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# A DOCTRINE FOR THE USE OF ELECTROMAGNETIC PULSE BOMBS

**By**

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## About the Author

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# INTRODUCTION

ElectroMagnetic Pulse[1] weapons are a powerful tool, with applications in electronic combat, offensive counter-air, combat air support and strategic air attack. The current development of conventional ElectroMagnetic Pulse devices allows their use in non-nuclear confrontations. This paper proposes a doctrinal foundation for the use of such devices in warhead and bomb applications.

# THE ELECTROMAGNETIC PULSE EFFECT

The ElectroMagnetic Pulse (EMP) effect was first observed during the early testing of high altitude airburst nuclear weapons. The effect is characterised by the production of a very short but intense electromagnetic pulse, which propagates away from its source with ever diminishing intensity, governed by the theory of electromagnetism. The ElectroMagnetic Pulse is in effect an electromagnetic shock wave.

The pulse of energy produces a powerful electromagnetic field, particularly within the vicinity f the weapon burst. The field can be sufficiently strong to produce short lived transient voltages of thousands of Volts (ie kilovolts) on exposed electrical conductors, such as wires.

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. Subject to the electromagnetic hardness of the electronics, a measure of the equipment's resilience to this effect, and the intensity of the field produced by the weapon, the equipment can be irreversibly damaged or in effect electrically destroyed. 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.

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 excess of several hundred 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

[1] ElectroMagnetic Pulse or EMP device is a generic term applied to any device, nuclear or conventional, which is capable of generating a very intense but short electromagnetic field transient. For weapons applications, this transient must be sufficiently intense to produce electromagnetic power densities which are lethal to electronic and electrical equipment. EMP weapons are EMP devices specifically designed as weapons. This paper concentrates upon the application of High Power Microwave (HPM) bombs, a category of EMP devices which use conventional explosives and operate in the microwave frequency bands. The terms 'conventional EMP weapon' and 'High Power Microwave weapon' will be used interchangeably in this paper, reflecting current usage in US journals (see footnote 2). This paper will not address the use of nuclear EMP, or alternate uses of HPM technology. HPM technology has a broad range of potential applications in EW, radar and directed energy weapons.

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 high voltage transients into the equipment.

Computers used in data processing systems, communications systems, displays, industrial control applications, including road and rail signalling, and those embedded in military equipment, such as signal processors, electronic flight controls and digital engine control systems, are all potentially vulnerable to the EMP effect.

Other electronic devices and electrical equipment may also be destroyed by the EMP effect. 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 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 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. Aircraft with non-hardened electronic flight controls can be rendered unflyable by the EMP effect, and if airborne at the time or exposure will be lost as a result.

The lethality of any EMP weapon is determined by the electromagnetic power level generated, and the spectral characteristics of the pulse. The shorter the pulse, the greater its power for a given weapon energy and hence the greater the intensity of the electromagnetic field produced.[2] Shorter pulses also produce a broader frequency spectrum, which improves the coupling of energy into targets.

Conventional EMP devices, using HPM technology, are currently in development[3] and have far less coverage than nuclear devices, as the amount of electromagnetic energy they can store and release during the weapon's detonation is many orders of magnitude lower than that of a nuclear device. However, since these devices operate in the microwave bands, they an be far more effective against electronic equipment. From a practical perspective, a HPM bomb with a lethal radius of even 300 metres (~ 1000 ft) would be of significant military usefulness. Virtual Cathode Oscillator (Vircator) devices have been demonstrated with power output levels of up to 20 GW

[2] It is significant that a short pulse will produce a power spectral distribution with a higher energy content at higher frequencies, ie, a well designed EMP device will be broadband in effect. The theoretical basis for this stems from the spectral characteristics of exponentially decaying sinusoids, which are readily apparent from the Laplace transform of this family of time functions. See Ramo *et al*. This has implications for the weapon's lethality which will be discussed further.
[3] Fulghum, D.A., 'ALCMs Given Non Lethal Role', *AW&ST*, Feb 22, 1993. This recent report indicates that the US has progressed significantly with its development work on EMP technology. An EMP warhead is being fitted to the USAF AGM-86 Air Launched Cruise Missile airframe, involving both structural and guidance system modifications.

at microwave frequencies, and such power levels are clearly of the order of magnitude which is useful for such applications.[4]

Quantifying the lethality of an EMP warhead is therefore not unlike quantifying the lethality of a conventional explosive device. Both weapons have a lethal footprint for some nominal level of target hardness, and the effect of overpressure produced by a conventional explosive device is analogous to the electromagnetic field strength produced by an EMP warhead. Both can inflict damage upon the target and both diminish with increasing distance from the point of detonation. Just as a conventional explosive device produces a shock wave of pressure in the atmosphere, an EMP warhead produces an electromagnetic shock wave, which will propagate through any material which will allow the passage of radio waves.

