Developing a Method for Indicating Explosive Effects Using Radio Frequency Energy.

Donald S. Williams

Private member not affiliated to a university
25 Yallourn St Fyshwick ACT Australia

dsw57@internode.on.net

ABSTRACT

An ongoing problem is how to demonstrate the effects of an explosion without causing the physical effects. The concept is: one form of physics (RF energy) can be used to indicate the effects of other forms of physics, being the hydrodynamics of blast and the ballistics of fragmentation. Blast effects, predicated on a range of explosives and explosive charge weights, can be indicated with a reasonable degree of accuracy in many situations. Software in transmitters and receivers determine the threshold distances at which the specified effects will be experienced in real-world conditions. Structural damage is also indicated by converting the peak incident pressures to reflected pressures based on a number of assumptions and comparing the results to published data. To a limited degree, the expected impact of high-velocity, low-trajectory fragmentation from IEDs has been demonstrated. The formula for fragment distances, while based on published data, is generic and applicable metal fragments from the casing of the IED resulting in the range for an impact of greater than 79 Joules. A 'proof of concept' model demonstrated the principle of using one form of physics to emulate others is feasible.

Keywords: Blast; Emulation; Simulation; Fragmentation; Innovation.

Context

A 2005 paper[1] asked the question: "Is it possible to use radio frequency energy to emulate blast effects?". A subsequent 2019 paper refined the question, stated the design criteria and provided a summary of the design and development progress. It is possible to use radio frequency energy to emulate explosive effects and it has been done. This paper explains how the use of one form of physics (RF) to emulate other forms of physics has been achieved.

The inability to emulate explosive effects in a 'real-time' and 'real-world' environment limited training, operational planning, emergency practices, protective security reviews and blast assessments. Those who require an understanding of blast and fragmentation effects include:

- structural, façade, safety and other engineers who require an understanding of the relationship between explosive charge weight, distance and damage;
- explosives engineers and specialists who provide and validate technical advice;
- bomb technicians and explosive ordnance disposal operators;
- military and law enforcement search personnel;
- incident commanders who need to understand and appreciate the distances at which explosive effects occur;
- emergency services staff and commanders who require accurate guidance on the establishment of cordons, command posts, access routes and related planning factors;
- security, safety and emergency managers who require reasonably accurate emulation of explosive effects on people and buildings; and
- emergency, security and other consultants who advise on evacuation routes and safe distances for assembly areas and procedures.

A capability was required that clearly showed distances at which explosive effects occurred.

The criteria for a 'blast emulation' system was defined as[2]:

- able to be scaled in some manner to indicate blast injury and structural damage at various distances related to selected explosive type and weight;
- be omni-directional;
- penetrate thin walls and materials;
- be reflected by strong walls and materials;
- be reflected around corners;
- flow over and around items using the principles of hydrodynamics;
- operate out to at least a distance equivalent to the injury distances for (say) 100 kilograms (~220 pounds) of TNT, later updated to 20,000 kg (~44,000 pounds);
- be simple to operate;
- be non-hazardous to store, transport and operate;
- be deployable in a wide range of physical environments;

[1] The papers presented to 2005 and 2019 Parari Explosive Symposia are available at www.layer 3services.net.au/html/products/ExploSim.html

[2] Williams D. Gibbs G. Alston M. Safe blast simulation: The potential to use radio frequencies to emulate blast effects Parari 2019 available at www.layer 3services.net.au/html/products/ExploSim.html

- be easily transportable across jurisdictions; and
- have a low cost of procurement and maintenance.

The only criterion the resultant design did not meet, given that radio frequency energy (RF) travels in straight lines, was the ability to “flow over and around items using the principles of hydrodynamics”.

Increased computing power and application of additional algorithms enabled the ability to include an indication of fragmentation effect.

Use of RF to Emulate Explosive Effects

The capability to use RF to emulate explosive effects is based on a transmitter which is programmed to represent a type and amount of explosive and a number of receivers which indicate specified effects at the distance from the transmitter. The receivers can be worn by participants or placed on equipment.

