System oriented view on High-Power Electromagnetic (HPEM) Effects and Intentional Electromagnetic Interference (IEMI)

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Abstract

The last two decades have witnessed increased interest in High-Power Electromagnetics (HPEM), particularly generation of high-power electromagnetic fields and their effects on electronics. Up to now most investigations on HPEM are characterizing the HPEM environment (e.g. source output, HPEM threat) employing frequency domain parameters of classical EMC. Nevertheless an efficient discussion of HPEM effects requires addition information on the time domain waveform as well as the probability of occurrence. This paper will analyze intentional electromagnetic interference (IEMI) as a system. A novel system based interference model, which will solve problems of current investigations will be introduced.

1. Introduction

The last two decades have witnessed increased interest in High-Power Electromagnetics (HPEM), particularly generation of high-power electromagnetic fields and their effects on electronics. As components for High-Power microwave (HPEM), wideband (WB) and ultra-wideband (UWB) technologies have achieved notable progress, high-power systems that were difficult or impossible to build ten years ago are now being used for an increasingly wide variety of applications. With the advent of HPEM sources capable of producing output powers in the GW range, there has been interest in using HPEM devices in military defense applications to disrupt or destroy offensive electronic systems. In numerous publications it has been reported that terrorists have the possibility to interrupt and/or damage sensitive electronics by generating Intentional Electromagnetic Interferences (IEMI) [1]-[4].

In addition electronic components and subsystems (e.g. microprocessor boards) are essential parts of modern civil and military systems like airplanes, communication, IT-infrastructure, traffic management, or safety systems. Since electronic components began to control safety critical functions, the concern grew over the vulnerability of electronic systems. Therefore the susceptibility of critical systems is of vital interest because a setup or failure in these systems could cause major accidents or economic disasters. The increase of non-metallic materials like carbon-fiber composite as well as the decrease of the signal levels result in decreased susceptibility levels of electronic systems. as a consequence the investigation of the susceptibility of electronic systems as well as their protection and hardening against HPEM threats is of great interest.

The main intention of this paper is to support the discussion on efficient and coordinated investigation of all HPEM aspects. The discussion of current problems will lead to a review of the employed interference model as well as the attempt to characterize the HPEM environment independent of the target system. In the second part a new approach, based on an holistic system model for HPEM interference, will be introduced. The essential idea of the new approach consists of the concept to treat the whole interference chain similar to an communication channel.

2. Methodology

Historically, the first susceptibility investigations were derived from standard EMC measurements. Investigators used narrow band sources to get information whether high-power fields were able to cause damages or other effects in electronic devices. Similar to classical narrow band EMC tests, the generated threats were characterized by frequency domain parameters, like peak electric field, polarization, center frequency, and energy contend. As ramification open literature is used to provide susceptibility information as a function of these frequency domain parameter. Investigations in the time domain tend to present their results in a similar way, using the polarization, the peak electric field, some times the duration, and the energy contend to structure results. Additionally, available wideband and ultra-wideband sources are mainly confined to one waveform. Therefore, most time domain waveform parameter could not be varied during an susceptibility investigation. On the other side, the waveforms that were used in reported susceptibility test diverge from each other and it becomes a real challenge to compare the waveforms as well as the results. Up to now most susceptibility or effect investigations are using the peak electric field, repetition rate, and some times the energy as independent variables. Due to this, groups that are working on the development and improvement of HPEM sources are employing the parameters peak electric field, peak power, average power, center frequency, and bandwidth as essential characteristics. Improvements are valued based on the peak electric field and delivered power. Optimization of the waveform, e.g. match of waveform to target system, has neither for susceptibility investigations nor for developments of sources been a strong and considered aspect.

Currently, diverse working groups are focusing on HPEM source development and HPEM susceptibility. Based on the assumption that specifications for the source can be treated as independent from target system and interference mechanisms are researcher focusing on detail problems in their main research area (i.e. HPEM susceptibility or HPEM source development). As a result, developments in both areas are not synchronized and are not necessarily supporting each other. As an example, recent investigations indicated that effects on the logical level, i.e. disturbances and malfunctions, are more influenced by time domain parameters like rise time, signal shape and repetition rate that by the energy contend or the peak electric field. As a consequence a field with the right waveform could cause the same effect with much lower field strength.

