DEVELOPMENT AND IMPLEMENTATION OF TEST TECHNIQUES FOR COMPLEX DISTRIBUTED SYSTEMS

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ABSTRACT

The Directed Energy Technology Office in support of the Joint Program Office for Special Technology Countermeasures is actively engaged in evaluating and understanding the impact of EMI on commercial infrastructures. These commercial infrastructures are usually examples of very complex communications and computer systems that use large assemblies of commercial electronics. While significant susceptibility testing of isolated electronics systems has been conducted in the community over the past decade, little to no testing of distributed systems has occurred. Two buildings have been constructed at the NSWCDD that allow for just this, the controlled testing of complex distributed systems in realistic settings.

INTRODUCTION

Electromagnetic interference (EMI) tests of single computers or other commercial electronics are not sufficient to characterize failure of an entire network of computer and communication systems. The connecting power and data cables form antennas that create significant coupling paths into the electronics that would otherwise not be there. In general, the Directed Energy Technology Office (DETO) is interested in characterizing the failures of the system as a whole, which must include such things as the building housing the electronics. Comprehensive tests have been conducted on various types of control and information systems for the purpose of establishing failure conditions for radio frequency (RF) effects, and for developing efficient countermeasures intended to mitigate those effects. Preliminary RF assessments have also been conducted on actual commercial infrastructures to include power, transportation, petroleum and potable water. The cite assessments allow for the identification of key electronic equipment which may be purchased for subsequent testing by DETO.

EMI TESTING OF COMPLEX SYSTEMS

EMI effects testing of large complex targets present numerous challenges. The obvious consequences of typical large system installations (such as long cable runs, distributed processing nodes, and multi-system power feeds) often influence or even dictate measured susceptibility levels. DETO has established a unique capability for efficient testing of complex systems at the NSWCDD EMI effects test site. Among a multitude of laboratory resources such as a bounded-wave facility, a GTEM cell, anechoic chambers, reverberation chambers and direct injection test beds, there are two buildings known as the Bastille and the Citadelle which were constructed solely for the purpose of testing distributed systems in as realistic an environment as possible.

The Bastille was the first of the two buildings to be constructed and covers an area of approximately 30 feet by 40 feet. It is a two-story building that has been used primarily for the testing of computer networks, as well as a few distributed systems. The Citadelle is specifically engineered for effects testing of large systems. An exterior view of the Citadelle is shown in Fig. 1. The three-story building covers an area of 40 feet by 60 feet. The facility is designed to support a wide spectrum of complex targets including but not limited to distributed control systems (DCS), supervisory control and data acquisition (SCADA) systems, and multi-node computer networks. In addition, the size of the facility allows for the simultaneous testing of large numbers of computer systems without requiring them to be placed unrealistically close to one another. The building's physical construction is designed to emulate both information-processing and industrial environments. The facility incorporates multiple types of power feed which enables the investigation of different coupling issues. The Citadelle is located near the original test structure, the Bastille, to allow for testing highly dispersed and distributed systems.

A typical electronic suite in the Bastille is shown in Fig. 2 and might include a computer network, which consists of the network cabling, routers, switches and the computers themselves as well as power cables for the equipment and the building itself. This setup allows not only for the determination of the failure thresholds of the individual computers, but also the failure mechanisms and thresholds of the computers while connected to the network. Different network topologies can be implemented and tested, monitoring and error correction techniques can be investigated and compared to the failure modes of the computers alone. In EMP coupling, currents from the outside power system would be expected, while other threats may not produce these types of coupling. The effectiveness of commercial line protection filters or uninterrupted power supplies can be considered both alone and in the whole system.

Commercial computer systems do not exist alone, they communicate with the outside world through a variety of means, both by conductors and by various types of guided waves. Each of these provides an entry point into a complete system and is considered when conducting full-scale tests within the Bastille and Citadelle facilities.

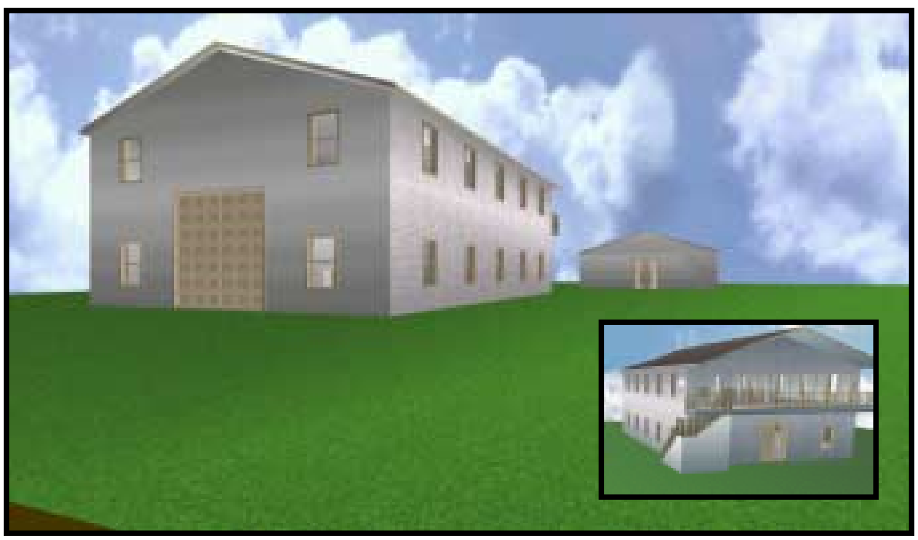

Fig. 1: Illustration of the Citadelle building with the Bastille building immediately behind it. A rear view of the Citadelle building is depicted in the smaller box.