It is recognised there are differences between the electromagnetic energy and the hydrodynamic properties of blast. These are summarised as:

- Radio waves travel in straight lines and do not flow over objects.
- Electromagnetic waves dissipate based on a square root basis whereas blast decreases on a cube root basis, an issue overcome through programming of the system.
- The effects of an explosion are dependent upon the amount, type and confinement of the energetic material. The effects of a radio transmission are dependent on the strength and frequency of the signal. This was addressed through the development of special software.
- Electromagnetic signals reflect immediately and do not build up an increased pressure against a surface in the manner of a blast wave. As a result, there is no simulation of reflected pressure. See below for conversion from indication of peak incident to reflected pressure when considering structural damage.
- Electromagnetic signals travel at the speed of light, blast travels at a greatly reduced speed. The practical differences in time will not be observable by the operator[3].
- The ability for an electromagnetic wave to penetrate a wall does not represent structural damage, which means buildings are not damaged.
- There is no replication with an electromagnetic wave of the blast wave’s shock front.
- An electromagnetic signal has no propulsive effect and does not generate fragmentation. The system indicates fragmentation damage based on calculations developed from open-source references and in-house algorithms.
- The effects of ‘secondary fragments’ from surrounding items are not indicated.
- An electromagnetic signal does not simulate the manner in which a human body can be accelerated and projected resulting in impact-related injuries.
- An electromagnetic signal does not simulate the negative pressure phase of an explosion.

Use of the globally available WiFi frequency of 2.4 MHz enabled the signal to pass through thin materials, be reflected by solid ones and reflect around corners. This effect is recognised by anyone losing the WiFi signal on their phones and other devices as they move inside solid structures.

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[3] For example, for a 100 kg charge at 30 m (using TNT as explosive material), the approximate distance for ear damage, the time of arrival of the blast is ~56 msec; calculated using CONWEP.

Explosive engineers, experienced IEDD and EOD operators, electronic and radio engineers combined their skills to develop a capability to emulate explosive effects in the 'real time' and 'real world' environment.

Blast Calculations

Blast calculations assume perfectly mixed, primed and detonated explosives and utilise ideal gasses and flat, usually infinite surfaces. Variations between the predicted distances and the system's indication of effects is due to variations in the actual environment which will affect RF, blast and fragmentation.

These variations reflect the reality of practical experience. If a person is facing away from the seat of the explosion and whether the person is breathing in or out at the time will alter the injuries received particularly ear, lung and other soft tissue damage. Similarly, if the person wearing a receiver is facing away from the transmitter and thereby shielding the receiver the indicated damage may vary compared to a person nearby with their receiver facing the transmitter.

The developed capability is not presented as a blast modelling analysis tool, the differences between RF and blast dynamics preclude this. Rather, it provides an indication of effects in the actual built and natural environments.

Blast calculations are based on the normal cube root scaling for a hemispherical (ground based) explosion where the blast scaling factor k = R /W^0.33. Where R = range, W = explosive charge weight.

For the calculations, the energetic material is considered to be "confined" i.e. contained within some form of thick skinned container. For the scenarios demonstrated, the difference between confined and unconfined is minimal.

Calculations stem from work by Kingerly and Bulmash[4]. The calculations were cross referenced against level-one blast software such as the ExpSAFE Blast Calculator[5].

A library of 25 explosives divided into 'Common' and 'Military,' and nine pre-determined IEDs, has been created. "Common" does not relate to availability rather that they are commercial, industrial, laboratory or home-made explosives. Additional explosives can be added if requested. The explosives currently represented in the system are:

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4 Kingery, C.N. and Bulmash, G. (1984), Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst, Technical Report ARBRL-TR-02555, US Army Armament Research and Development Centre, Ballistic Research Laboratory, Aberdeen Proving Ground, United States.

5 Gibbs Software.

Common	Military
TNT	C4 / PE4
ANFO	SEMTEX
PETN or Penthrite	RDX
Pentolite	HMX
Blasting AN/water gel	PBX
Dynamite	Tritonal
Gelignite	Composition B
Ammonium Nitrate	Tetryl
Picric Acid	Octol
TATP	
HMTD	
Black powder	
Nitrocellulose	
Guncotton	
AMATOL	
Nitro-glycerine	

The relative effects of the explosives are based on their TNT equivalency which is drawn from a range of references. It is accepted that for home-made explosive's such as TATP and HMTD the equivalency factor will be a rough approximation.

