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THESIS

ASSESSMENT ON RADIATED SUSCEPTIBILITY TESTING WITHIN THE DoD AND INDUSTRY

by

Carlos G. Solis

September 2018

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13. ABSTRACT (maximum 200 words)

The war on terrorism has been a major driving factor for warfighter use of commercial off-the-shelf (COTS) items. Multiple COTS products have been introduced in the field that have been tested to industry standards, immunity testing, rather than to Department of Defense (DoD) military standards—a subset for Electromagnetic Environmental Effects (E3) testing called Radiated Susceptibility (RS) 103 testing, and External Radio Frequency Electromagnetic Environment (External RF EME) testing. The DoD needs to determine the minimum acceptable test for radiated susceptibility (RS)/Immunity in order to determine the risk, if any, to the operators using these products in the field. Many of the COTS products that have been introduced for DoD use were purportedly assessed to a military specification while being tested to an industry test. This thesis assesses the difference between DoD and industry RS/Immunity testing to determine the worst-case test scenario for ground systems.

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ASSESSMENT ON RADIATED SUSCEPTIBILITY TESTING WITHIN THE DoD AND INDUSTRY

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ABSTRACT

The war on terrorism has been a major driving factor for warfighter use of commercial off-the-shelf (COTS) items. Multiple COTS products have been introduced in the field that have been tested to industry standards, immunity testing, rather than to Department of Defense (DoD) military standards—a subset for Electromagnetic Environmental Effects (E3) testing called Radiated Susceptibility (RS) 103 testing, and External Radio Frequency Electromagnetic Environment (External RF EME) testing. The DoD needs to determine the minimum acceptable test for radiated susceptibility (RS)/Immunity in order to determine the risk, if any, to the operators using these products in the field. Many of the COTS products that have been introduced for DoD use were purportedly assessed to a military specification while being tested to an industry test. This thesis assesses the difference between DoD and industry RS/Immunity testing to determine the worst-case test scenario for ground systems.

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LIST OF ACRONYMS AND ABBREVIATIONS

3G	third generation wireless telecommunication
4G	fourth generation wireless telecommunication
5G	fifth generation wireless telecommunication
AM	amplitude modulation
CB	citizens band
COTS	commercial off the shelf
CI	commercial items; see COTS
CS	conducted susceptibility
CW	continuous wave
dB	decibel logarithmic ratio unit
DoD	Department of Defense
DoDI	Department of Defense Instruction
DISA	Defense Information Systems Agency
E3	electromagnetic environmental effects
EM	electromagnetic
EMC	electromagnetic compatibility
EME	electromagnetic environment
EMF	electromagnetic field
EMI	electromagnetic interference
EUT	equipment under test
External RF EME	external radio frequency electromagnetic environment
Fc	carrier frequency
FCC	Federal Communications Commission
FM	frequency modulation
GHz	giga Hertz
GIG	global information grid
HIMARS	high mobility artillery rocket system
HPM	high power microwave
Hz	Hertz
IAW	in accordance with

IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISM	industrial, scientific, medical
ITU	International Telecommunication Union
JSC	Joint Spectrum Center
kHz	kilo Hertz
MHz	mega Hertz
MIL-HDBK	military handbook
MIL-STD	military standard
MRAP	mine resistant ambush protected
MTV	medium tactical vehicle
P3I	preplanned product improvement
P_{ave}	average power
PMO	Program Management Office
P_p	peak pulse power
Pulse	pulse modulation
PRF	pulse repetition frequency
PRI	pulse repetition interval
PW	pulse width
RAC	risk assessment code
RADAR	radio detecting and ranging
RDT&E	research, development, test, and evaluation
RF	radio frequency
RFI	radio frequency interference
RS	radiated susceptibility
SINCGARS	single channel ground and airborne radio system
T	1/PRI
UH	utility helicopter
UHF	Ultra High Frequency (RF band)
USN	United States Navy
USS	United States Ship
V/m	volts per meter

EXECUTIVE SUMMARY

> The war on terrorism has taught us that future threats to our national security will come from many diverse areas—domestic and international terrorists, state- and non-state-sponsored threats, computer hackers, and others. (Brown 2010, 8)

We now, more than ever, must be attentive and respond to any threat posed to our nation and allies. As the Department of Defense (DoD) procures assets to have the technological edge, they must rely on previous technological advancements or industry to modernize that technology for the safety of the nation. With the emphasis of rapid fielding initiatives to get warfighters the proper tools to complete their mission effectively, DoD must increasingly rely on commercial components.

The rapid fielding initiative integrates commercial off-the-shelf (COTS) electronic equipment to existing military technology to maximize mission effectiveness. This initiative, implemented to ground systems, increases survivability and mobility in any topography. It also enhances the lethality of our forces.

As part of this thesis, a literature review was completed to understand and document the difference between industry and DoD test standards for ground systems. The main focus for this thesis was the application of industry and military standards for radiated susceptibility (RS)/Immunity testing. Through the similarities between industry and DoD test standards to comply with electromagnetic compatibility (EMC), this thesis demonstrates, at a high level, a study to determine a baseline for all ground systems to be evaluated from.

This thesis begins with DoD incidents of notwithstanding electromagnetic interference (EMI) and then provides a reference to what the radio frequency (RF) spectrum entails. Then, it determines the difference, if any, between Industry and DoD RS/Immunity testing. The industry and DoD test standards are reflected below.

1. Industry conducts immunity testing under the International Electro-technical Commission (IEC) test standards:

    a. IEC-61000-1 (IEC 2005a): Immunity for Residential, Commercial and Light Industrial.

b. IEC-61000-2 (IEC 2005b): Immunity for Industrial Environments.

2. The DoD uses military standards (MIL-STD) for testing. It will be a subset for Electromagnetic Environmental Effects (E3) testing called

   a. MIL-STD-461G (DoD 2015): RS 103 testing.

   b. MIL-STD-464C (DoD 2010b): External Radio Frequency Electromagnetic Environment (External RF EME) testing.

Industry and DoD have separate test standards and testing methodologies. According to studies developed by the DoD, risk mitigation techniques are currently being incorporated to justify COTS items for DoD use. Without adequate RS/Immunity test standards and methodologies or an effective baseline, ground systems are susceptible to interference, which could render them ineffective.

The research provided in this study, along with the recommendation for External RF EME in accordance with (IAW) MIL-STD-464C (DoD 2010), is the worst-case scenario for RS/Immunity testing. This worst-case scenario explains what radio frequency interference (RFI) can be encountered in the operating environment, or battlefield, and serves as the baseline for ground systems to undergo testing.

Continuation of this study and further in-depth research is necessary in order to evaluate any risk assumed in the DoD's approach to EMC for COTS use. Thus, in order to accommodate the increasing field strengths and the ever-expanding RF spectrum utilization as technology advances; the RFI environment in the battlefield will need to be re-verified frequently.

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I. INTRODUCTION

The digital era has transformed the world into what it is today, many hand-held electronic devices for the consumer to use. Such technology has helped facilitate advancements in economical, educational, health, and everyday life for the average person. The introductions of chat rooms and video calling have made the world seem like a much smaller place. One can text and talk to relatives, friends, or acquaintances across the globe in seconds. One can also order products from other parts of the country and other countries with the click of a button. With the introduction of mobile electronics, one can take his office or entertainment center into the woods for the weekend without having to miss a meeting or a television episode. The transformation of the digital era is made possible through the increased use of the electromagnetic spectrum.

A. RADIO FREQUENCY INTERFERENCE-RELATED INCIDENTS

Several unclassified incidents have caused headlines throughout the world due to the severity of such incidents, the Department of Defense (DoD) implemented research to assess the accidents and conduct mitigation techniques to control such actions.

The following two examples are accidents, which if their causes were not addressed, could repeatedly cause injury or mission disruption. Both are a result of Radio Frequency Interference (RFI), a subcategory of electromagnetic interference (EMI), encountered in the operating environment.

Example 1: "Aircraft systems have experienced self-test failures and fluctuations in cockpit instruments, such as engine speed indicators and fuel flow indicators, caused by sweeping shipboard radio detecting and ranging (RADAR) during flight-deck operations. These false indications and test failures have resulted in numerous unnecessary pre-flight aborts" (DoD 2010b, 73).

Example 2: "Aircrews have reported severe interference to communications with and among flight deck crew members. Ultra-High Frequency (UHF), radio frequency (RF) band, emissions in the flight deck environment caused interference severe enough that crews could not hear each other for aircrew coordination. This problem poses a serious hazard to personnel with the potential for damage to, or loss of, the aircraft and aircrew during carrier flight deck operations" (DoD 2010b, 73–74).

The following examples caused great bodily injury or death and are representative of what can happen if systems are not properly safeguarded against RFI.

One major incident for the United States Navy (USN) happened on the aircraft carrier United States Ship (USS) *Forrestal* (CVA 59) (USN 2009):

> On 20 July 1967, the USS Forrestal was deployed off the coast of North Vietnam. The carrier deck contained numerous attack aircraft that were fueled and loaded with 1000-pound bombs, as well as air-to-air and air-to-ground missiles. One of the aircraft missiles inadvertently deployed, striking another aircraft and causing an explosion of its fuel tanks and the subsequent death of 134 service members. The problem was thought to be caused by the generation of RF [radio frequency] voltages across the contacts of a shielded connector by the ship's high power search radar. (Paul 2006, 13)

Another incident, this time affecting the U.S. Army, was to a utility helicopter (UH)-60 Black Hawk:

> On 8 November 1988, various news agencies reported that the Black Hawk Helicopter was susceptible to electromagnetic emissions. Evidence was revealed that indicated most of the crashes of the Black Hawk since 1982, which killed 22 service members, were caused by flying too close to radar transmitters, possibly even CB [citizens band] transmitter. The susceptibility of the helicopter's electronically controlled flight control system to these electromagnetic emissions was thought to have caused these crashes. (Paul 2006, 13)

These events served as the catalyst for the introduction of the field of Electromagnetic Compatibility (EMC) for the Navy. It is noted that the Army later followed the Navy in the indoctrination of EMC for Army assets. The EMC field expanded within the DoD to become Electromagnetic Environmental Effects (E3) testing.

B. RADIO FREQUENCY SPECTRUM

The electromagnetic spectrum is the characterization of electromagnetic waves across a wide range of frequency spectra. Figure 1 is the electromagnetic spectrum, from audio to cosmic rays.

This thesis is concerned with the radio frequency (RF) spectrum portion of the electromagnetic spectrum, from 0.01 Mega Hertz (MHz) to 50 Giga Hertz (GHz), approximately denoted by the red box in Figure 1. Most of our modern technology operates within the RF spectrum, which includes any electrical device that can be considered a system or subsystem. Systems and subsystems can be devices from manufacturers; which includes residential, commercial, light industrial and industrial devices. Much of the modern technology mentioned above is characterized as either a transmitter or receiver. Most receivers are considered potential transmitters. Potential transmitters contain a crystal oscillator, much like in laptops, desktops, and other mobile devices, which can emit RF noise due to clock speeds.

The magnitude of such electronic transmitters in the confined RF spectrum can cause adverse effects to each other. Thus, EMI has become a big concern in the digital era. One of the top journals for electromagnetics states that EMI is characterized as "any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics and electrical equipment" (Institute of Electrical and Electronics Engineers [IEEE] 2009, 19).

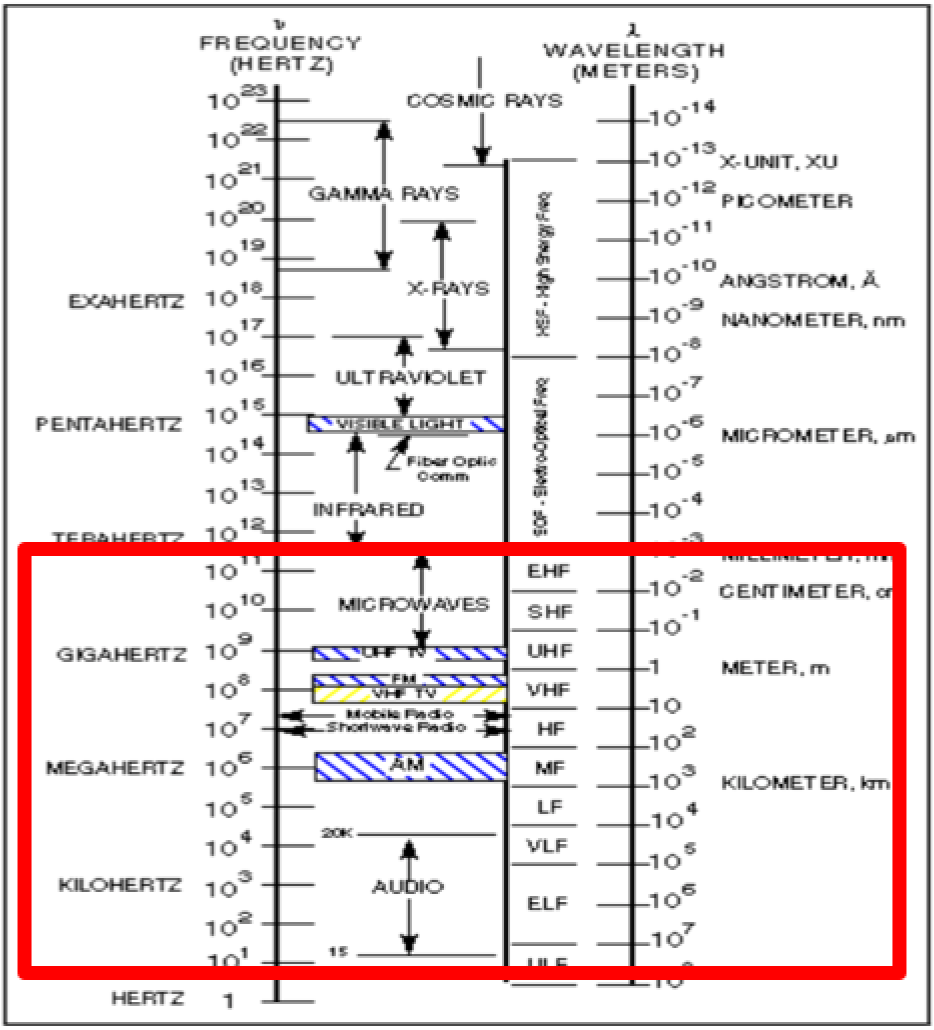

Figure 1. Electromagnetic Radiation Spectrum. Adapted from Avionics Department (2013, 2-3.1).

C. PROBLEM STATEMENT AND RESEARCH QUESTIONS

Most modern technologies are COTS items which the DoD integrates into weapon systems, giving more capability to the warfighter. The main advantage of using COTS is to reduce research and development costs from the acquisition life cycle. Thus, the DoD is getting away from sole source, propriety technology designs and going to open source, integrated COTS solutions. Another advantage is that the DoD mitigates parts obsolescence by introducing practical COTS solutions.

It is critical to stay attentive and respond to possible threats to our nation and allies. As the DoD procures assets for technological advantage, it relies on COTS for modernization with the emphasis placed on rapid fielding initiatives to arm warfighters with the proper tools to complete their mission effectively. The DoD increasingly relies on COTS items to execute missions.

Industry and DoD have separate test standards and methodologies for incorporating EMC to safeguard the user. Without adequate radiated susceptibility (RS)/Immunity test standards and methodologies, ground systems are susceptible to RFI, which could render them ineffective or dangerous to operate. To address the aforementioned problem, this thesis is organized as follows: Chapter I is an introduction to RF; Chapter II defines the methodology and terminology for this study; Chapters III and IV provide a look into test standards; Chapter V conducts a comparison of such standards; Chapter VI presents a case study; and, finally, Chapter VII is the conclusion. This thesis analyzes the main differences between industry and DoD, RS/Immunity test standards and their respective methodologies in order to consider the baseline for ground systems. The following research questions are investigated:

- What are the industry's RS/Immunity test standards and methodologies?
- What are the DoD RS/Immunity test standards and methodologies?
- Are commercial off-the-shelf (COTS) items at risk in the military operating environment?

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II. METHODOLOGY AND TERMINOLOGY FOR RADIATED SUSCEPTIBILITY

This chapter addresses assumptions, basic terminology, the four fundamental electromagnetic phenomena, modulations and schemes in order to understand both DoD and industry test standards. Most test standards are very detail orientated, intended for those that are in the field of electromagnetics: more likely for Electrical Engineers and Physicists. Therefore, the key factors for electromagnetics will be discussed within this chapter in order to better understand DoD and industry test standards.

A. BACKGROUND

The use of mobile electronics has introduced a variety of conflict scenarios in the RF realm of the digital era. One major phenomenon for electronic devices is the propagation of RF noise from other items inflicting symptoms on other electronic devices. Many RF experts mitigate this phenomenon by conducting research and assessment for EMC.

> The increasing significance of electromagnetic compatibility considerations in the design and application of electrical and electronic equipment is directly related to the expanding sophistication of the functions performed by such equipment in industrial, civilian, and military activities. In order to assure the designer and user that equipment of concern to them will function in the intended application, it is necessary to control the electromagnetic environment adequately. The environment will vary from one application to another, as will the performance requirements. (IEEE 1996)

Radiated susceptibility is significant to the EMC mitigation of products sold in the United States and across the world. Industry and DoD test standards exist to mitigate a product's susceptibility to electromagnetic fields. Most RFI can lead to catastrophic problems to electronics for consumers in the privacy of their own home or for industrial/commercial use (e.g., hospitals, emergency rescue, laboratories, and DoD use).

> The purpose of these tests (RS) is to ensure that the product will operate properly when it is installed in the vicinity of high power transmitters. The common types of transmitters are Amplitude Modulation (AM) and Frequency Modulation (FM) transmitters and airport surveillance radars.

> Manufacturers test their products to these types of emitters by illuminating the product with a typical waveform and signal level representing the worst case-exposure of the product and determining whether the product will perform satisfactorily. If the product cannot perform satisfactorily in such installations, this deficiency should be determined prior to its marketing so that "fixes" can be applied to prevent a large number customer complaint and service calls. (Paul 2006, 81)

B. METHODOLOGY

The methodology for this thesis is to first analyze the industry and DoD test methodologies to determine the main difference between them. The next step is to analyze the environments that the industry standards are designed to protect against and those that the DoD standards will protect against.

1. Limitations and Assumptions

The limitation for this thesis is that the material herein is unclassified. This limits the use of data and criteria from specific documentation.

A *ground system* entails a DoD platform that is, though not limited to, a tracked vehicle (manned or unmanned), wheels-with-an-axle type vehicle (manned or unmanned), soldier-mounted equipment, a ground station, weapon mounted equipment, and hand held electronic equipment. Such examples for ground systems entail the following: mine resistant ambush protected (MRAP) vehicles, M1 Abrams, soldier mounted equipment like single channel ground and airborne radio system (SINCGARS) man-pack radios, Picatinny rail mounted equipment, and High Mobility Artillery Rocket System (HIMARS) mounted on a standard Army Medium Tactical Vehicle (MTV) truck. Such ground systems are depicted in Figure 2, note that ground systems interact with air and sea vehicles too.

Figure 2. Various DoD Assets. Source: DoD (2012a, cover page).

Other considerations for ground systems can include electronics that are not assigned to aerospace/sea/deep sea operations, or ordnance. Ground systems can include systems and subsystems that are devices from manufacturers; which includes residential, commercial, light industrial and industrial electronic devices.

2. Terminology

A literature review was conducted for published papers, textbooks, and standards within the past ten years detailing the criteria for RS/Immunity test standards between industry and DoD. Such criteria entail the following key terms: EMC, EMI, E3, RS/Immunity, Dwell Time, Field Strength, Modulation Schemes, and Frequency Range.

a. Electromagnetic Compatibility

> The systems approach considers EMC throughout the design; the designer anticipates EMC problems at the beginning of the design process, finds the remaining problems in the breadboard and early prototype stages, and tests the final prototypes for EMC as thoroughly as possible. This way, EMC becomes an integral part of the electrical, mechanical, and in some cases, software/firmware design of the product. As a result, EMC is designed into- and not added onto- the product. This approach is the most desirable and cost effective. (Ott 2009, 5)

In order for a COTS system to operate for its intended use without any susceptibilities, EMC mitigation techniques are applied. Engineers and product designers incorporate such techniques to mitigate any EMI/RFI to safeguard the consumer. Figure 3 describes the bathtub concept for product design, in which it is better to implement EMC mitigation techniques early in the design of a product. "As equipment development proceeds, the number of available noise-reduction techniques goes down. At the same time, the cost of noise reduction goes up" (Ott 2009, 5). Sometimes integration of COTS can be costly, due to EMC being an after design upgrade/ modification.

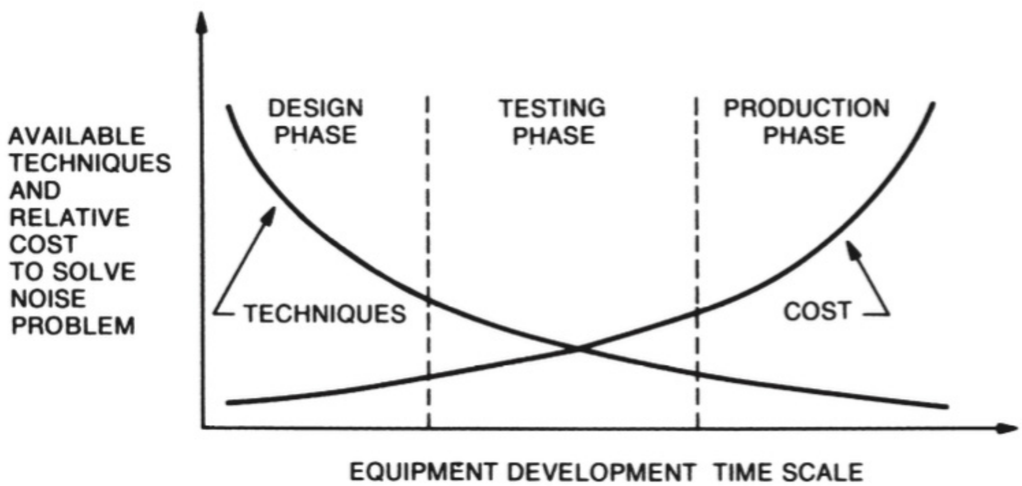


Figure 3. Bathtub Concept. Source: Ott (2009, 5).

b. Electromagnetic Interference (EMI)

> EMI is defined as: any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics and 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. (IEEE 2009, 19)

The undesirable signal that can be parasitic to a system due to its surroundings is called EMI. Victim-Source relationship occurs between the transmitter/potential transmitter (source) and another system (victim), which susceptibilities are occurring. RFI is a subset of EMI where the undesirable signal is within the RF spectrum. The incidents in Chapter I, Section A are examples of victim-source scenarios.

c. Electromagnetic Environmental Effects (E3)

The term E3, by an industry stand point, is "the impact of the EME [electromagnetic environment] on the operational capability of military forces, equipment, systems, and platforms. It encompasses all electromagnetic disciplines, including EMC and electromagnetic EMI" (IEEE 2009, 19).

The DoD imposes E3 testing under specific military standards in order to incorporate EMC. It starts in the research, development, test, and evaluation (RDT&E) phase of every DoD program, during acquisition and/or procurement, and throughout the military asset's life cycle. All Army, Navy, and Air Force ground systems must undergo E3 testing. Most COTS items are assessed by E3 testing.

d. RS/Immunity Test

RS/Immunity test is the term used to describe the test standard and methodology from either industry or DoD to determine which is the worst-case scenario, baseline, for ground systems to be tested to. In industry, the test standard conducts immunity testing under the International Electro-technical Commission (IEC), and within the DoD military standards, it will be a subset for E3 testing called RS 103 testing and External RF electromagnetic environment (EME) testing.

