*Paper delivered to the Parari symposium 2005 Canberra, Australia*

*This was the first time the concept of using RF to indicate blast effects was presented.*

*The initial proof-of-concept models demonstrated the concept was feasible but at that time the technology was not up to the concept.*

*The project was resurrected by Layer 3 Services Pty Ltd in 2019 and improvements in RF technology and miniaturised computing power enabled the emulation of explosive effects using RF to occur. See paper delivered to the 2019 Parari symposium.*

**TITLE: USE OF THE ELECTROMAGNETIC SPECTRUM TO SIMULATE THE DYNAMIC EFFECTS OF BLAST.**

**Abstract:** This paper addresses how the requirement was identified for a system that would qualitatively, inexpensively, effectively and non-destructively simulate blast effects. The paper describes: how the design criteria were defined; how the concepts were identified; and how the resultant technology was developed. The result is a system based upon a capability to use radio emissions to qualitatively simulate some blast effects.

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# USE OF THE ELECTROMAGNETIC SPECTRUM TO SIMULATE THE DYNAMIC EFFECTS OF BLAST

## Background:

The original requirement stemmed from bomb disposal technicians[[1]](#endnote-1) who, after an improvised explosive device disposal (IEDD) re-qualification course were discussing the deficiencies of existing training techniques. During such courses it is common for IEDs to be manufactured and deployed in different scenarios and for the devices to be fitted with either flash bulbs, or very small electrically initiated explosive charges (a few grams of low explosive composition) and/or small smoke generating charges. These charges are used to simulate the detonator and indicate if the device would have functioned and hence to test the effectiveness of the render-safe procedure (RSP) employed by the bomb technician. If the bulb or pyrotechnic charge functioned it was taken as an indication that the main charge of the device would have detonated.

There are a number of limitations in the training system described above.

* It is often not possible to tell if the device functioned prior to the RSP as the student and umpires are usually removed from the device and the charge weights of the simulators are small and may not damage the outer package of the device.
* It is not possible to tell if the simulator functioned during the RSP (often a shot from a water cannon) in which case the technician can argue that the full effect of the potential explosive charge of such a device would be greatly reduced as the detonator would have been separated from the main charge due to the disruptive technique employed.
* There is no indication of the appropriate safety distance from the device for the command post and others involved in the incident. This distance is usually estimated based on blast/damage tables and an awareness of the potential protective strength of barrier buildings and materials.
* The system employs the use of live explosives, admittedly of very small net explosive quantity (NEQ), but often limiting their use to licenced range areas. Therefore, their use for training others involved in IEDD operations such as search teams, incident commanders, responding emergency services, emergency managers, response planners, etc is limited to specific geographic sites.

## Requirement:

A requirement was identified for a blast simulator that was non-destructive, safe to use and simple in its operation. This simulator would have to qualitatively and effectively simulate blast effects without endangering life or property whilst also meeting all legislative and regulatory requirements of the jurisdiction. Ideally it would also be inexpensive and simple to use.

The stated requirement led to the development of design requirements for a blast simulator. In addition to the above there was a need for the system to be able to simulate a wide range of explosive charge weights. The process used should, to the greatest degree possible, simulate the basic mechanics of a blast pressure wave in that it should: reflect from solid walls, penetrate thinner walls, dissipate over distance based on a cube root scale and the mechanism should be able to indicate various levels of “damage” at all distances out to the expected maximum for the selected charge weight.

This is obviously a difficult statement of requirement to fulfil, particularly the scaling of the wave as a function of the cube root as it is the hydro/gas-dynamic effect of the shock wave travelling through the ambient air that causes the decay in the wave at this rate.

The challenge was to find a mechanism whereby the physical characteristics of a blast wave could be simulated without achieving the phenomenon of BFD (Building Fall Down).

## Initial Concept:

It had been noted that in some aspects and under certain conditions radio frequency transmissions (RF) had some similarities to blast, in that the signal could be reflected from solid walls yet would penetrate thinner walls. This led to an investigation into what other common elements could be identified. The other major similarity was that “impact” of the RF signal could be modified over distance by adjusting the signal strength.

