jamming* or *Interference*. Meaconing is "a system of receiving radio beacon signals and rebroadcasting them on the same frequency to confuse navigation." (Electromagnetic) intrusion is "the intentional insertion of electromagnetic energy into transmission paths in any manner, with the objective of deceiving operators or of causing confusion." The most common type of intrusion is voice intrusion. Jamming is simply the deliberate radiation or reflection of electromagnetic energy with the intention of impeding the effectiveness of electronics equipments. All these first three categories share the characteristic that they are the results of intentional actions. The final category is interference, which, casually, is a generic term for any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades the performance of electronic equipment. Almost all incidents of interference are unintentional.

During 1988, the number of MIJI reports filed was 1451, with 92 percent of these being interference, 4 percent hostile, and the remainder undetermined. Such a large percentage of incidents attributable to unintended interference suggests that improvements to spectrum management are in order. Below we examine some ways in which this is being done.

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[11]Procedures for reporting of these for analysis, evaluation, and dissemination are found in the military service instructions AFR 55-3, AR 105-3, OPNAVINST 3430.18D, and MCO 3430.3C, titled "Reporting Meaconing, Intrusion, Jamming, and Interference of Electromagnetic Systems; RCS: JCS-1066 (MIN)(U)."

Toward Improving EMC: Automation and Deconfliction

The possibilities for generating tools to create EMC are endless. Examples of categories of these include (but are certainly not limited to) such things as databases, EMC analysis models, measurement methods and protocols, and administrative procedures. Illustrative of the breadth of potential aids in the field is the list of database and EMC modelling capabilities of the ECAC, but one of many agencies concerned with EMC and which concentrates primarily on the technical, intersystem subset of all EMC issues. The ECAC's database for EMC analysis encompasses:

- Background environmental data,
- Worldwide DoD frequency assignments,
- Tactical data,
- Equipment characteristics information,
- Space systems data,
- Electro-optical systems data, and
- Topographic data.

In addition, the classifications of EMC models comprising the ECAC's analysis capabilities cover the areas of:

- Antennas,
- Propagation,
- Transmitters,
- Frequency assignments,
- Cosite analysis,
- Environmental analysis,
- Radar analysis,
- Air traffic control (ATC), IFF, and navigation system analysis,
- Electro-optical systems analysis, and
- Space systems analysis.

A common factor to all these (and other EMC areas) is the need to effectively handle voluminous information demands generated by the myriad and relentlessly multiplying uses for the spectrum. Fortunately, the technology explosion spawning these new uses has also supplied a means for accommodating some of their requirements; the personal computer, workstations, and minicomputers are well along toward changing the way in which spectrum management is conducted in operations. An example of this is the Technology Transfer Program (TTP) of the ECAC, which is designed to provide periodic releases of the ECAC's analysis capabilities adapted for personal and minicomputer use in field applications.[12]

Presently, the tools used to perform spectrum management functions vary widely among DoD agencies for compelling and diverse reasons. These include differences in command roles in conflict situations, views of frequency management in different agencies, organizational roles, and characteristics of systems, their expected roles and application environments. The tools range from manual record-keeping, to automated systems designed for use in specific theater applications, to DoD-wide databases. In what follows, we survey some efforts at automating and developing specialized tools for various areas of spectrum management. Then we examine an ambitious proposal to integrate such tools. Specifically, we will first examine the database blanketing all DoD spectrum usage, which is invaluable in everyday spectrum assignments and in planning for operations. Then, as examples of the types of tools recently developed, we will provide some details of two computer-assisted methods for ensuring EMC in prescribed applications. Additionally, we will review ECAC activity in providing support to automate efforts in Operation Desert Shield. Next, we will address the special concerns for automating that subset of spectrum management dealing with EW. Finally, we will survey an umbrella effort to integrate and automate all the specialized tools of spectrum management for command in a joint operation.

Prior to the early 1970s, spectrum management records for the DoD were neither kept in a set format nor immediately accessible from a single source. Consequently, in an attempt to establish order in record keeping for DoD-wide spectrum management, the Frequency Resource Record System (FRRS) was established at the ECAC to house all DoD frequency assignments worldwide. The FRRS has grown over the years to its present 175,000 records, and it requires daily updating. Participating in the FRRS are: the Chairman, MCEB, who acts as its manager; the military departments; the unified commands and their subordinate units; and ECAC, which develops and maintains the central database. As a DoD-wide database, the FRRS maintains records of frequencies assigned to:

- U.S. Commanders in Chief of the European, Pacific, Atlantic, Central, Southern, and Special Operations,

[12]Our treatment closely follows those of Esses and Hodges (1990). Other information was made available by W.R. Swart, Technical Director of the Joint Electronic Warfare Center in San Antonio, Texas.

- The Defense Communications Agency (DCA),
- The National Security Agency,
- The DoD Area Frequency Coordinators, and
- The offices of frequency management of the three military departments.

The FRRS provides the information for all DoD applications requiring national-level approval as well as the data necessary for the daily engineering and frequency assignments of the military frequency managers. At present, the FRRS is a highly centralized structure, receiving and incorporating all new assignment data, requests for data, proposals for assignments, and providing all reviews and notification messages regarding spectrum assignments as well as data from the database.

While the FRRS has served a useful purpose by providing much-needed uniformity and a central repository of information, the growing volume and complexity of spectrum management work has introduced a need for greater autonomy and decentralization within the community. This need goes hand in glove with the emergence of the ubiquitous personal computer. Herein lies the crux of ECAC's proposed next-generation FRRS: a distributed data system, with participating agencies having their own on-site computer facilities; each agency would be responsible for its own domain of the database and would have its own local spectrum maintenance and processing abilities. In addition, the system would provide automated information exchange between the agencies, ECAC, the military departments, and the unified and specified commands.

As envisaged, a worldwide computer network of standard configuration Digital Equipment Corporation (DEC) microVAX computers will act as hosts for the enhanced FRRS. The central FRRS database will remain at ECAC, which will have a host computer on the network, and each of the other hosts will have a subset of the total database appropriate for their area and the necessary computing tools for maintaining that subset, supporting local and remote terminals and personal computers. Subnets will comprise the network, with each subnet consisting of one or more of these host computers linked to each other and to other subnets by the Defense Data Network (DDN).

