SANDIA REPORT
SAND2010-2609
Unlimited Release
Printed April 2010

Electromagnetic Coupling Between Transmitters and Electro-Explosive Devices Located Within an Enclosure

R.E. Jorgenson, L.K. Warne, and R.S. Coats

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2010-2609
Unlimited Release
Printed April 2010

Electromagnetic Coupling Between Transmitters and Electro-Explosive Located Within an Enclosure

R.E. Jorgenson, L.K. Warne, and R.S. Coats
Electromagnetic Effects Department (01653)

Sandia National Laboratories
P.O. Box 5800
Albuquerque NM 87185-1152

Abstract

This report documents calculations conducted to determine if 42 low-power transmitters located within a metallic enclosure can initiate electro-explosive devices (EED) located within the same enclosure. This analysis was performed for a generic EED no-fire power level of 250 mW. The calculations show that if the transmitters are incoherent, the power available is 32 mW—approximately one-eighth of the assumed level even with several worst-case assumptions in place.

Acknowledgement

This work was sponsored by Dr. James M. Shuler, manager of the Department of Energy (DOE) Packaging Certification Program, within DOE's Environmental Management, Office of Packaging and Transportation. The authors are indebted to Dr. Shuler for his support and vision in pursing advanced technologies that enhance the safety and security of nuclear materials.

Contents

Nomenclature

E	electric field
EED	electro-explosive devices
FCC	Federal Communications Commission
Q	quality factor
RFID	radio frequency identification

Electromagnetic Coupling Between Transmitters and Electro-Explosive Located Within an Enclosure

Introduction

Statement of Problem

This report addresses the question: Can the radio frequency (RF) energy radiated from numerous low-power RF identification (RFID) transmitters tags located in the same enclosure as electro-explosive devices (EED) couple sufficient energy to the EEDs and result in an initiation?

Approach

Scenarios were developed as a means of investigating this problem. The radiated power from numerous RFID tags was combined and parameters that can enhance this combination were considered. The analysis compared the possible power levels against a 250 mW generic no-fire level of an EED. The following sections discuss the parameters associated with the analysis, to include coupling mechanisms, and the resulting calculations.

RFID Parameters

For this assessment, RFID tags and readers manufactured by Savi Technologies. Inc.[1] were used. As an upper-bound case, as many as 40 RFID tag transmitters were postulated to exist within a metallic enclosure along with one fixed and one mobile reader. Each RFID transmitter typically has a power output of 0.18 mW at 433.92 MHz. With an atypical ground reflection, the transmitter can output a maximum of 0.6 mW [1]. The fixed reader has a maximum power output of 0.15 mW [2] and the mobile reader has a maximum power out of 0.6 mW [3]. A worst-case assumption is that all transmitter power is radiated from the antenna (none of it is absorbed by the impedance of the transmitter), all 42 transmitters broadcast simultaneously, and all transmitters emit 0.6 mW. A further reasonable assumption—not worst-case—is that the transmitters broadcast incoherently so that the powers (but not the fields) of the antennas add. This results in a maximum combined power output of 25 mW.

EED Parameters

Because this is generic analysis, the no-fire levels of the EEDs has been selected to be 250 mW.

[1] Savi Technology, Inc. 615 Tasman Drive Sunnyvale, CA 94089-1707

Constructing the Calculations

CONSIDERATION 1: 100 PERCENT POWER ABSORPTION NON PHASED LOCKED

The first level assessment is to consider the situation where one EED absorbs 100 percent of the power from the RFID sources. The combined power is 25 mW; the EED sensitivity level 250 mW. Consequently, the EED will not initiate. If the EED sensitivity level is higher (the actual no-fire level of the EED were to be 1 W), the conclusions would remain unchanged. If the assumed EED sensitivity level is too low—i.e., if the actual no-fire level of the EED were to be 1 mW—the simple method proposed in this report could not be used.

CONSIDERATION 2: PHASED LOCKED

If the transmitters can phase-lock to each other and broadcast simultaneously and coherently, the fields will add and the power will scale as the square of the number of transmitters. This results in a maximum power of 1.1 W, which exceeds the assumed no-fire level of the EED. If coherence is a possibility, more detailed calculations can be developed in an attempt to dismiss the problem. This would require much more detailed information on characteristics of the phase-locking process, transmitter locations, and EED locations. Another solution is to reduce the number of transmitters to fewer than 20. In the actual application, there is no practical way the sources can become phase locked. Consequently, this scenario can be dismissed.

CONSIDERATION 3: ACCOUNTING FOR TRANSMITTER ANTENNA EFFECTIVE GAIN

From the Savi ST-676 specification, the RFID transmitters themselves are not tested, but each transmitter/antenna combination is tested to ensure it meets a Federal Communications Commission (FCC) requirement for the electric field (*E*) at 3m from the transmitter to be less than 94 dBμV/m (E = 5×10^{-2} V/m). The mobile reader is also tested to this same specification. The fixed reader is not mentioned except for the statement that all readers are constrained to transmit 85 dBμV/m except when communicating with the RFID tag. In this situation, the reader has a power output of 3 to 4 dB higher [4]. As a bound, therefore, it can be assumed that all transmitters—tags and readers—emit a 5×10^{-2} V/m *E* field at 3m. Assuming the *E* specification was given as a root-mean-square (RMS) value and that 3m is the far-field of the antenna, the power density at 3 m is

$$\begin{aligned} p &= \frac{E^2}{\eta} \\ &= 6.66 \times 10^{6} \ W/m^2 \end{aligned}$$

where η is the free-space wave impedance (377 Ω). Assuming an isotropic radiator, the following is obtained for the radiated power

$$\begin{aligned} P_{rad} &= 4\pi\tau^2 p \\ &= 0.75 \quad mW \end{aligned}$$

where τ is the distance from the transmitter to measurement point (3 m). With this power, 42 incoherent transmitters/antenna combinations provide a maximum power output of 32 mW. Again, while slightly greater than the simple 100 percent absorption case (Consideration 1), 32 mW is too small to initiate the assumed 250 mW no-fire EEDs.