The major differences between RF and blast dynamics were:

* The previously mentioned strength over distance problem where blast dissipates based on a cube root rule; and
* The issue of impulse, where blast pressure (being subject to the laws of gas and hydro-dynamics) increases against the target surface as a measure of pressure applied over time.
* Another major difference was the effect of the relevant energy when interfacing with the human body. The human body has a large water content (nominally 66%) and its own electromagnetic energy field which can disrupt RF signals. The effect of blast impact can be enhanced when it impacts on a complex structure such as the human body which contains elements (organs) of different consistency and with interfaces with varying gas and liquid interfaces. This is contrary to the transference of peak incidence (blast) pressure on soft tissue, particularly one with high water content and varying densities of, and interfaces between internal materials, which can augment blast effects.

The initial concept which was considered worthy of investigation was the use of RF energy to simulate the peak incident pressure of blast. The initial thought was of a transmitter (TX) unit transmitting to a number of receiver (RX) units that could be issued to participants such that when the device functioned, the TX unit would emit a signal and the RX units would qualitatively indicate the amount of blast damage that would have occurred at whatever distance they were from the “explosion”.

Ideally the TX unit could be connected to a training device (IED), booby trap, or manually triggered for other scenarios.

## RF ISSUES

### Blast/Damage Distances

The first requirement was for an accurate blast damage/distance table. It was decided to create a table based on three well researched standards of blast injury and damage (referred to hereafter as damage): glass breakage, ear damage threshold, and lung damage threshold.

A review of published data demonstrated differences between a number of the available blast/damage tables (but within allowable margins). As discussed in depth at the last Parari, it was acknowledged that many of the published blast/damage tables[[2]](#endnote-2) err on the side of caution by adding safety margins. These margins are added as the tables are normally used as guides for those planning safety distances for potential explosive events and a conservative figure is desirable.

Therefore, the first task in the development of a blast simulation system was to review existing data and generate a table that is as accurate as possible i.e. without a conservative (safety) bias.

This enabled the development of look-up tables giving RF energy distance, strength and required response (glass breakage, ear damage threshold, lung damage threshold), using TNT as the reference explosive material.

### Penetration/Frequency

Considerable work has been done on the penetrative effects of the RF spectrum. Indeed, most of the recent research appears to have been in areas relating to various forms of tomography[[3]](#endnote-3)3 and in relation to wireless-based IT communication[[4]](#endnote-4), although the penetrative nature of selected RF bands has also been identified as having benefit in relation to other specialist areas of research[[5]](#endnote-5).

 The other area in which RF penetrative capabilities has been studied in some considerable detail is for electromagnetic protective and security standards such as TEMPEST rating[[6]](#endnote-6). No research could be found in relation to penetration and reflection of RF energy as would be required to simulate the interaction of a blast wave with different construction materials. The aim of the research was to find a frequency that would reflect from a solid surface such as concrete and yet penetrate thin materials (e.g. glass, plaster [dry wall] board). The signal should also be variable so that as the simulated explosive charge weight increased so the RF penetrative power would increase. In addition, the specific frequencies selected should ideally be accessible to common users in Australia and if possible, around the world.

The frequency had to be safe for both humans and equipment, including pacemakers, computers, communication equipment, etc.

### Reflection

In relation to reflective properties, it was desirable that where the RF signal did not penetrate a surface, it would reflect from vertical surfaces, both normal and angled. It was also recognised that the RF signal would reflect in the same way that rays do, particularly as it passed around corners, whereas blast would both reflect, and “flow” around the corner.

While accepting that the effects of reflection around a corner will vary due to the different physical characteristics of the energy, it may offer enough evidence to demonstrate to the participants the ability of a blast wave to be reflected around corners where the structure remains intact.

The RF signal should also be reflected from ground surfaces of a solid nature. In this manner it was hoped to simulate a hemispherical surface burst. If the TX unit was placed on a relatively thin surface (i.e. a wooden floor) or on soft soil, an amount of signal would penetrate into the surface. If the TX unit was placed on a solid surface little would penetrate and most would be reflected. Again, the differences in the reflected effects of RF and blast are acknowledged.

The major difference in relation to reflection is the effect of peak reflected pressure (rp). In the case of blast, because it obeys the laws of gas dynamics, the pressure against the surface continues to build until either the wall fails or the blast wave is reflected from the surface with a greater pressure than the initial pressure, and obviously the impulse against the surface increases with the time that the pressure is applied. In the case of RF there is no increase in signal strength over time due to reflection.

### Cube root dissipation.

This was the most challenging part of the design, to have a qualitative method of comparing the RF signal at a given point and through intervening materials that could be represented as a measure of blast effect.

