ELECTRO-EXPLOSIVE DEVICES

Electro-Explosive Devices (EED's) (often referred to as Squibs) are extremely vulnerable to electrical noise and radiation. The trend of explosive design has been to produce more sensitive explosive initiators. The more electrically sensitive the explosive unit, the smaller the amount of energy required for its initiation. This fact, while of primary interest to the designer attempting to overcome limitations of space and weight, generally has an adverse effect on safety unless due consideration is given to this extremely important factor. As a result of mounting reports of inadvertent initiation of explosive devices by radio-frequency energy, spurious signals, heat, and vibration, more attention is being given to the selection of these devices. Engineers are at last acknowledging the fact that these hazards are real and are making analyses of these hazards to develop preventive measures for their elimination. Now the problem is that of introducing these hazards and their elimination procedures to persons designing, integrating, and evaluating systems containing EED.

It is recommended that the design engineer consider the extreme conditions likely to be encountered in operation in performing RF interference investigations for the choice of an explosive device and its installation. RF incidents have been reported that have been documented, authenticated, and proved by duplication in the laboratory. However, the number of reported cases of RF energy firing explosive initiators are few compared to the number of sensitive devices being used in systems. To explain this, first examine the odds of occurrence and, second, the sources of information. The odds against RF initiation occurring would be extremely high because a combination of the following variables would have to fall into place. It would be necessary that: (1) a sensitive initiator be used, (2) the initiator or any conductors connected thereto be in a field of radiation (direct or reflected), (3) the power density be sufficient to cause the heating of the bridgewire if energy is picked up, (4) the frequency being transmitted be the frequency at which the initiator connecting wires are approximately resonant for maximum pickup, and (5) the installation containing the initiator and any conductors connected thereto offers little or no natural shielding or acts as a reflector, resonant cavity, or director to amplify the energy pickup. It can, therefore, be concluded that initiation by RF energy would be difficult to detect and, thus, very few cases have been reported. The sources of information must also be examined. Realize that an RF incident is extremely hard to document and authenticate. The investigator of such an incident would, no doubt, be looking for a more tangible cause of the inadvertent actuation of the explosive. Also, if the inadvertent actuation occurred while an aircraft was airborne, it might not be detected until landing or if actuation was detected in the air, the exact position of the aircraft at the time of actuation usually would go unknown; therefore, the source is often speculative and actuation could have been caused by a hazard still to be discovered. Unless a laboratory attempts to duplicate the RF initiation and prove the possibility of initiation by RF, the conclusion may still be only a matter of opinion; therefore, not only are the odds against occurrence great, but it is conceivable that RF incidents have occurred of which the conclusion was "cause unknown." This incident would not be reported as one of RF interference. Also, some incidents have been discounted for statistical purposes because of hazy facts and poor documentation.

Indications are that appreciable degradation of safety is caused by interference. Sometimes the effects are only annoying, but in many cases the equipment does not function properly or functions prematurely thereby causing serious hazards to personnel and equipment. In airborne equipment the problem is more intense because of the increasing number of many types of sensitive equipment being used. The problem is aggravated still further by the severe size and weight limitations imposed on the equipment.

The Falsity of Safety Margins:

A widely used EED is one with no-fire characteristics of one watt dc/one ampere dc for five minutes. When calculating safety margins, engineers generally use this dc no-fire level as a base line for AC and RF currents. However, questions arise when we think of the cooking phenomena of microwave ovens. Microwave energy, generally in the frequency range of 2 GHz, is used to stimulate molecular activity in food stuffs, which turn generates internal heat. Thus the food cooks itself. Microwaves are used because of their wave lengths and penetration abilities while the cooking (heating) action is largely dependent upon the molecular structure and density of the product being cooked. DC or low frequency fields are not used for the ovens, since the radiated electromagnetic energy cannot be effectively concentrated, and similar molecular reactions have not been observed. The DC. or low frequency energy, can effectively heat a resistive element and cook the food through heat radiation. This is the principle of a normal electric range. Therefore, we cannot really compare the cooking phenomena of DC heating to RF radiation. Yet, engineers attempt to do this when establishing safety margins for EED's.