Presently, some aspects of the enhanced FRRS are already in place. Four subnets have been established, one for the continental U.S. (CONUS) and one each for the different CINC areas of Europe (CINCEUR), the Atlantic (CINCLANT), and the Pacific (CINCPAC). These subnets already are capable of supporting spectrum management for most mission needs during peacetime and contingency operations. Additional plans include provisions for expanded data distribution, geographic retrievals, and open frequency selection.

As an example of other activities toward automation of spectrum management, ECAC, under the joint sponsorship and funding of the Army and the Air Force, is developing the Air-Ground-Air Frequency System (AGAFES) to address the unique issues related to the very limited spectrum available for the purpose of allowing aircraft to communicate with ground control and with other aircraft in a particular geographic area. At present, the air-ground-air frequency assignment process requires a manual search through microfiche data records with limited or no EMC analysis prior to making the assignment. The process is essentially a trial-and-error approach to minimizing interference, taking up to several days to complete. With AGAFES, it is intended that the process become automated and interactive, driven by user-friendly menus, taking only minutes to complete and including the option of a thorough EMC analysis.

AGAFES is designed to consider permanent frequency assignments for fixed installations while temporarily assigning frequencies for tactical purposes. Assigning those frequencies requires consideration of the electromagnetic environment in the immediate vicinity (cosite) as well as sharing requirements beyond (intersite). Cosite-dependent factors studied include intermodulation effects, harmonic interactions, and frequency separation from currently assigned frequencies. Intersite-dependent factors considered include power, location, and altitude of the transmitter, co- and adjacent channel frequency assignments, and the operations area. With AGAFES, the user has access to up to 40 frequency resource lists, allowing the user to classify frequencies by geographic area and radio type. Coupled with this is the ability to simultaneously construct a number of differing criteria for frequency selection for a single radio type in order to facilitate different assignments for that radio depending upon its location and mission.

A promising prototype of AGAFES has been installed at the 5th Signal Command to support the U.S. Army in Europe. Experiences there will be used to refine and expand its capabilities for further applications.

Another frequency engineering capability sponsored by ECAC has been developed to assist in the management of the high frequency (HF) band and has recently been adapted for use on smaller computers such as the DEC MicroVAX II and the personal computer. The program, Frequency Assignment System-High Frequency (FAS-HF), is designed to optimize the use of HF resources by all echelons of command within an operations area by centralizing the assignment process.

The propagation characteristics at HF are strongly dependent upon the variable state of the ionosphere. Consequently, a feature of FAS-HF that is exceptionally useful is its ability to form predictions for propagations rapidly from empirical data gathered in near-real-time. Specifically, it uses samplings of portions of the ionosphere for maximum observed frequencies obtained by a network of oblique sounders. If these are not available, solar flux data in the 10cm wavelength band or sunspot number are used for the calculations.

FAS-HF was used for the first time in operations in 1988 during a joint exercise in Europe. Based upon those experiences, it was modified and improved and was field tested the following year, with results sufficiently heartening to use on a year-round basis.

Recently, the ECAC has had the opportunity to assist in automating spectrum management for Operation Desert Shield.[13] As the keeper of the FRRS, the ECAC began assisting USCENTCOM by developing a specialized subset of the FRRS as a Desert Shield Frequency Assignment Database (Fig. 1 provides a diagrammatic rendering of the arrangements), using an expediently shortened form of the Standard Frequency Action Format (SFAF). Within a week of the initial request for assistance, the database was operating, and as of mid-December 1990 it had over 14,000 entries. Additionally, the ECAC extended the use of this database to forward personnel by producing a personal computer hosted version called the CENTCOM Frequency Resource System (CFRS). With careful automated coordination of frequency assignment records, frequency assignment needs were identified and processed, and corresponding updates to the database were provided, with the entire cycle executed twice weekly.

A particularly troubling area of EMC considerations is the use of EW. Although the issues of incorporating EW into operations are but a subset of spectrum management issues, they are accorded special status because they, out of all spectrum uses, are distinguished by their *intent*; only EW *seeks* to abridge use of the spectrum by others.[14] EW is an area that has undergone automation only recently, with promising but guardedly optimistic results. The primary mechanism for optimizing the use of electronic countermeasures (ECM) against hostile targets while protecting friendly communications and intelligence collection activities from unintentional jamming is *EW deconfliction*. EW deconfliction, as developed at the JEWC for application in a joint command, is a spectrum management concept based upon creation and use of a database of frequencies categorized according to the impact upon operations should they be jammed. This Joint Restricted Frequency List (JRFL) is essentially a list of frequencies prohibited from use by ECM units. Creation and maintenance of the JRFL to reflect dynamically changing priorities during battle requires

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[13]Private communication with J. L. Hodges.

[14]While this distinction is useful, it is worth stressing again that the *physics* involved does *not* traffic in such distinctions of intent.

