ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

A Study of Electromagnetic Pulse Based Weapon Systems

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ABSTRACT:High Power Electromagnetic Pulse generation techniques and High Power Microwave technology have matured to the point where practical E-bombs (Electromagnetic bombs) are becoming technically feasible, with new applications in both Strategic and Tactical Information Warfare. The development of conventional E-bomb devices allows their use in non-nuclear confrontations. This paper discusses aspects of the technology base, weapon delivery techniques and proposes a doctrinal foundation for the use of such devices in warhead and bomb applications.

KEYWORDS: Electromagnetism, E-bomb, military, warfare, high power microwave devices

I. INTRODUCTION

An e-bomb (electromagnetic bomb) is a weapon that uses an intense electromagnetic field to create a brief pulse of energy that affects electronic circuitry without harming humans or buildings. At low levels, the pulse temporarily disables electronics systems; mid-range levels corrupt computer data. Very high levels completely destroy electronic circuitry, thus disabling any type of machine that uses electricity, including computers, radios, and ignition systems in vehicles. Suchweapons are now both technically feasible and relatively economical to build, incomparison with established weapons of mass destruction such as the nuclear bomb. A wide range of existing targeting and delivery techniques may be employed in usingsuch weapons. These devices are electromagnetic weapons, and the foremost of theseis the electromagnetic bomb (E-bomb).

The Electromagnetic Pulse (EMP) effect was first observed during the early testing of high altitude airburst nuclear weapons. The effect is characterized by the production of a very short (hundreds of nanoseconds) but intense electromagnetic pulse, which propagates away from its source with ever diminishing intently, governed by the theory of electromagnetism[1]. This pulse of energy produces a powerful electromagnetic field, particularly within the vicinity of the weapon burst. The field can be sufficiently strong to produce short lived transient voltages of thousands of Volts (i.e. kilovolts) on exposed electrical conductors, such as wires, or conductive tracks on printed circuit boards, where exposed.Commercial computer equipment is particularly vulnerable to EMP effects, as it is largely built up of high density Metal Oxide Semiconductor (MOS) devices, which are very sensitive to exposure to high voltage transients. What is significant about MOS devices is that very little energy is required to permanently wound or destroy them, any voltage in typically in excess of tens of Volts can produce an effect termed gate breakdown which effectively destroys the device. Even if the pulse is not powerful enough to produce thermal damage, the power supply in the equipment will readily supply enough energy to complete the destructive process. Wounded devices may still function, but their reliability will be seriously impaired. Shielding electronics by equipment chassis provides only limited protection, as any cables running in and out of the equipment will behave very much like antennae, in effect guiding the high voltage transients into the equipment. Telecommunications equipment can be highly vulnerable, due to the presence of lengthy copper cables between devices. Receivers of all varieties are particularly sensitive to EMP, as the highly sensitive miniature high frequency transistors and diodes in such equipment are easily destroyed by exposure to high voltage electrical transients. Therefore radar and electronic warfare equipment, satellite, microwave, UHF, VHF, HF and low band communications equipment and television equipment are all potentially vulnerable to the EMP effect.

It is this aspect of the EMP effect which is of military significance, as it can result in irreversible damage to a wide range of electrical and electronic equipment, particularly computers and radio or radar receivers. The damage inflicted is not unlike that experienced through exposure to close proximity lightning strikes, and may require complete replacement of the equipment, or at least substantial– portions thereof[2]. Thus it is significant that modern military platforms are densely packed with electronic equipment, and unless these platforms are well hardened, an EMP device can substantially reduce their function or render them unusable.

II. TECHNOLOGIES FOR NON NUCLEAR ELECTROMAGNETIC PULSE GENERATION

Key technologies which are extant in the area are explosively pumped Flux Compression Generators (FCG), explosive or propellant driven Magneto-Hydrodynamic (MHD) generators and a range of HPM devices, the foremost of which is the Virtual Cathode Oscillator or Vircator. This paper will review the basic principles and attributes of these technologies, in relation to bomb and warhead applications.