Explosive devices can be built to produce a directional effect, and this is readily achievable with a microwave EMP warhead; in both instances the destructive energy of the weapon can be focused in a specific direction. As with explosive devices of a given technology, the lethality of an EMP warhead is proportional to its size, as a larger weapon of a given technology can discharge more energy.

Another aspect of EMP weapon lethality is its detonation altitude, and by varying the detonation altitude, a tradeoff may be achieved between the size of the lethal footprint and the intensity of the electromagnetic field in that footprint. This provides the option of sacrificing weapon coverage to achieve kills against targets of greater electromagnetic hardness, for a given weapon size (Figure 1). This is not unlike the use of airburst explosive devices.

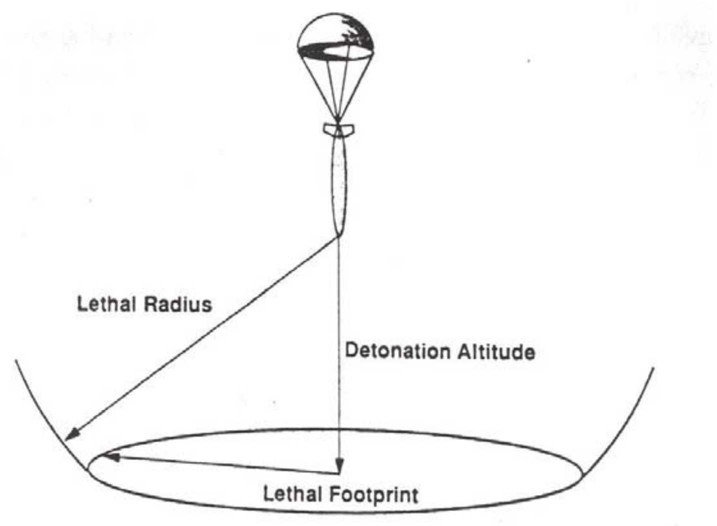


**Figure 1 - Lethal Footprint of an EMP Weapon in Relation to Altitude**

4 Staines G. W., *High Power Microwave Technology – Part 4,* Draft ERL Research Report. Vircator devices have been built and tested in the US, with one device demonstrating a 0.5 GW power output and another experiment producing as much as 20GW of power, both in the microwave band. Microwave devices offer great potential in such applications as the energy discharge may be focused and thus the power on target significantly improved, in comparison with omni-directional devices operating at lower frequencies. The frequency characteristics of microwave devices are also well suited to attacking targets such as receivers, radars and computer equipment.

An important factor in assessing the lethal coverage of an EMP weapon is atmospheric propagation. While the relationship between electromagnetic field strength and distance from the weapon is one of an inverse square law in free space, the decay in lethal effect with increasing distance within the atmosphere will be greater due to quantum physical absorption effects.[5] This is particularly so at higher frequencies, and significant absorption peaks due to water vapour and oxygen exist at frequencies above 20 GHz. These will therefore contain the weapon's effect to shorter radii than are ideally achievable in the K and L frequency bands.

There are a number of techniques available for the production of very high power, short duration microwave pulses. The vircator device discussed previously is one such technique. Vircator devices use a high power microwave oscillator which is fed by an explosive pumped flux compression generator. The output power limitations of these devices are primarily determined by the capability of the flux generator and its explosive pumping mechanism. Whilst alternative techniques do exist, at this time the vircator is the most mature and its performance potential most readily apparent.

Microwave EMP devices suitable for bomb or warhead applications are characterised by the production of a short high power burst of microwave energy. (Figure 2 depicts an idealised output; in practical devices resonances in the oscillator, antenna and its feed mechanism would alter this characteristic.)

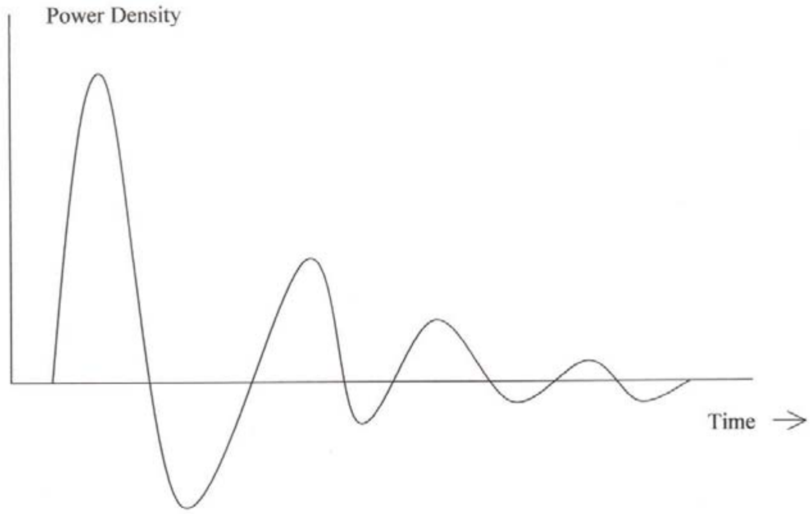


**Figure 2 - Generic Conventional EMP Transient Characteristic**

Because of the immaturity of conventional EMP weapon technology it is difficult at this time to more precisely quantify the relationship between lethality and weapon size. It is reasonable to assume that with ongoing development it will improve, until fundamental physical and engineering constraints are reached. These will be determined by the characteristics of the oscillator device used and its power source. Whilst much engineering work remains to perfect deployable weapons devices suitable for bombs and warheads, results such as those achieved with vircator devices are clearly very promising.

