NEW DEVELOPMENTS IN INTENTIONAL ELECTROMAGNETIC INTERFERENCE (IEMI) AND HIGH-ALTITUDE ELECTOMAGNETIC PULSE (HEMP) (Invited)

W. Radasky

Metatech Corporation, 358 S. Fairview Ave., Suite E, Goleta, CA 93117 USA, E-mail: wradasky@aol.com

ABSTRACT

In 2004 two major milestones occurred with regard to the related areas of Intentional Electromagnetic Interference (IEMI) and High-altitude Electromagnetic Pulse (HEMP). In the field of IEMI, the Special Issue on High-Power Electromagnetics (HPEM) and Intentional Electromagnetic Interference (IEMI) was published in the IEEE Transactions on EMC in August 2004. With regard to HEMP, a U.S. Congressional Commission reported on the potential impact of HEMP on the civil infrastructure.

This paper will review several of the important aspects of both documents and will further discuss some of the technical contributions in the area of electric power system vulnerabilities.

INTRODUCTION

In 2004 two major milestones occurred with regard to the related areas of Intentional Electromagnetic Interference (IEMI) and High-altitude Electromagnetic Pulse (HEMP). IEMI is defined as the intentional malicious generation of electromagnetic energy introducing noise or signals into electric and electronic systems, thus disrupting, confusing or damaging these systems for terrorist or criminal purposes [1]. HEMP is defined as an electromagnetic pulse produced by a nuclear explosion outside of the earth's atmosphere [1].

In the field of IEMI, the Special Issue on High-Power Electromagnetics (HPEM) and Intentional Electromagnetic Interference (IEMI) was published in the IEEE Transactions on EMC in August 2004 [2]. This special issue was divided into four main topical areas including: Environments and Test Capabilities; Coupling to Cables and Systems; IEMI Effects on Equipment, Systems, and Communications; and Protection, Measurements and Standards. This paper will review the highlights of the special issue and will indicate the implications of the work that has been published. In particular, the different types of IEMI waveforms and the ability to generate test waveforms are crucial to establishing equipment and system vulnerabilities. The actual test results that have been published indicate clearly the areas of concern, and this information leads directly to the development of protection methods and standards.

With regard to HEMP, a congressional commission was established in the United States in 2001 to investigate the potential impact of HEMP on the U.S. with emphasis on the civil infrastructure, and a summary of the results of this study were published in April 2004 as "Report of the Commission to Assess the threat to the United States from Electromagnetic Pulse (EMP) Attack"[3]. This report is remarkable in its scope as it discusses the nature of the EMP threat, methods of protection against the threat and methods to recover from an attack. The civil infrastructure is analyzed with regard to the electric power system, telecommunications, banking and finance, fuel and energy, transportation, food, water supply, emergency systems, space systems, and government.

This paper will review several of the important aspects of the commission report and will further discuss some of the technical contributions in the area of electric power system vulnerabilities. The technical work performed for the electric power system included the examination of the impact of the three temporal components of the HEMP (identified in the report as E1, E2, and E3). An important point identified by the commission is the fact that the late-time HEMP (E3) resembles a natural phenomenon known as geomagnetic storms. Geomagnetic storms have been known to cause large area power outages due to their interaction with the high voltage transmission grids. This information can be used to study the response of power grids to HEMP E3 fields.

IEEE EMC SPECIAL ISSUE ON HPEM AND IEMI

In order to discuss the subject of Intentional Electromagnetic Interference (IEMI), it is important to explain how it is related to high power electromagnetics (HPEM). The term HPEM has been used for many years and is used to describe

different types of phenomena that generate significant electromagnetic fields from the standpoint of high peak power. Although there is not a precise definition of "high power", the IEC Subcommittee 77C has defined a peak electric field of 100 V/m or higher as one definition to be followed. This was selected in order to separate these environments from those that are typically considered in the field of electromagnetic compatibility (EMC). It most cases the peak radiated narrowband electric fields considered for the EMC of commercial equipment are in the range of 3 to 10 V/m [4].

Given this definition, the following phenomena are included as part of HPEM:

- Lightning (fields produced by a near-stroke)
- Radar fields
- Fields produced near an electrostatic discharge (ESD) arc
- Electromagnetic Pulse (EMP) produced by a nuclear detonation at any altitude
- High power microwaves (HPM)
- Ultrawideband (UWB) fields

It should be noted that the above list includes both natural and intentional threats to electronic equipment and systems. In a resolution published by URSI in 1999 [5], the use of EM tools (or sources) by criminals was defined as a threat to be considered by the electronics community as an intentional threat. The term IEMI was discussed over the next few years and was later accepted by the IEC with the following definition: "Intentional malicious generation of electromagnetic energy introducing noise or signals into electrical and electronic systems, thus disrupting, confusing or damaging these systems for terrorist or criminal purposes" [1].

