SAFE INDICATION OF EXPLOSIVE EFFECTS USING RF

BY DONALD S. WILLIAMS CPP ASECM

The ability to demonstrate blast and fragmentation effects without injuring people and damaging buildings has always been a problem. The increasing restrictions on a dwindling number of live demolition ranges makes live demonstrations difficult. This article explains how the ability to 'emulate' explosive effects using radio frequency energy was developed.

Those who require an understanding of blast and fragmentation effects include:

- bomb technicians and explosive ordnance disposal operators;
- military and law enforcement search personnel;
- breaching teams;
- incident commanders;
- emergency services staff and commanders who establish cordons, command posts, access routes, media points and related sites;
- security, safety and emergency managers;
- managers responsible for compliance with company and legislated standards;
- emergency, security and other consultants who advise on evacuation routes, assembly areas and procedures;
- structural, façade, safety and other engineers who require an understanding of the relationship between explosive charge weight, distance and damage; and,
- explosives engineers and specialists who provide and validate technical advice.

The concept of using one form of physics, radio frequency energy, to emulate the hydrodynamics of blast and ballistics of fragmentation was considered as a possible means of safely 'emulating' explosive effects. Research and an international patent search showed than the concept had not been explored. The earliest reference was a paper delivered by this author in 2005[1].

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;
- be simple to operate;
- be non-hazardous to store, transport and operate;
- be deployable in a wide range of physical environments;
- be easily transportable across jurisdictions; and
- have a low cost of procurement and maintenance.

It is acknowledged 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. Peak incident pressures (Pi) is used as the basis for damage indication. Pi can be converted to reflected pressure based on a range of assumptions as described below.
- 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.
- 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.
- In relation to fragmentation, the effects of 'secondary fragments' from surrounding items are not indicated.

Explosive engineers, IEDD and EOD operators, and electronic and radio engineers combined their skills to emulate explosive effects in a 'real time' and 'real world' environment using RF energy. A proof-of-concept model was developed in 2021 which showed the concept of using RF was feasible.

The one criterion the use of RF did not meet was the ability to "flow over and around items using the principles of hydrodynamics." Given that blast is fundamentally hydro-dynamics and RF is straight line transmission, meeting this criterion was always unlikely. A proof-of-concept model included the added ability to indicate fragmentation injuries and an increased maximum charge weight of 20,000 kg (~44,000 pounds).

Safety considerations raised included: as a simulator it should not be capable of initiating a firing system; the system should transmit on as low power as is consistent with performance; the system should be safe to use wherever RF transmission is permitted; and, the power sources should be safe for transport in accordance with UN and IATA requirements.

USE OF RF TO EMULATE EXPLOSIVE EFFECTS

The globally available WiFi frequency of 2.4 MHz met the criteria including the ability for the signal to pass through thin materials, be reflected by solid ones and reflect around corners.

The capability is based on a transmitter and receivers. When the transmitter sends the signal, the receivers use signal attenuation and 'fine time management' chips to calculate their distance from the transmitter. Based on the type and quantity of explosive selected for input to the transmitter the receivers illuminate the appropriate LED, being: blast lethality, indicated by a Red LED; blast injury, Orange LED; or fragment injury, Blue LED. The injury readings can be converted to expected structural damage.

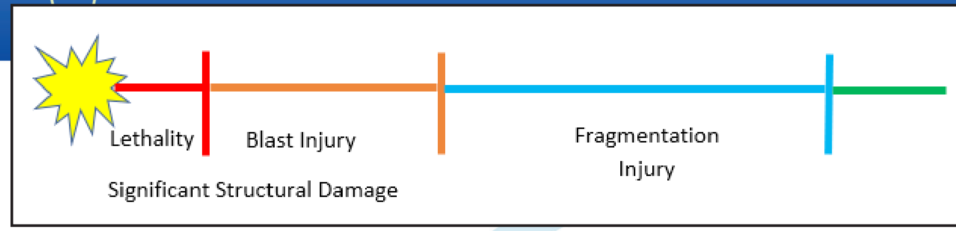

Figure 1 Indicative depiction of distances from an explosion

The current generation of finely tuned RF antennae and miniaturised computing capability resulted in accuracy to within ~ two feet (600 mm) depending on the site.

BLAST CALCULATIONS

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.

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

For the calculations, the energetic material is considered to be 'confined,' i.e. contained within some form of thick skinned container.