[5] See *International Countermeasures Handbook*, 14th Edition, p 104.

## THE DELIVERY OF CONVENTIONAL EMP DEVICES

As with explosive warheads, EMP warheads will occupy a volume of physical space and will also have some given mass (weight), determined by the density of the internal hardware. Like explosive warheads, EMP warheads may be fitted to a range of delivery vehicles.

Known existing applications[6] involve fitting an EMP warhead to a cruise missile airframe. The choice of a cruise missile airframe will restrict the weight of the weapon to about 340 kg (750 lb), although some sacrifice in airframe fuel capacity could see this size increased. A limitation in all such applications is the need to carry an electrical energy storage device, eg. a battery, to provide the energy used to pump up the EMP device prior to its discharge. Therefore the available payload capacity will be split between the electrical storage and the weapon itself.

Since basic electromagnetic theory dictates that the EMP device will experience some ongoing energy loss prior to its discharge, any onboard energy source will therefore have to have the capacity to pump up the EMP warhead, and then maintain its energy charge until it is detonated. This will place some limits on the ratio of usable EMP warhead size and airframe borne-electrical energy storage. This limitation will be a generic constraint upon the size of an EMP warhead fitted to any air delivered weapon, in that the electrical energy needs of the device must be wholly supplied by onboard storage.

An EMP bomb delivered by a conventional aircraft can offer a much better ratio of EMP device mass to total weapon mass, as most of the bomb mass can be dedicated to the EMP device installation itself. It follows, therefore, that for a given technology, an EMP bomb of identical mass to an EMP warhead equipped missile can have a much greater lethality, assuming equal accuracy of delivery and technologically similar EMP device design.

A missile borne EMP installation will comprise the EMP device, an electrical energy converter, and an onboard storage device such as a battery. As the weapon is pumped, the battery is drained. The EMP device will be detonated by the missile's onboard fusing system. In a cruise missile, this will be tied to the navigation system; in an anti-shipping missile, to the radar seeker; and in an air-to-air missile, to the proximity fusing system. The warhead fraction (ie. the ratio of total payload [warhead] mass to launch mass of the weapon) will be between 15% and 30%.[7]

An EMP bomb warhead will comprise an EMP device, an electrical energy converter and an energy storage device to pump and sustain the EMP device charge after separation from the delivery platform. Fusing would be most effectively provided by a radar altimeter fuse to airburst the weapon, although a barometric fuse is an option.

[6] Fulghum, 'ALCMs Given Non Lethal Role'. The description in this report suggests the use of an explosive pumped flux generator feeding a device such as a vircator. References to magnetic coils almost certainly relate to the flux generator hardware.

[7] This may be readily determined by calculating the ratio of warhead mass to total weapon launch mass, for representative missile types. Taking the AGM-78 Standard as a lower limit yields 15.9%, whereas taking the AGM/BGM-109 Tomahawk as an upper limit yields about 28%. Figures are derived from manufacturers' brochures and reference publications, eg. Jane's Air-Launched Weapons.

The warhead fraction could be as high as 85%, with most of the usable mass occupied by the EMP device and its supporting hardware.

Due to the potentially large lethal radius of an EMP device compared to an explosive device of similar mass, all EMP devices necessitate standoff delivery. Whilst this is an inherent characteristic of weapons such as cruise missiles, potential applications of these devices to glidebombs, anti-shipping missiles and air-to-air missiles would dictate fire and forget guidance of the appropriate variety, to allow the launching aircraft to gain adequate separation of several miles before warhead detonation.

The delivery of free-fall EMP bombs will require lofting, as with tactical nuclear devices, to enable the launch aircraft to escape the lethal radius of the weapon. A feasible installation would include a retarding drogue parachute or ballute, deployed by the radar altimeter fusing system once the weapon is above target, to provide additional time for escape. Launch aircraft nav-attack delivery algorithms would therefore require suitable crosswind and air density compensation.[8]

A conventional lofting delivery would involve a low altitude run in to the IP (initial point), followed by a pull-up, weapon release, and an Immelmann or similar manoeuvre, a dive to low altitude and egress from the target area. It is desirable that the launch aircraft be below the horizon at the time of weapon detonation, to ensure that it is not within the line of sight of the detonation.

