

TESTING AND EVALUATION OF AN ULTRA-WIDEBAND PULSE GENERATOR FOR HPM WEAPON SIMULATION*

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Abstract

The potential for High Power Microwave (HPM) and Radio Frequency Weapons (RFW) to degrade or destroy electronics has been studied for decades. However, the fast pace of change in the underlying digital technologies of modern electronics makes it necessary to continually re-evaluate the susceptibilities of such systems. The Directed Energy Technology Office has developed a major test complex at the Naval Surface Warfare Center-Dahlgren Division (NSWCDD) to study the effectiveness of a variety of HPM and RFW prototypes. The facility consists of two concrete block buildings populated with a variety of modern commercial infrastructure electronics. In this paper we discuss a recent project which typifies the testing activities at the NSWCDD facility.

Schriner Engineering, Inc. built a pulse generator, the S-30, to simulate an ultra-wideband RF weapon. The S-30 operates from AC mains and uses a series of AC and pulsed transformers to charge a wide-band antenna structure up to 100's of kV. The S-30 radiates a fast risetime short pulse (<3 ns) when an oil-filled spark gap switch closes. We report our evaluation of the S-30 design and operation, measurements of the radiated output, and modeling of the antenna pattern. We also describe the electronic systems which were tested for susceptibility to the S-30 and the test protocol that was followed.

I. INTRODUCTION

The Directed Energy Technology Office (DETO) at the Naval Surface Warfare Center-Dahlgren Division engages in High Power Microwave (HPM) Electromagnetic Interference (EMI) effects testing as part of their broader mission to assess both military and civilian infrastructure vulnerability to HPM weapon systems.

The United States relies heavily on computer systems, electrical power, and industrial processes to maintain our economy and quality of life. The basic elements of the electrical power system are generation, transmission and distribution (T&D), while critical components of other industrial systems include transportation and processing. All of these elements rely heavily on industrial control

systems (ICS) to maintain a high level of efficiency, safety, protection and overall control of the processes with the minimal amount of human intervention.

ICSs come in many types depending on the function or process in need of control. Distributed Control Systems (DCS) have a major part in power generation and petroleum processing, protective relays are used in T&D and supervisory control and data acquisition (SCADA) systems are widely deployed for petroleum pipeline control. Although these systems are referred to by different names and perform different specific tasks, they all have two common functions: communications and control. The test configuration of the industrial control systems was designed to exercise these two functions within the limited bounds of the test volume.

II. TEST FACILITY

The Maginot Open Air Test Site (MOATS) is located at the Naval Surface Warfare Center in Dahlgren, Virginia. MOATS has been specifically designed for testing the RF susceptibility of electronic equipment to potential HPM weapon systems. The site consists of two test buildings, the Bastille and the Citadelle, located on a large paved area adjacent to an abandoned runway and a set of trailers for instrumentation and monitoring electronics as shown in Figure 1. The MOATS facility is cleared of FCC frequency allocation restrictions for testing.

The Bastille test building is a single story 30' by 40' building with an attic. It is constructed of 12" thick concrete blocks with a wooden framed attic and roof area. The rebar in the building is fiberglass to allow different construction methods to be simulated. The current systems installed in the Bastille are: PBX (Private Branch Exchange) phone system consisting of analog and digital phone support and voice mail and a security & access control system with motion detectors, window and door sensors, video surveillance (inside & outside), fingerprint and hand geometry readers, and magnetic locks.

The Citadelle test building is a three story 40' by 60' structure constructed in the same manner as the Bastille (fiberglass rebar, dielectric bolts, fiberglass cable troughs,

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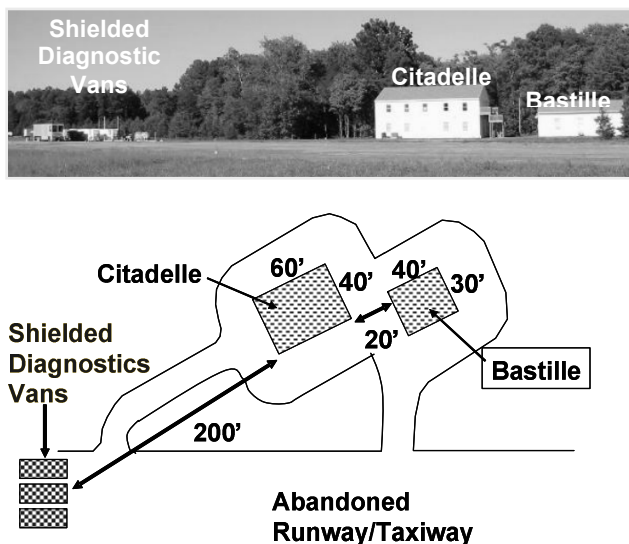


Figure 1. MOATS Test Facility

and central air conditioning with inflatable fiberglass ducts). The first two floors are concrete block, and the third floor is wooden frame construction. It has a deck on the back, a large garage door (12' clearance) on the ground floor able to accept large industrial equipment, and two power feeds – underground and overhead. The systems installed in the Citadel consist of two supervisory control and data acquisition systems (SCADAs) – one controlling an industrial flow process and the other an industrial level control process; a distributed control system (DCS) controlling an industrial simulator emulating a steam power generation process; and multiple PC and UNIX computer networks emulating specific commercial and military configurations. The network controllers are COTS-based C3I and C2I systems representative of systems deployed worldwide.