DC energy or a pulse is quite effective in producing the hot flash or flame effect whereas RF may not. However, engineers should not overlook the molecular reactions which can be stimulated by RF radiation emitted from the bridgewire (fusing wire) into the chemical primers and explosive chemicals. The heat in the wire itself may not be significant since the microwave energy propagates only along the wire surface (skin effect), but sufficient chemical reaction may occur which could dud the EED or cause an inadvertent firing. The dudding effect, caused by chemical change, could be more serious in many cases since it could occur prior to the installation of the EED, and cannot be detected through continuity tests. Obviously, more research is needed in this area, but engineers would be wise to protect their EED's against RF energy to the most practical extent.

DEFINITIONS

The following are definitions with which ordnance design engineers should be familiar:

Bridgewire–Part of and is contained within the EED and consists of a resistance wire. (Sometimes simulated by a fuse.)

Continuity Test–A dc test to verify that there is electrical continuity in the EED firing circuit.

Detonator–A device containing an explosive charge designed to produce a high velocity shock wave for the subsequent initiation of an explosive train or fuel. A detonator will normally use a separate EED for ignition.

Dudding–The process of degrading an EED so it is changed to a permanently degraded state that makes an explosive process difficult or impossible.

Electroexplosive Subsystem (EES)–For the purpose of this standard, the term electroexplosive subsystem includes all items, components, and parts of ordnance subsystems such as EEDs, squibs, igniters, ignition wires, connectors, power supplies, guards, cables, etc.

Firing Circuit–The conducting path or paths which electric current is intended to follow to cause initiation of an EED or several EEDs simultaneously.

Igniters–An electrical initiator and a flame-producing pyrotechnic material designed to ignite propellant.

Initiator–A small pyrotechnic charge and electrical bridgewire designed to give a high pressure and temperature for subsequent initiation of pyrotechnic train.

Maximum No-Fire Current–The current sensitivity at which there is a confidence of 95 percent that no more than 5 EEDs per ten thousand will fire.

No-Fire Power–The power sensitivity at which there is a confidence of 95 percent that no more than 5 EEDs per ten thousand will fire.

Safe and Arm Device–A mechanical or electromechanical device intended to break the continuity of the explosive train. These devices sometimes use "g" switches and similar sensors so that arming can occur only under certain conditions.

Triboelectricity–Pertaining to electrification generated by friction.

TEST PROCEDURES:

The following are two standard statistical test procedures for EED's which are most often used:

a. Bruceton–Establish the sensitivity of a log of EEDs when this sensitivity is normally distributed with respect to the test response. The procedure consists of a staircase approach wherein the test level for each device is determined by the response of the previously tested EED. If an EED initiates at a given test level, the next EED is tested at a previously determined lower level. If an EED fails to initiate, the next EED is tested at a previously determined higher level. From these tests one can compute a mean firing stimulus and standard deviation. It is the desirable technique when minimum hardware is available.

b. Probit–An experimental procedure or a method of collecting available data to establish the sensitivity of a lot of EEDs when the sensitivity is normally distributed with respect to the test response. In this technique a specified number of EEDs are fired at a number of preassigned levels, and any one response is not dependent upon the previous response. The data can be plotted on special probit paper. It is a desirable procedure when specific probability levels are of concern and sufficient hardware available.

DESIGN GUIDELINES:

Most electrical engineers are more concerned about the design of the EES rather than the EED by itself. With this in mind, the following guidelines are presented:

1. Electroexplosive subsystems should be designed to use as high a firing signal as possible/feasible. The actual levels used should be selected to make firing signals compatible with system requirements for available electrical power, weight, reliability, and performance characteristics.

2. All wire and cable used with electroexplosive subsystems should meet the following requirements:

All EES circuits should be balanced.

3. All cables should be shielded. Shielding integrity should be maintained before, during, and after installation of electroexplosive devices. Each layer of braid should provide at least 85% coverage. The total number of layers should be specified by the subsystem designer.

4. **Umbilical Cables**–Umbilical cables connecting the rocket or weapon to other structures should be minimized and be as short as practicable. When an umbilical cable connects a rocket or weapon to other structures, the case should be electrically bonded by low impedance jumper straps, or preferably by metallic contacting surfaces.