A major advantage of using EMP bombs is that they may be delivered by any tactical aircraft with a nav-attack system capable of accurate lofting delivery; no specialised equipment would be required other than a suitable arming system.

Because of the simplicity of EMP bombs in comparison to weapons such as Anti Radiation Missiles (ARM), it is not unreasonable to expect that they should be cheaper to manufacture and easier to support in the field, thus allowing for more substantial weapon stocks.

## DEFENCE AGAINST EMP WEAPONS

The most effective defence against EMP weapons 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

[8] An unguided weapon will experience a delivery error which will increase with lofting distance. This error is comprised of uncertainties in the aircraft's position relative to the target at the time of release, typically for modern equipment in the order of metres, timing errors in weapon release, and a cumulative error due to atmospheric effects during the flight of the weapon to its target. The latter error results from the inhomogeneous nature of the atmosphere, and the effects of crosswind. Since air density varies both locally due to immediate temperature gradients, and globally with altitude, this will result in a range error due to variations in drag force experienced during flight to target. The presence of an arbitrary crosswind will add an additional error, its magnitude and direction determined by the magnitude and direction of the crosswind experienced. As the crosswind may also vary with altitude, this error may be difficult to accurately model. The significance of these factors lies in the need to compensate their effects in the delivery algorithm of the nav-attack system, so as to minimise the aggregate error in weapon delivery.

be expected to suffer exposure to the EMP effect must be electromagnetically hardened.

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 fibres 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, EMP 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 EMP devices. Current reports from the US[9] indicate that hardening measures attuned to the behaviour of nuclear EMP devices do not perform well when dealing with some conventional microwave EMP device designs.

It is significant that hardening of systems must be carried out at a system level, as EMP damage to any single element of a complex system could inhibit the function of the whole system. Hardening new build equipment and systems will add a substantial cost burden. Older equipment and systems may be impossible to harden properly and may require complete replacement.

An interesting aspect of electrical damage to targets is the possibility of wounding semiconductor devices thereby causing equipment to suffer repetitive intermittent faults rather than complete failures. Such faults would tie down considerable maintenance resources while also diminishing the confidence of operators in the equipment's reliability. Intermittent faults may not be possible to repair economically, thereby causing equipment in this state to be removed from service permanently, with considerable loss in maintenance hours during damage diagnosis. This factor must also be considered when assessing the hardness of equipment against EMP attack, as partial or incomplete hardening may in this fashion cause more difficulties than it would solve.

## LIMITATIONS OF EMP WEAPONS

The limitations of EMP weapons are determined by weapon implementation and means of delivery. Weapon implementation will determine the electromagnetic field strength achievable at a given radius, and its spectral distribution.

[9] Staines, *High Power Microwave Technology – Part 4,* Fulghum, 'ALCMs Given Non Lethal Role'. This is entirely consistent with theoretical expectations, as the different spectral characteristics of microwave EMP warheads, compared to nuclear EMP weapons, will significantly affect the effectiveness of protective filters. What is important from an electrical engineering viewpoint is that a filter designed to stop signals in the lower frequency bands may perform very poorly at microwave frequencies.

The field strength and its spectral characteristics will determine the amount of damage which may be inflicted upon a given target type. A weapon which has been optimised to discharge moderate energy at microwave frequencies, over short discharge periods (ie. nanoseconds) will be most lethal against electronic equipment such as unhardened computers and receives, which are vulnerable to low energy pulses, providing that a sufficiently high instantaneous voltage is produced. More robust electrical equipment will not be damaged, as the delivered energy is too low to introduce thermal damage.

A lower frequency EMP weapon delivering a large amount of energy (eg. a nuclear EMP device), over a longer discharge period may damage electrical equipment due to breakdown and thermal effects, but its ability to damage equipment such as receivers will depend critically upon its spectral characteristics; significantly, the longer the discharge period, the less the power content at higher frequencies, which is required to kill communications equipment.[10]

Of particular importance is the manner in which the energy is coupled into the target. Two principal coupling modes are recognised,[11] front door coupling and back door coupling. Front door coupling is applicable to radar and communications equipment, where the microwave EMP is collected by the antenna of the targeted device and then enters the receiver, which it then damages. Back door coupling is typically applicable to computer equipment where resonance effects on conductors or cables running into the equipment capture the energy of the pulse and conduct it into the equipment, where sensitive components may be damaged. The spectral characteristics of the discharge are of major importance, and broadband microwave devices are most effective in this respect, due to their ability to exploit any possible resonant effect which may lie within their bandwidth.

In the context of targeting military equipment, it must be noted that thermionic technology (ie. vacuum tube equipment) is substantially more resilient to the EMP effect than solid state (ie. transistor) technology. Therefore a weapon optimised to destroy solid state computers and receivers may cause little or no damage to a thermionic technology device, for instance early 1960s Soviet avionic equipment. Therefore a hard electrical kill may not be achieved against such targets unless a suitable weapon is used.