The instrumentation system used at MOATS is the Multidomain Automated Test & Data Acquisition System (MATDAQ). It is available to support a wide variety of tests. The equipment covers broad frequency ranges and a wide range of power levels. The diagnostics and instrumentation system consists of 16 channels (expandable) of automated, real-time frequency correction of time domain and frequency domain measurements. A full array of test equipment such as transient digitizers, network analyzers, fiber-optic telemetry systems, spectrum analyzers, antennas, field probes (E & H), and current probes provide the capability for both time and frequency domain measurements, electric field measurements from 10 kHz to 3 GHz, magnetic field measurements from 10 kHz to 150 MHz, and current measurements from DC to 1 GHz. All of the test instruments are connected via fiber optic cable to the oscilloscopes in the shielded diagnostics vans.

A. Asset Description-Computer Systems

The local area network in the Citadel building consists of 60 computer systems on the second floor and

20 computer systems on the third floor. Each of the 80 computers in the Citadel building serve a different purpose as either a network server or a client workstation which helps simulate a live network. It is for this reason that there is a variety of computer types with Intel Pentium (Pentium I, II, III, and IV), Intel Celeron, and RISC-based SPARC processors on laptop computers, desk top computers, and workstations. The Operating Systems used on these computers range from Windows 95 to Windows XP. Six of these computers act as network servers and run either Linux or Sun OS (UNIX).

The Citadel network is centered around a Cisco 3600 series router. This router is used to connect 4 separate sub-networks (made up of the 80 total workstations) which were designed to mirror a typical live network. All workstations, regardless of which of the 4 sub-networks it belongs to, connects to one of five 10/100 Mb (megabit) Ethernet switches via category 5 UTP cable. The Cisco router also has a fiber interface which connects to a remote diagnostic and monitoring van outside of the Citadel building.

B. Asset Description-Infrastructure Test Objects

The first floor of the Citadel contains infrastructure test objects as shown in Figure 2. The systems include two Supervisory Control and Data Acquisition (SCADA) systems, a distributed control system (DCS), and a protective relay. These systems were selected to represent typical commercial systems that are commonly used in industrial control processes.

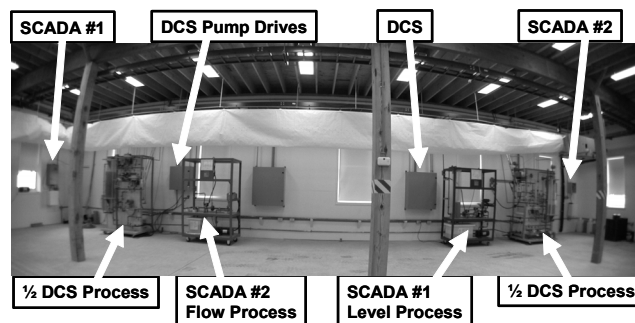


Figure 2. Infrastructure Test Objects

III. S-30 SOURCE DESCRIPTION

The S-30 ultra-wideband transmitter (Figure 3) consists of a 110-Vac step-up transformer circuit with an air-filled spark gap to pulse-charge a broadband, tapered antenna structure.[1] The charging network, located inside a 55-gallon, oil-filled drum, is pictured in Figure 4 with the labeled components being: (A) a toroidal pulse transformer with a 3-turn primary and 30-turn secondary; (B) High Voltage Doorknob Capacitors with 36 parallel stacks of 2 in series for a total capacitance of 30.6nF rated at 60kV; (C) High Voltage Rectifier capable of handling 75kV with 2 diode boards per side with each board containing 75 diodes and 75 1-MΩ resistors; (D) Spark Gap Assembly with tungsten electrodes with firing controlled with gas pressure; and (E) a power transformer

(with laminated steel E-core) rated at 120Vac input and $\pm 45\text{kV}$ output with a four-section bobbin secondary.