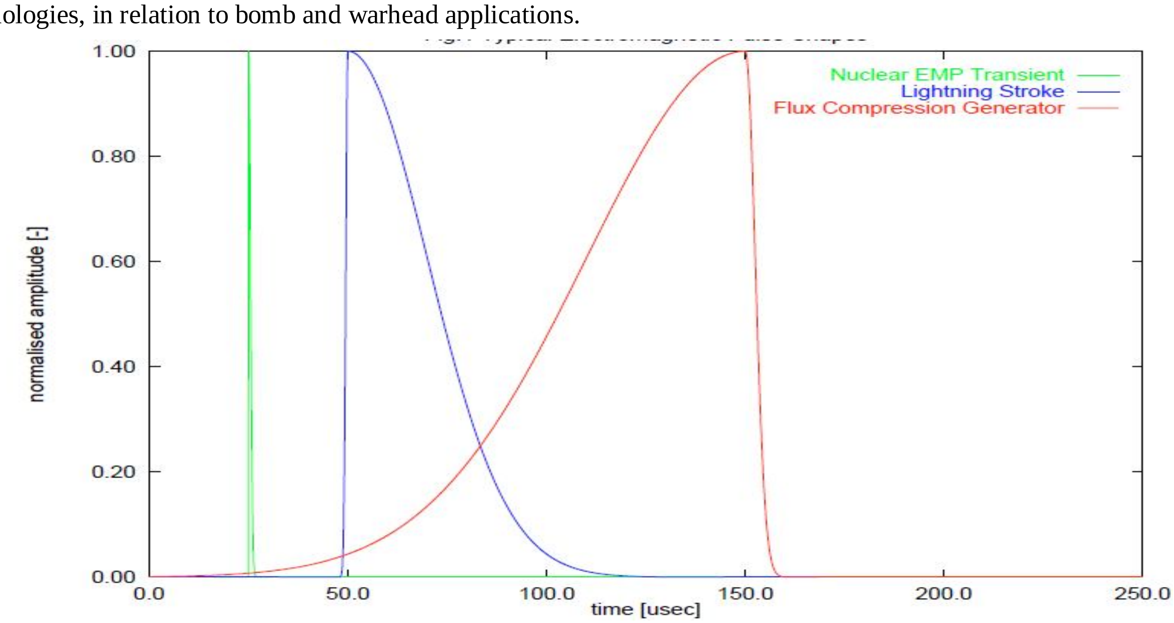

Fig. 1 Electromagnetic pulse shapes.

In the fig. 1, we can see the comparison of shape of electromagnetic pulse generated by a nuclear bomb to that generated by a lightning strike and a flux compression generator. With similar peak amplitudes, the power can be destructive if properly directed using antennas.

(a) Explosively Pumped Flux Compression Generators

An explosively pumped flux compression generator (EPFCG) is a device used to generate a high power electromagnetic pulse by compressing magnetic flux using high explosive. The central idea behind the construction of FCGs is that of using a fast explosive to rapidly compress a magnetic field, transferring much energy from the explosive into the magnetic field. An EPFCG can be used only once as a pulsed power supply since the device is physically destroyed during operation. An EPFCG package that could be easily carried by a person can produce pulses in the millions of amperes and tens of terawatts, exceeding the power of a lightning strike by orders of magnitude. They require a starting current pulse to operate, usually supplied by capacitors.

In a typical coaxial FCG, a cylindrical copper tube forms the armature. This tube is filled with a fast high energy explosive. A number of explosive types have been used, ranging from B and C-type compositions to machined blocks of PBX-9501. The armature is surrounded by a helical coil of heavy wire, typically copper, which forms the FCG stator. The stator winding is in some designs split into segments, with wires bifurcating at the boundaries of the segments, to optimize the electromagnetic inductance of the armature coil. It is typical that the explosive is initiated when the start current peaks. This is usually accomplished with an explosive lens plane wave generator which produces a uniform plane wave burn (or detonation) front in the explosive. Once initiated, the front propagates through the explosive in the armature, distorting it into a conical shape (typically 12 to 14 degrees of arc). Where the armature has

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ISSN (Online): 2278 – 8875

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expanded to the full diameter of the stator, it forms a short circuit between the ends of the stator coil, shorting and thus isolating the start current source and trapping the current within the device. The propagating short has the effect of compressing the magnetic field, whilst reducing the inductance of the stator winding. The result is that such generators will producing a ramping current pulse, which peaks before the final disintegration of the device [3].