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[10] Further discussion in this area exceeds the scope of this paper. It must be noted in this context that the complexity of the mechanisms by which HPM pulses are coupled into target equipment precludes simple modelling and an empirical approach will yield more meaningful results. This requires a suitable test range, an EMP generator with variable performance parameters, and sample targets. Targets would then be exposed to EMP effects with known parameters, and the damage assessed. A suitable statistical treatment would then yield relationships between EMP effect parameters and target damage, for given target sets. This information can in turn be used to optimise weapon designs for their nominal applications. This methodology is also applicable to assessing the effectiveness of hardening measures, and therefore also the EMP parameters required to kill targets with given hardening measures installed. It must be noted that research into the hardness of potential targets such as computers lags, at this time, well behind development achieved so far in the design of microwave EMP sources. Until more information is amassed on target set EMP hardness, the definition of specific weapon parameters such as power output and spectral characteristics, in relation to weapon lethal radius, can only be speculative. It is however primarily an engineering problem, and demonstrated technology clearly proves the potential of this family of weapons.

[11] Staines, *High Power Microwave Technology – Part 4*, pp 3.2, 3.3 provides a good introduction into coupling mechanisms.

Atmospheric propagation limits will further constrain the lethal radius of the weapon, and these must be reconciled with the factors discussed previously, in determining the limitations to the weapon’s lethality.

Means of delivery will limit the lethality of an EMP device by introducing limits to the weapon’s size and the accuracy of its delivery. Should the delivery error be of the order of the weapon’s lethal radius for a given detonation altitude, lethality will be significantly diminished. This is of particular importance when assessing the lethality of EMP bombs, as delivery errors will be more substantial than those experienced with guided weapons.

Therefore accuracy of delivery and achievable lethal radius must be considered against the allowable collateral damage for the chosen target. Where collateral electrical damage is a consideration, accuracy of delivery and lethal radius are key parameters. An inaccurately delivered weapon of large lethal radius may be unusable against a target should the likely collateral electrical damage by beyond acceptable limits.

## A DOCTRINE FOR THE APPLICATION OF CONVENTIONAL EMP WEAPONS

Complex organisational systems such as governments, industries and military forces cannot function without the flow of information through their structures. Information flows within these structures in several directions, under typical conditions of function. A trivial model for this function would see commands and directives flowing outward from a central decision making element, with information about the state of the system flowing in the opposite direction. Real systems are substantially less complex.

This is of military significance because stopping this flow of information will severely debilitate the function of any such system. Stopping the outward flow of information produces paralysis, as commands cannot reach the elements which are to execute them. Stopping the inward flow of information isolates the decision making element from reality, and thus severely inhibits its capacity to make rational decisions which are sensitive to the currency of information at hand.

The recent evolution of air warfare indicates a growing trend toward targeting strategies which exploit this most fundamental vulnerability of any large and organised system.[12] The Desert Storm air war of 1991 is a good instance, with a substantial effort expended against such targets. Indeed, the model used for modern strategic air attack places leadership and its supporting communications in the position of highest targeting priority. No less importantly, modern Electronic Combat concentrates upon the disruption and destruction of communications and information gathering sensors used to support military operations. Again the Desert Storm air war provides a good illustration of the application of this method.

[12] Gary Waters, *Gulf Lesson One*. Chapter 16 provides a good discussion of both the rationale and implementation of this strategy.

An air warfare strategy which stresses attack upon the information processing and communications elements of the systems which it is targeting offers a very high payoff, as it will introduce an increasing level of paralysis and disorientation within its target. EMP weapons are a powerful tool in the implementation of such a strategy.

## ELECTRONIC COMBAT USING EMP WEAPONS

The central objective of Electronic Combat (EC) operations is the command of the electromagnetic spectrum, achieved by soft and hard kill means[13] against the opponent's electronic assets. The underlying objective of commanding the electromagnetic spectrum is to interrupt or substantially reduce the flow of information through the opponent's air defence system, air operations environment and between functional elements of weapon systems.

In this context the ability of EMP weapons to achieve kills against a wide range of target types allows their general application to the task of inflicting attrition upon an opponent's electronic assets, be they specialised air defence assets or more general C3 and air assets.

EMP devices can be a means of both soft and hard electrical kill, subject to the lethality of the weapon and the hardness of its target. A hard electrical kill by means of an EMP device will be achieved in those instances where such severe electrical damage is achieved against a target so as to require the replacement of most if not all of its internal electronics.

Electronic combat operations using EMP devices involve the use of these to attack radar, C3 and air defence weapon systems. These should always be attacked initially with an EMP weapon to achieve soft or hard electrical kills, followed up by an attack with conventional munitions to preclude possible repair of disabled assets at a later time. As with conventional SEAD operations, the greatest payoff will be achieved by using EMP weapons against systems of strategic importance first, followed in turn by those of operational and tactical importance.