The next terms are specific technical terms to DoD and industry test standards. Sometimes the terms are assumed to be known because they are not in the glossary for such test standards.

e. Dwell Time

The dwell time is the duration time lapse for the illumination of non-ionizing radiation towards the Equipment Under Test (EUT), in this case COTS. Both industry and DoD have a dwell time for testing.

f. Field Strength

The field strength is the electric field present in volts per meter (V/m). Both industry and DoD monitor the field strength for a set of frequencies. The field strength is the maximum amplitude an EUT can undergo testing. Susceptibilities can occur at different field strengths.

g. Modulation Schemes

Modulation schemes are the RF signals waveform that illuminates the EUT for RS/Immunity testing. Both industry and DoD provide different modulation schemes for a set of frequencies. Susceptibilities can occur at different modulation schemes.

h. Frequency Range

The frequency range is the set of frequencies within the RF spectrum that the EUT must undergo for testing measured in Hertz (Hz). Both industry and DoD conduct testing to a variety of frequencies. The frequencies are monitored during industry and DoD testing. Susceptibilities can occur at different frequencies and multiples of frequencies called harmonics.

i. E3 Hardening

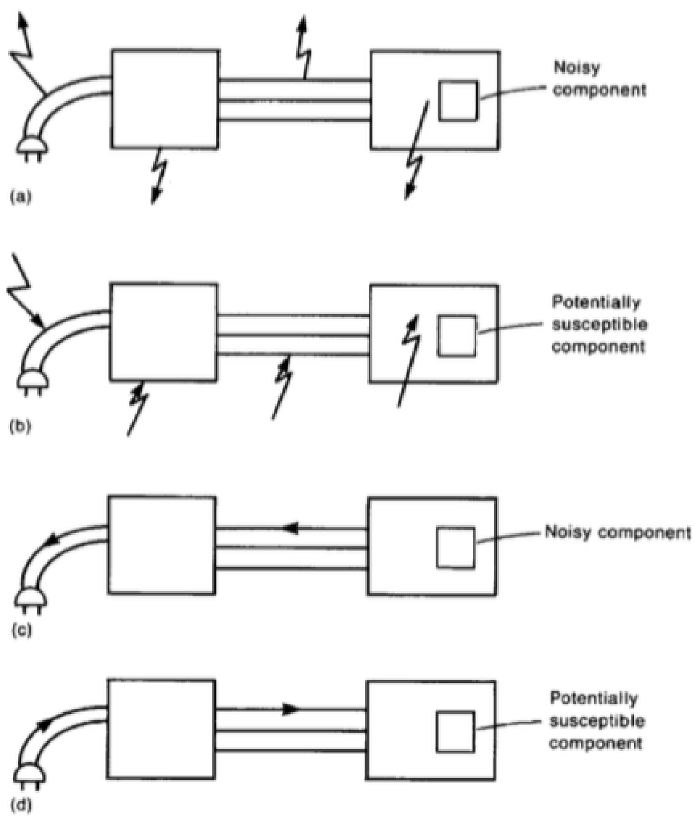
The mitigation techniques to overcome susceptibilities from EMI, and be electromagnetic compatible to the electronic units' surroundings, its operating environment. Such hardening techniques can be very costly to a program if not synthesized during initial design. EMC and E3 hardening have the same meaning.

j. Wavelength

The physical distance that pertains to a specific frequency. The wavelength is inversely proportional to frequency.

C. RADIATED SUSCEPTIBILITY

There are four basic phenomena of EMC issues; Figure 4 visually explains all four sub-problems. The squiggly arrow/ single arrow determines what direction the RF is being propagated. This paper will focus on radiated susceptibility (one of the four sub-problems which is labeled (b) in Figure 4).



(a) Radiated Emissions; (b) Radiated Susceptibility; (c) Conducted Emissions; (d) Conducted Susceptibility.

Figure 4. The Four Basic EMC Sub-problems. Source: Paul (2006, 5).

The unintentional propagation of the RF spectra from other electrical devices that can affect one's electronic device is called RS. The DoD and industry must safeguard the operator(s) from any electronic device being used. This is the main reason why the DoD and industry conduct such RS/Immunity testing.

1. Modulations and Schemes

There are a variety of different types of modulation schemes that both DoD and industry use. These basic modulations are the following: AM, Continuous Wave Modulation (CW), FM, and Pulse Modulation (Pulse). One must understand these modulations to conduct testing in accordance with (IAW) military and industry test standards. The following is a brief overview of the basic modulations and schemes so that we can interpret the difference between military and industry test standards. One can convert from the time domain to the frequency domain using Fourier Analysis, in order to better visualize the modulation and schemes.

a. Amplitude Modulation

Amplitude Modulation is the modulation of the amplitude of RF signals to be propagated through space. Figure 5 demonstrates this in the time domain, the left most side of the figure. The RF carrier signal is being modulated in amplitude, and forms two distinct sinusoidal AM envelops. In the frequency domain, the carrier frequency is the middle frequency, denoted as Fc. The side bands are the AM envelops, which can each be 25 % of the power from the carrier frequency. This holds true only if the modulation index is set to 100%.

Modulation Index is a modulation scheme for AM, RF signals. It is intended to shape the RF signal's spectra and produce higher power of up to a magnitude of 1.5 times more of the AM, RF signal with a 100% modulation. Mathematically, modulation index is the ratio between the amplitudes of both: the RF signal envelop peak and the un-modulated signal.

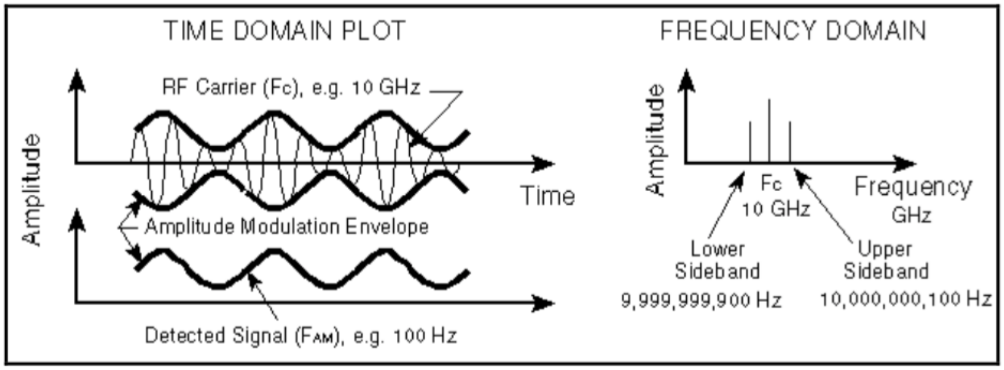


Figure 5. Sine Wave Modulated RF Signal (AM). Source: Avionics Department (2013, 2-11.1).

b. Continuous Wave Modulation

Continuous Wave is an individual sinusoidal RF signal to be propagated through space. The signal has a specific amplitude without varying. The signal has no modulation associated with it. Figure 6 shows it in the time domain, left most side of the figure. The signal is a sinusoidal, un-modulated RF signal. In the Frequency domain, the sinusoidal, un-modulated RF signal has only one peak. The MATLAB code for Figure 6 is located in the Appendix A.

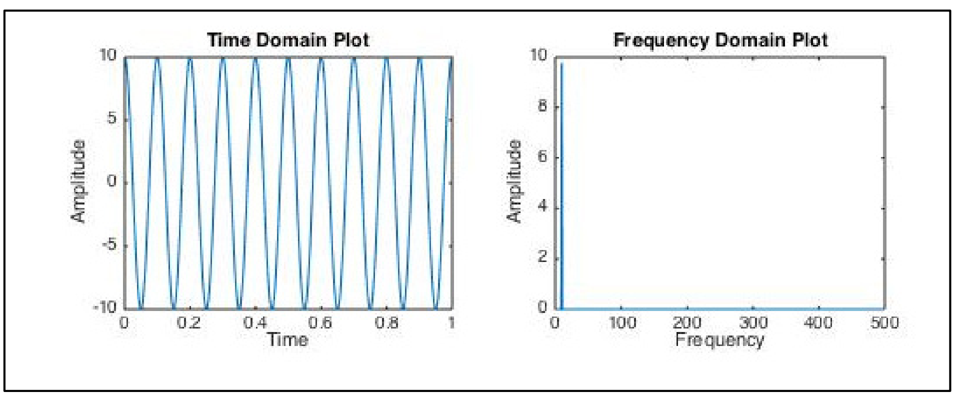


Figure 6. Cosine Wave Modulated RF Signal CW

c. *Frequency Modulation*

Frequency Modulation is the modulation with respect to time of RF signals to be propagated through space. Figure 7 shows the RF signal being modulated with respect to time in the time domain plot. It has distinct oscillations at different time periods from t1 to t4, but in the frequency domain, one can determine the different peaks in frequency, which represents the distinct signal spectra from the time domain plot.

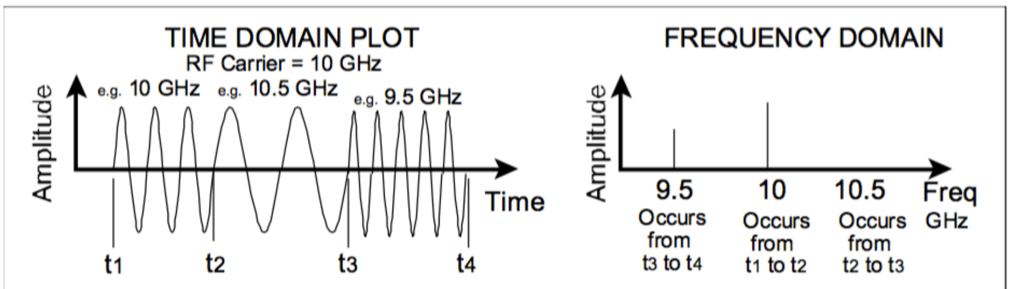


Figure 7. RF Signal with Frequency Modulation. Source: Avionics Department (2013, 2-11.1).

d. *Pulse Modulation*

Pulse Modulation is a simulated AM, RF signal to be propagated through space, (which resembles a pulse train). Figure 8 provides a visual representation of how a pulse signal mimics an AM signal in the time domain with an associated duty cycle.

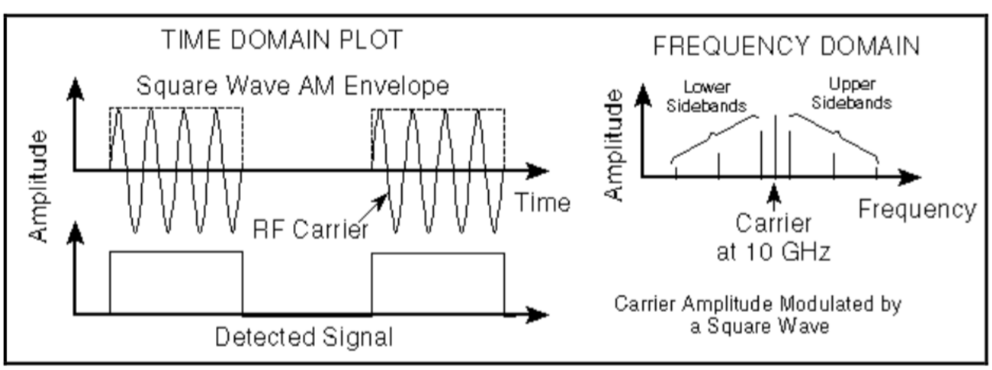


Figure 8. Square Wave Modulated RF Signal (50% Duty Cycle). Source: Avionics Department (2013, 2-11.1).

e. Duty Cycle

Duty Cycle phenomena are for pulsating modulations as described in Figure 9. It can be characterized by a square wave, CW signal or a Pulse signal.

"Pulses at a fixed interval of time arrive at a rate or frequency referred to as the pulse repetition frequency (PRF) of so many pulse per second. Power measurements are classified as either peak pulse power, Pp, or average power, Pave" (Avionics Department 2013, 2-5.1).

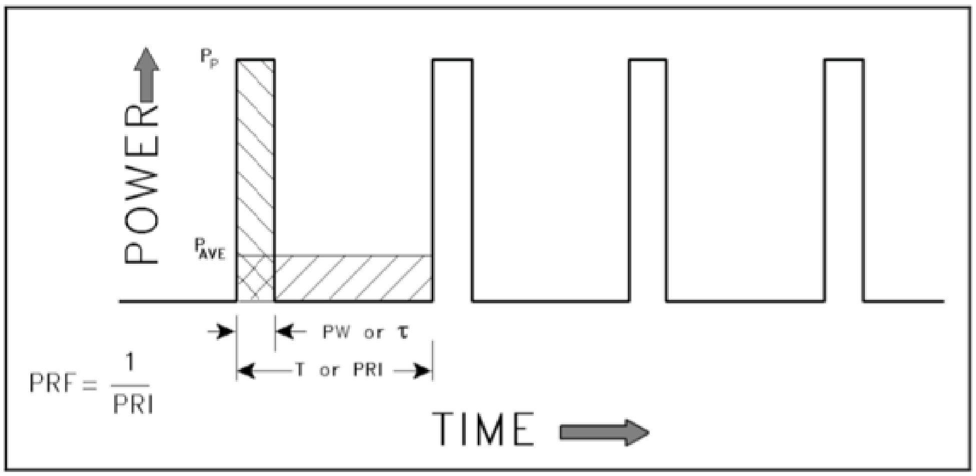


Figure 9. RF Pulse Train. Source: Avionics Department (2013, 2-5.1).

2. Operating Environment

The operating environment is the environment/vicinity to where compatibility issues can exist within a few meters or large distances depending on frequency range, modulations and field strength, during peace time and in theatre, between systems and subsystems. Electronic devices can create susceptibilities to other equipment or be susceptible to other equipment within its vicinity if EMC is not addressed.

The operating environment between industry and DoD are similar in some ways yet different in others. Both, industry and DoD, mitigate RFI/EMI from the operating environment to safeguard the user by conducting EMC/E3 hardening. According to Paul, A system is electromagnetically compatible with its environment if it satisfies three criteria:

1. It does not cause interference with other systems.

2. It is not susceptible to emissions from other systems.

3. It does not cause interference with itself. (Paul 2016, 2)

From the mid-1990s until today, everyone across America had to convert from their old television sets to flat digital displays. It was the end of analog television broadcasting. Such movement improved the allocation of broadcasting spectrum and made room for digital broadcasting like cellular mobile phones and cable TV.

The whole globe follows the International Telecommunications Union (ITU) guidelines of the RF spectrum for use in industry. The ITU has three distinct regions of governance as shown in Figure 10.

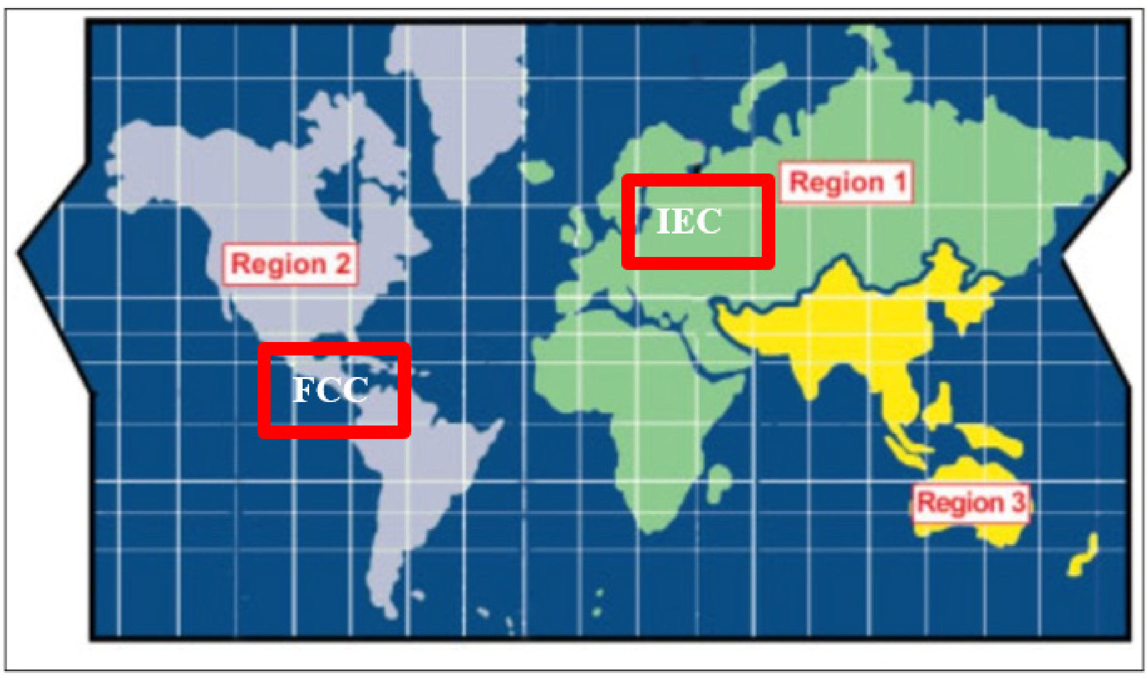


Figure 10. International Telecommunications Union Regions. Adapted from Department of the Navy (2010, 5).

For example, if one reaches for one's own mobile phone they can see two distinct registered trademark symbols: that of the IEC and that of the Federal Communications Commission (FCC) located on the back of the electronic device. If the electronic device only has one symbol, either IEC or FCC, that device complies with the designated RF spectrum assigned by the ITU for the specific region.

One is to follow the specific regions associated with the region from the ITU for mobile phone operation of the RF Spectrum. Region 1 follows the guidelines of the ITU and guidelines of the IEC. While Region 2 follows the guidelines of the ITU and guidelines of the FCC. Region 3 is not included in this thesis. The regions set forth by the ITU is to mitigate clutter in the RF spectrum for industry.

Unfortunately, The ITU did not mitigate RF spectrum clutter for the DoD. Thus, at the time, third generation (3G) wireless telecommunication became a negative impact to the DoD in a specific frequency range.

> 3G impacts all of DoD spectrum utilization was the initiative from the May 2000 World Radio Conference, which identified 1710–1885 MHz and 2500–2690 MHz as two of the candidate bands for 3G systems to promote worldwide harmonization. In the United States, the range 1755–1850 MHz is an exclusive federal government band. The DoD uses the 1755–1850 MHz frequency span to support critical systems. (Department of the Navy 2010, 10)

The operating environment is comprised of DoD and industry frequency allocations of systems throughout the RF spectrum as shown in Figure 11. From Figure 11, one can see how the clutter of the RF spectrum between the *military uses* and *competing uses* can affect each other by causing RFI susceptibilities. The 3G spectrum clutter is highlighted in red box.

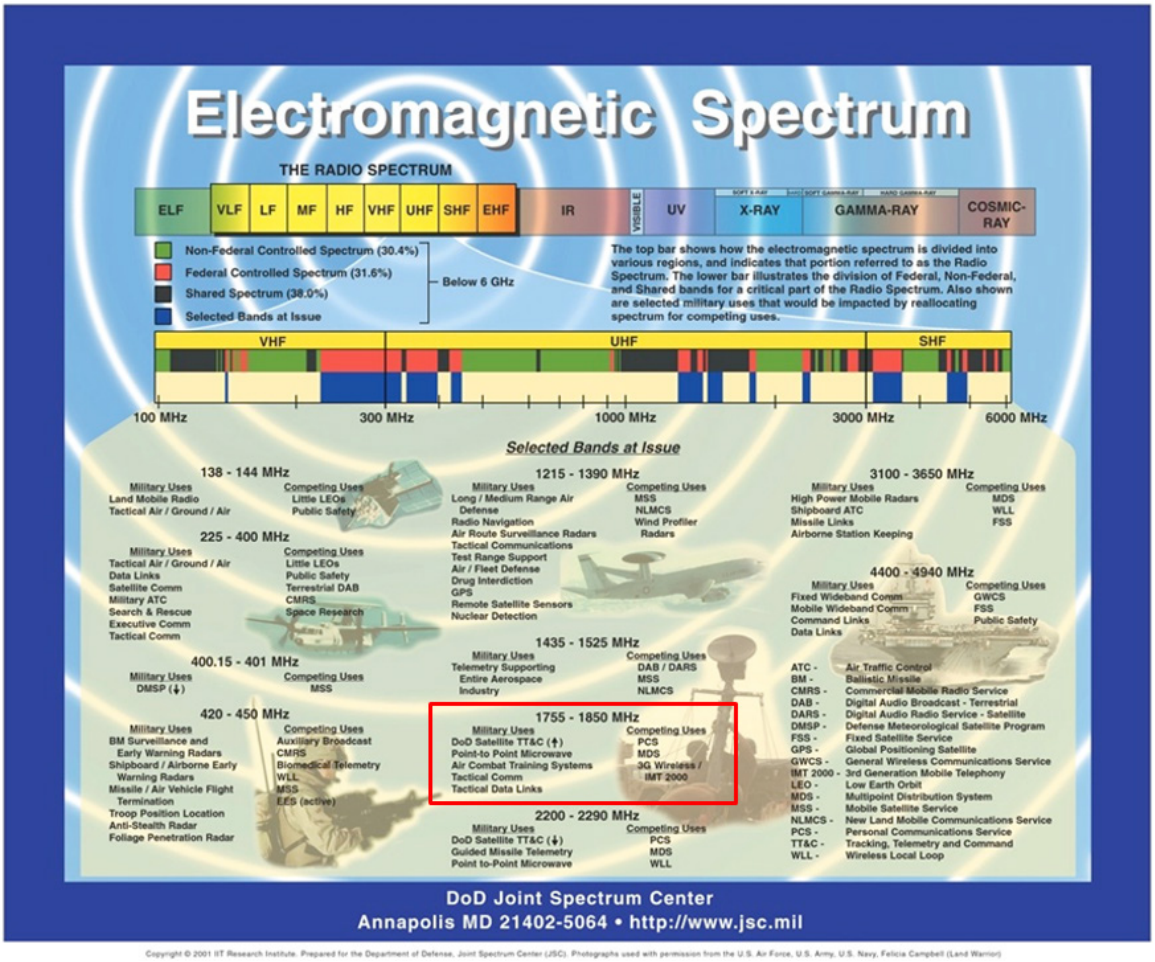


Figure 11. The Electromagnetic Spectrum. Source: Defense Acquisition University (2017).

As manmade transmitters and other equipment are in close proximity of each other EMI/RFI effects are known to exist. "Military tactics, which involve the use of a mix of different system equipment in different phases, contingencies and maneuvers in operations tend to create a very complex and dynamic EM environment. The battlefield EM environment is constituted by a very large number of electromagnetic emitters and receptors within a limited geographical area" (Singh 1995).

As the DoD pursues future capabilities and commercial telecommunications keeps evolving into 4G, 5G and other future communication systems, mitigation of the RF spectrum is to be taken into consideration. An example of future capabilities for the DoD is the net centric Global Information Grid (GIG) as shown in Figure 12, which encapsulates assets in ground, sea, air and space. Thus, industry and DoD assets must operate in harmony.