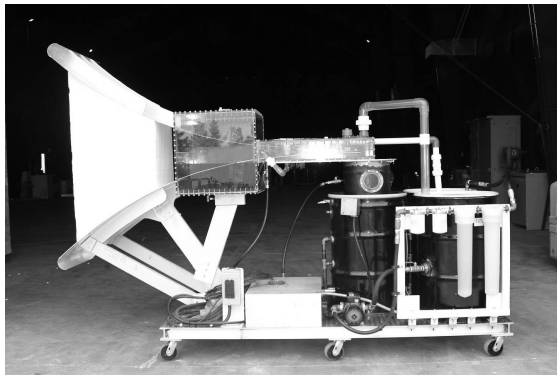


Figure 3. S-30 Ultra-Wideband Transmitter

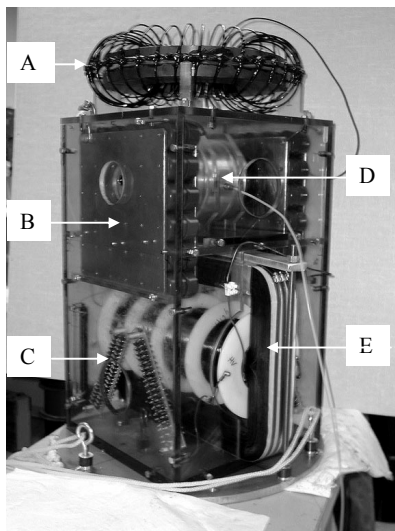


Figure 4. S-30 Charging Network

A wideband RF output pulse (Figure 5) is initiated when an oil-filled spark gap at the small end of the antenna structure fires. The design uses a cyclic charging, voltage doubler approach to charge the horn antenna structure that acts as the energy storage network. With this approach, the output of the high-voltage step-up transformer was used to charge two banks of ceramic capacitors on alternate half cycles. These capacitors, charged to opposite polarities, are then discharged in series through the pressurized air spark gap such that a voltage of approximately 100 kV is quickly discharged into a three-turn primary ferrite-core transformer with a 1 to 10 step-up ratio. With this design, the desired voltage to charge the antenna structure should be approximately 1 MV. In practice, the peak voltage measured on the plates of the horn antenna was about 300kV as shown in Figure 6 where several traces from different firing sequences are shown.

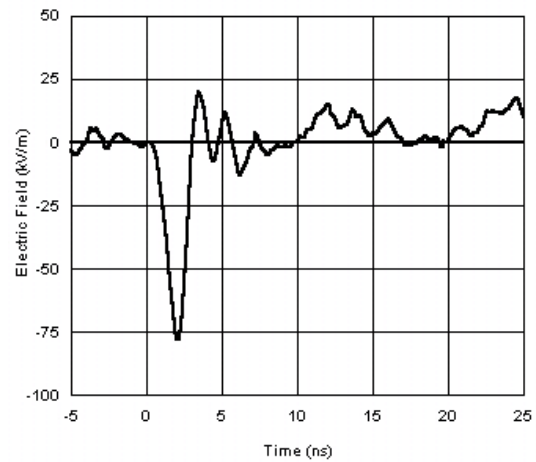


Figure 5. Typical Output from S-30 Transmitter

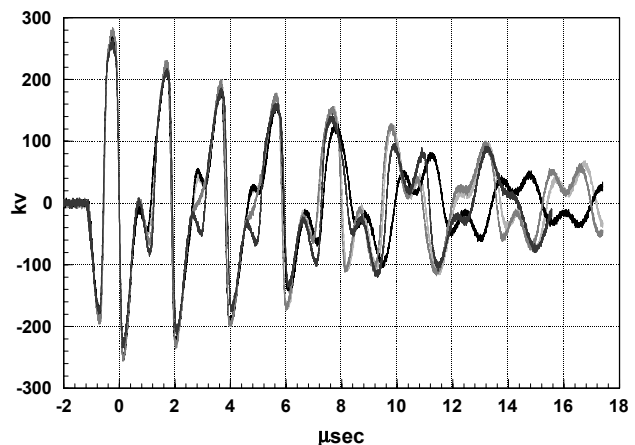


Figure 6. Voltage Measurements on S-30 Source

IV. SOURCE MODELING

The S-30 transmitter source has been modeled using a CUBIT^{*} generated mesh chosen to represent a perfect electrical conductor at 300 MHz, and the oil-filled spark gap was modeled as a “shorted” wire.

At low frequencies, the source behaves like a dipole radiator with no directivity in the radiated pattern. At higher frequencies, the source behaves like a horned radiator and shows directivity in the direction of the horn antenna (-x) as shown in Figure 7. From the modeled pattern shown in Figure 7, the radiated field appears to be drifting upward, and this agrees with experimental measurements that found the electric field levels on the second floor of the Citadelle building to be higher than those on the first floor. A two-dimensional slice of Figure 7 is shown in Figure 8 along with a scaled block diagram depicting the Citadelle building at a distance of ~30m from the source.