The computer systems contained in the Bastille and Citadelle buildings allow for the investigation of variances due both to the placement of each system within the building, as well as variances attributable to changes in the network wiring geometry and connections. In other words, when a susceptibility test is performed with a specific RF source, there are a number of variances present in the recorded susceptibility observations. These variances may be due in part to the specific placement of each computer system. If one so desired, the computer systems could be moved around and testing repeated. This would allow for the identification of variances in susceptibility results due to the placement of the computers within the building. Fig. 3 illustrates the flexibility of the target sets, which facilitates the investigation of these questions.

The physical mechanisms that lead to the upset and damage of electronic systems may be different in different frequency ranges. In other words, at low frequencies (MHz) coupling to long runs of cable are assumed to be the dominant means for observed system susceptibilities. The Bastille and Citadelle buildings are designed to allow for the investigation of this question. If in fact, coupling to the network cables is a significant contributor to susceptibility observations, then disconnecting the network cables should reduce observed susceptibilities. This experiment was performed at the Bastille facility and it was demonstrated that system effects were substantially degraded when the network cables were removed. An interesting aside to the aforementioned experiment is associated with the computer system effects themselves. Although observed effects are much greater when the computers are networked, the computer effects are not restricted to network functions alone. In fact, computer peripherals such as the mouse and keyboard are observed to be affected more readily when they are part of a networked system.

Fig. 2: The Bastille test facility

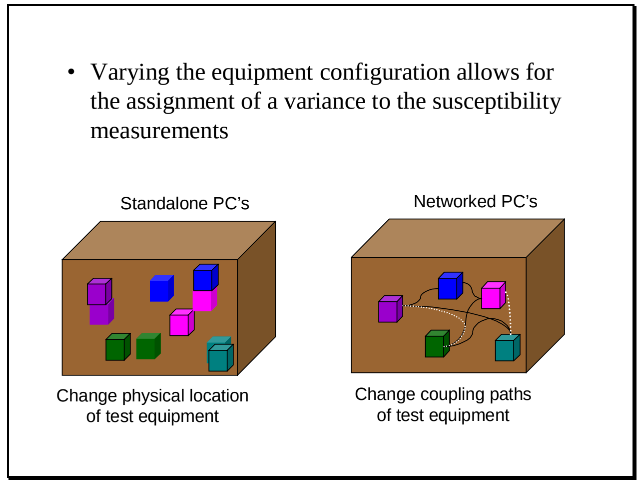

Fig. 3: Illustration of the configuration variations possible within either the Bastille or the Citadelle

In addition to system configuration issues, another crucial piece to the puzzle is associated with building materials. The electromagnetic environment produced within a building due to an intentional RF illumination may vary greatly with differing building materials. Both the Bastille's and the Citadelle's designs are sufficiently flexible that the protection accorded by various types of building construction can be considered. Various types of rebar design, for example, can be installed and tested not just to show a degree of shielding effectiveness but also to show the actual degree of protection afforded the computer system. Fig. 4 and Fig. 5 illustrate variations in rebar configurations that are possible with the Bastille test facility. It should be noted that two different rebar configurations are slated for testing on the Bastille in the spring 2002 time frame.