The principal technical issues in adapting the FCG to weapons applications lie in packaging, the supply of start current, and matching the device to the intended load. Interfacing to a load is simplified by the coaxial geometry of coaxial and conical FCG designs. Significantly, this geometry is convenient for weapons applications, where FCGs may be stacked axially with devices such a microwave Vircators. The demands of a load such as a Vircator, in terms of wave form shape and timing, can be satisfied by inserting pulse shaping networks, transformers and explosive high current switches.

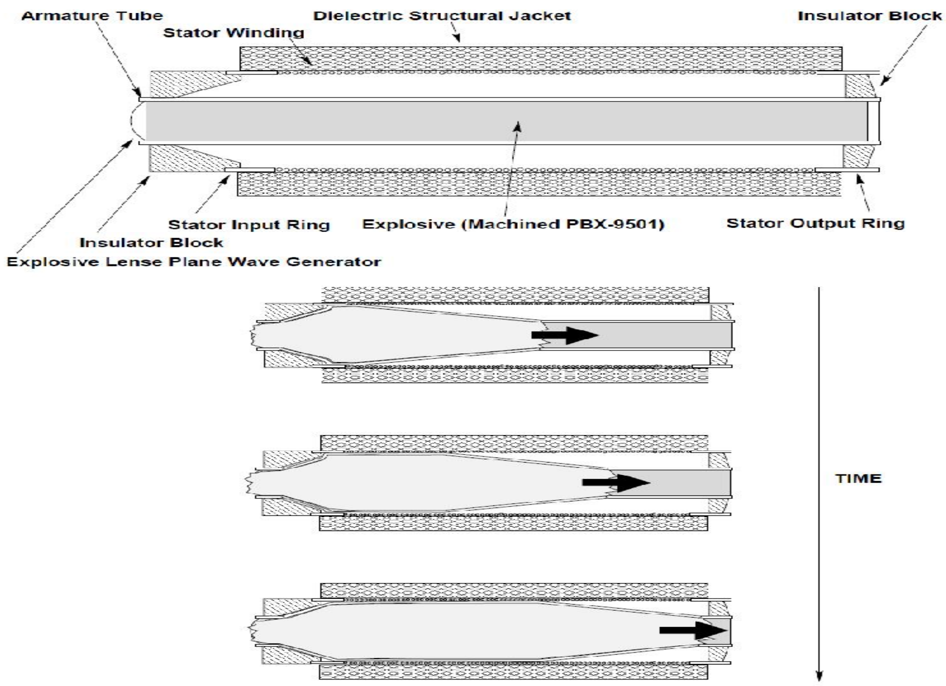

Fig. 2 Explosively pumped Flux Compression Generator.

In fig. 2, we see the working of explosively pumped flux compression generator. The explosive, initiated when the priming current has peaked, burnsthrough distorting and shorting the armature and the stator and bypassing the start current source. As the burn progresses the armature forms a conical shape and propagates along the length of the generator. The propagating short compresses the magnetic field and reduces the winding inductance, which causes the winding current to ramp up until the generator disintegrates.

(b) Explosive and Propellant Driven MHD Generators

The design of explosive and propellant driven Magneto-Hydrodynamic generators is a much less mature art that that of FCG design. Technical issues such as the size and weight of magnetic field generating devices required for the operation of MHD generators suggest that MHD devices will play a minor role in the near term. In the context of this paper, their potential lies in areas such as start current generation for FCG devices [4].

The fundamental principle behind the design of MHD devices is that a conductor moving through a magnetic field will produce an electrical current transverse to the direction of the field and the conductor motion. In an explosive or propellant driven MHD device, the conductor is a plasma of ionised explosive or propellant gas, which travels through the magnetic field. Current is collected by electrodes which are in contact with the plasma jet.

(c) High Power Microwave Sources – The Vircator

Whilst FCGs are potent technology base for the generation of large electrical power pulses, the output of the FCG is by its basic physics constrained to the frequency band below 1 MHz Many target sets will be difficult to attack even with

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very high power levels at such frequencies, moreover focusing the energy output from such a device will be problematic. A HPM device overcomes both of the problems, as its output power may be tightly focused and it has a much better ability to couple energy into many target types. A wide range of HPM devices exist. Relativistic Klystrons, Magnetrons, Slow Wave Devices, Reflex triodes, Spark Gap Devices and Vircators are all examples of the available technology base. From the perspective of a bomb or warhead designer, the device of choice will be at this time the Vircator, or in the nearer term a Spark Gap source. The Vircator is of interest because it is a one shot device capable of producing a very powerful single pulse of radiation, yet it is mechanically simple, small and robust, and can operate over a relatively broad band of microwave frequencies [5].