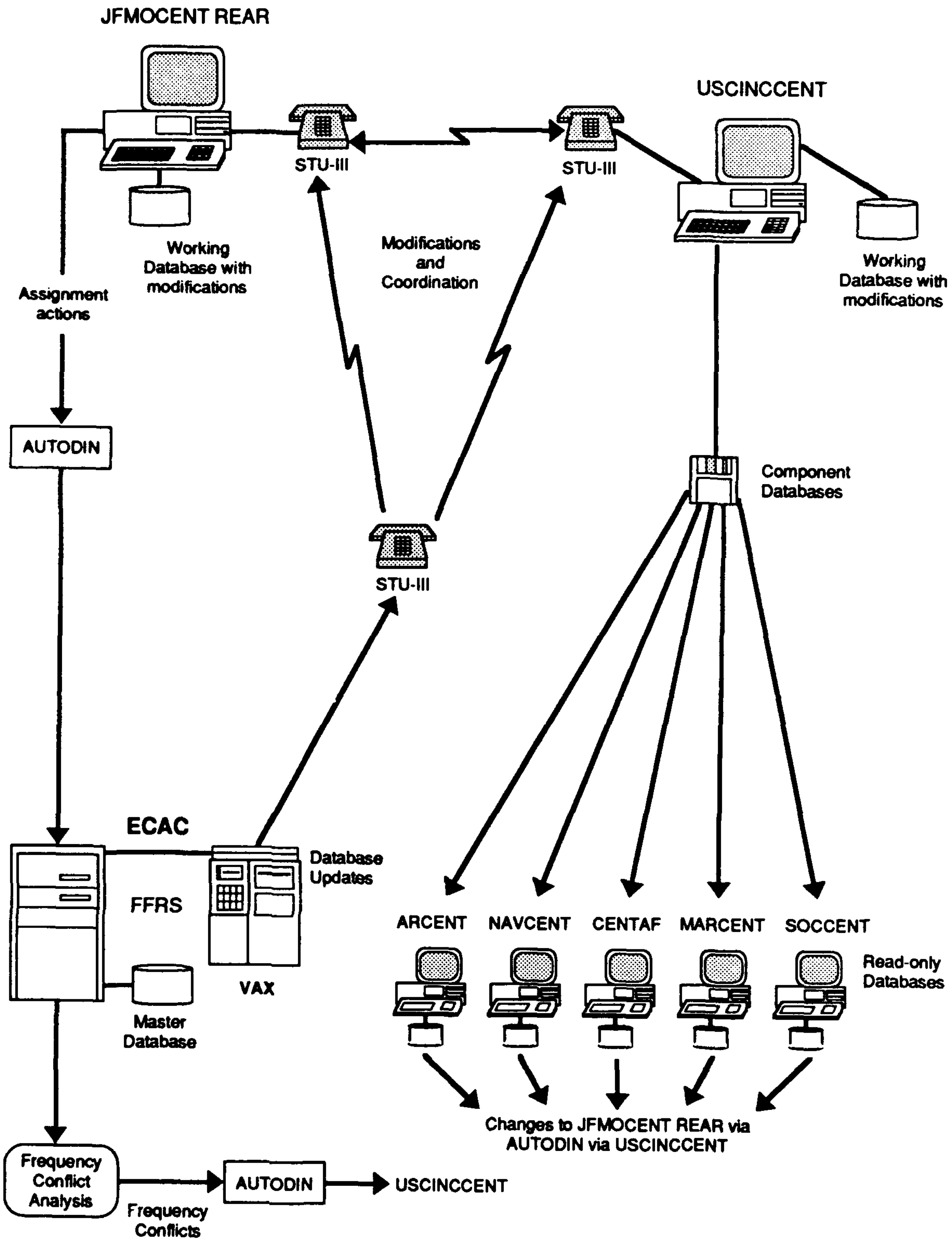

Fig. 1—Desert Shield Frequency Assignment Database and CFRS operation

careful coor 'ination and cooperation among ECM units and communications-electronics, operations, and intelligence staffs.[15] Those frequencies identified in the JFRL are classified as:

- *Taboo* frequencies: inviolable frequencies used for such occasions as emergencies or nuclear release.
- *Guarded* frequencies: useful for intelligence gathering.
- *Protected* frequencies: for friendly command and control links.

To augment manual deconfliction tasks, the Army's Communications-Electronics Command (CECOM) at Fort Monmouth, New Jersey, sponsored the development of an automated deconfliction program called DECON for use in the 30–88 MHz band. DECON was developed specifically to perform three functions:

- Plan for optimal use of EW assets with minimal unintentional interference to friendly emitters.
- Keep the JRFL current.
- Resolve conflicts when EMI is experienced by users of friendly communications-electronics.

Using computed propagation losses for the signal path of the desired signal and for the signal path of the interfering signal, DECON calculates the signal-to-noise ratio required for the desired link and the signal-to-interference ratio it experiences from the interfering signal in order to evaluate the expected performance of the desired receiver. The first use of DECON was in a NATO exercise; the results were impressive, one person accomplishing in fifteen minutes what had previously taken two people six hours.

The preceding has described some activities toward enhanced EMC capabilities performed by the ECAC and the JEWC. Beyond these agencies, however, there are and have been many others actively engaged in creating automated aids in support of EMC. For example, the original Army Tactical Frequency Engineering System (ATFES), sponsored by CECOM, developed a prototype that primarily acted as an analysis of the restricted frequency list as a predecessor to DECON. Presently the Army is enhancing and updating functional ATFES programs and developing new software programs under the Army

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[15]The procedures to ensure that this occurs are found in Appendix D, *JCS Pub. 3-51.1* and in *JDD 2-87*.

Frequency Engineering Software (AFES) and the EMC Analysis System (EMCAS), which will eventually reside in the Integrated Systems Control (ISYSCON). Additionally, the Navy is developing its Frequency Assignment Computer Terminal System (FACTS). The U.S. Marine Corps (USMC) has developed and is preparing to distribute its Spectrum Planning, Engineering, and Evaluation Device (SPEED), which incorporates site planning tools and databases into a graphics analysis facility. Also, the Pacific Air Forces (PACAF) has developed and is currently using the Tactical Frequency Record Management System (TFRMS), and the National Security Agency is developing hardware to automatically provide input into DECON databases. While this discussion is intended to illustrate EMC automation activities within the DoD, it is by no means comprehensive.

All of the preceding discussions of automated tools supporting EMC capabilities in operations have specific missions. In general, most existing and planned automated tools:

- Address limited portions of the spectrum,
- Pertain to specific equipments only,
- Demand extensive knowledge to operate,
- Require substantial manual input of data,
- Are not designed to interface with other systems and tools,
- Are not developed for automated data input of FRRS-type data,
- Are written in assorted software languages, and
- Are possibly executable only with specific hardware.

These characteristic limitations preclude adequate responsiveness to the total needs of spectrum management in planning and execution of joint operations. An attempt to remedy this situation is found in a proposed Joint Spectrum Management System (JSMS).

