HIGH POWER ELECTROMAGNETIC EFFECTS : METHODOLOGY AND ASSOCIATED TOOLS

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ABSTRACT

The procurement agency of the French ministry of defense has developed large test facilities to study the susceptibility of electronic-based weapons to HPE.
To illustrate a methodology and its associated tools, this paper focus on the High-Power Microwaves whose methodology needs the use of original capabilities. At first, the best coupling and susceptibility are studied in terms of frequency, polarization and incidence. Then, the vulnerability is determined with high-level test systems.

CONTEXT

The general evolution of the electronic technology has brought the High Power Electromagnetic threat to light.
Due to the increased miniaturization and reduced operating power of electronic devices and integrated circuits, newer generation of electronics have become more susceptible to both naturally occurring and man-made radiation induced and other electromagnetic effects.
On the battlefields, immunity to hostile EM environments takes an added importance for the electronic-based weapons. These systems must be capable of operating through aggression as lightning, ESD (electrostatic discharge), HIRF (high intensity radiated fields), EMC (electromagnetic compatibility), transmitters, NEMP (nuclear electromagnetic pulse), HPM (high power microwaves) and so-called RF weapons...

INTEGRATION OF HPE THREATS

The integration of HPE threats appears to be an obvious approach for dealing with these environments. A common engineering approach must be applied to a maximum of electromagnetic environments. Difficulties arise because some threats are continuous wave (CW) in nature, for example, HIRF, while others are defined in the time domain, for example, high altitude nuclear EMP. A substantial effort has been achieved to consolidate different types of electromagnetic signal waveforms that are observed at the box level and to define specific test levels that depend on the operational environment of a given system.

The development of new systems implies to consider the electromagnetic protection since the very early stage. Many tools have been developed to help the system designers in their work such as general guidelines to choose the appropriate topological approach, numerical codes to predict the interaction between the electromagnetic environments and the system, hardening procedures that enable equipment to withstand the specified test levels, standards and specifications…
At the end of the development phase, it is indispensable to reproduce these electromagnetic environments on the system itself to validate the technical choices, to characterise safety margins and reinforce the confidence.

EXAMPLE : THE HIGH POWER MICROWAVES

Among the different HPE, the High Power Microwaves are an original and interesting topic to illustrate effects on electronic systems. As described below, not only the coupling but also the effects are statistical in nature : this characteristic has led to original methodology and associated tools to observe these effects.

High Power Microwaves coupling

Once microwave beam reaches a target, the energy arrival can be affected via either front-door or back-door paths. A front-door path is referred to as in intended path for microwave transmission and reception, for example an antenna

connected to a coaxial cable terminating at an electronic box. A back-door path is an inadvertent Point Of Entry for energy penetration, such as windows, thin slots, gaskets, faulty cable shields or connectors…
The coupling of HPM to a complex system and particularly into cavities implies a statistical approach. This coupling depends on so many parameters : the size of the apertures, the incidence and polarization of the illumination, the position of the wires, the ageing of the protections…

High Power Microwaves effects

The failures of electronics under microwave illumination have very various origins :

- rectification
- intermodulation
- latchup
- punch-through
- thermal damage
- upset of digital circuits

As the coupling, the failure of an electronic component and the occurrence of an upset are statistical in nature. Moreover, the responsible characteristic of the incident signal for the failure is not clearly determined : its energy, its time-domain peak, its power, its peak time rate of change…

Methodology

To observe HPM effects on a system, a complementary set of experimental and numerical tools is required. Two limiting factors must be taken into account :

- short duration of the of the tests because of their costs and the availability of the systems
- no deterioration of the system before having analyzed its behavior

This second limitation implies a gradual approach in the methodology : before the high-level tests, it is necessary to know the worst cases of aggression in terms of :

- frequency (carrier wave)
- repetition rate
- beam direction (azimuth and elevation)
- beam polarization