The physics of the Vircator tube are substantially more complex than those of the preceding devices. The fundamental idea behind the Vircator is that of accelerating a high current electron beam against a mesh (or foil) anode. Many electrons will pass through the anode, forming a bubble of space charge behind the anode. Under the proper conditions, this space charge region will oscillate at microwave frequencies. If the space charge region is placed into a resonant cavity which is appropriately tuned, very high peak powers may be achieved. Conventional microwave engineering techniques may then be used to extract microwave power from the resonant cavity. Because the frequency of oscillation is dependent upon the electron beam parameters, Vircators may be tuned or chirped in frequency, where the microwave cavity will support appropriate modes. Power levels achieved in Vircator experiments range from 170 kilowatts to 40 Gigawatts over frequencies spanning the decimetric and centimetric bands.

The two most commonly described configurations for the Vircator are the Axial Vircator (AV), and the Transverse Vircator (TV). The Axial Vircator is the simplest by design, and has generally produced the best power output in experiments. It is typically built into a cylindrical wave guide structure. Power is most often extracted by transitioning the wave guide into a conical horn structure, which functions as an antenna. AVs typically oscillate in Transverse Magnetic (TM) modes. The Transverse Vircator injects cathode current from the side of the cavity and will typically oscillate in a Transverse Electric (TE) mode. Technical issues in Vircator design are output pulse duration, which is typically of the order of a microsecond and is limited by anode melting, stability of oscillation frequency, often compromised by cavity mode hopping, conversion efficiency and total power output. Coupling power efficiently from the Vircator cavity in modes suitable for a chosen antenna type may also be an issue, given the high power levels involved and thus the potential for electrical breakdown in insulators.

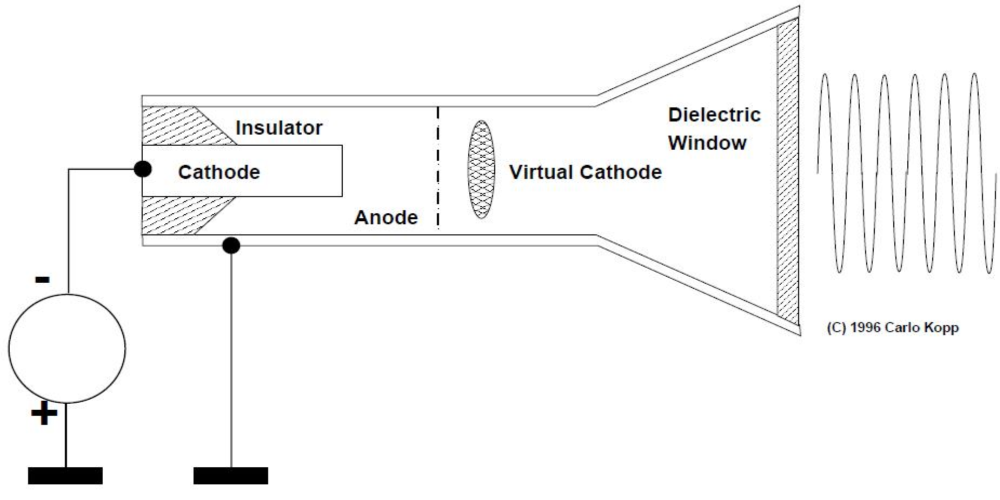

Fig. 3 Axial Virtual Cathode Oscillator

In fig. 3, we see the basic structure of a Vircator.The electrons which have passed the anode form a bubble of space charge, termed as a virtual cathode, behind the anode. The virtual cathode under the normal conditions is unstable, however if placed in a microwave cavity it tends to oscillate in the microwave band. Large peak power levels may be extracted from the oscillating virtual cathode, using established microwave engineering techniques. However, the anode will typically vaporise or melt after about a microsecond of operation.