The events leading up to current efforts at creating a JSMS begin as early as 1982, when an ECAC study recommended development of an automated data processor (ADP) network for unified commands and selected components to gain access to the ECAC database and analysis capabilities. Although the idea received favorable responses from the JCS and the U.S. Commanders in Chief (USCINC), funding and agreement on capabilities and architecture were not forthcoming. Based upon recommendations from the OSD Joint Test and Evaluation (JT&E) Senior Advisory Council, the Deputy Director, the OSD Defense Research and Engineering (Test and Evaluation) (OSD/DDR&E(T&E)), selected the field of joint electromagnetic interference (JEMI) for study to determine its feasibility for joint test and evaluation during fiscal year (FY) 1988. The study concluded with recommendations for such a JEMI joint test and evaluation (JEMI-JT&E). Accordingly, on October 7, 1988, the JEMI-JT&E was chartered for a 36-month period; the Air Force was designated the lead service agency, its Tactical Air Warfare Center (USAFTAWC), located at Eglin Air Force Base, Florida, to act as executive agent to conduct the JEMI-JT&E. An important outgrowth of that initial feasibility study was the reaffirmation that computer-assisted spectrum management is needed for joint operations planning and execution. As one of the tasks of the JEMI-JT&E to develop procedures, guidelines, and employment concepts to minimize EMI in joint operations, funds were allocated to begin work on the JSMS.

The charge of the JSMS effort is to develop a system to assist the commander in joint operations (and the developer during acquisition) in matters related to spectrum management and EMC support. As envisaged, the JSMS is not intended to supplant existing or planned resources but to act as an umbrella system, coordinating among them and providing a user-friendly mechanism for utilizing them for planning and real-time applications. Essentially, the JSMS is to identify and resolve potential sources of EMI and guide the user through possible operational workarounds for those remaining problems.

In order to accomplish these goals, the unified commands, frequency management offices of the individual military services, joint command representatives, and others are to be polled to identify basic requirements for a prototype JSMS. Following that, the existing tools for EMC support will be evaluated for their appropriateness as contributors to the JSMS. Next, a prototypical model, or Initial Capability System (ICS), will be developed using minimal integrating software development to demonstrate whether the concept of the JSMS is indeed a valid one. It is expected that, met with success, this will form the basis for follow-on development of the JSMS. The ICS is expected to be completed by the end of FY 1991.

Joint Service EMC Methodology, Testing, and Evaluation

Our discussion of the JSMS alludes to the frontier of EMC issues in the broader context of joint operations. For the past several decades, the emphasis in the West has been on the use of technological superiority as a force multiplier to counter numerical superiority of the Eastern Bloc. Consequently, there has been pressure to place electronics equipments on existing platforms to supply that advantage, with attention focused primarily on integrating that equipment with the remainder of the platform. Within the individual military services, the focus sometimes extended beyond this intraplatform EMC to aspects of interplatform EMC. Until recently, however, considerations of EMC did not exceed the bounds of interplatform applications within an individual military service. Pushing back those boundaries was the charge of the JEMI-JT&E.[16]

The two steps leading to the JEMI-JT&E included a feasibility study to determine the appropriateness and need for the joint test and evaluation, followed by the test and evaluation phase, if indicated. The feasibility study, conducted by the USAFTAWC at Eglin AFB, Florida, in concert with representatives from the Army and Navy, took place from February to September of 1988 and concluded by recommending the JEMI-JT&E. Additionally, the Technical Advisory Group of the feasibility study proposed that the thrust of the JEMI-JT&E be toward providing a validated methodology to be institutionalized within the DoD to minimize EMI. Plans for the test and evaluation were to be structured accordingly. In October 1988 the JEMI Joint Test Force (JTF), consisting of the same management and organizational structure that had performed the feasibility study, was given a three-year charter to conduct the JEMI-JT&E. The missions of the JEMI-JT&E were to identify and quantify the effects of EMI among friendly electronics systems likely in joint operations, to develop and validate an improved methodology for anticipating and mitigating the impact of such EMI, and to provide for the implementation and institutionalization of the methodology and its associated tools within a permanent organization of the DoD, which was to be identified and involved in the JEMI-JT&E at the earliest possible time.

As of this writing, progress toward the development of a methodology for JEMI control (sometimes referred to as a "JEMI methodology") has produced a three-phased, structured feedback process, with the phases being:

- Identification of possible EMI conflicts to be investigated.
- Characterization and prioritization of the significance of such conflicts upon operations.
- Resolution to the maximum extent practicable.

Each of these phases consists of multiple steps. The process considers EMI conflicts among pairs of equipments to be used in a particular scenario.

In the identification phase, the specific scenario is applied, the equipments to be used in the scenario are listed and identified for management emphasis, and the concepts of employment (COEs) for the scenario are specified. The equipments are then examined to

[16] Our treatment closely follows those of Hooton (1990) and Quisenberry (1990).

determine all potentially interfering pairs of equipments, using field/fleet reports, historical data, and analysis. Following this step, the COEs are applied to the equipments in the scenario to assess the range of their tactical applications. Finally, the equipment characteristics are evaluated to determine the spatial and frequency separation thresholds for interference between equipment pairs. This information results in the identification and prediction of potentially interfering pairs based upon their electromagnetic characteristics and tactical use.

During the second phase of characterizing and prioritizing the potentially interfering pairs for their impact on operations, the predicted pairs are evaluated to determine if they do indeed pose a significant impediment to operations. If so, they are subjected to further refined methods assessing the degree of degradation and resulting impact on operations they are likely to experience. Used in conjunction with appraisals of the difficulty likely to be involved in resolving the problems, these pairs are prioritized for resolution.

The final phase of the methodology is devoted to problem resolution. During this phase, testing may be done to confirm and characterize the predicted interference before and after operational procedures, guidelines, and employment variations are prescribed.

The development and validation of the methodology is a primary task of the JEMI-JT&E. Throughout its refinement, tests and laboratory measurements are used in its validation. Accordingly, the JEMI-JT&E has scheduled four laboratory measurements, six one-on-one "mini-tests" equipment pairs, and a many-on-many controlled test using the twelve equipment pairs of the mini-tests and twenty-four nontested equipment pairs.

The purpose of the laboratory measurements is to obtain spectral data necessary to complete analysis predictions for the mini-tests. Those equipments measured were Compass Call, the AN/PPN-19 Ground Beacon of the Marine Corps, the AN/ALQ-99 aboard a USMC EA-6B, and an AN/ALQ-99 aboard a USAF EF-111. Results of the Compass Call measurements demonstrate that spectral output is predictable. Data were forwarded to the ECAC for analysis in the indicated validation mini-test, using the Compass Call and Army communications equipment as potentially interfering pairs. For those tests, it was predicted that single-channel radios and the AN/TRC-145 would experience interference and that second- and third-channel harmonic interference for single-channel radios would be limited. Results of the PPN-19 receiver measurements and laboratory simulations confirmed TPS-25 interference with the PPN-19, and the data were forwarded to the ECAC for mini-test analysis. The data on the AN/ALQ-99 aboard the USMC EA-6B consisted of ground and airborne measurements and were also forwarded to the ECAC for use in analysis for a mini-test involving the AN/ALQ-99 and the AN/MPQ-53 (Patriot).