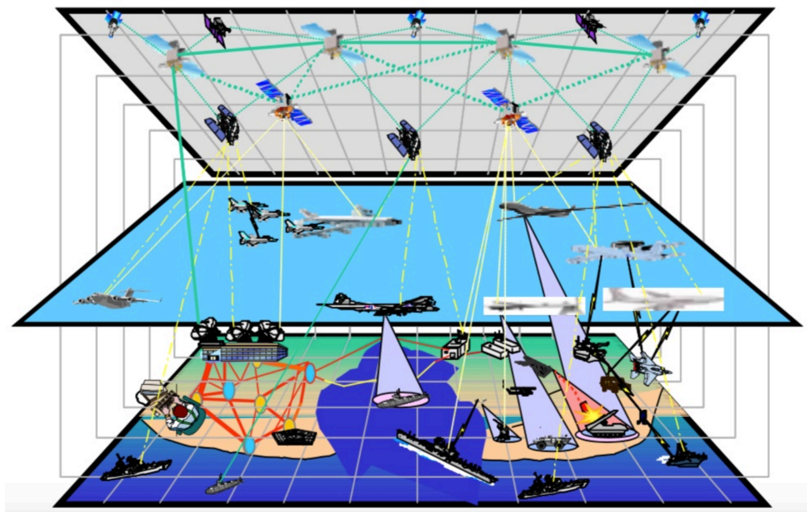


Figure 12. Global Information Grid. Source: DoD (2008, 14).

This chapter showed key terminology and various modulations in order to understand DoD and industry test standards. Both, DoD and industry, must mitigate RF spectrum clutter to withstand RFI/EMI in order to have a fully functioning product. In this case any overlap/clutter of the frequency range can potentially cause susceptibilities to assets from industry and the DoD within the operating environment.

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III. INDUSTRY IMMUNITY TESTING

Now that the common terminology has been established from Chapter II, and RFI incidents, called susceptibilities, from Chapter I were introduced, we can dive into the industry standards to validate the operating environment that COTS must overcome in order to mitigate RFI. The following factors will be used as the main factors for comparison between DoD and industry RS/Immunity test methodologies: frequency range, field strength, modulation schemes, and dwell time.

A. INDUSTRY STANDARDS

In industry, the IEC standards are taken into consideration because any manufacturer must comply with IEC standards to promote and sell their products globally. The IEC is well established with over 30 nations including the United States of America. There are many textbooks that reference different forms of radiated electromagnetic field immunity testing. The industry standard IEC-61000-4-3 or sometimes commonly referenced as IEC 1000-4-3 is the overarching standard for testing.

> Radiated electromagnetic field immunity. IEC 1000–4-3 is concerned with the immunity of electronic equipment when subjected to radiated electromagnetic fields, such as those generated by radio transceivers or any other device that will generate continuous wave, radiated electromagnetic energy. IEC 1000–4-3 establishes a test procedure and test levels that can be used as a common reference against which to test equipment. The testing frequency range is between 80–1000 MHz with 80% AM modulation at 1 kilo Hertz (kHz). The severity of the RF fields varies from 1 to 10 volts per meter (V/m) depending on the type of equipment and the operating RF environment. (White 1997, I-2)

This thesis will focus on two distinct industry immunity test methodologies: IEC-61000-6-1 (IEC 2005a) and IEC-61000-6-2 (IEC 2005b), both standards are for immunity test requirements for commercial equipment.

B. IEC-61000-6-1

The industry standard, IEC-61000-6-1, *Immunity for Residential, Commercial and Light Industrial Environments* (IEC 2005a), this environment entails a basic city infrastructure from rural to urban areas, for example from downtown of a city to the outer city limits and everything in between. It entails household electronic equipment like desktop computers and cellphones.

Under IEC-61000-6-1 (IEC 2005a), for immunity tests conducted, the EUT will be tested on a port-to-port or one-cable-at-a-time methods as required. Table 1 displays the four previously mentioned factors for immunity testing: frequency range, field strength, modulation scheme, and dwell time which will be used as the main factors for comparison between DoD and industry RS/Immunity test methodologies. This testing would be used for devices such as soldier mounted mobile electronic devices, e.g., communication gear and other hand held mobile devices.

Table 1. Immunity-Enclosure Ports. Adapted from IEC (2005a, 23).

Environment	**Frequency Range**	**Field Strength**	**Modulation**	**Dwell Time**	**Applicability**
RF-Electro-magnetic field (EMF)	80 MHz to 1 GHz	3 V/m	AM 80 % @ 1 kHz	Not specified	Applicable only to apparatus containing devices susceptible to magnetic fields
RF-EMF	1.4 GHz to 2 GHz	3 V/m	AM 80 % @ 1 kHz	Not specified	Applicable only to apparatus containing devices susceptible to magnetic fields
RF-EMF	2 GHz to 2.7 GHz	1 V/m	AM 80 % @ 1 kHz	Not specified	Applicable only to apparatus containing devices susceptible to magnetic fields

C. IEC-61000-6-2

The industry standard, IEC-61000-6-2 *Immunity for Industrial Environments* (IEC 2005b), entails the Industrial, Scientific and Medical (ISM) band as well as broadcast systems: Transmitters, antennas and associated cables. It can also include class 5 or higher for truck sizes. (*Truck classes* are determined based on weight by the Department of Transportation and is beyond the scope for this thesis.)

Under IEC-61000-6-2 (IEC 2005b), for immunity tests conducted, the EUT will be tested on port-to-port or by the one-cable-at-a-time method. Table 2 has a higher field strength than the previous IEC standard demonstrating that industrial environments are harsher than residential and light industrial environments in the lower frequency range. This testing would be used for devices such as vehicle mounted electronic devices, e.g., communication gear and RADAR that could be installed into tanks and MRAPS.

Table 2. Immunity-Enclosure Ports. Adapted from IEC (2005b, 21).

Environment	Frequency Range	Field Strength	Modulation	Dwell Time	Applicability
RF-Electro-magnetic field (EMF)	80 MHz to 1 GHz	10 V/m	AM 80 % @ 1 kHz	Not specified	Applicable only to apparatus containing devices susceptible to magnetic fields
RF-EMF	1.4 GHz to 2 GHz	3 V/m	AM 80 % @ 1 kHz	Not specified	Applicable only to apparatus containing devices susceptible to magnetic fields
RF-EMF	2 GHz to 2.7 GHz	1 V/m	AM 80 % @ 1 kHz	Not specified	Applicable only to apparatus containing devices susceptible to magnetic fields

This chapter showed the frequency range, field strength, modulation scheme and dwell time that products in industry must comply with in order to overcome susceptibilities. Industry must take into consideration any susceptibility encountered during this testing in order to insure quality and reliability of their product for the consumer.

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IV. MILITARY E3 TESTING

This chapter describes how the DoD mitigates EMC by testing to the E3 military standards. The DoD tests to a broader operating environment in order to be effective in all conflicts around the world. From urban regions to desolate deserts, the DoD is capable to adapt to all environments.

A. DoD MILITARY STANDARDS

Before military standard (MIL-STD)-461 and its revisions, each DoD agency detailed its own specific EMI/RFI/EMC mitigation specifications. These EMI/RFI/EMC mitigation specifications were not compatible with other DoD agencies and thus could have caused other incidents related to EMI/RFI. Table 3, from Mazzola (2009), shows the numerous specifications prior to consolidation.

Table 3. EMI Specification History—Pre-MIL-STD-461. Source: Mazzola (2009, 2).

SPEC. NUMBER	TITLE	TYPE	ERA
MIL-I-6181	Interference Control Requirement	Co-ordinated	06/1950-05/1987
MIL-S-10379	Suppression, Radio Interference, General Requirements, Vehicle	Co-ordinated	07/1951-09/1971
MIL-S-12348	Suppression, Radio Interference, General Requirements for Railway Rolling Stock and Maintenance Way Equipment	Co-ordinated	08/1958-09/1971
MIL-I-43121	Interference Reduction for Electronic Hand Tools	Co-ordinated	12/1962-09/1971
MIL-E-55301	Electromagnetic Compatibility	Army	04/1965-03/1968
MIL-I-16910	Interference measurement, Electromagnetic, Methods and Limits	Navy	08/1954-11/1967
MIL-I-17623	Interference Measurement, Electromagnetic, Methods and Limits For Electric Office Machines, Printing and Lithographic Equipment	Navy	09/1953-12/1967
MIL-STD-826	Interference Control Requirement, Aeronautical Equipment	Air Force	06/1958-01/1962

B. MIL-STD-461G

The interdepartmental/inter-agency EMI/EMC specifications from Table 3 transformed into *MIL-STD-461*. Currently, the DoD conducts E3 testing IAW MIL-STD-461G (DoD 2015), *Radiated Susceptibility (RS) 103*, electric field testing. The RS 103 E3 testing is valid for subsystems. A family of subsystems can be interconnected and integrated into platforms for ground systems for Army, Navy and Air Force.

The MIL-STD-461G (DoD 2015), *Radiated Susceptibility (RS) 103,* electric field testing, section entails the test method, purpose, and applicability to many DoD programs. In this thesis, we are only interested in its applicability to ground systems. The MIL-STD-461G (DoD 2015), states that while conducting RS 103, one must verify that the output signal is checked from now on, in order to verify the RF signal being radiated to the EUT.

> Starting in MIL-STD-461G, verification of the presence of correct modulation by monitoring output signals is specified in the CS114 and RS103 sections. Correct modulation is essential for evaluating EUT performance. (DoD 2015)

In Section 4.3.10.4.2, *Modulation of susceptibility signals*, "susceptibility test signals for conducted susceptibility (CS) 114 and RS103 shall be pulse modulated (on/off ratio of 40 decibel (dB) minimum) at a 1 kHz rate with a 50% duty cycle" (DoD 2015, 204). Other modulations schemes are encouraged for use too. Susceptibilities are documented while the test is being conducted. Most of the time, susceptibilities can become classified due to the security classification guide for that particular system.

Table 4 entails the maximum field strength level for Army, Navy and Air Force ground system platforms. This thesis is focused on the seventh column titled Ground from Table 4, which is boxed in red. 30 MHz -18 GHz is the requirement. From 2 MHz to 30 MHz and 18 GHz to 40 GHz is optional for testing.

Table 4. RS103 Limit. Source: DoD (2015, 145).

PLATFORM / FREQ. RANGE		LIMIT LEVEL (VOLTS/METER)							
		AIRCRAFT (EXTERNAL OR SAFETY CRITICAL)	AIRCRAFT INTERNAL	ALL SHIPS (ABOVE DECKS) AND SUBMARINES (EXTERNAL)*	SHIPS (METALLIC) (BELOW DECKS)	SHIPS (NON-METALLIC) (BELOW DECKS) **	SUBMARINES (INTERNAL)	GROUND	SPACE
2 MHz	A	200	200	200	10	50	5	50	20
↓	N	200	200	200	10	50	5	10	20
30 MHz	AF	200	20	-	-	-	-	10	20
30 MHz	A	200	200	200	10	10	10	50	20
↓	N	200	200	200	10	10	10	10	20
1 GHz	AF	200	20	-	-	-	-	10	20
1 GHz	A	200	200	200	10	10	10	50	20
↓	N	200	200	200	10	10	10	50	20
18 GHz	AF	200	60	-	-	-	-	50	20
18 GHz	A	200	200	200	10	10	10	50	20
↓	N	200	60	200	10	10	10	50	20
40 GHz	AF	200	60	-	-	-	-	50	20

KEY: A = Army
N = Navy
AF = Air Force

* For equipment located external to the pressure hull of a submarine but within the superstructure, use SHIPS (METALLIC)(BELOW DECKS)

** Equipment located in the hanger deck of Aircraft Carriers

Table 5 is a copy of that column but includes the four main factors, e.g., frequency range, field strength, modulation scheme and dwell time. Under MIL-STD-461G (DoD 2015), the EUT is subject to the following non-ionizing radiation for a minimum dwell time of three seconds. The field strength varies across the frequency range, for example 50 V/m from 2 MHz – 40 GHz for Army Ground, 10 V/m from 2 MHz – 1,000 MHz (1 GHz), and then 50 V/m from 1 GHz – 40 GHz for Air Force and Navy. One can note that above 1 GHz all three platforms have the same field strength of 50 V/m and the modulation and schemes is the same throughout the frequency range.

Table 5. Ground System Field Strength for the Various DoD Platforms. Adapted from DoD (2015, 135).

Frequency Range	**Platform**	**Field Strength for Ground systems (V/m)**	**Modulations**	**Dwell Time**
2 MHz–30 MHz	Army	50	AM 30–80% modulation index, Pulse 1 kHz tone, 50% duty cycle, and CW.	Minimum dwell time of 3 seconds
	Navy	10		
	Air Force	10		
30 MHz–1 GHz	Army	50		
	Navy	10		
	Air Force	10		
1 GHz–18 GHz	Army	50		
	Navy	50		
	Air Force	50		
18 GHz–40 GHz	Army	50		
	Navy	50		
	Air Force	50		

C. MIL-STD-464C

Another test that the DoD conducts for E3 testing is External RF Electromagnetic Environment (External RF EME) IAW MIL-STD-464. External RF EME is for system's E3 testing. This can include complete platforms, systems of systems, of ground systems for Army, Navy and Air Force.

Under MIL-STD-464C (DoD 2010b), there is a section for *External Radio Frequency Electromagnetic Environment (External RF EME)*. It has a frequency range from 0.01 MHz up to 50 GHz with field strength that vary within different RF bands. External RF EME is a test that uses various high power transmitters and can be combined with RS103 criteria to assess the system, subsystem and associated cabling for that environment.

Thus, it is similar to the industry immunity testing in that all tests illuminate the EUT. Modulation schemes (e.g., CW, AM, and Pulse modulations) are utilized in E3 testing to mimic those modulations encountered in real world environments. The MIL-STD-464C (DoD 2010b), makes a specific point that AM at 1 kHz tone, with a 50% duty cycle has been found to be the worst-case modulation for inducing susceptibilities. The standard also states that other modulation schemes are acceptable for testing in order to provide other information to programs to assess any susceptibilities encountered during testing.

Frequency scanning and thresholds for susceptibilities are similar to that of MIL-STD-461G (DoD 2015). Unless specified by the program's authority to tailor the frequency range, modulation schemes, and/or field strength for a test, it is to remain IAW the MIL-STD-464C (DoD 2010b).

Table 6 is that of MIL-STD-464C (DoD 2010b) and its associated field strength in peak and average values. This thesis is only focusing on the average values for comparison to industry.

Table 6. Maximum External EME for Ground Systems. Source: DoD (2010b, 15).

Frequency Range (MHz)		Electric Field (V/m – rms)	
		Peak	Average
0.01	2	73	73
2	30	103	103
30	150	74	74
150	225	41	41
225	400	92	92
400	700	98	98
700	790	267	267
790	1000	284	267
1000	2000	2452	155
2000	2700	489	155
2700	3600	2450	219
3600	4000	489	49
4000	5400	645	183
5400	5900	6146	155
5900	6000	549	55
6000	7900	4081	119
7900	8000	549	97
8000	8400	1095	110
8400	8500	1095	110
8500	11000	1943	139
11000	14000	3454	110
14000	18000	8671	243
18000	50000	2793	76

MIL-STD-464C (DoD 2010b), differs from the previous standard, MIL-STD-464A (DoD 2002), in that the frequency range goes beyond 40 GHz to 50 GHz. MIL-STD-464C (DoD 2010b), varies in field strength across the frequency range too, instead of 50 V/m across 2 MHz to 40 GHz.

The most recent standard, MIL-STD-464C (DoD 2010b), increased in frequency and field strength to adapt to the compatibility issues within the DoD within the past 8 years, whereas industry has not undergone such change. Table 7 entails the four main factors, such as frequency range, field strength, modulation scheme, and dwell time IAW MIL-STD-464C (DoD 2010b).

> U.S. platforms and systems and their associated transmitters and antennas were evaluated and used to create the various EME tables found in parts 2C

through 10 that lead up to the worst-case tables of MIL-STD-464. Potential hostile (high power microwave) HPM systems also were used to derive the EME levels in part 8. The transmitter/antenna characteristics were collected from databases and models residing at the Defense Information Systems Agency (DISA)/Joint Spectrum Center (JSC) as well as manufacturers' data sheets, technical manuals, and EME survey reports. (DoD 2010a, 16)

Table 7. Maximum External EME for Ground Systems. Adapted from DoD (2010b, 15).

Frequency (MHz)	Field Strength (V/m)	Modulation and Schemes	Dwell Time
0.01-2	73	AM 1 kHz tone, 30–80% modulation index, Pulse 1 kHz tone, 50% duty cycle, CW and FM.	Up to 3 minutes
2-30	103		
30-150	74		
150-225	41		
225-400	92		
400-700	98		
700-790	267		
790-1000	267		
1000-2000	155		
2000-2700	155		
2700-3600	219		
3600-4000	49		
4000-5400	183		
5400-5900	155		
5900-6000	55		
6000-7900	119		
7900-8000	97		
8000-8400	110		
8400-8500	110		
8500-11000	139		
11000-14000	110		
14000-18000	243		
18000-50000	76		

In summary, this chapter showed how the DoD has evolved over the years. The DoD consolidated most of its EMC standards into two distinct E3 testing standards that where introduced here in this chapter. Thus, the DoD also takes into consideration the frequency range, field strength, modulation scheme and dwell time to mitigate RFI.

V. COMPARISON AND ASSOCIATED RISK

After reviewing the RS/Immunity test standards from the previous two chapters, one now has a better understanding of the criteria associated between industry and the DoD. In this chapter, this thesis will make a comparison among both industry and DoD test standards and review the DoD's view of risk associated with COTS use.

A. RS/IMMUNITY COMPARISON

Table 8 depicts the different industry and DoD test standards addressed. Note that both IEC standards are split between a residential to light industrial to a heavy industrial equipment, whereas within the DoD it is based on platform and what agency it will be designed for. Thus, COTS equipment can be used as a Class A or Class B electronic devices in industry and they can also be a subsystem or a full system within the DoD. This thesis will focus on a full system that uses COTS.

Table 8. RS/Immunity Test Standards

TEST STANDARD **Name**	**TITLE**	**TYPE**
IEC-61000-6-1(IEC 2005a)	Immunity for residential, commercial, light industrial environments	Industry Immunity Testing
IEC-61000-6-2 (IEC 2005b)	Immunity for industrial environments:	Industry Immunity Testing
MIL-STD-461G (DoD 2015) RS 103, electric field	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment	DoD E3 RS Testing
MIL-STD-464C (DoD 2010b) External RF EME	Electromagnetic Environmental Effects Requirements for Systems	DoD E3 RS Testing

As can be seen from Table 1 and Table 2, both industry standards are below the field strengths of MIL-STD-461G (DoD 2015) for Army ground, but IEC-61000-6-2 (IEC 2005b) field strength is similar for Navy and Air Force below 1 GHz at 10 V/m. The industry standards have a different modulation scheme, AM of 80% duty cycle, which provides a lower stress level to electronic equipment as compared to MIL-STD-461G (DoD 2015). The industry standards also require testing to be conducted at the ports and not on the subsystem or system as a whole, no full-body illumination. Industry standards also do not have a specific dwell time to test under, which makes it difficult to replicate or take into consideration a susceptibility occurred at a specific time, dwell time.

For External RF EME IAW MIL-STD-464C (DoD 2010b), the amount of time, also known as a dwell time, to provide the EUT with the proper non-ionizing radiation exceeds the time allowed from MIL-STD-461G (DoD 2015) for subsystems that undergo testing. For example, system A can perform functionality checks within one minute. For External RF EME, the transmitter can provide the field strength, non-ionizing radiation, for up to one and half minutes. See Table 11 for industry, IEC, standards do not specify. This is crucial because the frequency response from the EUT is unique.

External RF EME is a more stringent standard as compared to MIL-STD-461G (DoD 2015). Therefore, it is also more stringent than IEC-61000-6-1 (IEC 2005a) and IEC-61000-6-2 (IEC 2005b). External RF EME is a much harder standard to meet. Engineers and designers must adequately master E3 hardening techniques to withstand the susceptibilities encountered during testing and in the military operating environment. Note that MIL-STD-464C (DoD 2010b), has higher field strengths and wider frequency range than the other standards.

Table 9 summarizes the main comparison between industry and DoD RS/Immunity test standards and methodologies. The four distinct factors for testing are dwell time, field strength, modulation schemes and frequency range.

Table 9. Main Comparison for RS Testing and Methodologies between Industry and DoD Standards

	INDUSTRY		DoD	
FACTORS	**IEC-61000-6-1 (IEC 2005a)**	**IEC-61000-6-2 (IEC 2005b)**	**MIL-STD-461G (DoD 2015)**	**MIL-STD-464C (DoD 2010b)**
Dwell Time	Not Specified	Not Specified	Greater than 3 seconds	Up to 3 minutes
Field strength (V/m) Frequency Dependent	3 or 1 (V/m)	10, 3, or 1 (V/m)	10 or 50 (V/m)	Varies within 41 – 267 (V/M)
Modulation Schemes	AM 80% Modulation Index, 1 kHz tone	AM 80% Modulation Index, 1 kHz tone	AM 1 kHz tone, 30–80% modulation index, Pulse 1 kHz tone, 50% duty cycle, and CW	AM 1 kHz tone, 30–80% modulation index, Pulse 1 kHz tone, 50% duty cycle, CW and FM
Frequency Range	80 MHz – 2.7 GHz	80 MHz – 2.7 GHz	2 MHz – 40 GHz	0.01 MHz – 50 GHz

B. DoD ASSESSMENTS ON GROUND SYSTEMS

The DoD has assessed the need to verify and validate COTS or commercial items for use.

> In selecting commercial items (CI) for military purposes one must relate the characteristics of the anticipated electromagnetic environment (EME) to the characteristics of the equipment under consideration. In order to determine whether a CI is adequate for a particular military application, it is necessary to determine which commercial standards are applicable to the equipment, evaluate whether the commercial standards are adequate for the intended applications, and if not, to determine which additional requirements can be imposed, and what they are. (DoD/Industry 2001, 7)

The DoD developed a flow chart to easily trace how the intended COTS item will function within DoD agencies. The flow chart determines if the COTS item can meet its intended mission requirement. What is the risk associated with the COTS item and is the risk acceptable? If the risk is not acceptable, can the COTS item be modified, and if so does it need additional testing? See the flow chart in Figure 13.

Some DoD assets do not need to go through the rigorous E3 testing as prescribed in MIL-STD-461G (DoD 2015). Such items can be DoD-furnished equipment such as diagnostic tools in a hanger, machine shop, or other depot related equipment. Other equipment can include laptops and printers in an office setting of a military installation.