CONSIDERATION 4: EFFECTS OF ENCLOSURE

Single EED

Can the enclosure affect the results? If it is first assumed that the enclosure itself is lossless so that the only loss mechanism is a single EED and the power source is a single transmitter that outputs 32 mW, it would be expected that the power density in the enclosure would increase until the power lost in the EED is equal to the source power. At this point the system is at steady-state because all the power provided by the source is being absorbed by the EED and the power density in the enclosure would no longer increase. Next, if the walls of the enclosure are assumed to be lossy, the source power will be divided between the EED and the enclosure walls, which would increase the margin of safety even more.

Temporary Removal of EED (nonlinear condition)

A nonlinear condition can be postulated by temporarily removing the EED from a lossless enclosure —perhaps have it behind a sliding door or by invoking some other nonlinear phenomenon such as an open switch that prevents current from flowing through the EED—allow the power density to build in the enclosure (now limited only by the losses in the source) and finally instantly put the EED back into the enclosure by opening the door or by closing the switch, the EED could be made to absorb all the stored energy in the enclosure; this could be a significant amount. Since the assumed nonlinear devices do not exist, the EED is always in the enclosure. Consequently, this situation will not occur.

Next, consider the loss of the enclosure walls. For this discussion, it is assumed that the enclosure is associated with a metallic shell approximately the size of a standard tractor-trailer shipping container. Measurements on similar enclosures show a quality factor (Q) of less than 40. This implies that the stored energy in the enclosure is quickly damped—on the order of tens of nanoseconds. Therefore, if the power density is increased in the enclosure by removing the EED and then put it back in, the enclosure can only deliver the power to the EED over a few periods of the 434 MHz signal. By the same token, when the EED is removed from the enclosure, the power density can only increase over the same few periods of the 434 MHz signal. This limits the power density to be slightly above that with the EED in the enclosure—the wall loss is dominating the behavior of the field. The EED cannot respond instantaneously to power. In fact, the time constant of a typical EED is on the order of milliseconds—hundreds of thousands of periods of the 434 MHz signal. Therefore, the power from a low Q cavity, even when invoking nonlinearity, cannot be delivered for a sufficient length of time to initiate the EED.

Non-perfectly Matched Antenna

Another way that the enclosure could affect the result is in the definition of the radiated power. The FCC requirement is probably checked in an anechoic chamber where the antenna is in a free-space environment. It is probable that, given the size of the antenna and the operating frequency, the impedance of the antenna is not perfectly matched to the transmitter impedance, and maximum power transfer is not being achieved in the FCC test.

When the antenna is placed inside a cavity (such as the test enclosure), the impedance of the antenna can change, fortuitously match to the transmitter impedance and radiate more power. This situation may have already been partially exercised with the transmission specification of 0.6 mW due to ground reflection [1]. Observing the quantity α [5] defined as

$$\alpha = \frac{k^3 V}{2\pi Q}$$

where k is the wave number (9.1 radians/m in this case), V is the volume of the enclosure (54.6 m^3) and Q is the quality factor of the enclosure (measured to be less than 40), $\alpha = 164$ is obtained. The fact that this quantity is much larger than 1 indicates that the cavity is over-moded and that the impedance of the antenna in the enclosure should be close to the antenna impedance in free space. This, in turn implies that the radiated power derived from the FCC test is indeed an upper-bound for antennas inside the enclosure.

Consideration 5: Pin-to-Case Breakdown

Pin-to-case breakdown susceptibilities typically require kilovolts at the EED terminals. The effective height of any antenna attached to the EED must certainly be smaller than 1 meter. The effective height bound times the tested FCC field level of 5×10^{-2} V/m yields a voltage of 5×10^{-2} V. Pin-to-case susceptibilities should not be an issue instance.

Summary

This set of calculations and associated considerations shows that for an EED no-fire level of 250 mW, multiple instances of Savi ST-676 RFID tags (40 each), and associated fixed and handheld readers all operational at the same time, can only produce an upper bound of 32 mW, well below the 250 mW level assumed.

References

1. Installation Guide: Savi SensorTag ST-676-I ISO Container Door Tag with Sensors, *Part number 805-05125-001 Rev C*, October 2007, p. 18.
2. Installation Guide: Savi Fixed Reader SR-650-101, Version 1.
3. User Guide: Savi Mobile Reader SMR-650 for the Intermec 751G/A Mobile Computer.
4. Jason Andrews, e-mail from JAndrews@savi.com to wdmorse@sandia.gov, Subject: Re: Antenna Type and Gain Data, October 9, 2009, 11:44 AM.
5. L.K. Warne, K.S.H. Lee, H.G. Hudson, W.A. Johnson, R.E. Jorgenson, and S.L. Stronach, Statistical Properties of Linear Antenna Impedance in an Electrically Large Cavity, *IEEE Transaction on Antennas and Propagation*, vol. 51, no. 5, May 2003, pp. 978–991.

Distribution

1 MS 0899 Technical Library, 9536 (electronic copy)

Sandia National Laboratories