Two of the six mini-tests were conducted during July 18–27, 1990, at the U.S. Army Electronics Proving Grounds (EPG), Fort Huachuca, Arizona. Both tests had the objectives of characterizing the interference and impact of Compass Call jamming. Consequently, the USAF's Compass Call aboard the EC-130H served as the interference source for both tests. The first test was to assess the impact of Compass Call on Army ground communications equipments and to test conditions to verify predicted interference, with the interference victims being SINCGARS, AN/VRC-46, and AN/PRC-77. While detailed analysis was not immediately available, results indicated adjacent channel and harmonic interference in the single channel mode and bit error rate (BER) increase in the agile mode. The objectives of the second mini-test were to characterize Compass Call's jamming impact on the interference victim AN/TRC-145 and to assess channel separation requirements between the pair.

Table 1

JEMI-JT&E PLANNED EMI MINI-TESTS

Mini-test	Source(s) and Platform	Victim(s)
1	Compass Call (EC-130H) (USAF)	Communications Equipment (Army) SINCGARS AN/VRC-46 AN/PRC-77 (ATCCS)
2	Compass Call (EC-130H) (USAF)	AN/TRC-145 Hawk Data Link (Army)
3	AN/TPS-25 BTF Radar (Army)	AN/PPN-19 Ground Beacon (USMC)
4	AN/ALQ-99 (EF-111A) (USAF) AN/ALQ-99 (EA-6B) (USN)	AN/MPQ-53 (Patriot) (Army)
5	AN/ALQ-99 (EF-111A) (USAF)	AN/AWW-9 (Walleye) (USN)
6	AN/APY-2 (E-3C AWACS) (USAF) AN/APY-1 (AEGIS) (USN)	AN/SPY-1 (AEGIS) (USN) AN/APY-2 (E-35 AWACS) (USAF)

Preliminary results confirmed adjacent channel interference in the single-channel mode. The complete list of mini-tests to be conducted is shown in Table 1. The final many-on-many controlled field test will involve four services in land, sea, and air operations in a dense, operationally representative environment. It is scheduled to be conducted in July 1991 at the Pacific Missile Test Center (PMTC), Point Mugu, California. Objectives of the test include validating the ability of the JEMI control methodology to predict EMI in a dense environment and verifying joint EMI reduction methods developed for the mini-tests.

The charter for the JEMI-JT&E is scheduled to expire by the end of 1991. At that time, the methodology, attendant tools, and observations are to be implemented and institutionalized within a permanent DoD organization. Consequently, a JEMI institutionalization study[17] was conducted from December 1989 to August 1990 at the office of the JEMI JTF at Eglin AFB to identify and appraise the alternatives, with emphasis on using existing resources and anticipating an austere budget. Four alternatives were evaluated. In order of their concluded desirability, these were:

- Develop JEMI staff positions within the OSD and JCS and create a permanent EMI working group under the MCEB.
- Establish JEMI positions at ASD/C^{3}I and JCS and form a Joint Program Office.
- Realign the responsibilities of existing organizations.
- Increase emphasis on EMI with no change in existing structure.

While the second of these options was considered to be most preferable, it would also be the most costly. The first of these options was recommended by the study as balancing the requirements of minimal or no additional manpower requirements against likely effectiveness. This alternative would require no organizational structure changes but would provide centralized oversight of JEMI matters by staff within the OSD and JCS. The specific functions of the JEMI control process would be assigned to various existing organizations and entities as preliminarily detailed in Fig. 2.

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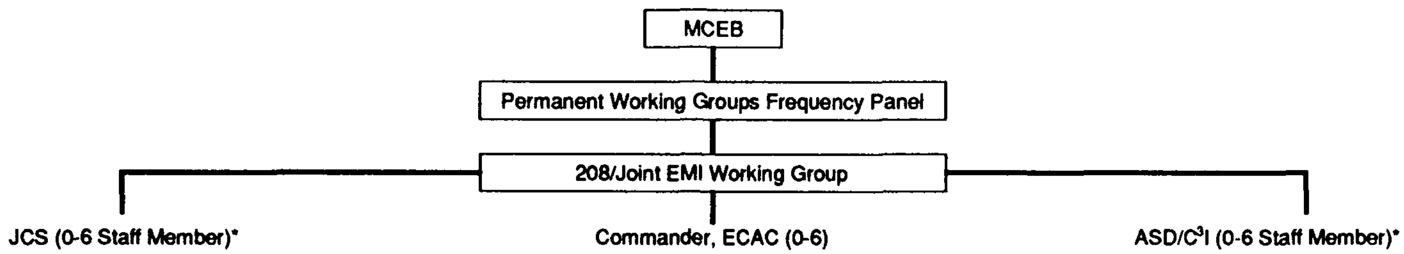
[17]Joint Electromagnetic Interference Jc ɩ est Force, *Draft Joint Electromagnetic Interference Institutionalization Study Report*, Eglin Air Force Base, FL, August 1990 (Unpublished).