Blast causes a range of injuries to the human body, mostly soft-tissue injuries. Two data points for blast pressures were selected, these being 207 kPa (30 psi) and 34 kPa (5 psi) peak incident pressures. The lungs and ears are particularly susceptible to damage from overpressure. A measure of lethality is the calculated damage to the lungs. The pressures indicated are the threshold for lung damage at 207 kPa (30 psi) and the threshold for ear damage at 34 kPa (5 psi)[6]. The receivers indicate levels of blast injury via Red and Orange LEDs.

When the transmitter sends the signal, each receiver determines if it is in the range that equates to blast lethality (receiver's Red LED), blast injury (Orange LED) or fragment injury (Blue LED).

[6] US Department of Homeland Security FEMA-426 Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings, Table 3.1 "Primary Injury Thresholds" quoting US Department of Defence 3-340-02, Structures to Resist the Effects of Accidental Explosions (2008).

Figure 1 Indicative depiction of distances from an explosion

Structural Damage

The system can be used to indicate damage to structures from an explosion.

If the structure does not fail immediately when it is struck by the initial peak incident pressure (Pi) the pressure will continue to build until either the structure fails or the reflected pressure (Pr) is reached. Table 1 shows indicative pressures for structural damage[7].

Type of damage	Pressures
Threshold of serious damage to Steel framed building (4 psi)	Pr 27.6 kPa (Pi 13 kPa)
Threshold of severe damage to reinforced concrete building (7 psi)	Pr 48.2 kPa (Pi 22 kPa)
Threshold of probable total destruction of most buildings (10 psi) **NOTE: roughly equates to the Injury (Orange) LED**	Pr 69 kPa (Pi 31 kPa)

Table 1 Structural damage pressures

The injury (Orange) LED indicates at ~ 35 kPa Peak Incident pressure (Pi) which roughly equates, depending on a range of variables, to a Reflected Pressure (Pr) of >70 kPa (~10 psi)[8] which exceeds the point at which structural failure will occur.

Some consideration of the scenario is required to determine the probable effects of an explosion at the nominated site. A small charge may cause significant damage to surrounding fixtures and damage nearby walls and facades but is unlikely to cause the destruction of an entire building. A large explosive device, if it impacts enough structural elements or if protection from progressive collapse was not a design criterion, may cause demolition of the building. Additional engineering and blast modelling will be required to determine the exact failure modes indicated by the scenarios.

Fragmentation Calculations

Fragmentation injuries are indicated by a Blue LED on the receiver. Fragmentation injuries occur at considerably greater distances than blast injuries.

Fragmentation calculations rely on a range of assumptions as to the size, shape and ballistic stability of the fragment. The system does not detail the likelihood or nature of the injury only that the receiver is in range of fragmentation strike. The formula for fragment distances, while based on published data, is generic and applicable to low-trajectory, high-velocity metal fragments from the casing of the IED or munition.

Fragmentation scaling is based on published algorithms for the computation of primary fragmentation distances described by M. Swisdak and M. Crull [9]. Hazardous Fragment Distances and Maximum Fragment Distance formulae were considered during the creation of the model. The model uses the Gurney equation to predict initial velocity range and striking velocity and mass distribution relies on

[7] FEMA-426 Table 4-3

[8] The conversion to Pr is based on assumptions related to the 34 kPa Peak Incident pressure used for the blast injury indication calculated at 10 kg TNT at 12.40 m, roughly equating to 76.91 kPa Reflected pressure.

[9] Swisdak M. Crull M. Primary Fragment Ranges for Explosives Safety Parari Conference 1999

Mott's distribution. The resultant deviation is a minor; worst case is 35% for 5 kg with the average deviation over the selectable explosive magnitudes of 5%. This is not a perfect curve fit but given the unknowns and variables with fragmentation provides the basis for indicating fragmentation strike based on charge weight and distance.

Due to the variables, the decision was taken to use scaled root equation that generally aligns with other similar mathematic estimations based on fragment lethality of 79 Joule[10] with a calculated probability of strike. As with the blast indication LEDs, the Blue LED illuminates out to the calculated maximum distance. Therefore, anyone within the Blue LED range is considered to be vulnerable to a lethal fragmentation strike. The indication does not consider the likelihood of being struck which is a factor of dispersion over distance, only that the receiver is within the calculated distance to which 79 Joule fragments may travel

During the design phase, consideration was given to using methods such as V50 formulas to try to improve the fragment lethality estimations but detailed device design specification would be needed.