From a more general point of view, a methodology is desired which: (1) establishes a stronger link between source and susceptibility related research work, (2) enables the identification of essential threat characteristics, and (3) offers the capitalization of research work on significant technical aspects. A possible start of a development process towards such a methodology is the analysis of the EMI coupling process from a superordinate point of view. The analysis should encompass all parts from generation of the electric field, the coupling up to the impact on the target. This holistic approach requires that the success and/or improvement is assessed with regard to aspects of the whole system (i.e. effect at target, needed energy, needed effort), instead of maximization of single parameters at an interior interface.

2.1 EMI Coupling Model

The EMI coupling process is a classical EMC problem, which can be described using a communication model consisting of source (EMI-source), coupling path and drain (in the EMI case the target or victim). This kind of model has been used in information theory for decades. In contrast to information theory, which transfers information through the channel, in the EMI area the first challenge appears if one has to define the variable which is to be transferred. Generally spoken a threat is transferred from the source towards the target, where it evokes an effect. Unfortunately, the threat can not be characterized by one unique parameter (like peak electric field or energy).

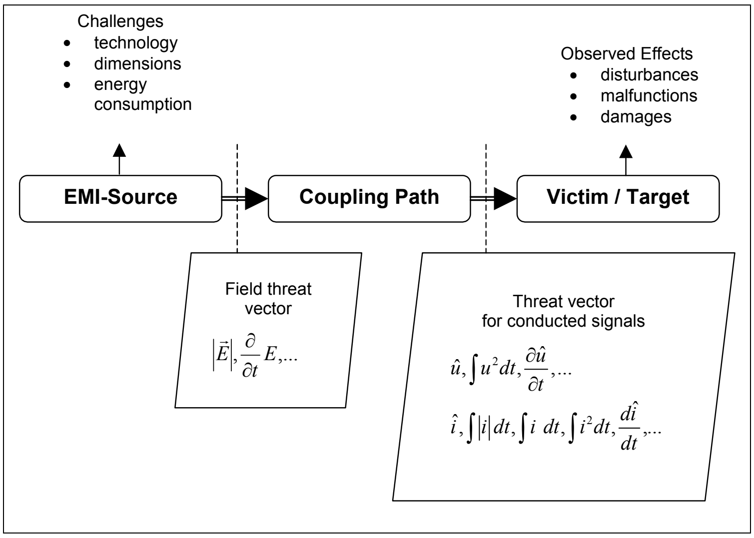

Figure 1: EMI coupling model.

In his PhD thesis [2] Nitsch has proposed the characterization of the threat by a threat vector, which consists of parameters that are relevant with regard to effects. The application of this approach leads to the next challenge, as the coupling model contains two interfaces, the first between the source and the coupling path and the second between the coupling path and the target.

To describe the threat at the first interface, the field interface, Nitsch has derived a norm-based description, employing an improved form of Höldernorms or P-norms. The components of the proposed threat vector are the edge frequencies of the spectrum, peak electric field, energy content, and a set of variables, which provide information on the efficiency in regard to a target system. The main benefit of this approach is, that the threat vector enables some kind of comparison between various threat waveforms based on a given target system and a particular kind of effect (disturbance, destruction). From a superordinate and system oriented point of view this model is a step forward, as it pays respect to the fact that the threat can only be assessed in regard to a specific target. Nitsch assess the efficiency employing measures for the amplitude and the energy in the frequency range set by the resonance behavior of the target system and a comparison with a reference threat. However, this model tries to be comparable with traditional threat descriptions as it spends only minor attention to the actual waveform and its impact on observed effects.