III. LETHALITY OF ELECTROMAGNETIC WARHEADS

The issue of electromagnetic weapon lethality is complex. Unlike the technology base for weapon construction, which has been widely published in the open literature, lethality related issues have been published much less frequently. While the calculation of electromagnetic field strengths achievable at a given radius for a given device design is a straightforward task, determining a kill probability for a given class of target under such conditions is not.

This is for good reasons. The first is that target types are very diverse in their electromagnetic hardness, or ability to resist damage. Equipment which has been intentionally shielded and hardened against electromagnetic attack will withstand orders of magnitude greater field strengths than standard commercially rated equipment. Moreover, various manufacturer's implementations of like types of equipment may vary significantly in hardness due the idiosyncrasies of specific electrical designs, cabling schemes and chassis/shielding designs used.

The second major problem area in determining lethality is that of coupling efficiency, which is a measure of how much power is transferred from the field produced by the weapon into the target. Only power coupled into the target can cause useful damage.

(a) Coupling Modes
In assessing how power is coupled into targets, two principal coupling modes are recognised in the literature:

• Front Door Coupling occurs typically when power from an electromagnetic weapon is coupled into an antenna associated with radar or communications equipment. The antenna subsystem is designed to couple power in and out of the equipment, and thus provides an efficient path for the power flow from the electromagnetic weapon to enter the equipment and cause damage.

• Back Door Coupling occurs when the electromagnetic field from a weapon produces large transient currents (termed spikes, when produced by a low frequency weapon) or electrical standing waves (when produced by a HPM weapon) on fixed electrical wiring and cables interconnecting equipment, or providing connections to mains power or the telephone network. Equipment connected to exposed cables or wiring will experience either high voltage transient spikes or standing waves which can damage power supplies and communications interfaces if these are not hardened. Moreover, should the transient penetrate into the equipment, damage can be done to other devices inside [6].

(b) Maximizing Electromagnetic Bomb Lethality

To maximize the lethality of an electromagnetic bomb it is necessary to maximize the power coupled into the target set.

• The first step in maximizing bomb lethality is to maximize the peak power and duration of the radiation of the weapon. For a given bomb size, this is accomplished by using the most powerful flux compression generator (and Vircator in a HPM bomb) which will fit the weapon size, and by maximizing the efficiency of internal power transfers in the weapon. Energy which is not emitted is energy wasted at the expense of lethality.

• The second step is to maximize the coupling efficiency into the target set. A good strategy for dealing with a complex and diverse target set is to exploit every coupling opportunity available within the bandwidth of the weapon. A low frequency bomb built around an FCG will require a large antenna to provide good coupling of power from the weapon into the surrounding environment.

IV. TARGETING ELECTROMAGNETIC BOMBS

The task of identifying targets for attack with electromagnetic bombs can be complex. Certain categories of target will be very easy to identify and engage. Buildings housing government offices and thus computer equipment, production

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facilities, military bases and known radar sites and communications nodes are all targets which can be readily identified through conventional photographic, satellite, imaging radar, electronic reconnaissance and humint operations. These targets are typically geographically fixed and thus may be attacked providing that the aircraft can penetrate to weapon release range. With the accuracy inherent in GPS/inertially guided weapons, the electromagnetic bomb can be programmed to detonate at the optimal position to inflict a maximum of electrical damage. Mobile and camouflaged targets which radiate overtly can also be readily engaged. Mobile and relocatable air defence equipment, mobile communications nodes and naval vessels are all good examples of this category of target.