Using the above definition, EM fields generated with specifically designed or available (e.g., radar) generators can produce IEMI, which impacts the operation of commercial equipment and systems. The waveforms producing IEMI are often referred to in terms of HPM (narrowband) or UWB (wideband) although these definitions are not precise, due to the possibilities of different types of modulations or repetitive pulses.

In this paper, the HEMP (EMP produced by a high-altitude nuclear burst) environment is considered separately, although in a broad sense HEMP could be considered to be part of IEMI.

In the following paragraphs the 16 papers of the Special Issue of the IEEE EMC Transactions on HPEM and IEMI are identified and briefly reviewed.

Introduction to the Special Issue

1. Radasky, W. A., C. E. Baum, M.W. Wik, "Introduction to the Special Issue on High-Power Electromagnetics (HPEM) and Intentional Electromagnetic Interference (IEMI)"

Environments and Test Capabilities

2. Giri, D. V., and F. M. Tesche, "Classification of Intentional Electromagnetic Environments (IEME)"
3. Sabath, F., M. Bäckström, B. Nordström, D. Sérafin, A. Kaiser, B. A. Kerr, D. Nitsch, "Overview of Four European High-Power Microwave Narrow-Band Test Facilities"
4. Prather, W. D., C. E. Baum, R. J. Torres, F. Sabath, D. Nitsch, "Survey of Worldwide High-Power Wideband Capabilities"

Coupling to Cables and Systems

5. Haase, H., T. Steinmetz, J. Nitsch, "New Propagation Models for Electromagnetic Waves Along Uniform and Nonuniform Cables"
6. Carlsson, J., T. Karlsson, G. Undén, "EMEC – An EM Simulator Based on Topology"
7. Parmantier, J.-P., "Numerical Coupling Models for Complex Systems and Results"

IEMI Effects on Equipment, Systems and Communications

8 Camp, M., H. Gerth, H. Garbe, H. Haase, "Predicting the Breakdown Behavior of Microcontrollers under EMP/UWB Impact Using a Statistical Analysis"
9. Nitsch, D., M. Camp, F. Sabath, J.-L. ter Haseborg, H. Garbe, "Susceptibility of Some Electronic Equipment to HPEM Threats"

10. Hoad, R., N. J. Carter, D. Herke, S. P. Watkins, "Trends in EM Susceptibility of IT Equipment"
11. Bäckström, M. G., K. G. Lövstrand, "Susceptibility of Electronic Systems to High-Power Microwaves. Summary of Test Experience"
12. Parfenov, Y. V., L. N. Zdoukhov, W. A. Radasky, M. Ianoz, "Conducted IEMI Threats for Commercial Buildings"
13. Jeffrey, I., C. Gilmore, G. Siemens, J. LoVetri, "Hardware Invariant Protocol Disruptive Interference for 100Base-Tx Ethernet Communications"

Protection, Measurements and Standards

14. Weber, T., R. Krzikalla, J.-L. ter Haseborg, "Linear and Nonlinear Filters Suppressing UWB Pulses"
15. Weber, T., J.-L. ter Haseborg, "Measurement Techniques for Conducted HPEM Signals"
16. Wik, M. W., W. A. Radasky, "Development of High-Power Electromagnetic (HPEM) Standards"

Summary of Special Issue Papers

Paper 1 introduces the entire issue and provides some background concerning the entire field of work. Papers 2-4 provide definitions of the different types of EM environments that may be produced and indicate the simulator capabilities that exist worldwide to simulate these types of waveforms.

In the coupling area, there are 3 papers (5-7) that deal with new developments in analytic and numerical analysis that can be useful in solving IEMI coupling problems. With regard to equipment and system effects due to intentional EM environments, papers 8-11 cover the effects from the component level, to the equipment level, to the system level. In addition to the effects of EM fields on electronic systems, one also finds a discussion concerning the threat of conducted environments to equipment inside of buildings (paper 12). Finally there is a detailed discussion of the impact of IEMI on communication channels (paper 13).

The special issue concludes with 3 papers dealing with protection methods and standardization (14-16). The entire issue is an important resource for those interested in understanding the importance of IEMI and also for those who wish to contribute to this area of technology in the future.