A library of 25 explosives divided into 'Common' and 'Military' and nine pre-defined IEDs was established for input via the transmitter. "Common" does not relate to availability, but rather that they are commercial, industrial, laboratory or home-made explosives. Additional explosives could be added. The selected explosives are:

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 drawn from a range of references. It is accepted that for home-made explosives 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. 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.

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 partially to the variance between radio frequency/ electromagnetic energy and the hydro-dynamic effects of explosives and also to variations in the actual built and natural environments which affect both RF and blast.

These variations reflect the reality of practical experience. If a person is facing away from the seat of the explosion and if the person is breathing in or out at the time will alter the injuries received, particularly 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.

When wearing a bomb suit or other protective equipment, the readings will need be adjusted. Depending on the type and effectiveness of the suit, for the Orange LED representing >34 kPa (~5 psi) it may be considered that blast injury is unlikely to occur. If the Red LED indicates >207 kPa (~30 psi), while the operator may not have suffered lethal injury, they would certainly be damaged, not least by being projected by the blast.

FRAGMENTATION CALCULATIONS

Fragmentation calculations rely on a range of assumptions as to the size, shape and ballistic stability of the fragment. 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 an IED or munition. The system does not detail the nature of the injury, only the likelihood of the receiver being in range of fragmentation strike.

Fragmentation scaling is based on published algorithms for the computation of primary fragmentation distances described by M. Swisdak and M. Crull[7]. 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 Mott's distribution. The resultant deviation is 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 provides the basis for indicating fragmentation strike based on charge weight and distance.

Due to the variables, the decision was made to use a scaled root equation that generally aligns with other similar mathematic estimations based on fragment lethality of 79 Joule[8] with a calculated probability of strike.

Consideration was given to using methods such as V50 formulas[9] to try to improve the fragment lethality estimations but detailed device design specification would be needed. It was deemed this would not be feasible when considering non-specific IED casings.

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 specifications 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 LED indication shows that a 79 Joule impact is possible, but it does not address the probability of a fragment strike.

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.

Again, the protective capability of bomb suits and body armour will need to be considered.

Structural Damage

An RF based-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 (below) shows indicative pressures for structural damage[10].

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)

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 >10 psi (~70 kPa) which exceeds the point at which structural failure will occur. 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.

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.

The distances from the transmitter at which significant structural damage can be expected to occur can be determined by laying out a number of receivers. Additional engineering and blast modelling will be required to determine the exact failure modes.

Relevance to IEDD and EOD Operators

Rf indication of explosive effects is relevant to IEDD and EOD operators as it can provide a real-world, real-time indication of effects should a training IED or EO device function due to timer run down, inappropriate handling, incomplete render-safe technique or remote detonation.

The distances at which blast and fragmentation injuries will be experienced can be used to validate policies, practices and procedures.

Relevance to Search Teams and Assault Teams

For Search and Breaching teams, multiple IEDs and booby traps may be encountered and the effects of entry charges may also need to be considered. The RF capability offers a means of representing multiple IEDs and for indicating the immediate effects of various breaching charges without endangering the participants.

Blast Assessments

Security, Emergency, Safety managers as well as Incident Commanders, engineers and others with a responsibility for protecting life and property from explosive incidents and for providing guidance on bomb security measures have lacked a capability to demonstrate explosive effects in the built and natural environments. The use of RF enables the safe emulation of such effects.

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

VALIDATION AND SUMMARY

The accuracy of the ability to use RF to emulate blast effects has been validated against the Kingery and Bulmash (CONWEP) calculations. Because the capability uses RF to indicate hydrodynamic effects, it is not an exact replication, hence the use of the term "emulation."

It is stressed that the capability does not indicate minimum safe evacuation distances from potential explosive effects. The evacuation distances must align with the site's emergency instructions.

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.

References:

_https://fs22.formsite.com/adminiabtiorg/images/ExploSim_References.pdf_

About the author:

Donald S. Williams CPP ASecM is a Distinguished Life Member of IABTI. He is a Certified Protection Professional and a member of ASIS-International, the Institute of Explosive Engineers and the International Association of Protective Structures. He has authored over 140 publications including "Bomb Safety and Security, the Manager's Guide." He was awarded the Australian Security Medal by his peers for services to the profession. He can be reached at **_don.williams@layer3services.net.au_**