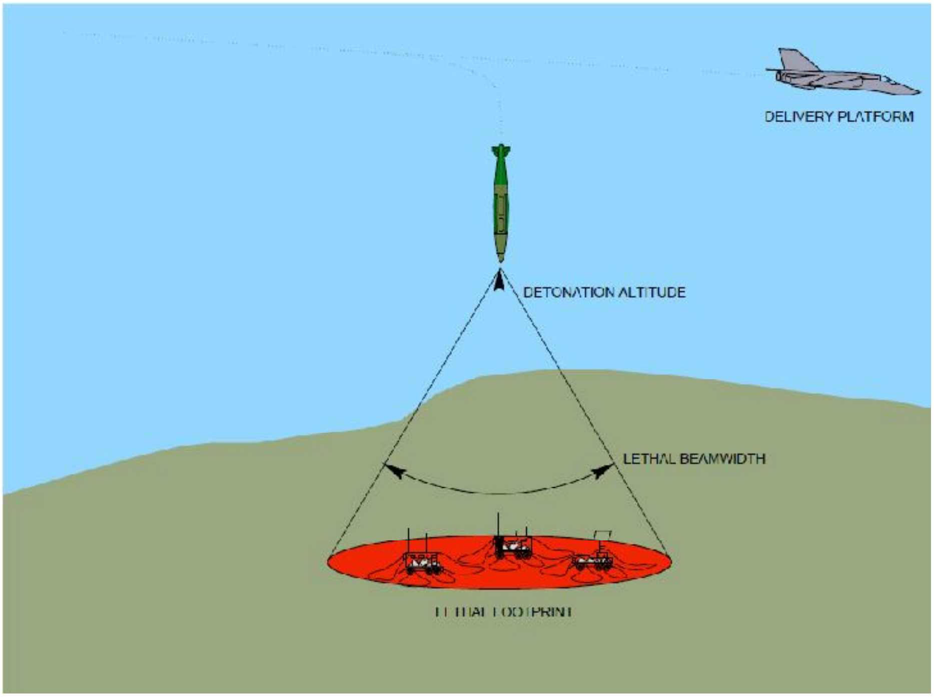

Fig. 4 Lethal footprint of a HPM E-Bomb in relation to altitude

In fig. 4, we can see the effective lethal footprint of an electromagnetic weapon in relation with the detonation altitude and the beamwidth. As seen, the lethal footprint increases with the detonation at higher altitude and higher beamwidth. However, the trade off in increasing footprint reduces the peak power delivered reducing its effectiveness.

V. DEFENCE AGAINST ELECTROMAGNETIC BOMBS

The most effective defence against electromagnetic bombs is to prevent their delivery by destroying the launch platform or delivery vehicle, as is the case with nuclear weapons. This however may not always be possible, and therefore systems which can be expected to suffer exposure to the electromagnetic weapons effects must be electromagnetically hardened [7].

The most effective method is to wholly contain the equipment in an electrically conductive enclosure, termed a Faraday cage, which prevents the electromagnetic field from gaining access to the protected equipment. However, most such equipment must communicate with and be fed with power from the outside world, and this can provide entry points via which electrical transients may enter the enclosure and effect damage. While optical fibers address this requirement for transferring data in and out, electrical power feeds remain an ongoing vulnerability. Where an electrically conductive channel must enter the enclosure, electromagnetic arresting devices must be fitted. A range of devices exist, however care must be taken in determining their parameters to ensure that they can deal with the rise time and strength of electrical transients produced by electromagnetic devices.

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VI. CONCLUSION

Electromagnetic bombs are Weapons of Electrical Mass Destruction with applications across a broad spectrum of targets, spanning both the strategic and tactical. As such their use offers a very high payoff in attacking the fundamental information processing and communication facilities of a target system. The massed application of these weapons will produce substantial paralysis in any target system, thus providing a decisive advantage in the conduct of Electronic Combat, Offensive Counter Air and Strategic Air Attack. Because E-bombs can cause hard electrical kills over larger areas than conventional explosive weapons of similar mass, they offer substantial economies in force size for a given level of inflicted damage, and are thus a potent force multiplier for appropriate target sets. The non-lethal nature of electromagnetic weapons makes their use far less politically damaging than that of conventional munitions, and therefore broadens the range of military options available. This paper has included a discussion of the technical, operational and targeting aspects of using such weapons, as no historical experience exists as yet upon which to build a doctrinal model. The immaturity of this weapons technology limits the scope of this discussion, and many potential areas of application have intentionally not been discussed. The ongoing technological evolution of this family of weapons will clarify the relationship between weapon size and lethality, thus producing further applications and areas for study.

E-bombs can be an affordable force multiplier for military forces which are under post. Cold War pressures to reduce force sizes, increasing both their combat potential and political utility in resolving disputes. Given the potentially high payoff deriving from the use of these devices, it is incumbent upon such military forces to appreciate both the offensive and defensive implications of this technology. It is also incumbent upon governments and private industry to consider the implications of the proliferation of this technology, and take measures to safeguard their vital assets from possible future attack. Those who choose not to may become losers in any future wars.

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