Joint operations		ECAC		Acquisition process	
	JEMI process functions	*Charter function*	*JEMI process functions*		*JEMI process functions*
JCS Unified/ Specified Commands	• JEMI methodology for war plans and scenario evaluations • EC system integration	a. Establish and maintain databases	• JEMI-related databases and JEMI-specific with special identifiers	USD acquisition	• Acquisition milestones • Review and coordination
JCS-J7	• JEMI methodology analysis requirement for joint plans	b. Establish and maintain library spectrum signatures for C-E equipment	• Include JEMI library with special identifiers	ASD/C³I	• Directives-policy and guidance
JCS-J6 CINCs	• Handbooks for JEMI specifics • JSMS	c. Develop math and computer analysis techniques investigation of EMC problems	• Include JEMI tools used to support JEMI methodology	DDDRE (T&E)	• Joint test and evaluation
MCEB	• Guidance on JEMI matters	d. Network of databases and models for DOD agency use	• Identify specific model/simulation which support JEMI process	MCEB	• Frequency allocation • J-12 process
JCS-J3	• Guidelines and procedures for COEs and workarounds for minimizing JEMI			Service Acquisition Commands and Agencies	• Weapon system acquisition programs • Test and evaluation • Standards and specifications • Design • Measurement techniques and instrumentation • Databases and analysis capabilities • Training
JEWC	• JEMI problem reporting	e. Provide analysis of C-E equipment in being, under development, or proposed to determine EMC; include degradation considerations	• Direct analysis of JEMI potential for both acquisition and operations with direct support from JEWC and military services		
Services Operations Commands	• Mission area analysis • Test and evaluations • Concept of employment • System modifications • Off-the-shelf equipment • EC systems integration • Frequency management • Training	f. Analyze frequency allocation and assigned planning, and provide support to MCEB considerations for MCEB with direct support from FMC	• Include JSMS tools and procedures; also include JEMI criteria for these analyses and JEMI DD Form 1494 • OPR for JEMI methodology		

*Alternate Board Chairperson position annually

Fig. 2—Proposed JEMI control functions by organization

VI. CURRENT EMC-RELATED ACTIVITIES AFFECTING THE DOD

Outside the DoD, there are other activities that will have a direct impact upon spectrum use and EMC-related activities of the DoD. On the U.S. national front, the NTIA has undertaken a comprehensive review of Government spectrum use that will be used as a basis for policy well into the next century. At the same time, Congress is considering legislation to shift major spectrum assets from the Government to private users. On the international front, the World Administrative Radio Conference (WARC '92) is scheduled to convene in Spain in 1992 as an international conference to consider spectrum reallocations. Below we discuss some of these activities and their ramifications for the DoD.

THE NTIA'S COMPREHENSIVE POLICY REVIEW OF USE AND MANAGEMENT OF THE RADIO SPECTRUM

In the fall of 1989, the NTIA initiated a study to be used in developing policy for use of the spectrum into the next century. The work, "Comprehensive Policy Review of Use and Management of the Radio Spectrum in the United States," is the first such study ever to be undertaken. It was launched with a question-filled Notice of Inquiry[1] covering six broad areas for responses:

- The regulatory process (of spectrum use),
- Block allocation issues,
- Alternatives for apportioning and valuating spectrum,
- Spectrum conservation,
- Technology issues, and
- Forecasting future spectrum requirements.

Responses to the NOI were forthcoming from numerous sources, including corporations, trade associations, U.S. federal government agencies, and private citizens. Additionally, comments on the above areas provided indications of the nature and scope of considerations to be addressed in the study.

The study area pertaining to the regulatory process of spectrum use involves examining international as well as domestic structures and procedures. Comments received by the NTIA seemed to confirm firm support for the present structure of spectrum

[1]Notice of Inquiry, Comprehensive Policy Review of Use and Management of the Radio Frequency Spectrum, *Federal Register*, Volume 54, Section III, p. 50694, December 8, 1989.

management, with general agreement that this structure has worked effectively. The administration procedures of the FCC were endorsed for their provision of due process in the public interest. Areas of possible change also receiving strong support included increased openness of the Government's proceedings, institution of a unified database for the NTIA and FCC with easy accessibility by the public, and improvements aimed at greater efficiency and effectiveness in preparation of U.S. positions for international consumption. Moderate to strong support was voiced for augmented resources for spectrum management and for a public policy planning and advisory organization.

In the area of the present system's block allocations of spectrum for designated uses, the comments demonstrated strong approval of the present allocation system, which would likely grow with added flexibility and efficiency of the block process. Nonetheless, some possible improvements were cited, including providing incentives for spectrum-efficient technologies and freeing of underutilized spectrum for more pressing needs.

Among the possible methods of apportioning and valuating the spectrum to be considered in the study are auctions, leases, spectrum use fees, and spectrum property rights. Comments received by the NTIA reflect an unsurprising opposition to changes in the current process that would be likely to impose greater financial burden on the users. Specifically, auctions were strongly opposed, while spectrum usage fees received tepid support. Generally, there was little enthusiasm for use of the spectrum as a means of enhancing revenues. Again, there was support for the status quo modified to increase flexibility in the process.

The issues to be studied under the heading of technology-related matters include balancing the needs of present technologies with those anticipated and unanticipated, and the impact of technical standards upon emerging technologies. Consequently, the study will require measurements and models of spectrum usage, and it will explore alternatives such as fiber optics to free spectrum for other uses. Comments received by the NTIA in this area confirmed the notion that industry should play a major part in setting standards and that those standards must be sufficiently flexible to not squelch new developments.

In its review of methods for forecasting and planning for long-range spectrum use, the NTIA will be considering several alternatives. Comments received have favored some changes, such as enhancing allocation flexibility by removing suballocations and creating spectrum reserves. Predictably, there was strong support for close planning and coordination between the FCC and the NTIA.

Although the NTIA will consider the comments it has received while it conducts its study, it will not be bound by them. Indeed, the study may conclude with recommendations for policy counter to some of the desires expressed. Whatever the outcome, the study will provide a useful basis for determining policy in the distant and immediate future.

CONGRESSIONAL INTEREST IN SPECTRUM USE

An area likely to invite immediate use of the NTIA study is in legislation currently before Congress. In an unprecedented manner, Congress last year began taking an active role in spectrum management with the introduction of H.R. 2965, "The Emerging Technologies Act of 1990," sponsored by Representative John Dingell (D-MI). This legislation was motivated by the idea that to retain economic competitiveness, the United States needs to assure that new technologies requiring spectrum support have increased access to the spectrum. Consequently, it sought to have the Secretary of Commerce identify 200 MHz of spectrum below a 5 GHz threshold to be removed from Government use and turned over to private industry. As by far the largest user of Government-held spectrum, the DoD stands to suffer significant impact from such a bill.

Other provisions of the bill included the appointment of an advisory committee, almost exclusively from the private sector, to advise the Secretary of Commerce in his recommendations to be issued in a final report within two years of enactment of the bill. Within six months of that final report, the President would reallocate the designated spectrum. Additionally, the private sector advisory body would make recommendations for improvements to the spectrum allocation process. Distribution of the newly available spectrum would be distributed gradually according to a plan to be developed by the FCC. A feature of the distribution was that a "significant portion" was to be remanded as a reserve for later needs.