Within the limits of proprietary information, the system developed was based on a series of coded conversations between the TX and RX units that enabled the RF strengths to be compared to the blast/damage table and demonstrated through a series of LEDs reflecting:

* Receipt of a signal (blast was heard but no damage was incurred).
* Glass breakage.
* Ear damage threshold.
* Lung damage threshold.

### Impulse Considerations

The amount of damage created by blast is, to a large extent, a product of the impulse (pressure x time (pt)). Research has shown that it is possible to simulate the impulse through the use of coding to adjust for the nominated EO charge weight over distance with an assumed time constant (t) nominally 4 milliseconds. It is recognised that the actual ‘t’ element of impulse varies based on a number of physical attributes, such as the resistive strength of the reflective surface, but the 4 millisecond constant is considered to provide a qualitative depiction of an average duration impulse for a high-explosive event with one reflective surface.

### Integrity

There is a need to ensure the integrity of the signal for safety reasons and to provide a qualitative simulation. The signal can be protected through the use of coded communications between TX and RX units thereby reducing the risk of spurious emissions from other sources triggering the RX units.

## ADDITIONAL DESIGN ISSUES

### Exercise Control

The simulator is designed as a training tool, and as such, there is a need for the training “umpires” to be able to control the equipment and to record the outputs of each RX unit. The umpires should be able to monitor responses and to prevent participants from “cheating” the system by resetting the recorded impulses on the RX unit. This requirement was met through a number of measures:

* Non-removable batteries with an option for storage of last recorded result in the RX unit’s non-volatile memory.
* Transmission of the resultant record from the RX back to the TX with the results for each linked RX unit shown on the TX display panel.
* The ability for RX units to be reset only from the TX unit.

### Power Issues

Power needs had to be adequate to allow a number of transmissions between recharging as it is expected that users will want to run a number of scenarios per session. The power supply had to meet the transmission power requirements as well as manage the on-board monitoring programs.

This called for small, safe, rechargeable batteries with enough power for monitoring and transmitting at required power. Commercial batteries that could be fitted by the user were considered, however, inbuilt batteries were selected for reasons relating to maintenance, weather protection, life, reliability and size.

### Packaging

As the system is to be used as a training tool under operational conditions for bomb and EOD disposal it was necessary that an appropriate level of environmental protection be provided. The system needed to be water and dust resistant, easy to clean and maintain but it was not considered necessary to the same level of environmental protection as operational equipment as this would add to the size and cost of the system. The casings for the TX and RX needed to be simple and robust. It was decided to make the components in bright colour to indicate that they were training tools. As a result, there is a need to hide or camouflage the TX units during search training exercise so as not to indicate the locations of the training IEDs or booby traps.

## DEVELOPMENT

### Prototype & Preproduction

A number of prototypes have been manufactured. First was a proof-of-concept demonstrator to show that the use of RF to simulate blast was viable. Then, the blast/damage results were tested in both free-field and complex environments. The aforementioned considerations resulted in the preproduction prototype (Mk2) which was demonstrated at the International Association of Bomb Technicians and Investigators (IABTI) Conference in the USA in June 2005 and the DESI equipment display in the UK in September 2005. Feedback from these demonstrations was used to further modify the system.

### Design of the System

The result was a design consisting of a TX unit which controls the process and initiates the signal. Initiation may be from:

* A training IED, with an electronic initiation system;
* Booby trap(s), with an electronic initiation system(s);
* Remotely by command wires, RF, IR, etc; or
* By use of the provided hand-held initiator.

The TX unit can be programmed to simulate a range of explosive charge weights from 500 g to 100 kg. Each system has five RX units tuned to the TX unit. The TX unit is able to confirm the status of the RX units before and after the signal is sent, and to reset the RX units at the end of the training scenario.

### Operation

For operation in training, the RX units are issued to participants or placed in the required locations such as computer rooms, incident command points, secondary hazard locations, etc. The TX unit is positioned in the potential explosive site (i.e. probable location of IED), a realistic explosive charge weight is selected and at the appropriate time, the triggering signal is sent to the TX unit.

Prior to transmission the TX unit interrogates the RX units to identify which ones are on-line. During transmission the TX unit sends a warning signal to prepare the RX units and then sends a signal indicating the programmed EO weight. The RX units determine the signal strength and compares it to the blast/distance table; this is then translated into an indication of damage given an assumed impulse time of 4 milliseconds.

All communications between TX and RX units are encoded to protect the electronic integrity of the system.

