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Conditions for Remote Detonation of Explosive Initiators Using RF Energy

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This article examines the conditions under which an explosive detonator could be triggered by an external source of RF energy

The possibility of remotely detonating an explosive device with a radio transmission has been a safety concern for many years. However, actual instances of detonation under these conditions are rare. This article defines the specific conditions under which detonation may occur. Further, the article presents a summary of a simulation model which may be employed to evaluate the probability of detonation. The radio frequency impedance characteristics of the subject initiator are required for this model, and a test procedure to obtain the required impedance characterization of an initiator at radio frequencies is presented. This information has been published for the benefit of the EOD community.

1. Introduction

Electrically detonated explosive device initiators, historically, have been comprised of a bridgewire in contact with some composition of flash charge. In 1954, U.S. Patent 2,696,191 described an electrically operated primer which consisted of a "single high resistance filament (bridgewire) with an ignition composition formed around the bridgewire." As stated in this patent, "The arrangement is such that the bridgewire is heated upon closing the firing circuit, the sensitive composition ignites and develops sufficient heat to set off the flash charge which in turn fires the main explosive or propellant charge of the device with which the primer is used."

In 1980, U.S. Patent 4,208,967 described the design of a squib detailing both the design of the bridgewire and the chemical compositions of the ignition charge. "The electrically initiated squib of this invention is comprised of a plug member with a pair of spaced apart electrical leads extending through the plug member into a holder member for containing a predetermined quantity of an easily-ignitable composition. A bridgewire that is constructed of a bimetallic composite (Pyrofuze) selected from palladium and aluminum, platinum and aluminum, and ruthenium-palladium alloy and aluminum is secured between the electrical lead ends that terminate the holder member of the squib. The holder member is loaded with a loose, easily-ignitable composition which is a finely ground and intimate mixture of a pyrotechnic which is a composition selected from the group consisting of 45% by weight zirconium and 55% by weight potassium perchlorate, 20% by weight boron and 80% by weight potassium nitrate, 45% by weight aluminum flake (17 to 44 microns) and 55% by weight potassium per chlorate (6 to 17 microns), and lead azide or lead Styphnate, or a single base, or a double base, or composite propellant composition in a powder or pellet form. The combination improves the reliability of the squib while reducing the controls on loading and assembly procedures. The amount of easily ignitable composition to ensure ignition need not be controlled, since the proximity of the easily ignitable composition to the bimetallic composite bridgewire is not critical. The amount of material that the bridgewire ignites may govern the squib output: however the reliability of ignition is ensured by the presence of the easily ignitable composition in the holder member where the bimetallic composite undergoes a violent exothermic reaction after being brought to its ignition temperature by the application of electric current. The violent exothermic reaction is accompanied by a deflagration or a throwing out of the high temperature constituents of the bimetallic bridgewire."

In 1982, U.S. Patent 4,329,924 described an electric primer with a conductive composition. "The primer comprises a conductive pyrotechnical priming composition, placed in contact with the useful pyrotechnical charge of the primer and the two electrodes and arranged in electrical contact with the conductive pyrotechnical composition. The two electrodes are connected to a stable electric resistor, connected in parallel to the conductive pyrotechnical composition."

And, in 2000, U.S. Patent 6,009,809 describes a bridgewire initiator "which is used to ignite a booster charge in an airbag inflator. A pair of connectors is electronically connected to a bridgewire disposed within a charge holder containing an ignition composition. The ignition composition is biased against the bridgewire by an output cup having a concave end telescoped over the charge holder. When firing current is applied to the connectors, the bridgewire is electrically heated thereby igniting the booster charge."

Initiators are detonated, in general, by passing an electric current through the bridgewire. The bridgewire heats to a temperature to where an adjacent pyrotechnic composition ignites, or to a temperature where the bridgewire itself undergoes an exothermic reaction, in turn, igniting a second pyrotechnic composition. The specific detonation profile of the initiator is characterized by establishing a specific electric current in the bridgewire and then measuring the time interval between the application of current and initiator detonation. From these measurements, and knowledge of the bridgewire's resistance, the energy required to achieve detonation, specified in joules, may be calculated. Detonation profiles are presented in terms of detonation statistics with absorbed energy as the independent variable. Under practical conditions, the energy required to detonate 5%, 50% and 95% of the test population is reported.

Under normal operating conditions, a DC electric current is employed to transfer energy to the bridgewire. However, given certain accommodations, any time varying electric current waveform may transfer energy to the bridgewire. Conventional transient spikes may detonate the initiator under specific conditions. Fundamentally, these conditions may be summarized as follows:

- The excitation must contain sufficient energy to heat the bridgewire to the composition's ignition temperature.
- There must be an optimum power transfer between the excitation source and the bridgewire.