In comparison with an AntiRadiation Missile (ARM), the established and specialised tool in the conduct of SEAD operations, an EMP weapon can achieve kills against multiple targets of diverse types within its lethal footprint. In this respect an EMP device may be described as a weapon of mass electrical destruction. Therefore EMP weapons are a significant force multiplier in electronic combat operations.

A conventional electronic combat campaign, or intensive electronic combat operations, will initially concentrate on saturating the opponent's electronic defences, denying information and inflicting maximum attrition upon electronic assets. The force multiplication offered by EMP weapons vastly reduces the number of air assets required to inflict substantial attrition, and where proper electronic reconnaissance has

[13] Soft kill means will inhibit or degrade the function of a target system during their application, leaving the target system electrically and physically intact upon the cessation of their application. Hard kill means will damage or destroy the target system, and are thus a means of inflicting attrition.

been carried out beforehand, also reduces the need for specialised assets such as ARM firing aircraft equipped with costly emitter locating systems.

The massed application of EMP weapons in the opening phase of an electronic battle will allow much faster attainment of command of the electromagnetic spectrum, as it will inflict attrition upon electronic assets at a much faster rate than is possible with conventional means.

Whilst the immaturity of conventional EMP weapons precludes an exact analysis of the scale of force multiplication achievable, it is evident that a single aircraft carrying an EMP bomb capable of concurrently disabling a SAM site with its collocated acquisition radar and supporting radar directed AAA weapons, will have the potency of the several ARM firing and support jamming aircraft required to accomplish the same result by conventional means. This and the ability of multirole aircraft to perform this task allows for a much greater concentration of force in the opening phase of the battle, for a given force size.

In summary the massed application of EMP weapons to Electronic Combat operations will provide for a much faster rate of attrition against hostile electronic assets, achievable with a significantly reduced number of specialised and multirole air assets. This will allow even a modestly sized force to apply overwhelming pressure in the initial phase of an electronic air battle, and therefore achieve command of the electromagnetic spectrum in a significantly shorter time than by conventional means.

## STRATEGIC AIR ATTACK USING EMP WEAPONS

Modern strategic air attack theory is based upon Warden’s Five Rings model, which identifies five centres of gravity in a nation’s warfighting capability. In descending order of importance, these are the nation’s leadership and supporting C3 system its vital industries, its transportation network, its population and its fielded military forces.

EMP weapons may be productively used against all elements in this model, and provide a particularly high payoff when applied against a highly industrialised and geographically concentrated opponent. Of particular importance in the context of strategic air attack is that while EMP weapons are lethal to electronics, they have little if any effect on humans. This is a characteristic which is not shared with established conventional and nuclear weapons.

This selectivity in lethal effect makes EMP weapons far more readily applicable to a strategic air attack campaign, and reduces the internal political pressure which is experienced by the leadership of any democracy which must commit to warfare. An opponent may be rendered militarily, politically and economically ineffective with little if any loss in human life.

The innermost ring in the Warden model (see Figure 3) is essentially comprised of government bureaucracies and civilian and military C3 systems. In any modern nation these are heavily dependent upon the use of computer and communications equipments. What is of key importance at this time is an ongoing change in the structure of computing facilities used in such applications, as these are becoming increasingly decentralised. A modern office environment relies upon a large number of small computers, networked to interchange information, in which respect it differs from the traditional model of using a small number of powerful central machines.