U.S. CONGRESSIONAL COMMISSION ON HEMP

First it should be mentioned that the scope of the commission's work was to deal with the EMP produced from a high-altitude nuclear burst and its effects (referred to as HEMP in this paper). The official tasking of the commission is given below:

- Review of the EMP Threat. The Commission shall assess:
    - the nature and magnitude of potential high-altitude EMP threats to the United States from all potentially hostile states or non-states that have or could acquire nuclear weapons and ballistic missiles enabling them to perform a high-altitude EMP attack against the United States within the next 15 years;
    - the vulnerability of the United States military and especially civilian systems to an EMP attack, giving special attention to vulnerability of the civilian infrastructure as a matter of emergency preparedness;
    - the capability of the United States to repair and recover from damage inflicted on United States military and civilian systems by an EMP attack; and
    - the feasibility and cost of hardening select military and civilian systems against EMP attack.
- Recommendation. The Commission shall recommend any steps it believes should be taken by the United States to better protect its military and civilian systems from EMP attack.

It is important to recognize from this tasking that a major effort was to evaluate civilian systems and their ability to withstand an EMP attack and to recommend hardening of selected systems. A review of the Executive Report [3] reveals that a considerable amount of work was performed. This author will summarize several important points below.

In terms of defining the HEMP environment, the Commission refers to three major components – First EMP Component (E1), Second EMP Component (E2), and Third EMP Component (E3). These terms are also defined in the work of the International Electrotechnical Commission (IEC) as the early-time, intermediate-time and late-time HEMP environment [7]. They can be identified in time as the first microsecond of HEMP field (after the arrival of the signal

from the burst), the field extending from 1 microsecond to 1 second, and the field extending beyond 1 second, respectively.

The Commission indicates that the E1 component has a rise time on the order of 1 nanosecond and is a threat to electronics-based control systems, sensors, communications systems, protective systems and computers. The E2 component is felt to be important as a following threat after E1, if protective systems are damaged. The E3 component can create disruptive currents in long high-voltage electrical transmission lines creating a possible loss of voltage control on networks (blackouts). It is important to note that the Commission indicates that "Geomagnetic storms, a natural phenomenon driven by the solar wind, may, by a different physical mechanism, produce ground-induced currents (GIC) that can affect the electrical system in a manner similar to the E3 component of EMP." This is an important connection since there is considerable experience with the impacts of geomagnetic storms on the power infrastructure including the failure of the Hydro-Quebec power grid due to the geomagnetic storm of March 13, 1989.

The most important power system effects that may occur from the HEMP are identified by the Commission in the following manner: E1 can cause damage and disruption to power system control and protective systems in generating plants and substations and can cause simultaneous impacts to power distribution line insulators over large areas; E3 may cause damage to high voltage components such as transformers and circuit breakers; and E2 and E3 may cause synergistic problems if the E1 environment prevents protective elements from working properly. The Commission concludes: "Widespread functional collapse of the electric power system in the area affected by EMP is likely."

The Commission emphasizes that partial protective measures for the power grid are feasible, but mainly to reduce the time for restoration after attack. Restoration approaches are discussed in the report, and future work is expected to be performed to establish the proper balance between protection and restoration.

CONCLUSIONS

Two major documents were briefly reviewed in order to inform the reader of significant new work in the areas of IEMI and HEMP effects on civil systems. Both documents will provide the reader with important insights into the problems created by intense electromagnetic fields on our modern electronic systems. It is also noted that significant standardization work is in progress in the IEC under Subcommittee 77C to produce standards to protect civil electronic systems from HEMP and IEMI.

REFERENCES

[1] IEC 61000-2-13, Electromagnetic Compatibility (EMC) – Part 2-13: Environment: "High-power electromagnetic (HPEM) environments – radiated and conducted," International Electrotechnical Commission, Geneva, Switzerland, 2005.

[2] "Special Issue on High-Power Electromagnetics (HPEM) and Intentional Electromagnetic Interference (IEMI)," IEEE Transactions on EMC, Vol. 46, No. 3, August 2004.

[3] "Report of the Commission to Assess the threat to the United States from Electromagnetic Pulse (EMP) Attack, Volume I: Executive Report," EMP Commission, April 2004.

[4] IEC 61000-6-1 and IEC 61000-6-2, Electromagnetic Compatibility (EMC) – Parts 6-1, 6-2: Generic standards: "Immunity for residential commercial and light-industrial environments and – Immunity for industrial environments," 2005.

[5] URSI Resolution on the Use of EM Tools by Criminals, URSI General Assembly, Toronto, 1999.

[6] IEC 61000-1-3, Electromagnetic Compatibility (EMC) – Part 1-3: General: "The effects of high-altitude EMP (HEMP) on civil equipment and systems," 2002.

[7] IEC 61000-2-9, Electromagnetic Compatibility (EMC) – Part 2: Environment – Section 9: "Description of HEMP environment – Radiated disturbance," International Electrotechnical Commission, Geneva, Switzerland, 1996.