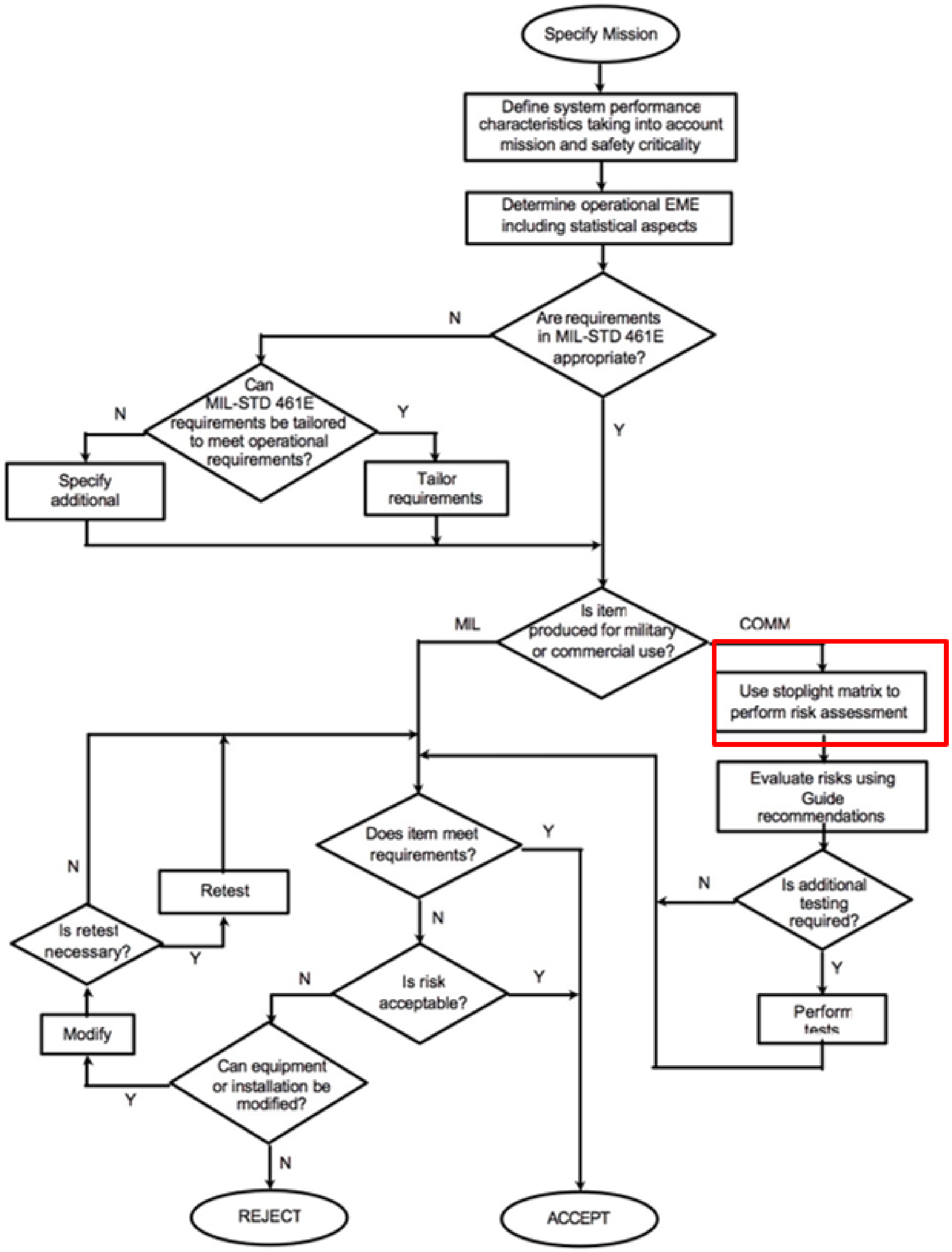

Figure 13. Chart for the Procurement of Electromagnetically Compatible Systems or Equipment. Source: DoD/Industry (2001, 9).

C. RISK TABLE

The stoplight matrix, highlighted by the red text box, referred to on the right side of Figure 13 is shown below in Figure 14. It shows the associated risk with the industry standards, as the DoD assessed them. Table 10 was created reproducing the risks associated with the *RS103* box, as can be found using the legend.

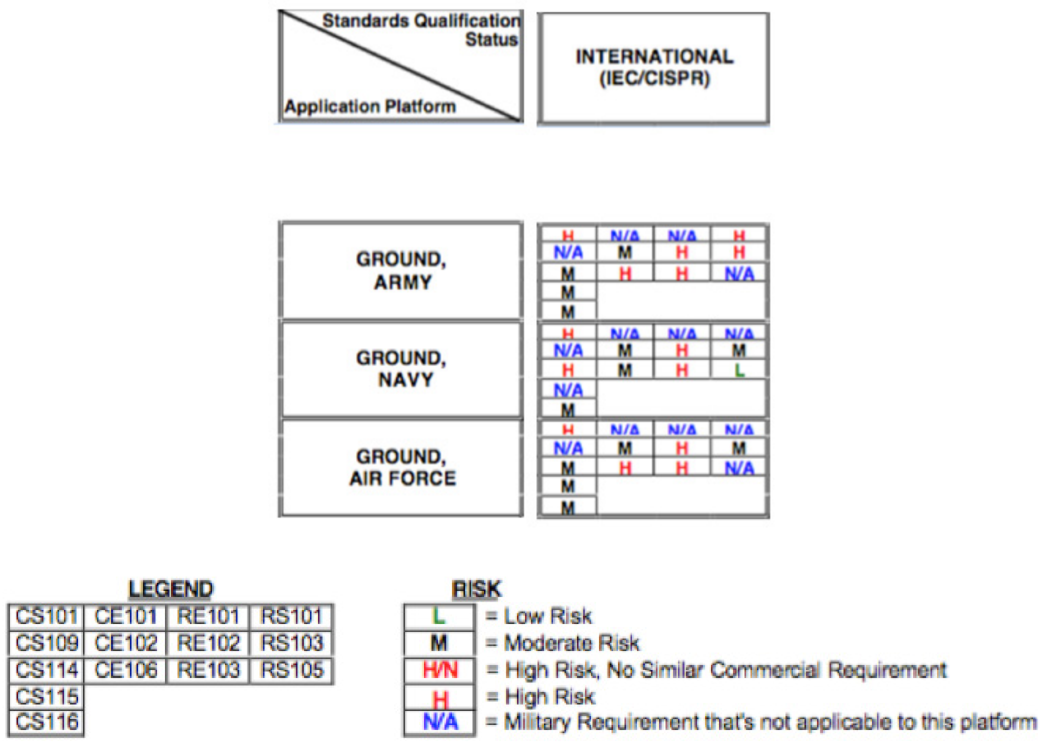

Figure 14. Assessment of Commercial Standards vs. MIL-STD-461E. Source: DoD/Industry (2001, 11).

Table 10. Risk Associated with IEC Standards. Adapted from DoD/Industry (2001, 11).

Ground System	IEC RISK
Army Ground systems	Level 5: High Risk
Air Force and Navy Ground systems	Level 3: Moderate Risk

As can be seen in Table 10, it has been determined that there is risk associated with using COTS items, tested to industry standards, in the military environment. For Army ground systems, COTS items tested to only industry standards are considered unacceptable due to high risk. Although COTS items are tested to industry standards they must be further assessed in order to meet the demands for Army use. “To reduce or eliminate the initially stated ‘risk’ level given, one must actually make a technical analysis of the differences in instrumentation, measuring technique and limits and evaluate their consequences” (DoD/Industry 2001, 8).

D. RISK ASSESSMENT CODE

The risk assessment code (RAC) is the basis of quantitative and qualitative criteria analogies so that there is a common interface for all DoD program assets to abide by for risk assessment IAW contractual constraints between the Program Management Office (PMO) and defense contractors. Recall that qualitative criteria falls under the *Design Phase* and quantitative criteria aligns more to the *Production Phase* from Figure 3 Bathtub Concept.

This standardization of risk entails a probability and severity level of potential flaws to a DoD program. It can be tailored for EMI/RFI susceptibilities under DoD E3 testing. The following figures, Figure 15 and Figure 16, give the criteria that both probability and severity levels are bounded by.

SEVERITY CATEGORIES		
Description	**Severity Category**	**Mishap Result Criteria**
Catastrophic	**1**	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M.
Critical	**2**	Could result in one or more of the following: permanent partial disability,injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	**3**	Could result in one or more of the following: injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M.
Negligible	**4**	Could result in one or more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K.

Figure 15. Severity Categories. Source: DoD (2012b, 11).

PROBABILITY LEVELS			
Description	**Level**	**Specific Individual Item**	**Fleet or Inventory**
Frequent	**A**	Likely to occur often in the life of an item.	Continuously experienced.
Probable	**B**	Will occur several times in the life of an item.	Will occur frequently.
Occasional	**C**	Likely to occur sometime in the life of an item.	Will occur several times.
Remote	**D**	Unlikely, but possible to occur in the life of an item.	Unlikely, but can reasonably be expected to occur.
Improbable	**E**	So unlikely, it can be assumed occurrence may not be experienced in the life of an item.	Unlikely to occur, but possible.
Eliminated	**F**	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.	Incapable of occurence. This level is used when potential hazards are identified and later eliminated.

Figure 16. Probability Levels. Source: DoD (2012b, 11).

With the criteria from Figure 15 and Figure 16, the DoD conducts the risk assessment matrix as shown in Figure 17. Typically, most of the current DoD programs in sustainment are located within the bottom right of the matrix. Following under column Negligible 4 by rows Occasional (C), Remote (D) and Improbable (E) as designated by the blue text box. Thus, there is minimal risk for the sustainment posture of DoD assets that undergo the full acquisition life cycle.

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Figure 17. Sustainment Risk Assessment Matrix. Source: DoD (2012b, 12).

This chapter explained the differences between DoD and industry test standards. If susceptibilities are not properly evaluated and addressed; COTS can be considered a safety risk to the war fighter since it does not undergo a full acquisition life cycle. As can be seen in Table 9, the aforementioned factors are important due to susceptibility incidents as described in the scenarios in Chapter I, Section A.

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VI. CONCEPT OF THE OPERATING ENVIRONMENT

To proceed with this study and determine the baseline for RS/Immunity testing, a case study was conducted, which used analysis in order to determine the impact of different RS/Immunity testing between industry and DoD. The EUT consists of the basic components of most modern electronic systems which entail a power source, circuitry, chassis ground, and other sub components. Thus, the outcome is to come up with an adequate weapon system, EUT, so that the war fighter can conduct their mission effectively.

A. FACTORS FOR CASE STUDY

The previously mentioned four main factors will be analyzed against theoretical susceptibilities encountered to a representative but non-existing ground system. This example was used in order to keep the thesis unclassified. The four main factors entail the following:

1. Frequency in MHz
2. Modulation schemes (AM, FM, CW, Pulse) used as 1, 2, 3 and 4, respectively. 0.5 represents no modulation for some figures.
3. Dwell Time in seconds
4. Field Strength in V/m

B. PROCESSING THE INPUT VARIABLES

The following figures entail the input variables which are Modulation schemes (AM, FM, CW, and Pulse), Dwell Time in seconds, and Field Strength in V/m with respect to DoD and industry standards. These input variables are graphed against frequency to see how they can influence the EUT during RS/Immunity testing. Such influences can cause nuances, degradations or other forms of susceptibilities to the weapon system/EUT. The frequency response of the EUT is taken into consideration for all susceptibilities encountered between RS/Immunity testing between industry and DoD. It is best to discover susceptibilities while undergoing testing in a controlled environment, rather than to discover susceptibilities while in operational mode where the operator could get hurt.

1. Inputs for Industry Test Standards

Figure 18 displays the pseudo random generation of the four distinct modulation schemes. From the figure, note that the modulations (AM, FM, CW, and Pulse) are represented by integers 1, 2, 3 and 4, respectively. The 0.5 value represents no modulation for Figure 18. Thus, the modulations are randomly determined with respect to the frequency range. For RS/Immunity testing within industry, the only testing modulation is AM.

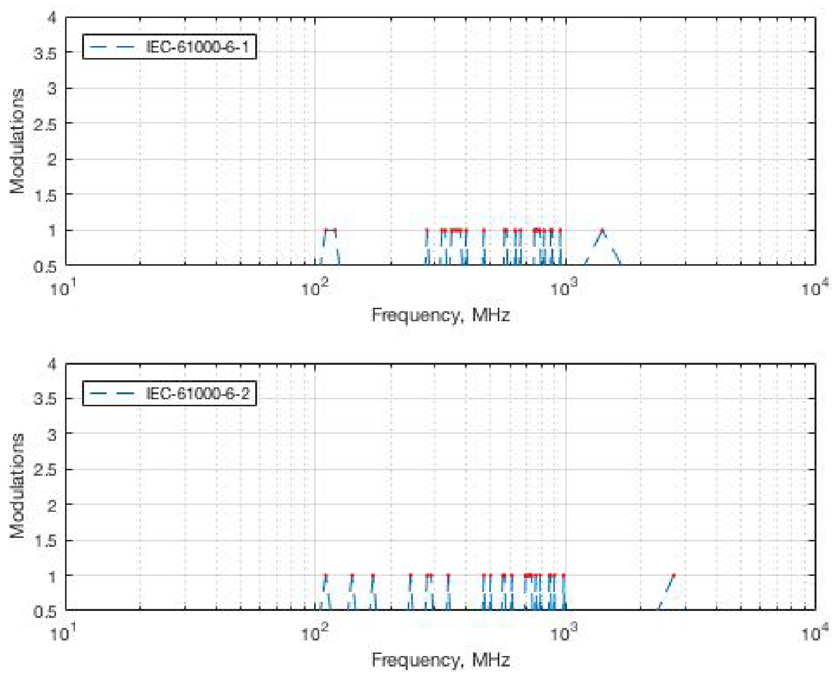


Figure 18. Industry Modulation AM

Figure 19 displays the pseudo random generation of the dwell time, from 1 second to 30 seconds of non-ionizing radiation to the EUT, while undergoing RS/Immunity testing. The dwell time, time duration for non-ionizing radiation to the EUT during testing, helps determine the time lapse for a susceptibility to occur, if any. This time lapse is called the frequency response of the EUT. The dwell time is randomly determined with respect to the frequency range.

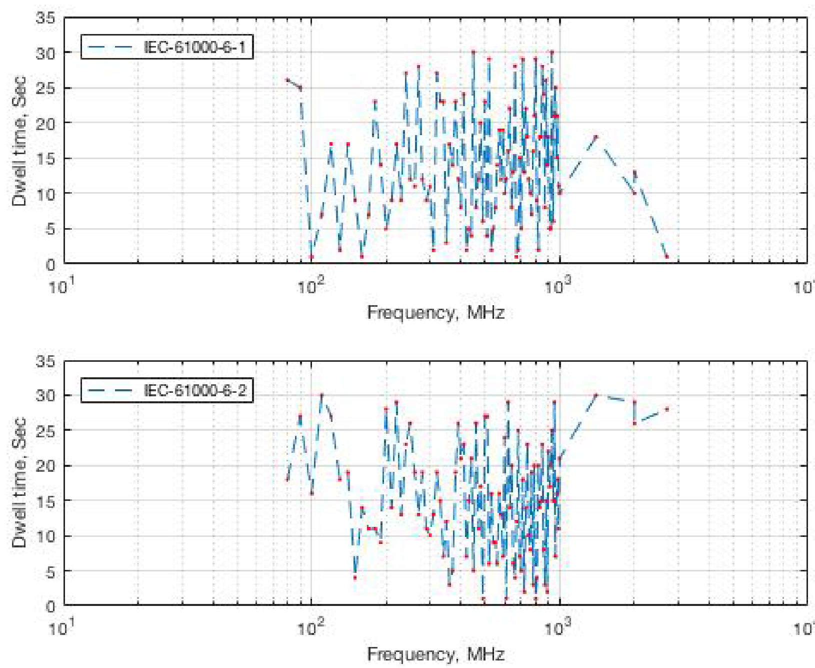
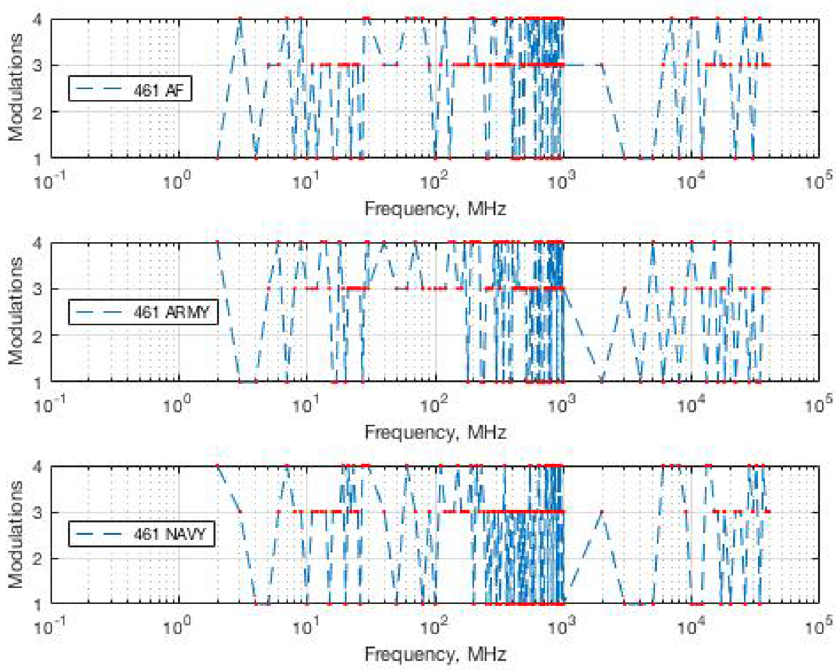


Figure 19. Dwell Time in Seconds for RS/Immunity Testing for Industry

2. Inputs for MIL-STD-461G (DoD 2015)

Figure 20 displays the pseudo random generation of the four distinct modulation schemes. From the figure, note that the modulations (AM, FM, CW, and Pulse) are represented by integers 1, 2, 3 and 4, respectively. These modulations are generated for the different platforms: Air Force, Army, and Navy ground sub-systems IAW MIL-STD-461G (DoD 2015). Thus, the modulations are randomly determined with respect to the frequency range. For the different platforms; only AM, CW and Pulse modulation schemes are required for RS/Immunity testing.



Note that MIL-STD-461G (DoD 2015) only conducts AM, CW and Pulse.

Figure 20. Modulations (AM, FM, CW, Pulse) as 1, 2, 3 and 4, Respectively, for the Various Platforms

Figure 21 displays the pseudo random generation of the dwell time, from 1 second to 60 seconds or 1 minute. This time duration is for non-ionizing radiation to the EUT for RS/Immunity testing. Figure 21 displays the different platforms as follows: Air Force, Army and Navy ground sub-systems. The dwell time, time duration for non-ionizing radiation to the EUT during testing, helps determine the time lapse for a susceptibility to occur, if any. This time lapse is called the frequency response of the EUT. The dwell time is randomly determined with respect to the frequency range.

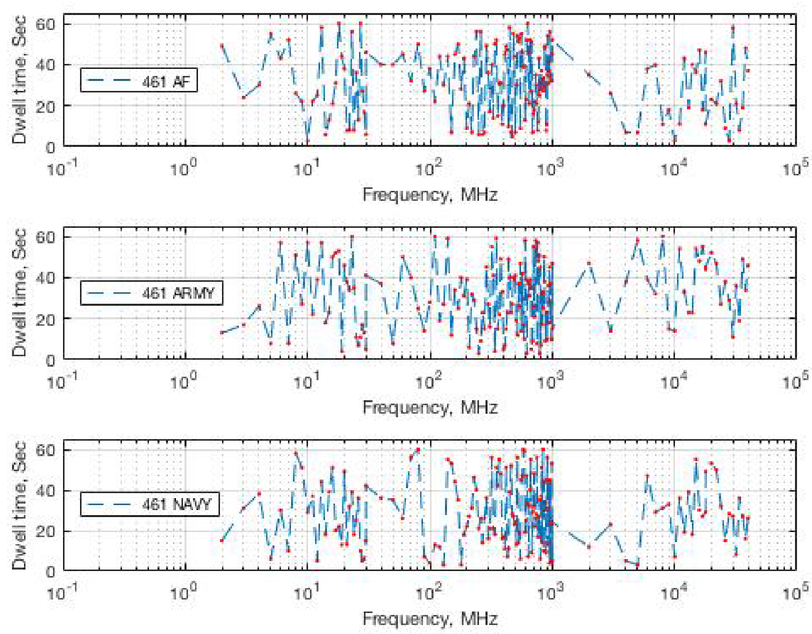
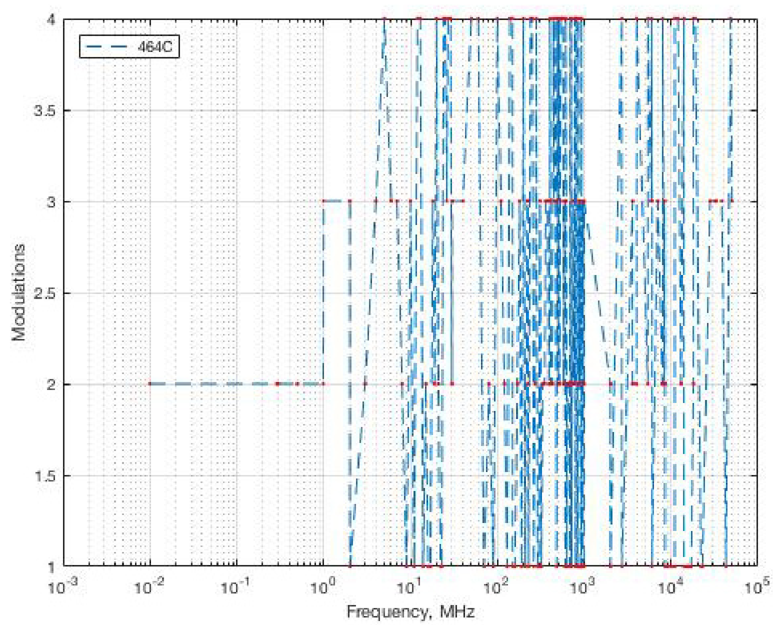


Figure 21. Dwell Time in Seconds for RS/Immunity IAW MIL-STD-461G (DoD 2015) for the Various Platforms

3. Inputs for MIL-STD-464C (DoD 2010b)

Figure 22 displays the pseudo random generation of the four distinct modulation schemes. From the figure, note that the modulations (AM, FM, CW, and Pulse) are represented by integers 1, 2, 3 and 4, respectively. These modulations are generated for systems IAW MIL-STD-464 (DoD 2010b). Thus, the modulations are randomly determined with respect to the frequency range. This military E3 standard conducts AM, FM, CW and Pulse modulation schemes for RS/Immunity testing to ground systems.



Ground systems undergoing RS/Immunity testing IAW MIL-STD-464 (DoD 2010b) conduct all four modulation schemes.

Figure 22. Modulations (AM, FM, CW, Pulse) as 1, 2, 3 and 4, Respectively

Figure 23 displays the random generation of dwell time, from 1 second to 180 seconds or 3 minutes. This time duration is for non-ionizing radiation to the EUT. The dwell time, time duration for non-ionizing radiation to the EUT during testing, helps determine the time lapse for a susceptibility to occur, if any. This time lapse is called the frequency response of the EUT. The dwell time is randomly determined with respect to the frequency range.

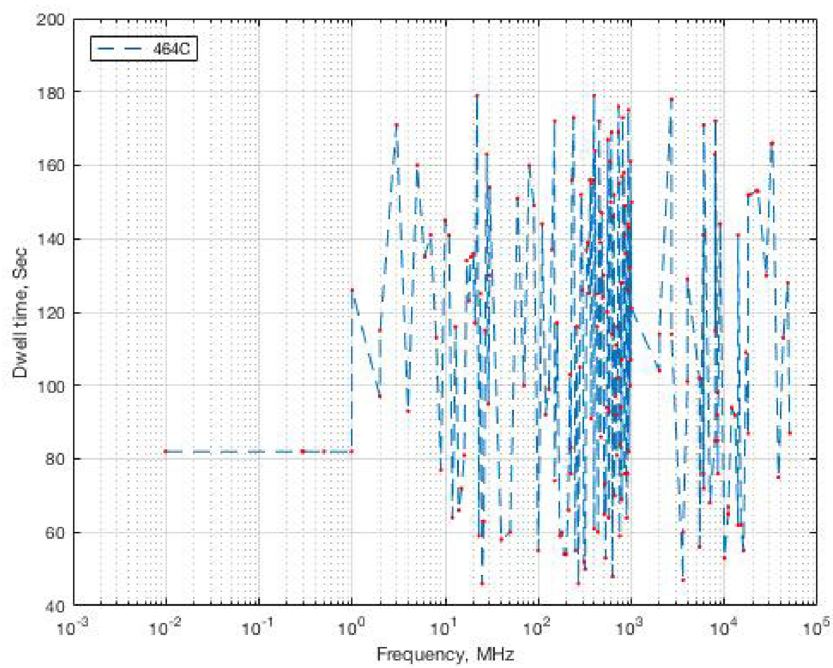


Figure 23. Dwell Time in Seconds for RS/Immunity IAW MIL-STD-464 (DoD 2010b) for Ground Systems

C. CASE SCENARIOS

Susceptibilities were determined in three different case scenarios, described below. Such susceptibilities are theoretical, encountered to a representative but non-existing ground system, in order to keep this thesis unclassified. The model used pseudo random code for 3 out of the four main factors while keeping the fourth factor, frequency range, constant and using IF statements in order to set up the case scenarios. This model encompasses overlap between RS/Immunity testing to determine the frequency response of the EUT. The three different case scenarios are listed as follows:

1. Low FS EMI: AM modulation, encountered at 20 seconds dwell time, at 2.5 V/m.
2. Medium FS EMI: AM modulation, encountered at 45 seconds dwell time, at 30 V/m.
3. High FS EMI: AM modulation, encountered at 100 seconds dwell time, at 70 V/m.