Not surprisingly, the bill met with some resistance from the Administration, which contended that it was based upon the inaccurate premise that the Government has reserved for its exclusive use substantial portions of the spectrum, many of which are not being utilized. Given the complexity of frequency allocations, a definitive repudiation or validation of such assertions is difficult, for the complexity admits substantial latitude for determining statistics. Estimates can vary widely, depending upon the aims of those doing the figuring and the extent of their sophistication in understanding the nuances of allocations (exclusive, shared, temporal, and spatial differences, etc.), including ubiquitous footnotes and cross-references. According to the Administration, however, 28.4 percent of the allocations below the 5 GHz threshold are exclusively for private sector use, 12.9 percent are exclusively for Government use, and 58.7 percent is shared.

Other objections to the bill were that the reallocation of the frequencies would represent considerable cost to the Government. There are 227,000 assignments to the Government and commensurate billions of dollars invested in support of those frequencies. It was asserted that in many—if not all—cases, reallocation would require the procurement and deployment of new and costly equipments, an especially difficult situation in the present atmosphere of growing budgetary constraints.

An unsubstantiated premise of the bill, according to the Administration, was that the private sector required more spectrum than was currently available. Even though requirements for new telecommunications systems had been documented, it had not been adequately demonstrated that these could not be met by the resources already available to the private sector with its combined exclusive and shared spectrum resources. The Administration tended to favor spectrum-sharing arrangements over reallocation measures.

Despite these and other Administration objections to H.R. 2965, the bill received wide support, especially among private telecommunications suppliers and other enterprises likely to benefit from its enactment. Among those reasons cited for favoring its quick passage was the perception that the United States already lagged its economic competitors in providing assurances to its industries that spectrum would be available when needed. The House bill was approved, but its Senate counterpart did not succeed before the close of the legislative session.

Although that bill did not become law, various similar bills[2] have surfaced in the present (102nd) Congress. All of them propose to turn over Government spectrum to private users as a means of nurturing technological development and economic competitiveness. The upper limit for candidate spectrum to be reallocated varies from 5 GHz to 6 GHz, and the amount of spectrum to be transferred is in the neighborhood of 200 MHz, either as a goal or a requirement. Other key elements under consideration to varying degrees by the different proposed bills[3] are:

- The introduction of competitive bidding for spectrum.
- Provisions for reimbursement to the Government for expenses incurred in complying with the reallocation.
- Provisions for an advisory committee to determine candidate spectrum for this reallocation.

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[2]As of this writing, those bills include: S 218, sponsored by Sen. Daniel K. Inouye (D-HI); H.R. 531, sponsored by Rep. John D. Dingell (D-MI); and H.R. 1407, sponsored by Rep. Don Ritter (R-PA).

[3]This is not to say that all of the bills contain all these ingredients.

- Timetables for implementation of the transfer.

The item most hotly contested thus far has been the introduction of competitive bidding for spectrum. Reasons for the debate have focused on such issues as whether a single bill should be the vehicle for the spectrum-use transfer and for competitive bidding, whether the proceeds from the bidding should be used as general revenue enhancements or simply applied to cover administrative or other related costs, whether appropriate guidelines may be established to ensure the needs of innovators with small financial resources, and whether the marketing of spectrum is indeed desirable.

The other elements found in the proposed legislation also will require answers to many questions. Should the membership of the advisory committee be drawn exclusively from the private sector, or should there be members to represent the Government agencies, for example? If so, how many? Would any of these be DoD representatives? At present, the consensus seems to be one or two Government representatives are to be appointed. If the Government spectrum users who are displaced are to be remunerated for their accessions, how will the appropriate form, amount, and schedules be determined? The timetable for implementation of the transfer of spectrum could be critical. Would it have mechanisms to allow systems to fulfill their life expectancy before their replacements would be required to be in place? Would it be able to weigh effectively the costs incurred by both the Government and the targeted new technologies in its timing of displacements? Regardless of how the various bills address these and other issues, momentum seems to favor passage of some form of legislation. In any case, the DoD has much at stake, whether in attempting to discourage its passage or otherwise influence its final form or in preparing to comply with the new law.

PREPARATIONS FOR WARC '92

Actions likely to have significant impact on the DoD will be among the topics under consideration during the World Administrative Radio Conference (WARC) to be held in Spain in 1992. The conference is the mechanism for changing international radio regulations, binding worldwide uses for the spectrum. Such conferences are called, as the need arises, by Plenipotentiary Conferences of the International Telecommunications Union (ITU). Their preliminary agendas are determined at the Plenipotentiary Conference, subject to changes agreed upon by the ITU Administrative Council. Before the actual conference, participants prepare their proposals and positions and, in some instances, issue provisional views. In mapping these out, the NTIA and the FCC assess their own individual interests and coordinate them, with the Department of State acting as the lead agency for their dissemination to the international community following Presidential approval.

The need for WARC '92 was determined at the Thirteenth Plenipotentiary Conference held in Nice, France, in May and June of 1989. At that time the agenda was recommended to include issues raised at three previous WARC conferences: the WARC for the Planning of the High Frequency Bands Allocated to the Broadcasting Service, Second Session, 1987 (HFBC-87); the WARC for the Mobile Services 1987 (MOB-87); and the WARC on the Use of the Geostationary Satellite Orbit and on the Planning of Space Services Utilizing It, Second Session, 1988 (ORB-88). Also recommended for consideration were two Articles and an Appendix of the Radio Regulations, as well as the possibility of defining some new space services and their allocations for frequencies in bands above 20 GHz. In 1990, the Administrative Council of the ITU agreed to broaden the agenda for WARC '92 to include, among other things, the allocation of spectrum for low earth-orbiting satellites. Explicitly, the final agenda for WARC '92 includes considering:

- Allocations of frequency bands above 20 GHz to new space service applications.
- Expansion of spectrum allocations in the HF band allocated exclusively to broadcasting.
- Allocation of frequency bands to broadcasting satellite services (sound) and associated feeder links in the bands from 500 MHz to 3 GHz.
- Allocation of frequency bands to broadcasting satellite services and associated feeder links to provide for wide radio frequency band high definition television worldwide.
- Mobile allocations in the 1–3 GHz bands.
- Mobile-satellite and associated feeder link allocations in the 1–3 GHz bands.
- Allocations of up to 5 MHz below 1 GHz to low-orbit satellites on the basis of appropriate sharing criteria.
- Fixed-satellite service allocations in the bands from 14.5–14.8 GHz.
- Space services allocations in the vicinity of 2 GHz.