The figure 1 represents the different steps of the methodology

ACTIONS	TOOLS	RESULTS
1. Topological approach : size and geometry of the system and of its apertures	/	Knowledge of the system
2. Susceptibility analysis at low level	Mode stirred reverberation chambers	Best frequencies in terms of susceptibility and coupling
3. Coupling analysis at low level	**Socrate** / Numerical codes	Best direction and polarization angles Best frequencies in terms of coupling Knowledge of the phenomena
4. High level tests	**Hypérion**	Susceptibility and vulnerability of the system

Figure 1 : Methodology for HPM vulnerability analysis

Description of the associated tools

Mode stirred reverberation chambers use the statistical properties of the EM field in over-moded cavities. The advantages and drawbacks of his tool are presented on Fig. 2.

Advantages	Drawbacks
Easy design Cheap maintenance (no absorbing bounds) Large bandwidth Short time of test (a few min) "Natural" test of subsystems which EM environment can be supposed to be the mode stirred chamber's one	No information about the best coupling angles Difficulties to compare the results with an anechoïc chamber's ones (the measured Coupling Cross Section is practically integrated because the coupling effects of all the incident angles are summed) The chambers size limit the systems size

Figure 2 : advantages and drawbacks of mode stirred chambers

Socrate (Fig.3) has been developed to analyze the coupling by a rapid near field measurement technique. The approach is based on the determination of the radiated pattern of the system under test, considered as transmitting antenna.

The coupling cross section is determined from to measures :

- the input impedance at the considered feeding point
- the near field radiated by the system under test

The input impedance is classically measured with a network analyzer

The near field is measured on a sphere (2m in diameter) around the system, from 100 MHz to 18 GHz.. Each Socrate's probe is calibrating using reference antenna for which the radiated pattern are well known.

A spherical near field to far field transformation is then worked out to obtain the radiated pattern of the system.

Using the reciprocity theorem, the coupling cross section is calculated from the radiated pattern and the input impedance.

The advantages of such a technique are :

- compact range
- arbitrary polarization and attitude angle
- rapidity

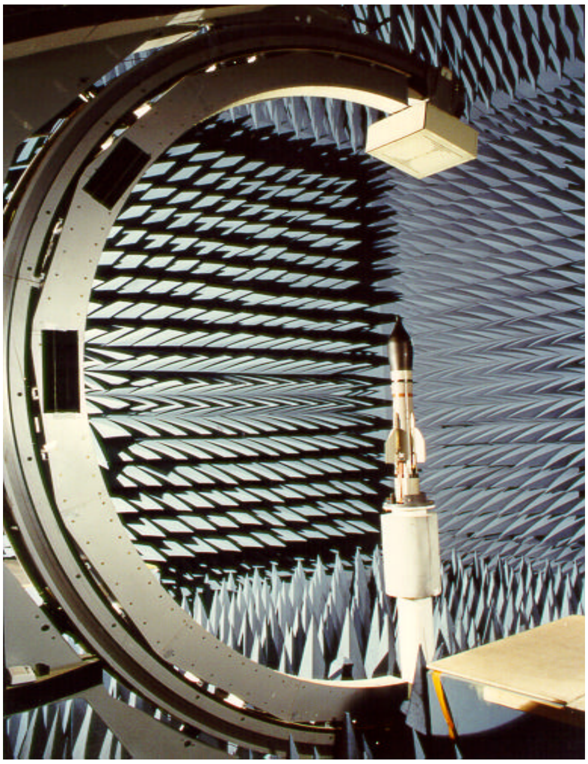

Figure 3 : Socrate

Numerical codes are used to evaluate and understand the coupling. In spite of the considerable CPU time and the voluminous size of the grids, the most widely used code in the DGA is FDTD based (GORF). The Figure 4 illustrates the coupling of microwaves to an internal wire of a missile at 4 different times.