D. DETERMINE THE UNIQUENESS OF THE DATA SET

To determine the difference between the DoD and industry test standards, a MATLAB code was used to read the data from Appendix C. The raw data for this model, Table 16, is provided in Appendix C. The raw data represents the four main factors associated with each RS/Immunity test standard between industry and DoD, and the theoretical susceptibilities encountered to the EUT from each of the three case scenarios. The Naval Postgraduate School's faculty member, Dr. Yakimenko, provided the read and scatter plot MATLAB code for the figures; it is located in Appendix B.

The chosen method for analyzing the data entailed using the *unique function,* from MATLAB, to minimize data duplication from Table 16. The *unique function* filters all six RS/Immunity test standards and eliminated three out of the six RS/Immunity test standards based on frequency range. This results in increased efficiencies in determining the impact of different RS/Immunity testing between industry and DoD.

Figure 24 depicts three significant RS/Immunity test standards that resulted from the unique function. The light blue scatter plots is IEC-61000-6-2 (IEC 2005b), the yellowish scatter plots is MIL-STD-461G (DoD 2015) Army platform and the purple scatter plots is MIL-STD-464C (DoD 2010b). Note that Figure 24 is plotted logarithmic in amplitude and graphs the RF Spectrum in frequency compared to the RS/Immunity test standards' frequency range (data point).

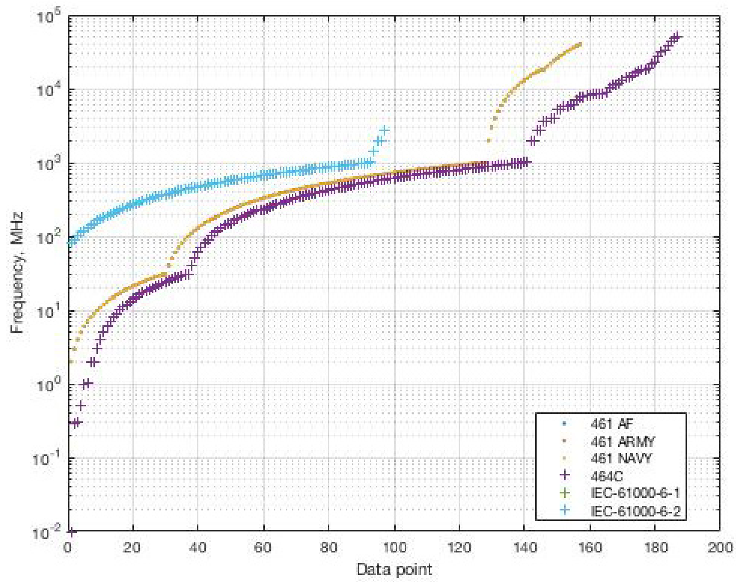


Figure 24. Scatter Plot of Frequency vs. DoD and Industry Standards

1. Case Scenario for Industry IAW IEC-61000-6-2 (IEC 2005b) Test Standards

Figure 25 displays two illustrations. The top illustration is the RS/Immunity test standard and below that, the case scenarios conducted. The RS/Immunity test standard IAW IEC-61000-6-2 (IEC 2005b) has a maximum field strength of 10 V/m from 80 MHz to 1 GHz. Next, the field strength is 3 V/m from 1.4 GHz to 2 GHz. Finally, the field strength reduces to 1 V/m from 2.01 GHz to 2.7 GHz. The RS/Immunity test standard IAW IEC-61000-6-2 (IEC 2005b) conducts testing with an AM signal being radiated to the EUT.

The following entails the details as to the three case scenarios conducted:

A. Case scenario one is Low FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 2.5 V/m for the duration of 20 seconds. The EUT did encounter susceptibilities undergoing RS/Immunity test IAW IEC-61000-6-2 (IEC 2005b) at 2.5 V/m throughout the frequency range. The field strength was assumed to decreas gradually from 1.01 GHz until it gets to 1.4 GHz, but this frequency range and field strength is actually empty since it is not stated specifically in the RS/Immunity test standard IAW IEC-

61000-6-2 (IEC 2005b). It was also assumed that the test could be conducted for 20 seconds, but the dwell time is not stated specifically in the RS/Immunity test standard IAW IEC-61000-6-2 (IEC 2005b).

B. Case scenario two is Medium FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 30 V/m for the duration of 45 seconds. The RS/Immunity test IAW IEC-61000-6-2 (IEC 2005b) cannot conduct case scenario two, Medium FS EMI, due to the fact that it exceeds the thresholds for field strength, and dwell time.

C. Case scenario three is High FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 70 V/m for the duration of 100 seconds. The RS/Immunity test IAW IEC-61000-6-2 (IEC 2005b) cannot conduct case scenario three, High FS EMI, due to the fact that it exceeds the thresholds for field strength, and dwell time.

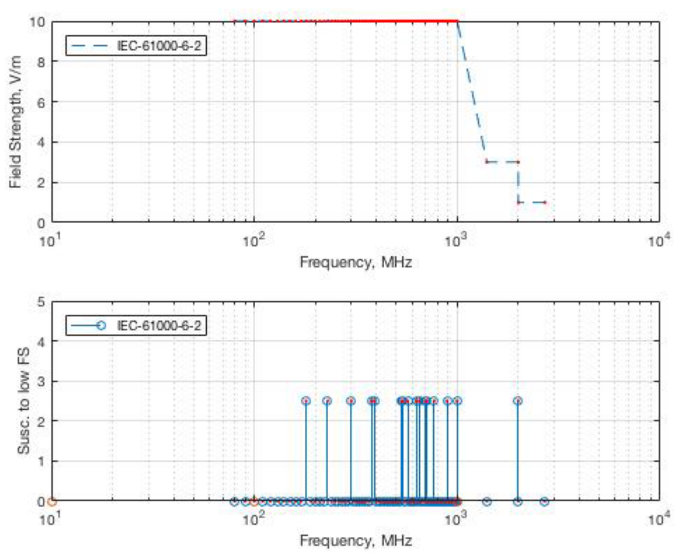


Figure 25. Industry RS/Immunity Test Susceptibilities Encountered During Case Scenario One: Low FS EMI

In summary, The EUT did encounter susceptibilities undergoing RS/Immunity test IAW IEC-61000-6-2 (IEC 2005b) at 2.5 V/m throughout the frequency range. The frequency response of the EUT is limited by the industry standard due to the following factors: low field strength, small dwell time and limited frequency range. Hence, the IEC-61000-6-2 (IEC 2005b) only applies to case scenario one, Low FS EMI. However, case scenario two, Medium FS EMI, and case scenario three, High FS EMI, exceed the IEC-61000-6-2 (IEC 2005b) thresholds.

2. Case Scenario for Army Platform IAW MIL-STD-461G (DoD 2015)

Figure 26 displays three illustrations. The top illustration is the RS/Immunity test standard and below that, two case scenarios conducted. The RS/Immunity test standard IAW MIL-STD-461G (DoD 2015), Army platform, has a maximum field strength of 50 V/m from 2 MHz to 40 GHz. The RS/Immunity test standard IAW MIL-STD-461G (DoD 2015), Army platform, conducts testing with AM or CW signal being radiated to the EUT. The RS/Immunity test standard IAW MIL-STD-461G (DoD 2015), Army platform, conducts testing while having a dwell time greater than three seconds.

The following entails the details as to the three case scenarios conducted:

A. Case scenario one is Low FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 2.5 V/m for the duration of 20 seconds. The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-461G (DoD 2015), Army platform, at 2.5 V/m throughout the frequency range and found more susceptibilities in the lower frequency range and higher frequency range than the industry standard IEC-61000-6-2 (IEC 2005b) evaluated.

B. Case scenario two is Medium FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 30 V/m for the duration of 45 seconds. The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-461G (DoD 2015), Army platform, at 30 V/m throughout the frequency range from 2 MHz to 40 GHz. It was assumed that this standard does not exceed 60 seconds of radiating time.

C. Case scenario three is High FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 70 V/m for the duration of 100 seconds. The RS/Immunity test IAW MIL-STD-461G (DoD 2015), Army platform, cannot conduct case scenario three, High FS EMI, due to the fact that it exceeds the thresholds for field strength, and dwell time.

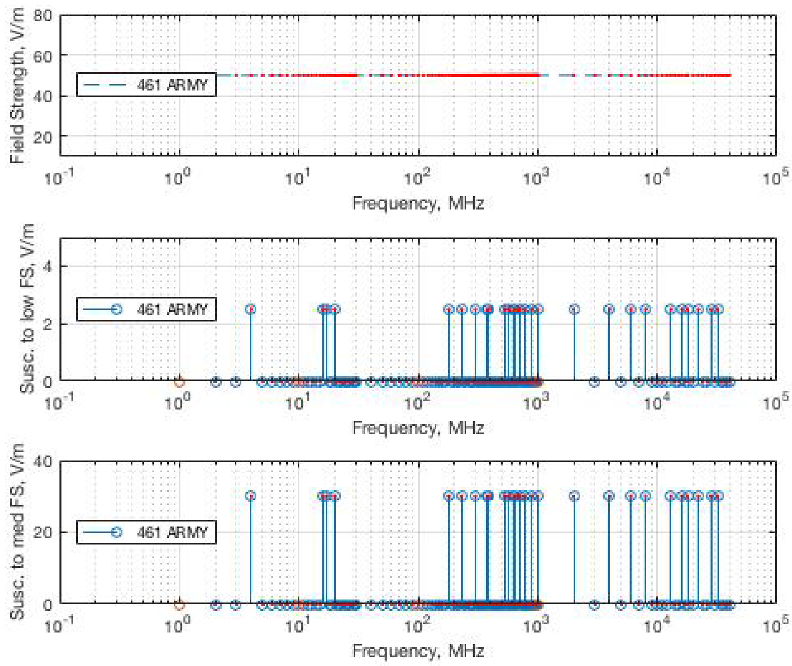


Figure 26. Army Platform IAW MIL-STD-461G (DoD 2015), RS/Immunity Test Susceptibilities Encountered During Case Scenario One: Low FS EMI, and Case Scenario Two: Medium FS EMI

In summary, The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-461G (DoD 2015), Army platform. The frequency responses of the subsystems of the EUT are limited by MIL-STD-461G (DoD 2015), Army platform, since its maximum field strength is 50 V/m throughout the frequency range. For this RS/Immunity test IAW MIL-STD-461G (DoD 2015), Army platform, the EUT can be evaluated to case scenario one, Low FS EMI, and case scenario two, Medium FS EMI. However, case scenario three, High FS EMI, exceed the MIL-STD-461G (DoD 2015) thresholds.

3. Case Scenario for MIL-STD-464C (DoD 2010b)

Figure 27 displays four illustrations. The top illustration is the RS/Immunity test standard and below that, three case scenarios conducted. The RS/Immunity test standard IAW MIL-STD-464C (DoD 2010b), has varied field strengths across the frequency range. The RS/Immunity test standard IAW MIL-STD-464C (DoD 2010b), has a minimum field strength of 41 V/m from 150 MHz to 225 MHz and has a maximum field strength of 267 V/m from 700 MHz to 1 GHz. The RS/Immunity test standard IAW MIL-STD-464C (DoD 2010b), conducts testing with either AM, CW, FM, or Pulse signal being radiated to the EUT. The RS/Immunity test standard IAW MIL-STD-464C (DoD 2010b), conducts testing while having a dwell time reaching a maximum duration of 3 minutes.

The following entails the details as to the three case scenarios conducted:

A. Case scenario one is Low FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 2.5 V/m for the duration of 20 seconds. The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-464C (DoD 2010b), at 2.5 V/m throughout the frequency range and found more susceptibilities in the lower frequency range and higher frequency range than both IEC-61000-6-2 (IEC 2005b) and MIL-STD-461G (DoD 2015), Army platform, had evaluated.

B. Case scenario two is Medium FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 30 V/m for the duration of 45 seconds. The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-464C (DoD 2010b), at 30 V/m throughout the frequency range from .01 MHz to 50 GHz and found more susceptibilities in the lower frequency range and higher frequency range than MIL-STD-461G (DoD 2015), Army platform, had evaluated.

C. Case scenario three is High FS EMI. In this case scenario, the EUT is tested to an AM modulation signal at 70 V/m for the duration of 100 seconds. The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-464C (DoD 2010b), at 70 V/m throughout the frequency range from .01 MHz to 50 GHz, where applicable.

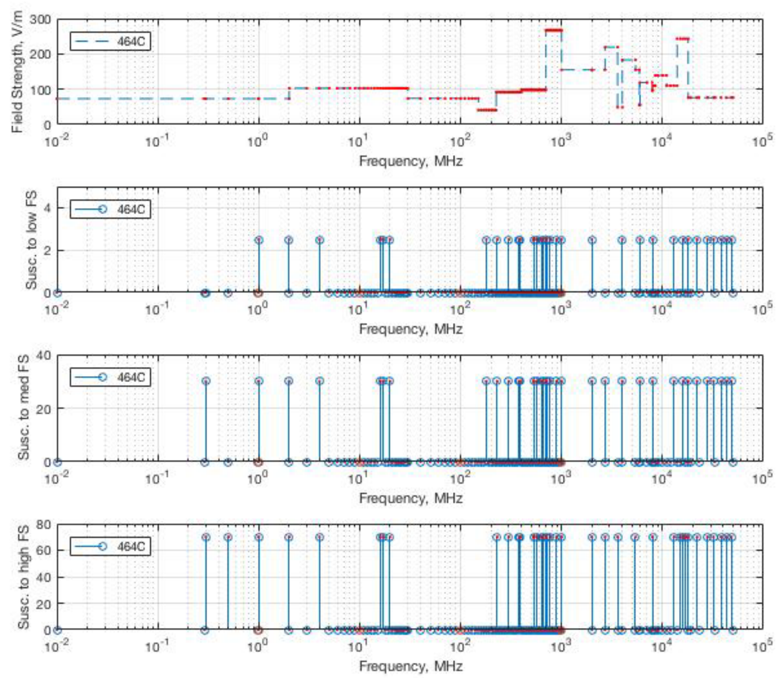


Figure 27. RS/Immunity Test for Ground Systems IAW MIL-STD-464C (DoD 2010b), Susceptibilities Encountered During All Three Case Scenarios Low, Medium and High FS EMI

In summary, The EUT did encounter susceptibilities undergoing RS/Immunity test IAW MIL-STD-464C (DoD 2010b). The frequency response of the EUT can be evaluated to all 3 case scenarios since this test conducts a full body illumination with the longest dwell time and wider frequency bandwidth with respect to the RF spectrum. The frequency response of the EUT is determined to be at 70 V/m throughout the frequency range as previous graphs have depicted. Figure 27 shows that the EUT had additional susceptibilities at both the lower end and higher end of the RF spectrum as compared to the previous figures. "Ideally, the entire system should be illuminated uniformly at full threat for the most credible demonstration of hardness" (DoD 2010b, 74). In other words, the EUT must withstand EMI even when overloaded by incident RF signals.

E. RESULTS AND PERCEPTIONS

With all three case scenarios that were conducted, from Figure 25 to Figure 27, the susceptibilities encountered to the EUT helped determine the vulnerabilities as compared to the four factors, which are:

1. Frequency in MHz
2. Modulation schemes (AM, FM, CW, Pulse) used as 1, 2, 3 and 4, respectively.
3. Dwell Time in seconds
4. Field Strength in V/m

The main observation of the three RS/Immunity test standards between industry and DoD, is that from each of the three case scenarios conducted, there were susceptibilities encountered to the EUT for the following reasons. 1) Each RS/Immunity test standard entails a different frequency range. The larger the frequency bandwidth the more susceptibilities that were identified across the frequency range. 2) As the case scenario's factors increased, dwell time and field strength, the EUT encountered additional susceptibilities. As the case scenario's factors increased so did the rigor of the tests and so did the susceptibilities encountered to the EUT. Without the more in-depth testing and the discovery of susceptibilities, the EUT can encounter RFI with a high risk factor. Without this increased level of testing and the discovery of potential susceptibilities, how a weapon system will perform in its intended environment is neither known nor mitigated. The identification and mitigation of these susceptibilities determine an EUT compatibility with other military equipment and electronic devices operating in the RF Spectrum. Table 11 depicts the top level requirements for RS/Immunity testing between industry and DoD ground subsystems and systems.

Table 11. Requirements for Ground Subsystems and Systems

Top Level System Requirements		
MIL-STD-461G (DoD 2015)		
Weapon Sub-System		Army
Weapon Sub-System		Air Force
Weapon Sub-System		Navy
MIL-STD-464C (DoD 2010b)		
Weapon System		Ground
IEC-61000-6-1 (IEC 2005a)		
Weapon System		Light Industrial/Residential
IEC-61000-6-2 (IEC 2005b)		
Weapon System		Industrial

Deeper insights into the differences between industry and DoD for RS/Immunity test standards are described in Table 12. This table depicts how each RS/Immunity test standard conducts testing to the three out of the four main factors: which are modulation schemes, field strengths, and dwell times. As can be seen, MIL-STD-464C (DoD 2010b) provides for testing all the factors depicted in Table 12. Now that the DoD conducts missions as a joint force, EMC is crucial to mission success.

Table 12. Factors for RS/Immunity Test between Industry and DoD

	Modulation				Field Strength			Dwell Time		
	AM	**FM**	**CW**	**Pulse**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
MIL-STD-461G (DoD 2015)										
Army	X		X	X	X	X		X	X	
Air Force	X		X	X	X			X	X	
Navy	X		X	X	X			X	X	
MIL-STD-464C (DoD 2010b)										
Ground	X	X	X	X	X	X	X	X	X	X
IEC-61000-6-1 (IEC 2005a)										
Light Industrial/Residential	X				X			X		
IEC-61000-6-2 (IEC 2005a)										
Industrial	X				X			X		

The operating frequency or carrier frequency of a weapon system can cause susceptibilities to another weapon system. Table 13 shows the frequency range of the RS/Immunity test standards between industry and DoD. Recall the RFI related incidents from chapter one; susceptibilities and their impacts, or victim-source relationship, must be overcome in order to have an EMC force. The DoD standard MIL-STD-464C (2010b) can test to more bandwidth of the RF spectrum while producing a full body illumination with mixed field strengths and longer duration of dwell time.

Table 13. Frequency Range for RS/Immunity Test between Industry and DoD

	MIL-STD-461G (DoD 2015)		MIL-STD-464C (DoD 2010b)	IEC-61000-6-1 (IEC 2005a)	IEC-61000-6-2 (IEC 2005a)
IEEE BANDS	**Army**	**Air Force/ Navy**	**Ground**	**Light Industrial/ Residential**	**Industrial**
VLF			X		
LF			X		
MF			X		
HF	X	X	X		
VHF	X	X	X	X	X
UHF	X	X	X	X	X
L-BAND	X	X	X		
S-BAND	X	X	X		
C-BAND	X	X	X		
X-BAND	X	X	X		
Ku-BAND	X	X	X		
K-BAND	X	X	X		
Ka-BAND	X	X	X		
V-BAND			X		

The risk assessment for this case study can potentially fall under these severity and probability as highlighted in Table 14. The DoD shall be aware of frequency and field strength creep as technology advances. Stricter guidelines should be in place for COTS use within the DoD operating environment, in order to conduct a safe and effective mission.

Table 14. Risk Assessment Code for This Case Study. Adapted from DoD (2012b, 12).

	Severity			
Probability	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)		High	Serious	
Probable (B)		High	Serious	
Occasional (C)	High	Serious	Medium	
Remote (D)	Serious	Medium	Medium	
Improbable (E)	Medium	Medium	Medium	
Elimiinated (F)				

In summary, if known susceptibilities occur to COTS under industry testing, then clearly those COTS items cannot withstand susceptibilities during DoD testing. Theoretically, the EUT should not encounter any susceptibilities during RS/Immunity testing. Recall from Figure 11, there are numerous competing uses for the RF spectrum between industry and the DoD, hence RFI issues between industry and DoD can arise. Figure 28 details the significant differences between RS/Immunity test standards between industry and the DoD with respect to field strength and frequency range. The MIL-STD-464C (2010b) can test more bandwidth of the RF spectrum with various field strengths, different modulation schemes and longer dwell times. An EMC/E3 hardened force must be available during peacetime, humanitarian missions, and in theatre for years to come to ensure mission success.

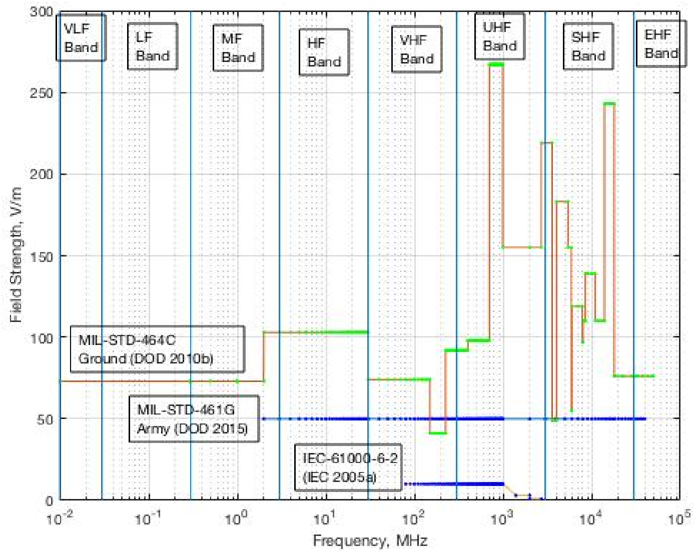


Figure 28. Frequency vs. Field Strength for RS/Immunity Test between Industry and DoD

VII. CONCLUSION

The war on terrorism has been a major driving factor for rapid fielded initiatives, which integrates COTS items to existing military assets to maximize mission effectiveness. Industry and DoD have separate test standards and methodologies. Without an effective baseline for RS/Immunity testing, ground systems may be susceptible to RFI, which could render them ineffective.

The case study helped highlight the differences for each RS/Immunity test standard between industry and DoD. With the limited criteria used in the case study, in order to keep the thesis unclassified, one can conclude that COTS items can be more susceptible to RFI and should be tested to DoD test standards in order to determine susceptibilities and vulnerabilities and hence viability for the war fighter.

A. RESEARCH QUESTION ANSWERS

The following entails the answer to the research questions: what are the industry's RS/Immunity test standards and methodologies, what are the DoD RS/Immunity test standards and methodologies, and are COTS items at risk in the military operating environment.

(1) What are the industry's RS/Immunity test standards and methodologies?

The two distinct industry immunity test methodologies from the ITU are IEC-61000-6-1 (IEC 2005a) and IEC-61000-6-2 (IEC 2005b). Both standards entail testing one cable or port at a time, which limits the operating environment for the EUT. The testing frequency range is from 80 MHz to about 3 GHz. The field strength is no more than 10 V/m for average power. The modulation scheme is AM with 80 % modulation index at 1 kHz tone.