Section 2 presents the energy transfer path between an excitation source and the bridgewire and further identifies the specific criteria which must be optimized to achieve detonation. A fundamental criterion in this path is the impedance of the bridgewire at the specific excitation frequency of interest. Section 3.0 presents an EOD range compatible test procedure which may be used to characterize the impedance of a specific initiator.

2. Initiator Detonation System

Figure 1 depicts a radio frequency (RF) based system for the remote detonation of explosive devices. The device's initiator bridgewire leads are connected to a firing circuit which is arbitrarily positioned with respect to a real earth ground of arbitrary constituent parameters. The excitation source consists of a radio transmitter and its antenna positioned at some distance from the firing circuit. Transmitter output power required to achieve remote detonation may be calculated from the following parameters:

- The energy required to detonate the initiator.
- The impedance of the initiator's bridgewire at the excitation frequency.
- The impedance of the firing circuit at the excitation frequency and the impedance mismatch between the bridgewire and the firing circuit at the excitation frequency.
- The efficiency of the firing circuit as an antenna at the excitation frequency.
- The coupling efficiency between the excitation antenna and the firing circuit.
- The efficiency of the excitation antenna.

Under normal operations, the energy required to detonate the initiator is calculated from measurements employing DC current. Similar measurements may be performed using RF current. If optimum power transfer is achieved between the test set and the bridgewire, the RF power required to achieve detonation will equal the DC power required to achieve detonation. The RF current

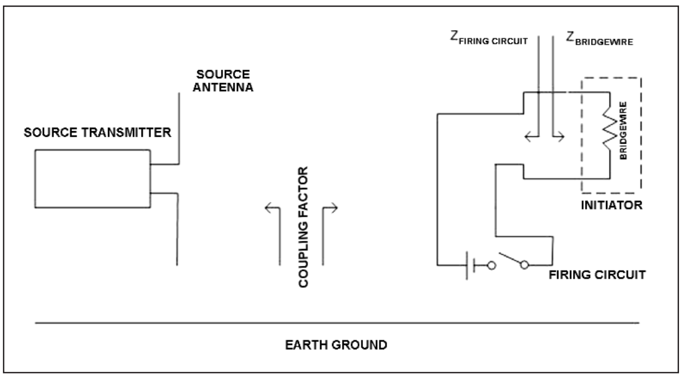

Figure 1 · RF remote detonation system.

RMS amplitude will, in general, differ from the DC current amplitude. However, the time interval between application of power and detonation will be the same for both test procedures.

At DC, the bridgewire behaves like a simple resistor. The current through the bridgewire may be calculated, using Ohm's Law, from the resistance of the bridgewire and the voltage applied across the firing circuit. At radio frequencies, parasitic inductive and capacitive circuit behavior combines with the bridgewire resistance to present a frequency dependant impedance across the bridgewire terminals. A detailed characterization of this impedance is crucial to determining the system transmitter output power required to achieve detonation. The bridgewire impedance is required to establish optimal power transfer from any test set employed to evaluate energy requirements for detonation. The test set output impedance must be complex conjugate matched to the bridgewire impedance in order to obtain accurate test results. Further, the impedance of the bridgewire, the driving point impedance of the firing circuit, and the impedance mismatch between the firing circuit and the bridgewire are significant parameters in the system calculation.

The efficiency of the firing circuit as an antenna at the excitation wavelength directly impacts energy delivery to the initiator's bridgewire. The firing circuit's ability to radiate energy, and by reciprocity, capture energy depends upon its physical dimensions in terms of excitation wavelength, and its position with respect to other objects, including ground. If the firing circuit is embedded in earth, as in some operational situations, it will be at least partially shielded from incident RF energy. In such instances, it may be theoretically possible to detonate the initiator, however, the transmitter output power required to accomplish this task would exceed practical limitations.

If the firing circuit exhibits suitable electromagnetic behavior, the final issues to evaluate are the coupling efficiency between the source antenna and the firing circuit, and the efficiency of the source antenna itself. The orientation of the source antenna with respect to the firing circuit must be such that polarization mismatch is minimized. The vector polarization of the energy radiated by the source antenna must be conjugately complementary to the energy that would be radiated from the firing circuit if the firing circuit were used as a source antenna.

The performance of the excitation source depends upon the efficiency of its antenna and the impedance match between its transmitter and its antenna. The efficiency of the source antenna is dependant upon its physical dimensions with respect to the excitation wavelength, and the materials with which it is constructed. An optimum match between the driving point impedance of the source's transmitter and antenna may be obtained by providing an impedance matching network either between the transmitter and the antenna, or within the transmitter itself.