5. **Pigtails**–Eliminate pigtails from the makeup of the electrical circuitry associated with ordnance systems.

6. **Isolation**–EES circuits should be physically separated from other power, control, electronic circuits, and other wire bundles.

7. **Connectors and Electrical Connections**–Connectors and electrical connections should insure the proper sequencing of connections and eliminate random configurations during transition periods, such as connect-disconnect, install, etc.

8. **Connectors**–Connectors for use with electroexplosive subsystems should meet the following requirements:

   a. The connectors should be designed so that the shielding connection is completed before the pin connections.
   b. Shield electromagnetic continuity should be continuous around the outside of the cable.
   c. The shell or shield should not be used to carry current.

9. **Arming and Safing**–The S&A device should provide means for remote arming and disarming by electrical signal and manual disarming from any position. Remote safing and manual safing should be accomplished in the same direction without going through the arm position. The devices should not be capable of being manually armed. The mechanism that accomplishes the arming and disarming of the device should be mechanically secured in the arm position when subjected to the flight environment of the missile.

10. **Electrical Isolation**–The control and monitor circuits should be completely independent of the firing circuits and should use a separate and non-interchangeable electrical connector. In A&D devices, the input firing circuit should use a separate and non-interchangeable electrical connector from the connector used in the output firing circuit. Electrical connectors used in firing circuits must contain only the minimum number of pins required to accomplish the circuit function, spare pins should not be provided. S&A and A&D devices should be designed so that when in the unarmed position, there is an open circuit between input and out terminals; the output terminals are disconnected from the firing circuit to the EED's; and the firing circuit is connected to ground. In addition, the S&A device should contain a mechanical safety barrier between the electrical initiators and the subsequent pyrotechnic or explosive elements. In the armed position, the S&A safety barrier must be aligned to permit ignition or detonation of the explosive train; in the safe (disarmed) position, inadvertent ignition of the electrical initiator must not result in ignition or detonation of other explosive elements. Establishing and breaking circuit continuity and shorting and unshorting of the electrical initiators should be accomplished by actuation of the mechanical safety barrier.

11. **Firing Circuit**–Prior to installation, EES includes all leads and connectors electrically connected to the electroexplosive element. To deny access of stray energy to electroexplosive devices, the following requirements are applicable:

   a. EES firing circuits should be isolated from other circuits and each other by means of individual shields. Shielded EES circuits may be routed together in a common secondary shield.
   b. All conductors that connect the EES with other system components should be provided with metallic shields to provide an integral shield without electrical and electromagnetic discontinuities or gaps.
   c. Carefully designed and tested filter elements are effective in suppressing stray currents. These may be used to protect against nearby sources of stray energy, such as missile borne radar beacons, telemetry transmitters, or very high power ground transmitters. The temperature rise of the filter due to dissipation of stray energy should be isolated from the EED.
   d. The EES firing circuit interface should be designed to preclude actuation by a false signal from internal or external stray electrical energy.
   e. The formation of multiple ground paths should be avoided to minimize low frequency electromagnetic coupling. Multiple grounds are required for high frequency protection.
   f. EES circuits should be electromagnetically shielded from all internal and external electromagnetic fields. The attenuation should be such that regardless of the "minimum fire" level of the device, the maximum current experienced in the bridgewire is 20 dB below the "no fire" point when exposed to the operational electromagnetic environment.
   g. Each EES circuit should be clearly identified from other electrical circuits by coding. Coding should be in accordance with MIL-STD-863.
   h. The case of an initiator should be electrically bonded in accordance with MIL-B-5087, Class R.

12. **Initiator Case Electrical Connections**–Electrical connections to the case should use a shielded connector. The case should not be used as a current-carrying conductor. A suitable waterproof stray energy shield should be provided for the male connector in the initiator case. When installed, but not connected to the firing circuit, the male connector should be in an open circuit configuration with an electrostatic shield installed. A mechanical shorting bar may be used in lieu of the electrostatic shield provided that proper electromagnetic and electrical safety is shown. Connector pins should not be damaged by either method.

(The information contained in this section is a combination of original work, excerpts from AFSCM 80-7 Part D, Chapter 3, and a proposed military standard, "Electroexplosive Subsystems, Electrically Initiated, Test Methods and Design Requirements".)