(2) What are the DoD RS/Immunity test standards and methodologies?

The DoD conducts E3 testing IAW MIL-STD-461, RS 103 for subsystems testing. Under MIL-STD-461G (DoD 2015), the testing frequency range is from 2 MHz to 40 GHz.

The field strength is 10 or 50 V/m for average power. The modulation scheme is AM 30% to 80% modulation index, Pulse with a 1000 Hz tone with a 50% duty cycle, and CW.

The DoD conducts E3 testing as External RF EME, IAW the most current test standard, MIL-STD-464C (DoD 2010b). It conducts full-body illumination where applicable to the EUT as a system. This means the EUT is engulfed by the non-ionizing radiation during testing which determines if the EUT is susceptible by overloading any external cable(s) or port(s), unlike the IEC standards, which conducts testing one port at a time from the EUT. Under MIL-STD-464C, the testing frequency range is from 2 MHz to 50 GHz. The field strength varies throughout the frequency range from 41 to 267 volts per meter for average power. The modulation scheme is AM 30% to 80% modulation index, Pulse with a 1000 Hz tone with a 50% duty cycle, CW, and FM. Thus, MIL-STD-464C can have a dwell time to match the functionality checkouts for a system. The EUT is being illuminated for a longer duration as compared to MIL-STD-461G (DoD 2015).

(3) Are COTS items at risk in the military operating environment?

Industry and DoD have equipment that operates in the same RF bands from the RF spectrum and they have different test standards with different test methodologies for incorporating EMC to safeguard the user. Recall that in industry, the test standard conducts Immunity testing under the IEC and within the DoD, military standards, it will be a subset for E3 testing called RS 103 testing and External RF EME testing. Without adequate RS/Immunity test standards and methodologies, ground systems are susceptible to RFI, which could render them ineffective or dangerous to operate.

The case study determined that industry test standards provide limited insights to the frequency response of a COTS item, whereas the DoD E3 standards have a broader RF bandwidth, higher field strengths, various modulations, and longer dwell times that one can use to mitigate RFI. It is better to discover susceptibilities while undergoing testing in a controlled environment, than discover them while in operational mode where someone could get hurt. As the digital era introduces more unique and modern technology, the DoD must take control of past, present, and future assets so that it can understand and mitigate susceptibilities and avoid potential catastrophic incidents.

B. RESULTS AND RECOMMENDATIONS

In summary, though similarities exist between industry and DoD test standards, namely that they are verified to be repeatable and used to assess EMC susceptibilities, there are significant differences between industry and DoD test methodologies as can be seen in Table 15. The DoD ground systems operate in a much more dense and diverse environment across the RF spectrum as compared to industry. Hence, the DoD can enhance the reliability and maintainability of its assets by conducting E3 hardening to mitigate EMI.

With the procurement and use of increasing amounts of COTS items, the DoD should take a closer look at EMC of COTS as technology advances. The field strengths keeps increasing and the frequency range keeps expanding as new standards supersede the previous standard for military use.

Table 15. Main Comparison for RS Testing and Methodologies between Industry and DoD Standards

	INDUSTRY		**DoD**	
FACTORS	**IEC-61000-6-1 (IEC 2005a)**	**IEC-61000-6-2 (IEC 2005b)**	**MIL-STD-461G (DoD 2015)**	**MIL-STD-464C (DoD 2010b)**
Dwell Time	Not Specified	Not Specified	Greater than 3 seconds	Up to 3 minutes
Field strength (V/m) **Frequency Dependent**	3 or 1 (V/m)	10, 3, or 1 (V/m)	10 or 50 (V/m)	Varies within 41 – 267 (V/M)
Modulation Schemes	AM 80% Modulation Index, 1 kHz tone	AM 80% Modulation Index, 1 kHz tone	AM 1 kHz tone, 30–80% modulation index, Pulse 1 kHz tone, 50% duty cycle, and CW	AM 1 kHz tone, 30–80% modulation index, Pulse 1 kHz tone, 50% duty cycle, CW and FM
Frequency Range	80 MHz – 2.7 GHz	80 MHz – 2.7 GHz	2 MHz – 40 GHz	0.01 MHz – 50 GHz

All DoD experts must effectively determine and justify if COTS items are acceptable based on specific requirements IAW MIL-STD-464. The risk associated with COTS items must be mitigated prior to DoD use in order to prevent susceptibilities.

DoD instruction (DoDI) 4650.01 (DoD 2009) specifically states it is DoD policy to "Pursue spectrum-efficient technologies to support the increasing warfighter demand for spectrum access and encourage development of spectrum dependent (S-D) systems that can operate in diverse electromagnetic environments (EMEs)" (DoD 2009, 2). Industry is now the driver of technology whereas before, the DoD was the vehicle for technological advancements. Though this may indicate increased frequency of industry testing for COTS, it also potentially reduces their reliability and increases their risk level. With DoDI 4650.01, the DoD should focus on EMC for COTS and validate the use of COTS by conducting Ext. RF EME IAW MIL-STD-464C (DoD 2010b).

C. ADDITIONAL RESEARCH AREAS

(1) How Can the DoD Mitigate the System of Systems Testing Interval?

As of today, there are some programs that may not meet the requirements of MIL-STD-464C (DoD 2010b) because they were tested to previous military standards. The current military standards supersede the previous version to a certain extent, depending on the test. Therefore, such programs should be tested to the most recent military standard. Programs undergo many tests during the design phase, up until deployment. "Preplanned product improvement (P3I) considers the ways and means to enhance the system beyond the scope of the current contractual arrangement" (Eisner 2008, 226). Thus, with a P3I plan to retest items after deployment can help improve the hardness surveillance for most programs and can guide DoD, RS/Immunity testing to grow proportionally with technological advancements that would otherwise create EMI issues.

It shall be up to the PMO with E3 subject matter experts to verify what tests need to be performed for the E3 and operational testing in order to verify the integrity of the system. If the program undergoes its previous E3 tests (threshold) and passes without susceptibilities, there will be no need for modifications? Then the DoD can move to see if the program can undergo testing to the latest E3 tests (objective)? Once the program undergoes the current military standard without any susceptibilities encountered, the program completes the objective for the E3 tests.

(2) How Can the DoD Establish COTS as a Solution for Parts Obsolescence to Subsystems?

The aging DoD force must be able to conduct obsolescence mitigation. Some integrated COTS items that are subsystems may not meet the requirements of MIL-STD-461G (DoD 2015) because they were tested to industry standards. It shall be up to the PMO with E3 subject matter experts to verify what tests need to be performed for E3 and operational testing in order to verify the integrity of the COTS items. Such tests will mitigate RFI while conducting parts obsolescence plans.

APPENDIX A. MATLAB CODE FOR FIGURE 6

Cosine Wave Modulated RF signal CW

```
Fs=1000;              %sample frequency
T=1/Fs;               %sampling period
L=1000;               %Length of sinusoidal signal
t=(0:L-1)*T;          %Time Vector
X=10*cos(2*pi*10*t);   %Sinusoidal Signal in Time Domain
subplot(2,2,1);
plot(t,X)
title('Time Domain Plot')
xlabel('Time')
ylabel('Amplitude')
n=2^nextpow2(L);
Y=fft(X);             %Convert to frequency domain using Fourier Transform
P2=abs(Y/n);
P1= P2(1:n/2+1);
P1(2:end-1) = 2*P1(2:end-1);
subplot(2,2,2);
plot(0:(Fs/n):(Fs/2-Fs/n),P1(1:n/2))
title('Frequency Domain Plot')
xlabel('Frequency')
ylabel('Amplitude')
```

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APPENDIX B. SOURCE DATA FOR MODELING IN CHAPTER VI

This Appendix presents source data that was used for modeling in Chapter VI.

MATLAB Code provided by Dr.Yakimenko, faculty member at NPS.

```
close all, clear all, clc
%% Import data from spreadsheet
[~, ~, raw] = xlsread('Thesis_Case_Study.xlsx','Sheet1','A2:H1017');
raw(cellfun(@(x) ~isempty(x) && isnumeric(x) && isnan(x),raw)) = {''};
cellVectors = raw(:,1);
raw = raw(:,[2,3,4,5,6,7,8]);
%% Create output variable
data = reshape([raw{:}],size(raw));
%% Allocate imported array to column variable names
Standard = cellVectors(:,1);
FrequencyMHz = data(:,1);
ModulationAMFMCWPULSE1234 = data(:,2);
DwellTimeSeconds = data(:,3);
FieldStrengthVm = data(:,4);
SusceptibilityLowFS = data(:,5);
SusceptibilityMediumFS = data(:,6);
SusceptibilityHighFS = data(:,7);
%% Clear temporary variables
clearvars data raw cellVectors;
%% Find unique standards
[U,ia,ic]=unique(Standard);
L=length(U);
for i=1:L
Ind{i,:}=find(ic==i)
end
% Plot data
figure
for i=1:3
   semilogy(FrequencyMHz(Ind{1,:}),'.'), hold on
end
for i=4:6
   semilogy(FrequencyMHz(Ind{i,:}),'+'), hold on
end
% for i=6
%     semilogy(FrequencyMHz(Ind{i,:}),'^'), hold on
% end
grid, xlabel('Data point'), ylabel('Frequency, MHz')
legend(U,'location','best')
%% 461G Modulation
figure
for i=1:3
subplot(3,1,i)
semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'.r')
ylabel('Modulations'), xlabel('Frequency, MHz')
legend(U(i),'location','w')
xlim([10^-1,10^5]), grid
```

```
end

%% 464C Modulation
figure
for i=4
subplot(1,1,i-3)
semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'.r')
ylabel('Modulations'),xlabel('Frequency, MHz')
legend(U(i),'location','nw')
xlim([10^-3,10^5]), grid
end

%% IEC Modulation
figure
for i=5:6
subplot(2,1,i-4)
semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'.r')
ylabel('Modulations'), xlabel('Frequency, MHz')
legend(U(i),'location','nw')
xlim([10^1,10^4]), grid
ylim([.5,4])
end

%% 461G Safety Critical Modulation
% figure
% for i=7
% subplot(1,1,1)
% semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'--'), hold
% semilogx(FrequencyMHz(Ind{i,:}),ModulationAMFMCWPULSE1234(Ind{i,:}),'.r')
% ylabel('Modulations')
% legend(U(i),'location','nw')
% xlim([10^-1,10^5]), grid
% end
% xlabel('Frequency, MHz')

%% 461G Dwell Time
figure
for i=1:3
subplot(3,1,i)
semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'.r')
ylabel('Dwell time, Sec'),xlabel('Frequency, MHz')
legend(U(i),'location','w')
xlim([10^-1,10^5]), ylim([0 65]), grid
end

%% 464C Dwell Time
figure
for i=4
subplot(1,1,i-3)
semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'.r')
```

```
ylabel('Dwell time, Sec')
legend(U(i),'location','nw')
xlim([10^-3,10^5]), ylim([40 200]), grid
end
xlabel('Frequency, MHz')

%% IEC Dwell Time
figure
for i=5:6
subplot(2,1,i-4)
semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'.r')
ylabel('Dwell time, Sec'),xlabel('Frequency, MHz')
legend(U(i),'location','nw')
xlim([10^1,10^4]), ylim([0 35]), grid
end

% %% 461F Safety Critical Dwell Time
% figure
% for i=7
% subplot(1,1,1)
% semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'--'), hold
% semilogx(FrequencyMHz(Ind{i,:}),DwellTimeSeconds(Ind{i,:}),'.r')
% ylabel('Dwell time, Sec')
% legend(U(i),'location','nw')
% xlim([10^-1,10^5]), ylim([0 65]), grid
% end
% xlabel('Frequency, MHz')

% 461G Army Platform Field Strength
figure
for i=2
subplot(3,1,1)
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.r')
ylabel('Field Strength, V/m'), xlabel('Frequency, MHz')
legend(U(i),'location','w')
xlim([10^-1,10^5]), ylim([10,80]), grid
end
%% 461G Army Platform Susceptibility to low FS
for i=2
subplot(3,1,2)
stem(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:})); hold
stem([1 10 100 1000],[0 0 0 0])
set(gca,'XScale','log')
semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:}),'.r')
ylabel('Susc. to low FS, V/m'),xlabel('Frequency, MHz')
legend(U(i),'location','w')
xlim([10^-1,10^5]), ylim([0,5]), grid
end

%% 461G Army Platform Susceptibility to med FS
for i=2
subplot(3,1,3)
```

```
stem(FrequencyMHz(Ind{i,:}),SusceptibilityMediumFS(Ind{i,:})); hold
stem([1 10 100 1000],[0 0 0 0])
set(gca,'XScale','log')
semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityMediumFS(Ind{i,:}),'.r')
ylabel('Susc. to med FS, V/m')
legend(U(i),'location','w')
xlim([10^-1,10^5]), ylim([0,40]), grid
end
xlabel('Frequency, MHz')
% %% safety critical 461G
% figure
% for i=7
% subplot(4,1,1)
% semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'--'), hold
% semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.r')
% ylabel('Field Strength, V/m')
% legend(U(i),'location','w')
% xlim([10^-1,10^5]), ylim([0,250]), grid
% end
% xlabel('Frequency, MHz')
% %% safety critical 461G to low FS
% for i=7
% subplot(4,1,2)
% stem(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:})); hold
% stem([1 10 100 1000],[0 0 0 0])
% set(gca,'XScale','log')
% semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:}),'.r')
% ylabel('Susc. to low FS, V/m')
% legend(U(i),'location','w')
% xlim([10^-1,10^5]), ylim([0,5]), grid
% end
% xlabel('Frequency, MHz')
% %% safety critical 461G to med FS
% for i=7
% subplot(4,1,3)
% stem(FrequencyMHz(Ind{i,:}),SusceptibilityMediumFS(Ind{i,:})); hold
% stem([1 10 100 1000],[0 0 0 0])
% set(gca,'XScale','log')
% semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityMediumFS(Ind{i,:}),'.r')
% ylabel('Susc. to med FS, V/m')
% legend(U(i),'location','w')
% xlim([10^-1,10^5]),ylim([0,40]), grid
% end
% xlabel('Frequency, MHz')
% %% safety critical 461G to high FS
% for i=7
% subplot(4,1,4)
% stem(FrequencyMHz(Ind{i,:}),SusceptibilityHighFS(Ind{i,:})); hold
% stem([1 10 100 1000],[0 0 0 0])
% set(gca,'XScale','log')
% semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityHighFS(Ind{i,:}),'.r')
% ylabel('Susc. to high FS, V/m')
% legend(U(i),'location','w')
% xlim([10^-1,10^5]), ylim([0,80]), grid
% end
```

```
% xlabel('Frequency, MHz')

%% 464C Field Strength
figure
for i=4
subplot(4,1,1)
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.r')
ylabel('Field Strength, V/m')
legend(U(i),'location','nw')
xlim([10^-2,10^5]), grid
end
xlabel('Frequency, MHz')
%% 464C Susceptibility to low FS
for i=4
subplot(4,1,2)
stem(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:})); hold
stem([1 10 100 1000],[0 0 0 0])
set(gca,'XScale','log')
semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:}),'.r')
hold on
ylabel('Susc. to low FS')
legend(U(i),'location','nw')
xlim([10^-2,10^5]),ylim([0,5]), grid
end
xlabel('Frequency, MHz')
%% 464C Susceptibility to med FS
for i=4
subplot(4,1,3)
stem(FrequencyMHz(Ind{i,:}),SusceptibilityMediumFS(Ind{i,:})); hold
stem([1 10 100 1000],[0 0 0 0])
set(gca,'XScale','log')
semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityMediumFS(Ind{i,:}),'.r')
ylabel('Susc. to med FS')
legend(U(i),'location','nw')
xlim([10^-2,10^5]), ylim([0,40]), grid
end
xlabel('Frequency, MHz')
%% 464C Susceptibility to high FS
for i=4
subplot(4,1,4)
stem(FrequencyMHz(Ind{i,:}),SusceptibilityHighFS(Ind{i,:})); hold
stem([1 10 100 1000],[0 0 0 0])
set(gca,'XScale','log')
semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityHighFS(Ind{i,:}),'.r')
ylabel('Susc. to high FS')
legend(U(i),'location','nw')
xlim([10^-2,10^5]),ylim([0,80]), grid
end
xlabel('Frequency, MHz')

%% IEC 61000-6-2 Field Strength
figure
for i=6
```

```
subplot(2,1,1)
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'--'), hold
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.r')
ylabel('Field Strength, V/m')
legend(U(i),'location','nw')
xlim([10^1,10^4]), grid
end
xlabel('Frequency, MHz')
%% IEC Susceptibility to low FS
for i=6
subplot(2,1,2)
stem(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:})); hold
stem([1 10 100 1000],[0 0 0 0])
set(gca,'XScale','log')
semilogx(FrequencyMHz(Ind{i,:}),SusceptibilityLowFS(Ind{i,:}),'.r')
ylabel('Susc. to low FS')
legend(U(i),'location','nw')
xlim([10^1,10^4]),ylim([0,5]), grid
end
xlabel('Frequency, MHz')



%%ALL TOGETHER%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
figure

%%461G ARMY
for i=2
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'-'), hold on
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.b')
ylabel('Field Strength, V/m')
grid

end
xlabel('Frequency, MHz')

% %% 461F safety critical
% for i=7
% semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'-'), hold on
% semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.r')
% end

%% 464C Field Strength
for i=4
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'-'), hold on
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.g')
end

%% IEC-61000-6-2 Field Strength
for i=6
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'-'), hold on
semilogx(FrequencyMHz(Ind{i,:}),FieldStrengthVm(Ind{i,:}),'.b')
end
```

```
hold on
line([.01,.01],[0,300]) %VLF
line([.03,.03],[0,300]) %LF
line([.3,.3],[0,300]) %MF
line([3,3],[0,300]) %HF
line([30,30],[0,300]) %VHF
line([300,300],[0,300]) %UHF
line([3000,3000],[0,300]) %SHF
line([30000,30000],[0,300]) %EHF
hold off
```

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APPENDIX C. SOURCE DATA FOR CASE STUDY