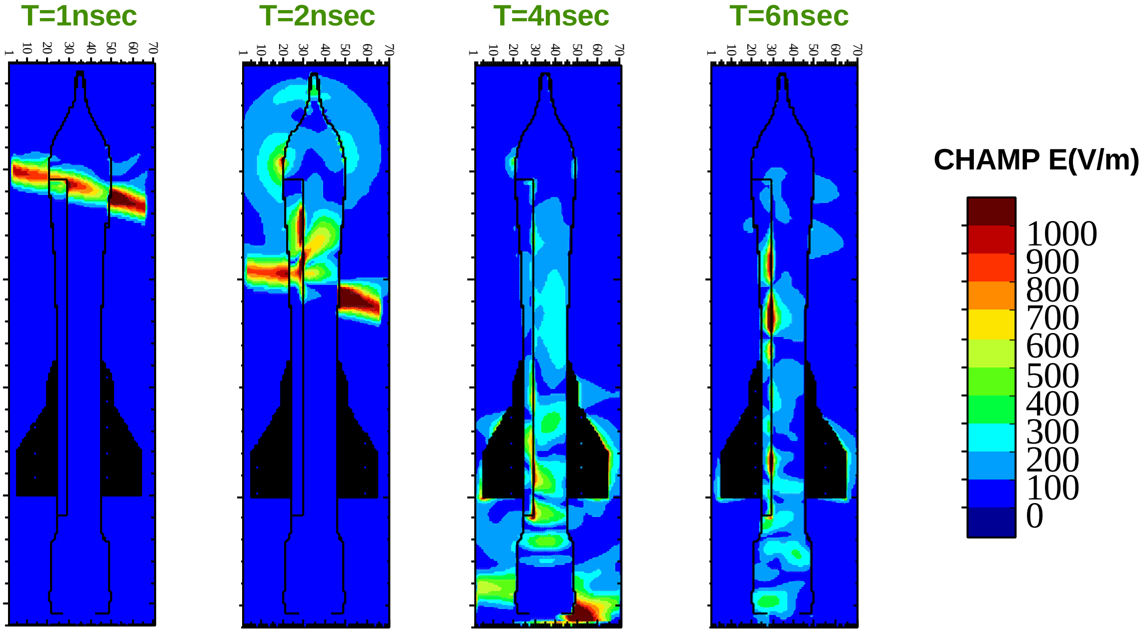

Figure 4 : Numerical simulation

Hyperion (Fig 5,6) is an high level test device. While running, the system is illuminated by microwaves.

Two types of source can be used (Magnetron and Reltron) at frequencies from 0,7 to 3,2 GHz. The generated wave is reflected by two planes which allow elevation angles from 10° to 30°.

The system under test is fixed on a gantry so that any azimuth angle can be obtained.

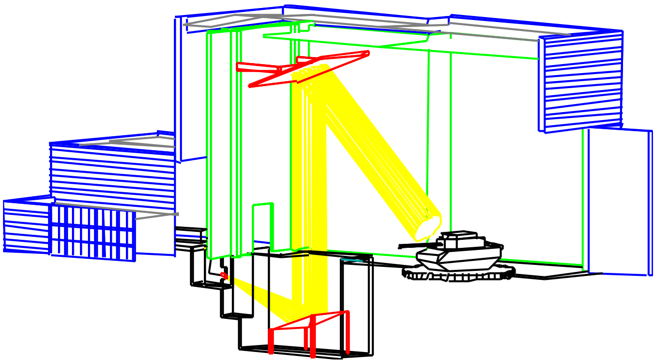

Figure 6 : HYPERION

Figure 5 : an airplane tested with HYPERION

CONCLUSION

This paper shows that the capabilities used to understand and evaluate the HPE effects are complementary. In spite of the progress of the computational speed, the numerical approach can not be sufficient without experiments. This is particularly true when the frequency or the complexity of the system increase. As such, HPM are still a good research subject for a certain time.