In its preparations representing Government users of the spectrum for WARC '92, the IRAC formed a special committee, Ad Hoc 206. Further, the specific areas of WARC '92's agenda were assigned to four subcommittees (Ad Hocs 206A–206D). In its preparations for WARC '92, in 1989 the FCC first issued a *Notice of Inquiry* (NOI)[4] inviting comments on the

[4]*Notice of Inquiry*, GEN Docket No. 89-554, 4 FCC Rcd 8546 (1989).

WARC '92 agenda. I~ October 1990, the FCC issued a *Second Notice of Inquiry* summarizing the comments received in the first notice and delineating preliminary proposals and positions. This *Second Notice of Inquiry*, as well as a supplemental NOI issued in March 1991, invited further comments and suggestions for use in the iterative process of honing final positions.

While these activities have been taking place, other international counterparts have been preparing their positions. Of special concern to the DoD is the position of a bloc of European communities, representing about 20 votes, that the waning Soviet threat must surely reduce the spectrum needs of military users and that additional spectrum should be allocated to commercial interests. Meanwhile, the military has little influence with those taking this position.

Of the specific agenda items for WARC '92 at hand, several pose problems for the DoD. Within the DoD, positions in preparation for WARC '92 are formulated (and updated) by ASD/C^3I and the Military Communications Electronics Board (MCEB). Although the process of developing positions is dynamic, below we note the preliminary viewpoints (on the potentially troubling agenda items) that might be adopted by the MCEB.

In considering HF broadcasting, respondents to the NOI have suggested as much as 1500 kHz reallocated for broadcasting in this band. It is likely, however, that the final U.S. position will recommend a somewhat smaller expansion. Even though an increase of HF broadcasting allocations is likely to further constrain military HF use, it would not eliminate it. Hence, a proposed MCEB position might be to accept such a move but not support it, while stipulating regulatory access to the newly expanded bands.

In the area of satellite sound broadcasting in the 500 MHz to 3 GHz range, the United States is considering two proposals:

- Use current broadcast bands, or
- Use the band 1435–1530 MHz.

The second of these options could have significant impact on the use of telemetry bands used by both the Government and industry. In addition, it could diminish spectrum for relay systems such as MSE. A position the MCEB might take is to strongly support the former alternative, preempting serious consideration of the latter.

On the issue of mobile use of the spectrum in the 1–3 GHz range, the Europeans propose that over 200 MHz be allocated for pan-European cellular mobile communications. This action would have serious impact on the U.S. Army's Mobile Subscriber Equipment

(MSE) as well as other radio relay operations. A possible MCEB response to this proposal would be to devise a strong position outlining minimum needs while negotiating terms with the German post and telecommunications authorities and with the Committee, European Post and Telecommunication (CEPT).

Regarding mobile-satellite communications allocations in the 1–3 GHz range, the United States and Europe maintain divergent visions. While the United States is considering an increase of 5 MHz, European interests have suggested 100 MHz. The European proposal would seriously curtail telemetry band use and force major design changes. A possible MCEB position might be one of appeasement by acceptance of the lesser expansion.

Proposals for revisions to allocations for fixed-satellite communications (satcom) uses in the 14.5–14.8 GHz bands pose serious problems for the DoD. It is being proposed on behalf of Intelsat that 14.5–14.8 GHz be reallocated from military mobile to commercial satcom use. Such a move is opposed by the FCC and the USSR, and by the CEPT, albeit to a lesser degree as being a negotiable point. This move could have serious impact on the United States, and a proposed MCEB position is that it be strongly opposed.

The process of preparing for a conference such as WARC '92 is a complicated and involved one. It will pass through many iterations as negotiations are pursued and positions of others evolve. Meanwhile, the DoD will remain an active participant in the coming months.

VII. CONCLUSION

As this Note has suggested, the field of electromagnetic compatibility is extremely broad and complex. Beyond the demanding scientific and engineering aspects of the topic lie administrative structures and procedures of extreme intricacy. Nevertheless, the Department of Defense has a vested interest in use of the electromagnetic spectrum and electromagnetic compatibility of its systems among themselves and other users of the spectrum. Unique among resources, however, the electromagnetic spectrum is at once undepletable yet limited, irrevocably wasted if unused, and uncontainable by political boundaries. The DoD must share that resource with an already large and growing community of national and international users. Meanwhile, the practical limits of spectrum utilization are upon us. With growing demand, the problems will only worsen. And as new uses for the spectrum emerge almost daily, the clamor for access to that limited resource will increase. For the DoD, this means that it must justify its use of the spectrum to a substantial community of largely unsympathetic competitors as well as to others. The first steps toward accomplishing this are thorough spectrum engineering and consideration of electromagnetic compatibility at all times.

Spectrum engineering requires a broad base of technical knowledge that must be updated continually and kept abreast of the advances of science. That knowledge must include, for both friendly and hostile forces, such things as equipment characteristics, uses, locations (earth-bound, shipborne, etc.), likely scenarios of deployment, as well as the obvious frequency and time requirements. In addition, management of the spectrum requires navigation through what can be a labyrinth of administrative structures.

EMC issues are of a nature that they are most likely to be noticed only after they cause failure—often, presumably, after a system has been procured on time and within budget as a consequence of waiving EMC requirements. In the short term, these facts provide little incentive for attention to EMC. But in the long term, reliance on hindsight can be disastrously costly. Within the DoD, many EMC and spectrum management issues remain problematic. Illustrative of these are waivers of EMC requirements in systems acquisitions and upgrades, segregation of the EW and EMC communities, fragmented and duplicated efforts among the services, and handling of EMC in special access programs. From these and other parts of the collage, the DoD must forge a coherent picture and frame it effectively in order to present its interests to the complex array of national and international parties—or face even worse conditions. The problems of EMC and spectrum use are here to stay. They are, however, much more likely to be rendered tractable with foresight and vigilance. And the DoD has, at a minimum, a serious stake in their resolution.

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