Table 16. Source Data for Case Study

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 ARMY	2	4	13	50	0	0	0
461 ARMY	3	1	17	50	0	0	0
461 ARMY	4	1	26	50	2.5	30	0
461 ARMY	5	3	8	50	0	0	0
461 ARMY	6	4	57	50	0	0	0
461 ARMY	7	1	8	50	0	0	0
461 ARMY	8	3	51	50	0	0	0
461 ARMY	9	4	27	50	0	0	0
461 ARMY	10	3	57	50	0	0	0
461 ARMY	11	3	22	50	0	0	0
461 ARMY	12	3	39	50	0	0	0
461 ARMY	13	4	57	50	0	0	0
461 ARMY	14	4	18	50	0	0	0
461 ARMY	15	3	23	50	0	0	0
461 ARMY	16	1	50	50	2.5	30	0
461 ARMY	17	1	52	50	2.5	30	0
461 ARMY	18	4	53	50	0	0	0
461 ARMY	19	3	4	50	0	0	0
461 ARMY	20	1	46	50	2.5	30	0
461 ARMY	21	3	38	50	0	0	0
461 ARMY	22	3	34	50	0	0	0
461 ARMY	23	3	60	50	0	0	0
461 ARMY	24	3	35	50	0	0	0
461 ARMY	25	3	11	50	0	0	0
461 ARMY	26	3	7	50	0	0	0
461 ARMY	27	1	11	50	0	0	0
461 ARMY	28	3	17	50	0	0	0
461 ARMY	29	4	13	50	0	0	0
461 ARMY	30	4	5	50	0	0	0
461 ARMY	30.01	3	41	50	0	0	0
461 ARMY	40	4	37	50	0	0	0
461 ARMY	50	3	8	50	0	0	0
461 ARMY	60	3	50	50	0	0	0
461 ARMY	70	4	40	50	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 ARMY	80	3	25	50	0	0	0
461 ARMY	90	3	14	50	0	0	0
461 ARMY	100	3	28	50	0	0	0
461 ARMY	110	3	60	50	0	0	0
461 ARMY	120	3	19	50	0	0	0
461 ARMY	130	4	27	50	0	0	0
461 ARMY	140	4	59	50	0	0	0
461 ARMY	150	3	12	50	0	0	0
461 ARMY	160	3	34	50	0	0	0
461 ARMY	170	4	25	50	0	0	0
461 ARMY	180	1	40	50	2.5	30	0
461 ARMY	190	4	31	50	0	0	0
461 ARMY	200	4	39	50	0	0	0
461 ARMY	210	4	6	50	0	0	0
461 ARMY	220	4	32	50	0	0	0
461 ARMY	230	1	29	50	2.5	30	0
461 ARMY	240	1	15	50	0	0	0
461 ARMY	250	3	3	50	0	0	0
461 ARMY	260	3	9	50	0	0	0
461 ARMY	270	3	23	50	0	0	0
461 ARMY	280	3	15	50	0	0	0
461 ARMY	290	4	45	50	0	0	0
461 ARMY	300	1	27	50	2.5	30	0
461 ARMY	310	4	16	50	0	0	0
461 ARMY	320	3	55	50	0	0	0
461 ARMY	330	4	41	50	0	0	0
461 ARMY	340	1	4	50	0	0	0
461 ARMY	350	4	59	50	0	0	0
461 ARMY	360	4	15	50	0	0	0
461 ARMY	370	4	22	50	0	0	0
461 ARMY	380	1	49	50	2.5	30	0
461 ARMY	390	1	33	50	2.5	30	0
461 ARMY	400	4	5	50	0	0	0
461 ARMY	410	3	7	50	0	0	0
461 ARMY	420	3	15	50	0	0	0
461 ARMY	430	3	23	50	0	0	0
461 ARMY	440	4	49	50	0	0	0
461 ARMY	450	3	40	50	0	0	0
461 ARMY	460	3	23	50	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 ARMY	470	3	27	50	0	0	0
461 ARMY	480	3	40	50	0	0	0
461 ARMY	490	3	39	50	0	0	0
461 ARMY	500	3	41	50	0	0	0
461 ARMY	510	3	19	50	0	0	0
461 ARMY	520	1	12	50	0	0	0
461 ARMY	530	1	37	50	2.5	30	0
461 ARMY	540	1	26	50	2.5	30	0
461 ARMY	550	3	47	50	0	0	0
461 ARMY	560	3	14	50	0	0	0
461 ARMY	570	1	42	50	2.5	30	0
461 ARMY	580	3	17	50	0	0	0
461 ARMY	590	3	10	50	0	0	0
461 ARMY	600	4	58	50	0	0	0
461 ARMY	610	3	39	50	0	0	0
461 ARMY	620	3	3	50	0	0	0
461 ARMY	630	1	38	50	2.5	30	0
461 ARMY	640	4	37	50	0	0	0
461 ARMY	650	1	31	50	2.5	30	0
461 ARMY	660	4	39	50	0	0	0
461 ARMY	670	4	35	50	0	0	0
461 ARMY	680	1	5	50	0	0	0
461 ARMY	690	1	9	50	0	0	0
461 ARMY	700	1	55	50	2.5	30	0
461 ARMY	710	1	26	50	2.5	30	0
461 ARMY	720	3	21	50	0	0	0
461 ARMY	730	3	58	50	0	0	0
461 ARMY	740	3	54	50	0	0	0
461 ARMY	750	3	8	50	0	0	0
461 ARMY	760	4	57	50	0	0	0
461 ARMY	770	1	48	50	2.5	30	0
461 ARMY	780	4	51	50	0	0	0
461 ARMY	790	1	3	50	0	0	0
461 ARMY	800	3	45	50	0	0	0
461 ARMY	810	4	7	50	0	0	0
461 ARMY	820	3	32	50	0	0	0
461 ARMY	830	4	17	50	0	0	0
461 ARMY	840	3	33	50	0	0	0
461 ARMY	850	3	25	50	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 ARMY	860	3	50	50	0	0	0
461 ARMY	870	4	38	50	0	0	0
461 ARMY	880	4	9	50	0	0	0
461 ARMY	890	1	23	50	2.5	30	0
461 ARMY	900	4	10	50	0	0	0
461 ARMY	910	4	23	50	0	0	0
461 ARMY	920	3	18	50	0	0	0
461 ARMY	930	4	36	50	0	0	0
461 ARMY	940	4	28	50	0	0	0
461 ARMY	950	3	45	50	0	0	0
461 ARMY	960	3	18	50	0	0	0
461 ARMY	970	4	37	50	0	0	0
461 ARMY	980	1	10	50	0	0	0
461 ARMY	990	3	10	50	0	0	0
461 ARMY	1000	1	47	50	2.5	30	0
461 ARMY	1000.01	3	15	50	0	0	0
461 ARMY	2000	1	47	50	2.5	30	0
461 ARMY	3000	3	14	50	0	0	0
461 ARMY	4000	1	38	50	2.5	30	0
461 ARMY	5000	4	58	50	0	0	0
461 ARMY	6000	1	39	50	2.5	30	0
461 ARMY	7000	3	32	50	0	0	0
461 ARMY	8000	1	60	50	2.5	30	0
461 ARMY	9000	3	15	50	0	0	0
461 ARMY	10000	4	14	50	0	0	0
461 ARMY	11000	3	54	50	0	0	0
461 ARMY	12000	3	33	50	0	0	0
461 ARMY	13000	1	23	50	2.5	30	0
461 ARMY	14000	3	23	50	0	0	0
461 ARMY	15000	4	54	50	0	0	0
461 ARMY	16000	1	48	50	2.5	30	0
461 ARMY	17000	3	55	50	0	0	0
461 ARMY	18000	3	44	50	0	0	0
461 ARMY	18000.01	1	45	50	2.5	30	0
461 ARMY	20000	4	52	50	0	0	0
461 ARMY	22000	1	47	50	2.5	30	0
461 ARMY	24000	3	27	50	0	0	0
461 ARMY	26000	3	38	50	0	0	0
461 ARMY	28000	1	29	50	2.5	30	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 ARMY	30000	3	11	50	0	0	0
461 ARMY	32000	1	36	50	2.5	30	0
461 ARMY	34000	1	19	50	0	0	0
461 ARMY	36000	3	49	50	0	0	0
461 ARMY	38000	3	34	50	0	0	0
461 ARMY	40000	3	46	50	0	0	0
461 NAVY	2	4	15	10	0	0	0
461 NAVY	3	3	31	10	0	0	0
461 NAVY	4	1	38	10	2.5	0	0
461 NAVY	5	1	6	10	0	0	0
461 NAVY	6	3	30	10	0	0	0
461 NAVY	7	4	10	10	0	0	0
461 NAVY	8	3	58	10	0	0	0
461 NAVY	9	3	51	10	0	0	0
461 NAVY	10	1	29	10	0	0	0
461 NAVY	11	3	37	10	0	0	0
461 NAVY	12	3	5	10	0	0	0
461 NAVY	13	3	44	10	0	0	0
461 NAVY	14	3	18	10	0	0	0
461 NAVY	15	1	39	10	0	0	0
461 NAVY	16	3	51	10	2.5	0	0
461 NAVY	17	3	20	10	2.5	0	0
461 NAVY	18	3	22	10	0	0	0
461 NAVY	19	4	13	10	0	0	0
461 NAVY	20	1	49	10	2.5	0	0
461 NAVY	21	4	13	10	0	0	0
461 NAVY	22	3	32	10	0	0	0
461 NAVY	23	4	39	10	0	0	0
461 NAVY	24	3	18	10	0	0	0
461 NAVY	25	3	25	10	0	0	0
461 NAVY	26	1	36	10	0	0	0
461 NAVY	27	4	10	10	0	0	0
461 NAVY	28	4	5	10	0	0	0
461 NAVY	29	4	6	10	0	0	0
461 NAVY	30	4	15	10	0	0	0
461 NAVY	30.01	4	42	10	0	0	0
461 NAVY	40	3	36	10	0	0	0
461 NAVY	50	1	35	10	0	0	0
461 NAVY	60	4	26	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 NAVY	70	3	56	10	0	0	0
461 NAVY	80	1	60	10	0	0	0
461 NAVY	90	3	7	10	0	0	0
461 NAVY	100	1	4	10	0	0	0
461 NAVY	110	4	13	10	0	0	0
461 NAVY	120	3	12	10	0	0	0
461 NAVY	130	3	3	10	0	0	0
461 NAVY	140	3	55	10	0	0	0
461 NAVY	150	4	53	10	0	0	0
461 NAVY	160	3	44	10	0	0	0
461 NAVY	170	3	35	10	0	0	0
461 NAVY	180	3	3	10	2.5	0	0
461 NAVY	190	4	18	10	0	0	0
461 NAVY	200	1	22	10	0	0	0
461 NAVY	210	4	27	10	0	0	0
461 NAVY	220	3	31	10	0	0	0
461 NAVY	230	4	46	10	2.5	0	0
461 NAVY	240	3	40	10	0	0	0
461 NAVY	250	1	21	10	0	0	0
461 NAVY	260	3	26	10	0	0	0
461 NAVY	270	1	14	10	0	0	0
461 NAVY	280	3	26	10	0	0	0
461 NAVY	290	3	36	10	0	0	0
461 NAVY	300	1	16	10	2.5	0	0
461 NAVY	310	3	21	10	0	0	0
461 NAVY	320	1	56	10	0	0	0
461 NAVY	330	3	21	10	0	0	0
461 NAVY	340	3	18	10	0	0	0
461 NAVY	350	4	51	10	0	0	0
461 NAVY	360	1	42	10	0	0	0
461 NAVY	370	3	55	10	0	0	0
461 NAVY	380	1	48	10	2.5	0	0
461 NAVY	390	3	16	10	2.5	0	0
461 NAVY	400	3	17	10	0	0	0
461 NAVY	410	1	11	10	0	0	0
461 NAVY	420	3	51	10	0	0	0
461 NAVY	430	3	7	10	0	0	0
461 NAVY	440	3	11	10	0	0	0
461 NAVY	450	1	39	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 NAVY	460	3	52	10	0	0	0
461 NAVY	470	1	28	10	0	0	0
461 NAVY	480	3	27	10	0	0	0
461 NAVY	490	1	23	10	0	0	0
461 NAVY	500	3	24	10	0	0	0
461 NAVY	510	1	13	10	0	0	0
461 NAVY	520	1	56	10	0	0	0
461 NAVY	530	3	14	10	2.5	0	0
461 NAVY	540	3	19	10	2.5	0	0
461 NAVY	550	4	6	10	0	0	0
461 NAVY	560	1	45	10	0	0	0
461 NAVY	570	1	47	10	2.5	0	0
461 NAVY	580	3	60	10	0	0	0
461 NAVY	590	1	59	10	0	0	0
461 NAVY	600	3	19	10	0	0	0
461 NAVY	610	3	25	10	0	0	0
461 NAVY	620	3	47	10	0	0	0
461 NAVY	630	3	33	10	2.5	0	0
461 NAVY	640	4	7	10	0	0	0
461 NAVY	650	4	32	10	2.5	0	0
461 NAVY	660	1	40	10	0	0	0
461 NAVY	670	3	55	10	0	0	0
461 NAVY	680	3	9	10	0	0	0
461 NAVY	690	1	29	10	0	0	0
461 NAVY	700	1	32	10	2.5	0	0
461 NAVY	710	1	48	10	2.5	0	0
461 NAVY	720	3	22	10	0	0	0
461 NAVY	730	4	26	10	0	0	0
461 NAVY	740	3	28	10	0	0	0
461 NAVY	750	4	56	10	0	0	0
461 NAVY	760	1	17	10	0	0	0
461 NAVY	770	3	17	10	2.5	0	0
461 NAVY	780	3	27	10	0	0	0
461 NAVY	790	3	35	10	0	0	0
461 NAVY	800	4	6	10	0	0	0
461 NAVY	810	4	37	10	0	0	0
461 NAVY	820	1	51	10	0	0	0
461 NAVY	830	4	14	10	0	0	0
461 NAVY	840	4	60	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 NAVY	850	3	10	10	0	0	0
461 NAVY	860	4	44	10	0	0	0
461 NAVY	870	3	30	10	0	0	0
461 NAVY	880	1	34	10	0	0	0
461 NAVY	890	3	9	10	2.5	0	0
461 NAVY	900	1	45	10	0	0	0
461 NAVY	910	4	56	10	0	0	0
461 NAVY	920	1	13	10	0	0	0
461 NAVY	930	4	31	10	0	0	0
461 NAVY	940	3	44	10	0	0	0
461 NAVY	950	4	4	10	0	0	0
461 NAVY	960	3	45	10	0	0	0
461 NAVY	970	1	23	10	0	0	0
461 NAVY	980	1	4	10	0	0	0
461 NAVY	990	3	53	10	0	0	0
461 NAVY	1000	3	5	10	2.5	0	0
461 NAVY	1000.01	1	24	50	0	0	0
461 NAVY	2000	3	12	50	2.5	30	0
461 NAVY	3000	1	23	50	0	0	0
461 NAVY	4000	1	5	50	2.5	30	0
461 NAVY	5000	1	3	50	0	0	0
461 NAVY	6000	4	47	50	2.5	30	0
461 NAVY	7000	4	29	50	0	0	0
461 NAVY	8000	4	31	50	2.5	30	0
461 NAVY	9000	3	33	50	0	0	0
461 NAVY	10000	1	7	50	0	0	0
461 NAVY	11000	1	36	50	0	0	0
461 NAVY	12000	1	19	50	0	0	0
461 NAVY	13000	4	39	50	2.5	30	0
461 NAVY	14000	4	18	50	0	0	0
461 NAVY	15000	3	55	50	0	0	0
461 NAVY	16000	3	30	50	2.5	30	0
461 NAVY	17000	1	27	50	0	0	0
461 NAVY	18000	3	29	50	0	0	0
461 NAVY	18000.01	3	49	50	2.5	30	0
461 NAVY	20000	1	53	50	0	0	0
461 NAVY	22000	3	50	50	2.5	30	0
461 NAVY	24000	3	32	50	0	0	0
461 NAVY	26000	1	15	50	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 NAVY	28000	4	28	50	2.5	30	0
461 NAVY	30000	3	27	50	0	0	0
461 NAVY	32000	4	8	50	2.5	30	0
461 NAVY	34000	1	36	50	0	0	0
461 NAVY	36000	4	27	50	0	0	0
461 NAVY	38000	3	16	50	0	0	0
461 NAVY	40000	3	26	50	0	0	0
461 AF	2	1	49	10	0	0	0
461 AF	3	4	24	10	0	0	0
461 AF	4	1	30	10	2.5	0	0
461 AF	5	3	55	10	0	0	0
461 AF	6	3	43	10	0	0	0
461 AF	7	4	52	10	0	0	0
461 AF	8	1	26	10	0	0	0
461 AF	9	4	22	10	0	0	0
461 AF	10	1	3	10	0	0	0
461 AF	11	3	22	10	0	0	0
461 AF	12	1	25	10	0	0	0
461 AF	13	3	58	10	0	0	0
461 AF	14	3	6	10	0	0	0
461 AF	15	3	13	10	0	0	0
461 AF	16	1	21	10	2.5	0	0
461 AF	17	1	31	10	2.5	0	0
461 AF	18	3	60	10	0	0	0
461 AF	19	3	44	10	0	0	0
461 AF	20	3	38	10	2.5	0	0
461 AF	21	3	8	10	0	0	0
461 AF	22	1	8	10	0	0	0
461 AF	23	3	56	10	0	0	0
461 AF	24	3	8	10	0	0	0
461 AF	25	3	36	10	0	0	0
461 AF	26	1	13	10	0	0	0
461 AF	27	1	60	10	0	0	0
461 AF	28	4	27	10	0	0	0
461 AF	29	4	17	10	0	0	0
461 AF	30	4	6	10	0	0	0
461 AF	30.01	4	46	10	0	0	0
461 AF	40	3	40	10	0	0	0
461 AF	50	3	40	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 AF	60	4	45	10	0	0	0
461 AF	70	4	32	10	0	0	0
461 AF	80	4	50	10	0	0	0
461 AF	90	3	27	10	0	0	0
461 AF	100	1	38	10	0	0	0
461 AF	110	3	22	10	0	0	0
461 AF	120	4	44	10	0	0	0
461 AF	130	1	30	10	0	0	0
461 AF	140	3	44	10	0	0	0
461 AF	150	3	7	10	0	0	0
461 AF	160	3	45	10	0	0	0
461 AF	170	3	50	10	0	0	0
461 AF	180	3	28	10	2.5	0	0
461 AF	190	4	43	10	0	0	0
461 AF	200	4	9	10	0	0	0
461 AF	210	3	21	10	0	0	0
461 AF	220	3	7	10	0	0	0
461 AF	230	3	44	10	2.5	0	0
461 AF	240	3	56	10	0	0	0
461 AF	250	1	6	10	0	0	0
461 AF	260	1	56	10	0	0	0
461 AF	270	3	6	10	0	0	0
461 AF	280	4	7	10	0	0	0
461 AF	290	4	49	10	0	0	0
461 AF	300	3	36	10	2.5	0	0
461 AF	310	3	17	10	0	0	0
461 AF	320	3	40	10	0	0	0
461 AF	330	3	14	10	0	0	0
461 AF	340	3	50	10	0	0	0
461 AF	350	3	52	10	0	0	0
461 AF	360	4	15	10	0	0	0
461 AF	370	3	31	10	0	0	0
461 AF	380	3	31	10	2.5	0	0
461 AF	390	4	11	10	2.5	0	0
461 AF	400	1	20	10	0	0	0
461 AF	410	3	45	10	0	0	0
461 AF	420	1	49	10	0	0	0
461 AF	430	1	47	10	0	0	0
461 AF	440	1	10	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 AF	450	1	58	10	0	0	0
461 AF	460	4	7	10	0	0	0
461 AF	470	3	5	10	0	0	0
461 AF	480	3	55	10	0	0	0
461 AF	490	1	44	10	0	0	0
461 AF	500	3	7	10	0	0	0
461 AF	510	4	30	10	0	0	0
461 AF	520	4	54	10	0	0	0
461 AF	530	4	51	10	2.5	0	0
461 AF	540	3	53	10	2.5	0	0
461 AF	550	4	9	10	0	0	0
461 AF	560	4	55	10	0	0	0
461 AF	570	3	46	10	2.5	0	0
461 AF	580	3	39	10	0	0	0
461 AF	590	4	39	10	0	0	0
461 AF	600	1	13	10	0	0	0
461 AF	610	3	23	10	0	0	0
461 AF	620	4	52	10	0	0	0
461 AF	630	3	60	10	2.5	0	0
461 AF	640	4	46	10	0	0	0
461 AF	650	3	21	10	2.5	0	0
461 AF	660	1	52	10	0	0	0
461 AF	670	1	27	10	0	0	0
461 AF	680	1	51	10	0	0	0
461 AF	690	3	7	10	0	0	0
461 AF	700	4	16	10	2.5	0	0
461 AF	710	3	18	10	2.5	0	0
461 AF	720	4	22	10	0	0	0
461 AF	730	3	35	10	0	0	0
461 AF	740	3	30	10	0	0	0
461 AF	750	1	21	10	0	0	0
461 AF	760	3	8	10	0	0	0
461 AF	770	4	12	10	2.5	0	0
461 AF	780	3	43	10	0	0	0
461 AF	790	3	25	10	0	0	0
461 AF	800	4	28	10	0	0	0
461 AF	810	4	31	10	0	0	0
461 AF	820	1	37	10	0	0	0
461 AF	830	3	33	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 AF	840	3	27	10	0	0	0
461 AF	850	4	33	10	0	0	0
461 AF	860	3	29	10	0	0	0
461 AF	870	1	48	10	0	0	0
461 AF	880	4	49	10	0	0	0
461 AF	890	3	8	10	2.5	0	0
461 AF	900	3	11	10	0	0	0
461 AF	910	3	35	10	0	0	0
461 AF	920	4	54	10	0	0	0
461 AF	930	1	31	10	0	0	0
461 AF	940	1	41	10	0	0	0
461 AF	950	3	37	10	0	0	0
461 AF	960	3	56	10	0	0	0
461 AF	970	3	34	10	0	0	0
461 AF	980	4	32	10	0	0	0
461 AF	990	3	32	10	0	0	0
461 AF	1000	3	45	10	2.5	0	0
461 AF	1000.01	3	52	50	0	0	0
461 AF	2000	3	35	50	2.5	30	0
461 AF	3000	1	26	50	0	0	0
461 AF	4000	1	7	50	2.5	30	0
461 AF	5000	1	7	50	0	0	0
461 AF	6000	3	38	50	2.5	30	0
461 AF	7000	4	40	50	0	0	0
461 AF	8000	1	11	50	2.5	30	0
461 AF	9000	3	18	50	0	0	0
461 AF	10000	4	3	50	0	0	0
461 AF	11000	4	11	50	0	0	0
461 AF	12000	1	43	50	0	0	0
461 AF	13000	3	19	50	2.5	30	0
461 AF	14000	3	40	50	0	0	0
461 AF	15000	3	36	50	0	0	0
461 AF	16000	4	47	50	2.5	30	0
461 AF	17000	3	18	50	0	0	0
461 AF	18000	3	46	50	0	0	0
461 AF	18000.01	3	11	50	2.5	30	0
461 AF	20000	3	23	50	0	0	0
461 AF	22000	1	21	50	2.5	30	0
461 AF	24000	3	32	50	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
461 AF	26000	4	9	50	0	0	0
461 AF	28000	3	3	50	2.5	30	0
461 AF	30000	1	58	50	0	0	0
461 AF	32000	3	21	50	2.5	30	0
461 AF	34000	4	8	50	0	0	0
461 AF	36000	3	19	50	0	0	0
461 AF	38000	3	48	50	0	0	0
461 AF	40000	3	37	50	0	0	0
Safety Critical	2	1	33	200	0	0	0
Safety Critical	3	1	33	200	0	0	0
Safety Critical	4	1	50	200	2.5	30	70
Safety Critical	5	3	32	200	0	0	0
Safety Critical	6	3	13	200	0	0	0
Safety Critical	7	3	20	200	0	0	0
Safety Critical	8	4	16	200	0	0	0
Safety Critical	9	3	44	200	0	0	0
Safety Critical	10	3	3	200	0	0	0
Safety Critical	11	3	8	200	0	0	0
Safety Critical	12	3	40	200	0	0	0
Safety Critical	13	3	10	200	0	0	0
Safety Critical	14	1	32	200	0	0	0
Safety Critical	15	1	36	200	0	0	0
Safety Critical	16	3	17	200	2.5	30	70
Safety Critical	17	3	29	200	2.5	30	70
Safety Critical	18	3	41	200	0	0	0
Safety Critical	19	1	19	200	0	0	0
Safety Critical	20	3	46	200	2.5	30	70
Safety Critical	21	3	18	200	0	0	0
Safety Critical	22	3	57	200	0	0	0
Safety Critical	23	1	38	200	0	0	0
Safety Critical	24	3	47	200	0	0	0
Safety Critical	25	3	25	200	0	0	0
Safety Critical	26	3	9	200	0	0	0
Safety Critical	27	4	4	200	0	0	0
Safety Critical	28	4	20	200	0	0	0
Safety Critical	29	4	56	200	0	0	0
Safety Critical	30	1	10	200	0	0	0
Safety Critical	30.01	3	51	200	0	0	0
Safety Critical	40	3	38	200	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
Safety Critical	50	3	40	200	0	0	0
Safety Critical	60	4	49	200	0	0	0
Safety Critical	70	4	45	200	0	0	0
Safety Critical	80	3	5	200	0	0	0
Safety Critical	90	3	43	200	0	0	0
Safety Critical	100	4	49	200	0	0	0
Safety Critical	110	3	57	200	0	0	0
Safety Critical	120	4	12	200	0	0	0
Safety Critical	130	3	30	200	0	0	0
Safety Critical	140	4	7	200	0	0	0
Safety Critical	150	3	39	200	0	0	0
Safety Critical	160	4	22	200	0	0	0
Safety Critical	170	3	41	200	0	0	0
Safety Critical	180	4	58	200	2.5	30	70
Safety Critical	190	1	48	200	0	0	0
Safety Critical	200	1	34	200	0	0	0
Safety Critical	210	3	49	200	0	0	0
Safety Critical	220	4	58	200	0	0	0
Safety Critical	230	4	59	200	2.5	30	70
Safety Critical	240	4	55	200	0	0	0
Safety Critical	250	3	60	200	0	0	0
Safety Critical	260	3	49	200	0	0	0
Safety Critical	270	3	48	200	0	0	0
Safety Critical	280	4	40	200	0	0	0
Safety Critical	290	3	23	200	0	0	0
Safety Critical	300	3	6	200	2.5	30	70
Safety Critical	310	3	58	200	0	0	0
Safety Critical	320	4	46	200	0	0	0
Safety Critical	330	3	47	200	0	0	0
Safety Critical	340	3	21	200	0	0	0
Safety Critical	350	4	3	200	0	0	0
Safety Critical	360	3	54	200	0	0	0
Safety Critical	370	1	45	200	0	0	0
Safety Critical	380	1	41	200	2.5	30	70
Safety Critical	390	3	56	200	2.5	30	70
Safety Critical	400	1	60	200	0	0	0
Safety Critical	410	4	52	200	0	0	0
Safety Critical	420	1	39	200	0	0	0
Safety Critical	430	3	47	200	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
Safety Critical	440	4	21	200	0	0	0
Safety Critical	450	4	19	200	0	0	0
Safety Critical	460	3	51	200	0	0	0
Safety Critical	470	3	11	200	0	0	0
Safety Critical	480	1	26	200	0	0	0
Safety Critical	490	4	58	200	0	0	0
Safety Critical	500	3	16	200	0	0	0
Safety Critical	510	1	56	200	0	0	0
Safety Critical	520	3	6	200	0	0	0
Safety Critical	530	1	34	200	2.5	30	70
Safety Critical	540	3	19	200	2.5	30	70
Safety Critical	550	4	37	200	0	0	0
Safety Critical	560	3	55	200	0	0	0
Safety Critical	570	3	34	200	2.5	30	70
Safety Critical	580	3	13	200	0	0	0
Safety Critical	590	3	50	200	0	0	0
Safety Critical	600	4	10	200	0	0	0
Safety Critical	610	3	14	200	0	0	0
Safety Critical	620	1	30	200	0	0	0
Safety Critical	630	3	12	200	2.5	30	70
Safety Critical	640	1	19	200	0	0	0
Safety Critical	650	1	26	200	2.5	30	70
Safety Critical	660	4	19	200	0	0	0
Safety Critical	670	3	55	200	0	0	0
Safety Critical	680	3	20	200	0	0	0
Safety Critical	690	3	8	200	0	0	0
Safety Critical	700	4	36	200	2.5	30	70
Safety Critical	710	1	10	200	2.5	30	70
Safety Critical	720	1	23	200	0	0	0
Safety Critical	730	1	45	200	0	0	0
Safety Critical	740	3	8	200	0	0	0
Safety Critical	750	3	58	200	0	0	0
Safety Critical	760	4	32	200	0	0	0
Safety Critical	770	4	51	200	2.5	30	70
Safety Critical	780	4	24	200	0	0	0
Safety Critical	790	3	50	200	0	0	0
Safety Critical	800	1	38	200	0	0	0
Safety Critical	810	4	19	200	0	0	0
Safety Critical	820	3	56	200	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
Safety Critical	830	4	49	200	0	0	0
Safety Critical	840	3	52	200	0	0	0
Safety Critical	850	1	41	200	0	0	0
Safety Critical	860	3	56	200	0	0	0
Safety Critical	870	3	14	200	0	0	0
Safety Critical	880	1	45	200	0	0	0
Safety Critical	890	4	56	200	2.5	30	70
Safety Critical	900	4	5	200	0	0	0
Safety Critical	910	3	41	200	0	0	0
Safety Critical	920	4	26	200	0	0	0
Safety Critical	930	4	40	200	0	0	0
Safety Critical	940	4	40	200	0	0	0
Safety Critical	950	1	56	200	0	0	0
Safety Critical	960	3	51	200	0	0	0
Safety Critical	970	1	19	200	0	0	0
Safety Critical	980	1	28	200	0	0	0
Safety Critical	990	3	26	200	0	0	0
Safety Critical	1000	1	8	200	2.5	30	70
Safety Critical	1000.01	1	5	200	0	0	0
Safety Critical	2000	3	59	200	2.5	30	70
Safety Critical	2002	3	59	200	0	0	0
Safety Critical	2699	3	59	200	0	0	0
Safety Critical	2700	3	59	200	0	30	70
Safety Critical	2701	3	59	200	0	0	0
Safety Critical	3000	1	45	200	0	0	0
Safety Critical	3600	1	45	200	0	0	70
Safety Critical	4000	1	23	200	2.5	30	70
Safety Critical	5000	3	59	200	0	0	0
Safety Critical	5399	3	59	200	0	0	0
Safety Critical	5400	3	59	200	0	0	70
Safety Critical	6000	3	29	200	2.5	30	70
Safety Critical	7000	1	41	200	0	0	0
Safety Critical	8000	3	44	200	2.5	30	70
Safety Critical	9000	3	9	200	0	0	0
Safety Critical	10000	4	20	200	0	0	0
Safety Critical	11000	1	20	200	0	0	0
Safety Critical	12000	3	16	200	0	0	0
Safety Critical	13000	3	27	200	2.5	30	70
Safety Critical	14000	4	40	200	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
Safety Critical	15000	3	39	200	0	0	70
Safety Critical	16000	4	58	200	2.5	30	70
Safety Critical	17000	1	54	200	0	0	70
Safety Critical	18000	3	49	200	0	0	0
Safety Critical	18000.01	1	58	200	2.5	30	70
Safety Critical	20000	3	25	200	0	0	0
Safety Critical	22000	3	36	200	2.5	30	70
Safety Critical	24000	3	53	200	0	0	0
Safety Critical	26000	1	48	200	0	0	0
Safety Critical	28000	4	27	200	2.5	30	70
Safety Critical	30000	3	58	200	0	0	0
Safety Critical	32000	3	57	200	2.5	30	70
Safety Critical	34000	3	38	200	0	0	0
Safety Critical	36000	3	6	200	0	0	0
Safety Critical	38000	1	33	200	2.5	30	70
Safety Critical	40000	3	33	200	0	0	0
464C	0.01	2	82	73	0	0	0
464C	0.29	2	82	73	0	0	0
464C	0.3	2	82	73	0	30	70
464C	0.5	2	82	73	0	0	70
464C	0.99	2	82	73	0	0	0
464C	1	3	126	73	2.5	30	70
464C	2	3	97	73	2.5	30	70
464C	2.01	1	115	103	0	0	0
464C	3	2	171	103	0	0	0
464C	4	3	93	103	2.5	30	70
464C	5	4	160	103	0	0	0
464C	6	3	135	103	0	0	0
464C	7	3	141	103	0	0	0
464C	8	2	113	103	0	0	0
464C	9	1	77	103	0	0	0
464C	10	3	145	103	0	0	0
464C	11	1	141	103	0	0	0
464C	12	4	64	103	0	0	0
464C	13	4	116	103	0	0	0
464C	14	1	66	103	0	0	0
464C	15	2	72	103	0	0	0
464C	16	1	81	103	2.5	30	70
464C	17	1	134	103	2.5	30	70