It is acknowledged that the approach taken to simulate lethal fragment distances is simplistic, any attempt to accurately predict fragment density and the probability to lethal fragment strike would require design specification of the IED, case to explosives ratio, nominal fragment mass and initial fragment velocity. In addition, data would be required on the placement of the IED, location of the detonator within the device, departure angle of fragments and intervening natural and built environmental factors. The system will be limited to high-velocity, low-trajectory fragments.

When considering fragmentation, consideration should be given to the expected packaging and containment of the proposed explosive device. In some scenarios, fragmentation will not be a consideration.

The protective capability of bomb suits and body armour will need to be considered but any exposed part of the body may be struck by a 79 Joule fragment.

Application of the Explosive Emulation System

Structural, façade, and other engineers and others with a responsibility for protecting life and property from explosive incidents need to understand the real-world, real-time effects of the proposed explosive event within their operating environment.

The system can be used to demonstrate the effects of nominated explosives within and outside the site under review.

The ability to use RF to emulate explosive effects can be used to practice bomb threat evaluation, site search and bomb incident response procedures.

The system can be used when planning procedural and physical security measures and to validate measures once implemented.

[10] 79 Joule is an accepted injury threshold for projectiles, see Henderson J (2010) Lethality Criteria for Debris Generated from Accidental Explosions UK Ministry of Defence

The system is not a replacement of CFD/FEA computer modelling. Rather, it offers an ability to identify the specific areas of concern where detailed analysis of how structures may be impacted can be undertaken.

Recording and Analysis

The nature and quantity of explosive of the event are recorded for downloading and analysis. The data is downloaded in Microsoft Excel format.

Concept expansion

Having demonstrated that indication of 'Hazard over Distance' is possible using RF, additional capabilities are being developed.

The ability to send data packs from a simulated explosion enables the development of sensors to provide an immediate indication of the expected peak incident and normally reflected pressures at a distance and based on the specified type and quantity of explosive. A proof of concept 'ExploMeter' system has been developed.

While the fragmentation calculations related to IEDs can only be generic, the fragmentation patterns and trajectories for munitions are well documented. It is possible to indicate both the maximum expected travel and the likelihood of lethal impact at a nominated distance from a specified munition. The ability to do this in an actual training environment will enhance training as casualty figures as well as the effect of cover will be demonstrated in the field. Unlike laser systems, the RF based system ('FragSim') can be range limited in accordance with the specified munition. The system will be limited to high-velocity, low-trajectory fragments.

Other types of hazards such as thermal energy and the down-wind contamination from radiological, chemical, biological materials are also feasible using RF. Subject matter advice is being sought for the systems under development 'FireSim' and 'CBRSim'. The nature of the inputs to the transmitter so the hazard can be defined and codified and the required receiver indications will be defined. The inputs will be based on published data relating to fragmentation patterns for the types and energy levels of fires and the characteristics of down-wind hazards. There will be limits of the level of replication but the ability to provide a degree of rea-time, real-world emulation will increase training and planning capabilities.

Summary

The ability to demonstrate 'hazard over Distance' using RF has been demonstrated.

The accuracy of the ability to use RF to emulate blast effects has been validated against the Kingery and Bulmash calculations.

Because the capability uses radio frequency to indicate hydrodynamic effects it is not an exact replication, hence the use of the term "emulation".

It has been demonstrated that electromagnetic energy can be used to replicate hydrodynamic blast effects to a degree of accuracy suitable to enable safe training and assessment.

Emulation of explosive effects in a ‘real time’ and ‘real world’ environment enhances training, operational planning, emergency procedures and practices, blast assessments and hence safety.

Additional capabilities are being researched and developed. Layer 3 Services welcomes discussion, input and suggestions on the development and use of this capability.

Author

Donald S. Williams CPP. *Don Williams served as an ammunition technical officer for 20 years. He holds qualifications in Security Management, Security Risk Management as well as Project and Resource Management and is a Certified Protection Professional (CPP). He is a member of the Institute of Explosive Engineers, ASIS-International, the International Association of Protective Structures, and is a Distinguished Life Member of the International Association of Bomb Technicians and Investigators. He is the author of over 140 publications relating to bomb safety and security, emergency management and related issues. Don is the Managing Director of Layer 3 Services Pty Ltd.* don.williams@layer3services.net.au.