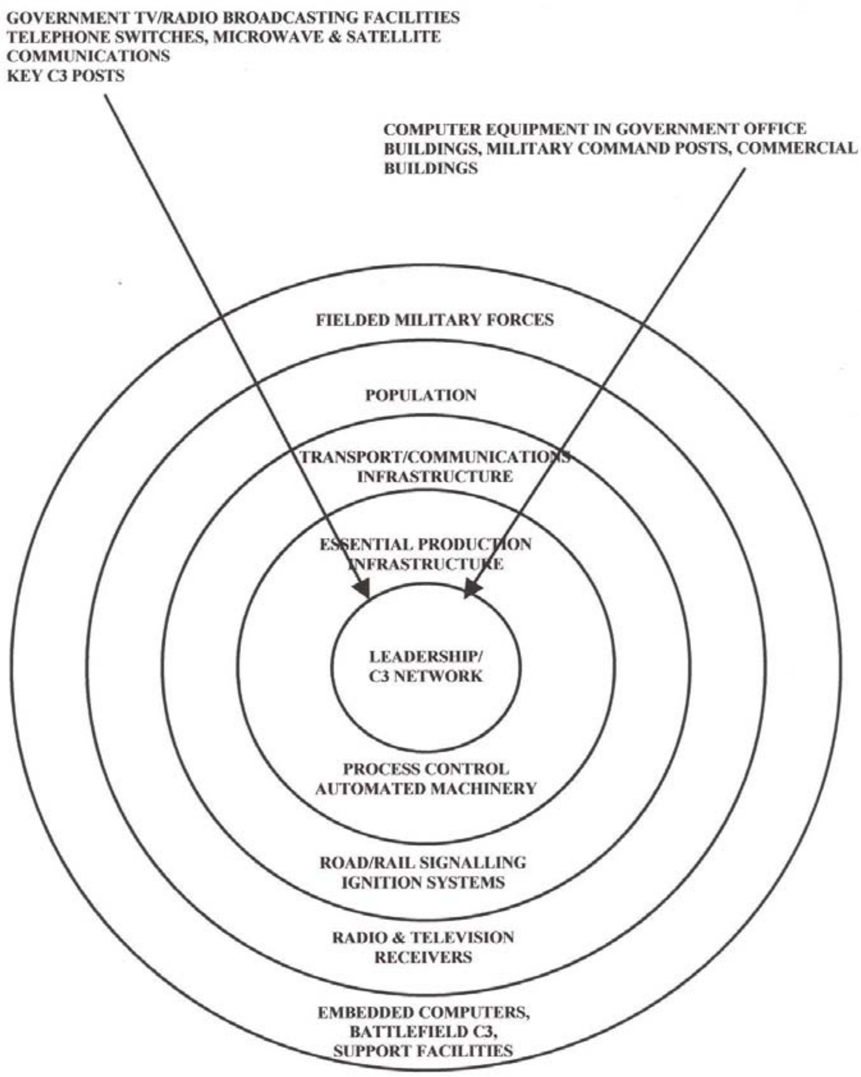


**Figure 3 - Warden's "Five Rings" Strategic Air Attack Model in the Context of EMP Vulnerable Targets**

This decentralisation and networking of information technology systems produces a major vulnerability to EMP attack. Whereas a small number of larger computers could be defended against EMP attack by the use of EMP hardened computer rooms, a large distributed network cannot. Moreover, unless optical fibre networking is used, the networking cables are themselves a medium via which EMP effects can be efficiently propagated throughout the network, to destroy machines. Whilst the use of distributed computer networks reduces vulnerability to attack by conventional munitions, it increases vulnerability to attack by EMP weapons.

Selective targeting of government buildings with EMP weapons will result in a substantial reduction in a government's ability to handle and process information. The damage inflicted upon information records may be permanent, should inappropriate backup strategies have been used to protect stored data. It is reasonable to expect most data stored on machines which are affected will perish with the host machine, or become extremely difficult to recover from damaged storage devices.

The cost of hardening existing computer networks is prohibitive, as is the cost of replacement with hardened equipment. Whilst the use of hardened equipment for critical tasks would provide some measure of resilience, the required discipline in the handling of information required to implement such a scheme renders its utility outside of military organisations questionable. Therefore the use of EMP weapons against government facilities offers an exceptionally high payoff.

Other targets which fall into the innermost ring may also be profitably attacked. Television and radio broadcasting stations, one of the most powerful tools of any government, are also vulnerable to EMP attack due to the very high concentration of electronic equipment in such sites. Telephone exchanges, particularly later generation digital switching systems, are also highly vulnerable to appropriate EMP attack.

In summary the use of EMP weapons against leadership and C3 targets is highly profitable, in that a modest number of weapons appropriately sued can introduce the sought state of strategic paralysis, without the substantial costs incurred by the use of conventional munitions to achieve the same effect.

Vital industries are also vulnerable to EMP attack. Manufacturing, chemical, petroleum product industries and metallurgical industries rely heavily upon automation which is almost universally implemented with electronic PLC (Programmable Logic Controller) systems or digital computers. Furthermore, most sensors and telemetry devices used are electrical or electronic.

Attacking such industrial targets with EMP weapons will halt production for the time required to either repair the destroyed equipment, or to reconfigure for manual operation. Some production processes however require automated operation, either because hazardous conditions prevent human intervention, or the complexity of the control process required cannot be carried out by a human operator in real time. A good example is larger chemical, petrochemical and oil/gas production facilities. Destroying automated control facilities will therefore result in substantial loss of production, causing shortages of these vital materials.

Manufacturing industries which rely heavily upon robotic and semiautomatic machinery, such as the electronics, computer and electrical industry, precision machine industry and aerospace industries, are all key assets in supporting a military capability. They are all highly vulnerable to EMP attack. Whilst material processing industries may in some instances be capable of function with manual process control, the manufacturing industries are almost wholly dependent upon their automated machines to achieve any useful production output.

Historical experience[14] suggests that manufacturing industries are highly resilient to air attack as production machinery is inherently mechanically robust and thus a very high blast overpressure is required to destroy it. The proliferation of electronic and computer controlled machinery hash produced a major vulnerability, for which historical precedent does not exist. Therefore it will be necessary to re-evaluate this orthodoxy in targeting strategy.