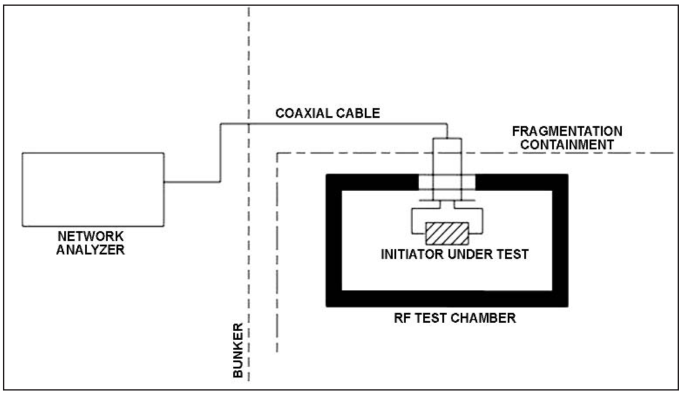

Figure 2 · Initiator impedance test procedure.

A specific prediction of the transmit power required to remotely detonate a particular explosive device, using a given RF frequency, may be formulated from a numerical model incorporating the above stated parameters. The specific RF power required to fire the initiator and the impedance of its bridgewire may be determined through the experimental procedure reported in Section 3 of this paper. The electromagnetic characteristics of a given firing circuit may be evaluated using analysis programs such as the Numerical Electromagnetics Code. The impedance match between the firing circuit and the bridgewire may be evaluated for RF circuit analysis. The coupling between the source antenna and the firing circuit may be evaluated using RF propagation analysis. The various analysis results may then be incorporated into a link budget equation (1):

$$P_T(dBW) = L_C(dB) + L_M + P_{DET}(dBW) \quad (1)$$

where P_T represented the transmit power required to achieve remote detonation, L_C represents the coupling loss between the source antenna and the firing circuit, L_M represents the mismatch loss between the firing circuit and the bridgewire, and PDET represents the power required to detonate the initiator. Note that all power levels are expressed in dBW, dB above 1 watt. This equation may now be used to determine the excitation transmit power required for a particular detonation scenario.

3. Initiator Radio Frequency Test Procedure

Figure 2 depicts an EOD range compatible procedure for the evaluation of initiator bridgewire impedance characteristics over a given range of radio frequencies. The initiator under test is installed in a pre-calibrated jig. The jig is then installed in a reinforced test chamber. The test chamber may be any EOD approved blast containment structure suitably lined with radio frequency absorbing material, such as Eccosorb, as shown. The RF test chamber is then positioned on the range and either buried to a depth suitable for frag containment or covered with sand bags sufficient to accomplish the same task. A coax cable is installed between the test chamber and the personnel bunker. A vector network analyzer, or vector impedance meter, is then used, in the safety of the bunker, to characterize the initiator's bridgewire.

After a full characterization of the initiator has been performed, the network analyzer may be replaced with a power signal generator and an impedance matching network (IMN). The IMN is tuned to establish an impedance match between the initiator and the signal generator. RF power is applied at specific levels to the initiator, through the coax cable, until detonation occurs. The RF power amplitude, monitored via instrument metering, and the time interval between application of RF power and detonation are then used to calculate the RF energy requirements for detonation.

4. Summary and Recommendations

This paper has presented the specific system parameters associated with the remote detonation of explosive devices using radiated RF energy. A system equation has been developed from which specific detonation scenarios may be simulated. Further, EOD compatible test procedures for the impedance characterization of initiators have been presented. The data obtained from these procedures is essential to accurate system modeling.

Anecdotal evidence clearly indicates that remote detonation of an explosive device by RF energy is a rare occurrence. This evidence is strongly supported by the system model developed in this paper. In the majority of operational scenarios, the system model is in a state of inequality. Specifically, for a given transmit power, the coupling losses between the source antenna and the firing circuit are, in nearly all practical cases, too great. Further the mismatch losses between the firing circuit and the bridgewire may be too great. In some situations, the transmitter may not be capable of transmitting sufficient power to heat the bridgewire to critical temperature. These parameters, in isolation or in random combination, will prevent the remote detonation of the device.

A course of action directed towards the practical development of a system for the intentional remote detonation of explosive devices must begin with a thorough simulation of numerous scenarios. Impedance characteristics for the anticipated initiator types must be evaluated and catalogued. Firing circuit geometries and positioning must be evaluated for electromagnetic characteristics. The results of these simulations will then establish the feasibility of such a system and provide a basis for any hardware development specifications which may follow.

Author Information

Dr. Walter D. Rawle received his PhD in electrical engineering from the University of Manitoba, and MASc and BEngEE degrees from the Technical University of Nova Scotia. Rawle's work experience areas include navigational aids, conventional and trunked land mobile radio systems, Part 15 consumer products, wireless networks; data communications, cable modems, missile guidance, homeland security technologies, and satellite launch safety. He holds two U.S. patents.

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