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
464C	18	3	123	103	0	0	0
464C	19	2	135	103	0	0	0
464C	20	4	136	103	2.5	30	70
464C	21	2	117	103	0	0	0
464C	22	1	179	103	0	0	0
464C	23	1	59	103	0	0	0
464C	24	4	125	103	0	0	0
464C	25	4	46	103	0	0	0
464C	26	3	63	103	0	0	0
464C	27	4	115	103	0	0	0
464C	28	4	163	103	0	0	0
464C	29	4	95	103	0	0	0
464C	30	2	130	103	0	0	0
464C	30.01	3	154	74	0	0	0
464C	40	3	58	74	0	0	0
464C	50	4	60	74	0	0	0
464C	60	4	151	74	0	0	0
464C	70	1	100	74	0	0	0
464C	80	2	160	74	0	0	0
464C	90	1	149	74	0	0	0
464C	100	4	55	74	0	0	0
464C	110	3	144	74	0	0	0
464C	120	2	92	74	0	0	0
464C	130	1	99	74	0	0	0
464C	140	4	137	74	0	0	0
464C	150	4	172	74	0	0	0
464C	150.01	1	74	41	0	0	0
464C	160	1	117	41	0	0	0
464C	170	2	59	41	0	0	0
464C	180	3	60	41	2.5	30	0
464C	190	1	54	41	0	0	0
464C	200	4	54	41	0	0	0
464C	210	1	66	41	0	0	0
464C	220	3	103	41	0	0	0
464C	225	3	76	41	0	0	0
464C	225.01	2	83	92	0	0	0
464C	230	1	156	92	2.5	30	70
464C	240	4	173	92	0	0	0
464C	250	4	55	92	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
464C	260	1	116	92	0	0	0
464C	270	2	46	92	0	0	0
464C	280	4	105	92	0	0	0
464C	290	1	152	92	0	0	0
464C	300	1	126	92	2.5	30	70
464C	310	3	52	92	0	0	0
464C	320	1	50	92	0	0	0
464C	330	2	137	92	0	0	0
464C	340	2	139	92	0	0	0
464C	350	2	125	92	0	0	0
464C	360	3	156	92	0	0	0
464C	370	3	91	92	0	0	0
464C	380	3	155	92	2.5	30	70
464C	390	2	156	92	2.5	30	70
464C	400	3	179	92	0	0	0
464C	400.01	4	61	98	0	0	0
464C	410	2	164	98	0	0	0
464C	420	2	125	98	0	0	0
464C	430	2	116	98	0	0	0
464C	440	4	60	98	0	0	0
464C	450	3	172	98	0	0	0
464C	460	4	139	98	0	0	0
464C	470	3	86	98	0	0	0
464C	480	1	147	98	0	0	0
464C	490	4	124	98	0	0	0
464C	500	2	130	98	0	0	0
464C	510	4	65	98	0	0	0
464C	520	2	73	98	0	0	0
464C	530	3	53	98	2.5	30	70
464C	540	4	94	98	2.5	30	70
464C	550	4	120	98	0	0	0
464C	560	4	167	98	0	0	0
464C	570	4	64	98	2.5	30	70
464C	580	2	93	98	0	0	0
464C	590	3	161	98	0	0	0
464C	600	1	150	98	0	0	0
464C	610	4	169	98	0	0	0
464C	620	3	114	98	0	0	0
464C	630	1	48	98	2.5	30	70

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
464C	640	2	146	98	0	0	0
464C	650	2	152	98	2.5	30	70
464C	660	2	70	98	0	0	0
464C	670	2	97	98	0	0	0
464C	680	1	111	98	0	0	0
464C	690	4	92	98	0	0	0
464C	700	2	81	98	2.5	30	70
464C	700.01	4	116	267	0	0	0
464C	710	1	102	267	2.5	30	70
464C	720	2	169	267	0	0	0
464C	730	2	176	267	0	0	0
464C	740	2	155	267	0	0	0
464C	750	3	59	267	0	0	0
464C	760	2	84	267	0	0	0
464C	770	4	94	267	2.5	30	70
464C	780	4	128	267	0	0	0
464C	790	1	107	267	0	0	0
464C	790.01	4	69	267	0	0	0
464C	800	4	157	267	0	0	0
464C	810	4	173	267	0	0	0
464C	820	4	128	267	0	0	0
464C	830	1	158	267	0	0	0
464C	840	1	141	267	0	0	0
464C	850	2	76	267	0	0	0
464C	860	4	149	267	0	0	0
464C	870	3	136	267	0	0	0
464C	880	2	76	267	0	0	0
464C	890	3	64	267	2.5	30	70
464C	900	1	76	267	0	0	0
464C	910	1	126	267	0	0	0
464C	920	1	144	267	0	0	0
464C	930	4	175	267	0	0	0
464C	940	1	82	267	0	0	0
464C	950	1	143	267	0	0	0
464C	960	2	132	267	0	0	0
464C	970	3	100	267	0	0	0
464C	980	2	161	267	0	0	0
464C	990	1	107	267	0	0	0
464C	1000	2	150	267	2.5	30	70

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
464C	1000.01	3	121	155	0	0	0
464C	2000	2	104	155	2.5	30	70
464C	2000.01	1	114	155	0	0	0
464C	2700	4	178	155	0	30	70
464C	2700.01	1	114	219	0	0	0
464C	3600	3	47	219	0	0	70
464C	3600.01	2	60	49	0	0	0
464C	4000	2	101	49	2.5	30	0
464C	4000.01	4	129	183	0	0	0
464C	5400	2	102	183	0	0	70
464C	5400.01	4	56	155	0	0	0
464C	5900	3	141	155	0	0	0
464C	5900.01	4	76	55	0	0	0
464C	6000	3	72	55	2.5	30	0
464C	6000.01	1	171	119	0	0	0
464C	7000	3	68	119	0	0	0
464C	7900	2	85	119	0	0	0
464C	7900.01	2	163	97	0	0	0
464C	8000	2	115	97	2.5	30	70
464C	8000.01	4	172	110	0	0	0
464C	8400	2	98	110	0	0	0
464C	8400.01	3	92	110	0	0	0
464C	8500	2	76	110	0	0	0
464C	8500.01	1	85	139	0	0	0
464C	9000	1	144	139	0	0	0
464C	10000	1	53	139	0	0	0
464C	11000	1	65	139	0	0	0
464C	11000.01	4	67	110	0	0	0
464C	12000	4	94	110	0	0	0
464C	13000	2	92	110	2.5	30	70
464C	14000	4	62	110	0	0	0
464C	14000.01	1	141	243	0	0	0
464C	15000	1	62	243	0	0	70
464C	16000	1	55	243	2.5	30	70
464C	17000	1	109	243	0	0	70
464C	18000	2	87	243	0	0	0
464C	18000.01	4	152	76	2.5	30	70
464C	19000	4	152	76	0	0	0
464C	22000	1	153	76	2.5	30	70

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
464C	23000	1	153	76	0	0	0
464C	28000	3	130	76	2.5	30	70
464C	32000	3	166	76	2.5	30	70
464C	33000	3	166	76	0	0	0
464C	38000	3	75	76	2.5	30	70
464C	43000	1	113	76	2.5	30	70
464C	48000	4	128	76	2.5	30	70
464C	50000	3	87	76	0	0	0
IEC-61000-6-1	80	0	26	3	0	0	0
IEC-61000-6-1	90	0	25	3	0	0	0
IEC-61000-6-1	100	0	1	3	0	0	0
IEC-61000-6-1	110	1	7	3	0	0	0
IEC-61000-6-1	120	1	17	3	0	0	0
IEC-61000-6-1	130	0	2	3	0	0	0
IEC-61000-6-1	140	0	17	3	0	0	0
IEC-61000-6-1	150	0	9	3	0	0	0
IEC-61000-6-1	160	0	1	3	0	0	0
IEC-61000-6-1	170	0	7	3	0	0	0
IEC-61000-6-1	180	0	23	3	2.5	0	0
IEC-61000-6-1	190	0	14	3	0	0	0
IEC-61000-6-1	200	0	5	3	0	0	0
IEC-61000-6-1	210	0	9	3	0	0	0
IEC-61000-6-1	220	0	17	3	0	0	0
IEC-61000-6-1	230	0	9	3	2.5	0	0
IEC-61000-6-1	240	0	27	3	0	0	0
IEC-61000-6-1	250	0	12	3	0	0	0
IEC-61000-6-1	260	0	11	3	0	0	0
IEC-61000-6-1	270	0	28	3	0	0	0
IEC-61000-6-1	280	1	12	3	0	0	0
IEC-61000-6-1	290	0	9	3	0	0	0
IEC-61000-6-1	300	0	11	3	2.5	0	0
IEC-61000-6-1	310	0	2	3	0	0	0
IEC-61000-6-1	320	1	27	3	0	0	0
IEC-61000-6-1	330	1	23	3	0	0	0
IEC-61000-6-1	340	0	23	3	0	0	0
IEC-61000-6-1	350	1	3	3	0	0	0
IEC-61000-6-1	360	1	17	3	0	0	0
IEC-61000-6-1	370	1	14	3	0	0	0
IEC-61000-6-1	380	1	23	3	2.5	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
IEC-61000-6-1	390	0	12	3	2.5	0	0
IEC-61000-6-1	400	1	8	3	0	0	0
IEC-61000-6-1	410	0	24	3	0	0	0
IEC-61000-6-1	420	0	2	3	0	0	0
IEC-61000-6-1	430	0	5	3	0	0	0
IEC-61000-6-1	440	0	4	3	0	0	0
IEC-61000-6-1	450	0	30	3	0	0	0
IEC-61000-6-1	460	0	8	3	0	0	0
IEC-61000-6-1	470	1	12	3	0	0	0
IEC-61000-6-1	480	0	20	3	0	0	0
IEC-61000-6-1	490	0	6	3	0	0	0
IEC-61000-6-1	500	0	23	3	0	0	0
IEC-61000-6-1	510	0	4	3	0	0	0
IEC-61000-6-1	520	0	29	3	0	0	0
IEC-61000-6-1	530	0	2	3	2.5	0	0
IEC-61000-6-1	540	0	5	3	2.5	0	0
IEC-61000-6-1	550	0	8	3	0	0	0
IEC-61000-6-1	560	0	14	3	0	0	0
IEC-61000-6-1	570	1	19	3	2.5	0	0
IEC-61000-6-1	580	1	12	3	0	0	0
IEC-61000-6-1	590	0	19	3	0	0	0
IEC-61000-6-1	600	0	10	3	0	0	0
IEC-61000-6-1	610	0	12	3	0	0	0
IEC-61000-6-1	620	0	16	3	0	0	0
IEC-61000-6-1	630	1	22	3	2.5	0	0
IEC-61000-6-1	640	0	8	3	0	0	0
IEC-61000-6-1	650	0	13	3	2.5	0	0
IEC-61000-6-1	660	1	28	3	0	0	0
IEC-61000-6-1	670	0	1	3	0	0	0
IEC-61000-6-1	680	0	2	3	0	0	0
IEC-61000-6-1	690	0	15	3	0	0	0
IEC-61000-6-1	700	0	5	3	2.5	0	0
IEC-61000-6-1	710	0	29	3	2.5	0	0
IEC-61000-6-1	720	0	13	3	0	0	0
IEC-61000-6-1	730	0	22	3	0	0	0
IEC-61000-6-1	740	0	18	3	0	0	0
IEC-61000-6-1	750	1	12	3	0	0	0
IEC-61000-6-1	760	1	10	3	0	0	0
IEC-61000-6-1	770	1	7	3	2.5	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
IEC-61000-6-1	780	1	16	3	0	0	0
IEC-61000-6-1	790	1	21	3	0	0	0
IEC-61000-6-1	800	0	29	3	0	0	0
IEC-61000-6-1	810	0	9	3	0	0	0
IEC-61000-6-1	820	1	2	3	0	0	0
IEC-61000-6-1	830	0	18	3	0	0	0
IEC-61000-6-1	840	0	18	3	0	0	0
IEC-61000-6-1	850	0	28	3	0	0	0
IEC-61000-6-1	860	0	24	3	0	0	0
IEC-61000-6-1	870	1	8	3	0	0	0
IEC-61000-6-1	880	1	26	3	0	0	0
IEC-61000-6-1	890	0	14	3	2.5	0	0
IEC-61000-6-1	900	0	18	3	0	0	0
IEC-61000-6-1	910	0	5	3	0	0	0
IEC-61000-6-1	920	0	5	3	0	0	0
IEC-61000-6-1	930	0	30	3	0	0	0
IEC-61000-6-1	940	0	6	3	0	0	0
IEC-61000-6-1	950	1	21	3	0	0	0
IEC-61000-6-1	960	0	25	3	0	0	0
IEC-61000-6-1	970	0	15	3	0	0	0
IEC-61000-6-1	980	0	21	3	0	0	0
IEC-61000-6-1	990	0	11	3	0	0	0
IEC-61000-6-1	1000	0	10	3	2.5	0	0
IEC-61000-6-1	1400	1	18	3	0	0	0
IEC-61000-6-1	2000	0	10	3	2.5	0	0
IEC-61000-6-1	2000.01	0	13	1	0	0	0
IEC-61000-6-1	2700	0	1	1	0	0	0
IEC-61000-6-2	80	0	18	10	0	0	0
IEC-61000-6-2	90	0	27	10	0	0	0
IEC-61000-6-2	100	0	16	10	0	0	0
IEC-61000-6-2	110	1	30	10	0	0	0
IEC-61000-6-2	120	0	27	10	0	0	0
IEC-61000-6-2	130	0	18	10	0	0	0
IEC-61000-6-2	140	1	19	10	0	0	0
IEC-61000-6-2	150	0	4	10	0	0	0
IEC-61000-6-2	160	0	14	10	0	0	0
IEC-61000-6-2	170	1	11	10	0	0	0
IEC-61000-6-2	180	0	11	10	2.5	0	0
IEC-61000-6-2	190	0	9	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
IEC-61000-6-2	200	0	28	10	0	0	0
IEC-61000-6-2	210	0	14	10	0	0	0
IEC-61000-6-2	220	0	29	10	0	0	0
IEC-61000-6-2	230	0	13	10	2.5	0	0
IEC-61000-6-2	240	1	23	10	0	0	0
IEC-61000-6-2	250	0	26	10	0	0	0
IEC-61000-6-2	260	0	19	10	0	0	0
IEC-61000-6-2	270	0	13	10	0	0	0
IEC-61000-6-2	280	1	19	10	0	0	0
IEC-61000-6-2	290	1	11	10	0	0	0
IEC-61000-6-2	300	0	10	10	2.5	0	0
IEC-61000-6-2	310	0	13	10	0	0	0
IEC-61000-6-2	320	0	19	10	0	0	0
IEC-61000-6-2	330	0	15	10	0	0	0
IEC-61000-6-2	340	1	7	10	0	0	0
IEC-61000-6-2	350	0	12	10	0	0	0
IEC-61000-6-2	360	0	3	10	0	0	0
IEC-61000-6-2	370	0	5	10	0	0	0
IEC-61000-6-2	380	0	19	10	2.5	0	0
IEC-61000-6-2	390	0	26	10	2.5	0	0
IEC-61000-6-2	400	0	21	10	0	0	0
IEC-61000-6-2	410	0	23	10	0	0	0
IEC-61000-6-2	420	0	7	10	0	0	0
IEC-61000-6-2	430	0	15	10	0	0	0
IEC-61000-6-2	440	0	21	10	0	0	0
IEC-61000-6-2	450	0	5	10	0	0	0
IEC-61000-6-2	460	0	26	10	0	0	0
IEC-61000-6-2	470	1	11	10	0	0	0
IEC-61000-6-2	480	0	17	10	0	0	0
IEC-61000-6-2	490	0	1	10	0	0	0
IEC-61000-6-2	500	1	27	10	0	0	0
IEC-61000-6-2	510	0	27	10	0	0	0
IEC-61000-6-2	520	0	6	10	0	0	0
IEC-61000-6-2	530	0	16	10	2.5	0	0
IEC-61000-6-2	540	0	9	10	2.5	0	0
IEC-61000-6-2	550	0	9	10	0	0	0
IEC-61000-6-2	560	1	6	10	0	0	0
IEC-61000-6-2	570	1	16	10	2.5	0	0
IEC-61000-6-2	580	0	13	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
IEC-61000-6-2	590	0	7	10	0	0	0
IEC-61000-6-2	600	0	24	10	0	0	0
IEC-61000-6-2	610	1	1	10	0	0	0
IEC-61000-6-2	620	0	29	10	0	0	0
IEC-61000-6-2	630	0	14	10	2.5	0	0
IEC-61000-6-2	640	0	20	10	0	0	0
IEC-61000-6-2	650	0	6	10	2.5	0	0
IEC-61000-6-2	660	0	4	10	0	0	0
IEC-61000-6-2	670	0	12	10	0	0	0
IEC-61000-6-2	680	0	25	10	0	0	0
IEC-61000-6-2	690	1	7	10	0	0	0
IEC-61000-6-2	700	1	5	10	2.5	0	0
IEC-61000-6-2	710	1	18	10	2.5	0	0
IEC-61000-6-2	720	1	2	10	0	0	0
IEC-61000-6-2	730	1	14	10	0	0	0
IEC-61000-6-2	740	0	23	10	0	0	0
IEC-61000-6-2	750	0	10	10	0	0	0
IEC-61000-6-2	760	1	8	10	0	0	0
IEC-61000-6-2	770	0	19	10	2.5	0	0
IEC-61000-6-2	780	0	3	10	0	0	0
IEC-61000-6-2	790	1	20	10	0	0	0
IEC-61000-6-2	800	0	1	10	0	0	0
IEC-61000-6-2	810	0	4	10	0	0	0
IEC-61000-6-2	820	0	20	10	0	0	0
IEC-61000-6-2	830	0	14	10	0	0	0
IEC-61000-6-2	840	0	15	10	0	0	0
IEC-61000-6-2	850	0	23	10	0	0	0
IEC-61000-6-2	860	1	8	10	0	0	0
IEC-61000-6-2	870	1	3	10	0	0	0
IEC-61000-6-2	880	0	15	10	0	0	0
IEC-61000-6-2	890	0	2	10	2.5	0	0
IEC-61000-6-2	900	1	22	10	0	0	0
IEC-61000-6-2	910	0	17	10	0	0	0
IEC-61000-6-2	920	0	20	10	0	0	0
IEC-61000-6-2	930	0	25	10	0	0	0
IEC-61000-6-2	940	0	15	10	0	0	0
IEC-61000-6-2	950	0	29	10	0	0	0
IEC-61000-6-2	960	0	7	10	0	0	0
IEC-61000-6-2	970	0	16	10	0	0	0

Standard	Frequency (MHz)	Modulation (AM, FM, CW, PULSE) 1,2,3,4 zero is no modulation	Dwell Time (Seconds)	Field Strength (V/m)	Susceptibility Low FS	Susceptibility Medium FS	Susceptibility High FS
IEC-61000-6-2	980	1	18	10	0	0	0
IEC-61000-6-2	990	0	11	10	0	0	0
IEC-61000-6-2	1000	0	21	10	2.5	0	0
IEC-61000-6-2	1400	0	30	3	0	0	0
IEC-61000-6-2	2000	0	29	3	2.5	0	0
IEC-61000-6-2	2000.01	0	26	1	0	0	0
IEC-61000-6-2	2700	1	28	1	0	0	0

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