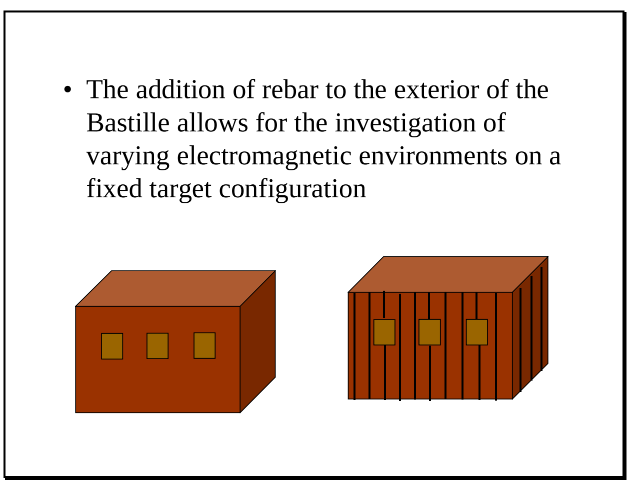

Fig. 4: Bastille with and without rebar

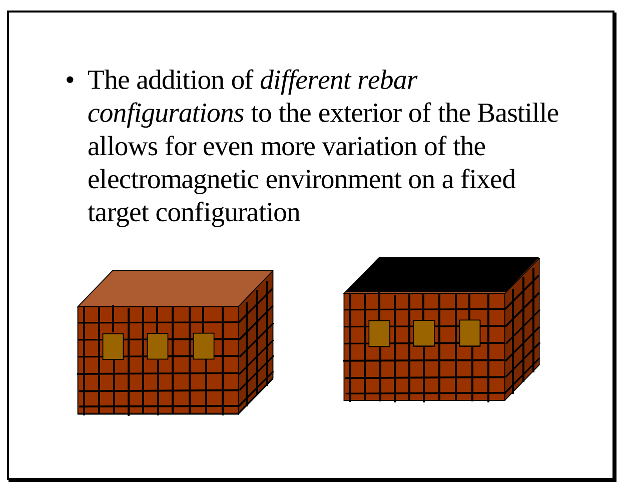

Fig. 5: Different rebar configurations on the Bastille

COMPUTER SIMULATIONS OF THE BASTILLE AND CITADELLE

Arguably there exist no substitutes for experimental tests, however there are a number of questions that lend themselves well to computer simulations. Moreover, simulations may be used to provide additional information for an experimental data set. For example, it is not practical to attempt measurements of the electric and magnetic fields at any appreciable number of points during a test on the Bastille or Citadelle. However, with the use of computer simulations in conjunction with a limited number of measurements, one is able to amply characterize the full electromagnetic environment the systems experienced during a test. The DETO modeling and simulation group is concerned with the application of simulated data to the EMI effects problem at hand. Fig. 6 illustrates the use of a volumetric visualization tool on a data set associated with the simulation of a pulse source incident on a model of the Bastille. The simulation results presented in Fig. 6 were obtained with a finite difference time domain (FDTD) code.

In addition to the ability to characterize test environments, computer simulations may be used to quantify certain aspects of building construction. In particular, as mentioned previously both the Bastille and the Citadelle test facilities are designed to allow for the easy addition and removal of rebar. However, for practical purposes this rebar is placed on the exterior of the building walls rather than in the center. The question then arises as to the impact of this choice. Specifically, it is desirable to be able to quantify this decision from and electromagnetic standpoint. Once again the FDTD code is used to produce computer simulations of the transmission coefficient through a cinder block wall with rebar placed either in the walls center, on the outside wall, or on the inside wall. Fig. 7 depicts the results. Although there is a difference if the rebar is placed in the center of the wall as opposed to placement on one of its outer surfaces, it is now possible for this difference to be quantified so that during the course of a test on either the Bastille or the Citadelle it is possible to adjust the field results to account for the rebar placement, if one so desires.

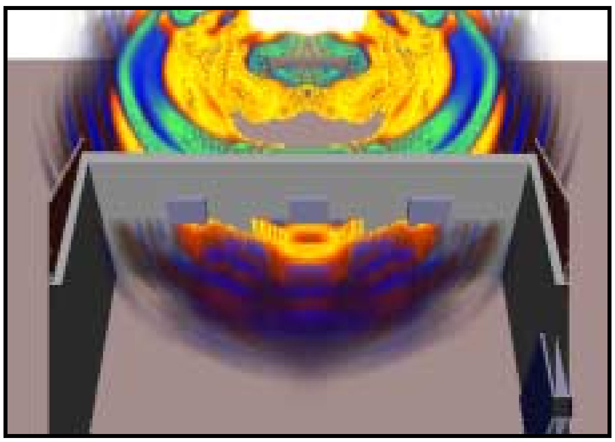

Fig. 7: The “traveling bubble” three-dimensional visualization of the electric field propagating into a structure. Very high and low amplitude regions have been set to be transparent to better study the structure of the propagating wave front.

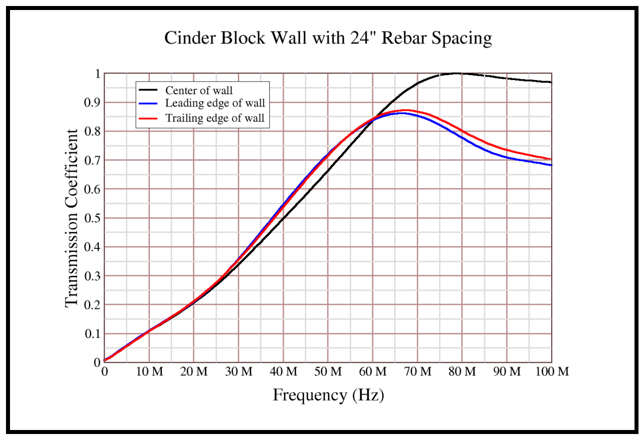

Fig. 6: Transmission coefficient calculated for a plane wave incident on a cinder block wall with 24 inch rebar spacing both vertical and horizontal.

CONCLUSIONS

For the first time ever, a test facility has been constructed solely for the purpose of conducting full-scale RF tests against complex distributed systems, and it is of little surprise to find that effects test results for distributed systems vary appreciably over those of single units tested in facilities such as a bounded-wave or an anechoic chamber. A full understanding of the electromagnetic test environment is accomplished with the use of computer simulations. The simulations also facilitate the investigation of choices in building construction and materials such as the placement of rebar on the test buildings.