^{*} CUBIT software from Sandia National Laboratories.

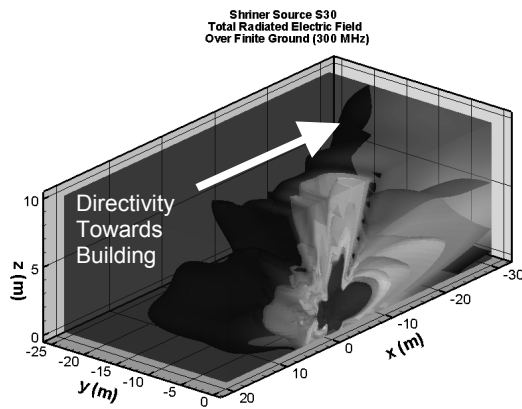


Figure 7. Radiated Pattern at 300 MHz

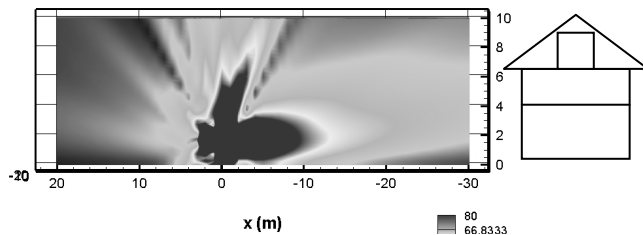


Figure 8. Two-Dimensional Slice of Field at 300 MHz

V. SYSTEM CHECKOUTS

The computer system checkouts are performed to record the effects of a shot on a suite of software utilities running on the personal computers during the shot. Hardware effects are also noted and recorded. The software utilities include: Boot Count (which counts the number of times a computer has rebooted during a shot), Keystroke Logger (which logs phantom keystrokes as a result of a shot and provides for easy testing of the keyboard), Network Browser (which loads a special webpage on one of the six server systems to help determine network impact of a shot), and CPU Load (which runs several iterations on the CPU during a shot to see the impact a test has on the processor itself).

The computer system effects are recorded on pocket PDAs using the scoring system described in Figure 9. The PDAs are synched with a laptop computer to archive the data, and Microsoft Excel macros are then used to compile a “stoplight” chart (Figure 10) that shows the recorded effects on the computer systems and allows for a quick interpretation of the data. Note that the data shown in Figure 10 is **simulated data** that is used for illustration purposes only and does not correspond to any realistic systems that have been tested.

5	Damage	Software, firmware or hardware damage
4	Upset	Intervention is required to restore normal system functionality
3	Disturbance	Effect is present some time after RF source is turned off, but system eventually recovers
2	Interference	Effect is present only when RF source is energized
1	No Effect	
0	Unknown	Unknown or not Observed

Figure 9. Effects Levels

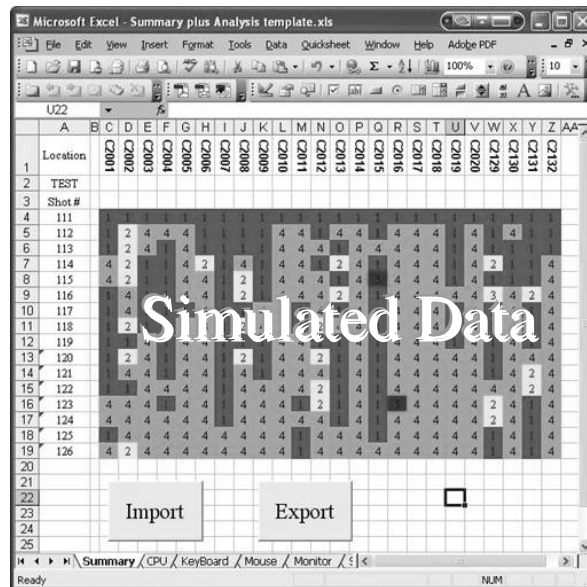


Figure 10. Simulated PDA Checkout Data for illustration purposes only

VI. SUMMARY

NSWC-Dahlgren has developed a sophisticated test facility capable of evaluating the potential of high-power microwave systems to interrupt, disturb, damage, or destroy typical components of industrial systems, security systems, and computer networks. The diagnostics for the facility include a number of electric field probes, magnetic field probes, and current sensors that allow for measurements in both time-domain and frequency-domain over a wide input range. The test methods and procedures used have been described along with the types of data obtained from source characterization and evaluation at the MOATS test facility.

VII. REFERENCES

- [1] Final Report S-30 Theory of Operation, Vulnerability Assessment of Radio Frequency, In Response to Exhibit A of Technical Services Agreement between TRW Systems and Shriner Engineering, Inc., Ridge Crest, CA, on Subcontract Number 4400073360, Issued by Director, Operational Test and Evaluation, June 20, 2004.