Upon receiving the signal the RX unit indicates one of four results:

* A signal has been received, but no damage was incurred (the ‘bang’ was heard).
* Glass breakage threshold pressure was received.
* Ear damage threshold was received.
* Lung damage threshold was received.

The exercise umpires can record each RX unit’s results by viewing the RX units or from the TX unit display panel.

### Transition to production

Ten demonstration models are currently in production, these will confirm design and build standards and be used to trial the equipment, supporting instructions and to validate the training guidelines.

### Limitations of System

The system has acknowledged limitations which stem from the use of one form of physics to simulate, to a reasonable degree, another form of physical behaviour:

* It can only simulate peak incident pressure not peak reflected pressure.
* The performance of the energy passing through surfaces is not the same as the effects of blast causing a surface to fail, but it does indicate the ability for blast to penetrate certain materials.
* It does not simulate fragmentation but alignment with a laser-based system would enable high velocity/low trajectory fragmentation to be represented.
* There may be places where it is inappropriate to use the system, such as in hospitals or near sensitive electronic equipment.

### Advantages of System

The resultant capability has a number of advantages:

* It is able to use one form of energy to represent the effects of another.
* It does simulate the damage/distance effects of blast.
* It does (to a degree) simulate the penetrative and reflective effects of blast.
* It is safe to use in most locations and does not require special range areas.
* It is simple to use.
* It can be triggered by a range of methods to assist with training of bomb technicians, high-risk searchers, emergency services managers, incident commanders, first responders, etc.
* The system provides an immediate visible record to the participants of the type of damage that could be expected at that distance from the selected explosive charge weight.

The system may also be used by emergency service managers to provide more realistic training for their personnel. For example, emergency medical services (EMS) can use the system to initiate an incident, assess the efficiency and effectiveness of the response teams, to time the response and to provide an indication of the nature and severity of injuries that could be expected from a blast of a predetermined size at given distances.

## Conclusion

It must be stressed that the resultant system is a qualitative simulation tool that does not replicate blast (hence no BFD) nor is it a measuring/validation tool. But, the system has demonstrated that RF can be used to augment training in relation to safe response practices for bomb disposal operators, search personnel, emergency services staff, incident commanders and emergency managers.

It has been demonstrated that it is possible to use the electromagnetic spectrum to simulate the dynamic effects of blast to within an acceptable degree for training purposes.

1. Improvised Explosive Device Disposal (IEDD) and Explosive Ordnance Disposal (EOD) Operators: personnel trained in the skills and techniques required to render safe improvised explosive devices and explosive ordnance. [↑](#endnote-ref-1)
2. Ryan, J.M.; Rich, N.M.; Dale, R.F.; Morgans, B.T.; Cooper, G.J., Ballistic Trauma: Clinical Relevance in Peace and War, p57, Arnold, London, 1997. Montanaro, P.E. (formerly Indian Head Division/Naval Surface Warfare Center); Swisdak, M.M. Jr. (Indian Head Division/Naval Surface Warfare Center); Ward, J.M. (Department of Defense Explosives Safety Board), The DDESB Blast Effects Computer -- From Circular Slide Rule to Excel Spreadsheet, 2000. White, C.S., The scope of blast and shock biology and problem areas in relating physical and biological parameters. Annals of the New York Academy of Sciences, 1968, 152: p. 98. Noon R. Engineering analysis of fires and explosions. Boca Raton: CRC Press, 1995 (page 191). CONWEP US Corps of Engineers Waterways Experimental Station. [↑](#endnote-ref-2)
3. E.g. Robitaille PM, Kangarlu A, Abduljalil AM RF penetration in ultra high field MRI: challenges in visualising details within the centre of human brain. Journal of Computer Assisted Tomography 1999 Nov-Dec 13(6): 845-9. [↑](#endnote-ref-3)
4. E.g. B Alexander 802.11 Wireless Network Site Surveying and installation. Cisco Press 2004. [↑](#endnote-ref-4)
5. E.g. C. Mielke (Los Alamos National Laboratory) et al, The use of RF techniques in high magnetic field to measure the penetration depth as a function of the magnetic field in superconducting compounds. Journal of Physics: Condensed Matter 13 (2001). [↑](#endnote-ref-5)
6. National Security Agency (NSA-USA) Specification No 65-6 and Defence Signals Directorate (Australia) ASCI 33. Also, US Army Corps of Engineers Pamphlet 1110-3-2 EMP and Tempest Protection for Facilities. [↑](#endnote-ref-6)