Recent research at the Leibniz University Hannover focused on the second interface, the conductive interface. Particular, the impact of time domain signal parameters, of the threaten voltage signal, on disturbances and malfunctions of digital components have been investigated [6]. First results indicated that disturbances, like malfunctions, bit-flips, and resets, are more influenced by charge, which is carried in a specific time interval and the repetition rate, than by the energy content. The Hannover team spends some effort on estimating the threat at the first interface by applying various models for the coupling path. The comparison with measurements on a specific system demonstrated that modeling techniques, which base on the energy or disregard the phase behavior, end up with a dramatic overestimation of needed field amplitude and energy contend. The main facts of this results are: (1) time domain characterization of threat waveforms (radiated and conducted) are important for non destructive effects, (2) it is necessary that models for the coupling path pay attention to the time domain signals (i.e. consider both amplitude and phase).

It is essential for further research and developments in the HPEM and IEMI area that electromagnetic interference is handled like a EMI-system, consisting of source, coupling and target. This means that the influence of any part of the system on other parts (e.g. the impact of the target (type of target system) on the occurrence of effects) are taken into consideration. Consequently, it is recommended that the efficiency of sources be assessed by effects and in regard with the type of target system.

In addition the operational or functional impact of observed effects has to be considered. For example flickering of a display can be irritating for the user but in most cases the flickering does not affect the functionality of the system. On the other hand a bit flip in a critical component could ruin the whole day.

Finally, threats need to be evaluated in terms of probability of occurrences. This means the possibility that a real life system will face the considered threat (source) in an every day situation, without being aware of the threaten situation. For example a high level of required technological knowledge, an increasing amount of consumed energy as well as large dimensions of the source system will limit the probability that any electronic system will face the EM environment generated by such HPEM source. Currently, these aspects are not part of the scientific discussion as most research is focused on the development of sources and the investigation of effects. However the relevance of research is strongly depending of the proximity to real life situations.

2.3 Classification of Effects

The classification of observed effects is essential for the comparison of different susceptibility investigations and as a consequent result for the assessment of the success of an HPEM attack or applied hardening measures.

The NATO RTO SCI 132 task group started the assessment on an operational level by employing a categorization that classifies the observed effects in regard to it’s duration. An improved version of this classification scheme was presented by Nitsch and Sabath at the AMEREM 2006 [7]. The duration of an HPEM effect provides the user with information on how long the desired function will be disturbed or broken down. The duration of an effect as a function of the threatening HPEM environment allows an estimation of status of an electronic system. The initial as well as the improved version by Nitsch and Sabath used a mixture of the effect duration, the need of human intervention, and destruction of components as differentiators.

If HPEM effects are analyzed and assessed in regard to the operational impact and the functionality of the system, operational condition (e.g. critical periods of time, critical functions, minimum performance) must be taken into consideration. On the other hand such an analysis is working on a higher level of abstraction, as no details on the physical mechanism are needed. Nitsch and Sabath introduced a classification of effects by its criticality for the main function or mission in [7] (Table 1). This classification provides the essential information on the functionality isolated from its duration.

But the classification requires analysis of the observed effect and its impact on the function of the system in regard to a particular application. Therefore this classification depends on the application and its operational conditions. Due to this fact test engineers will hardly be able to map an observed effect on a criticality level without assistance of system specialists.

Table 1: Classification of EM effects by criticality

Level	Effect	Description
U	unknown	Unable to determine due to effects on another component or not observed.
N	no effect	No effect occurs or the system can fulfill his mission without disturbances.
I	interference	The appearing disturbance does not influence the main mission.
II	degradation	The appearing disturbance reduces the efficiency and capability of the system.
III	loss of main function (mission kill)	The appearing disturbance prevents that the system is able to fulfill its main function or mission.

4. Conclusion

This paper discusses the efficiency and applicability of various research approached in the area of high-power electromagnetic (HPEM) and intentional electromagnetic interference (IEMI). Particular, the discussion of susceptibility investigation with regard to non-destructive effects, demonstrate that source systems, coupling mechanism and target systems can not be assumed as independent. The paper shows additionally, that time domain waveform characteristics have more impact on non-destructive effects that classical frequency domain parameters, which are used in classical EMC.

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