In summary there is a large payoff in striking at vital industries with EMP weapons, particularly in the opening phase of a strategic air attack campaign, as production may be halted or reduced with modest expenditure. This would then allow for more efficient scheduling of strikes with conventional munitions, as multirole assets are freed from the campaign for the control of the air.

Transport infrastructure is the third ring in the Warden model, and also offers some useful opportunities for the application of EMP weapons. Unlike the innermost rings, the concentration of electronic and computer equipment is typically much lower, and therefore considerable care must be taken in the selection of targets.

Railway and road signalling systems, where automated, are most vulnerable to EMP attack on their control centres. This could be sued to produce traffic congestion by preventing the proper scheduling of rail traffic, and disabling road traffic signalling, although the latter may not yield particularly useful results.

Significantly, the most modern automobiles and trucks use electronic ignition systems which are known to be vulnerable to the EMP effect, although opportunities to find such concentrations so as to allow the profitable use of an EMP weapon may be scarce.

The population of the target nation is the fourth ring in the Warden model, and its morale is the object of attack. The morale of the population will be affected significantly by the quality and quantity of the government propaganda it is subjected to, as will it be affected by living conditions.

Using EMP weapons against urban areas provides the opportunity to prevent government propaganda from reaching the population via means f mass media, through the damaging or destruction of all television and radio receivers within the footprint of the weapon. Whether this is necessary, given that broadcast facilities may have already been destroyed, is open to discussion. Arguably it may be counterproductive, as it will prevent the target population from being subjected to friendly means of psychological warfare such as propaganda broadcasts.

The use of EMP weapons against a target population is therefore an area which requires further study, and this paper will not present any specific proposals in this area.

[14] The classical argument here is centred upon Allied experience in bombing Germany during WW2, where even repeated raids on industrial targets were unable to wholly stop production, and in many instances only served to reduce the rate of increase in production. What must not be overlooked is that both the accuracy and lethality of weapons in this period bore little comparison to what is available today, and automation of production facilities was almost non-existent.

The outermost and last ring in the Warden model are the fielded military forces. These are by all means a target vulnerable to EMP attack, and C3 nodes, fixed support bases as well as deployed forces should be attacked with EMP devices. Fixed support bases which carry out depot level maintenance on military equipment offer a substantial payoff, as the concentration of computers in both automatic test equipment and administrative and logistic support functions offers a good return per extended weapon.

Any site where more complex military equipment is concentrated should be attacked with EMP weapons to render the equipment unserviceable and hence reduce the fighting capability, and where possible also the mobility of the targeted force. As discussed earlier in the context of Electronic Combat, the ability of an EMP weapon to achieve hard electrical kills against any non-hardened targets within its lethal footprint suggests that some target sites may only require EMP attack to render them both undefended and non-operational. Whether to expend conventional munitions on targets in this state would depend on the immediate military situation.

In summary the use of EMP weapons in a strategic air attack campaign offers a potentially high payoff, particularly when applied to leadership, $C^3$ and vital industrial targets, all of which may be deprived of much of their function for substantial periods of time. The massed application of EMP weapons in the opening phase of the campaign would introduce paralysis within the government, deprived of much of its information processing infrastructure, as well as paralysis in most vital industries. This would greatly reduce the capability of the target nation to conduct military operations of any substantial intensity.

Because conventional EMP weapons produce negligible collateral damage, in comparison with conventional explosive munitions, they allow the conduct of an effective and high tempo campaign without the loss of life which is typical of conventional campaigns. This will make the option of an air bombardment campaign more attractive to a Western democracy, where mass media coverage of the results of conventional strategic strike operations will adversely affect domestic civilian morale.

The long term effects of a sustained and concentrated air bombardment campaign using a combination of conventional and EMP weapons will be important. The cost of computer and communications infrastructure is substantial, and its massed destruction would be a major economic burden for any industrialised nation. In addition it is likely that poor protection of stored data will add to further economic losses, as much data will be lost with the destroyed machines.

## OFFENSIVE COUNTER OPERATIONS USING EMP WEAPONS

EMP weapons may be usefully applied to OCA operations. Modern aircraft are densely packed with electronics, and unless properly hardened, are highly vulnerable targets for EMP weapons.

The cost of the onboard electronics represents a substantial fraction of the total cost of a modern military aircraft, and therefore stock levels of spares will in most instances be limited to what is deemed necessary to cover operational usage at some nominal sortie rate. Therefore EMP damage could render aircraft unusable for substantial periods of time.

Attacking airfields with EMP weapons will disable communications, air traffic control facilities, navigational aids and operational support equipment if these items are not suitably EMP hardened. Conventional blast hardening measures may not be effective, as electrical power and fixed communications cabling will carry EMP induced transients into most buildings. Hardened aircraft shelters may provide some measure of protection due to electrically conductive reinforcement embedded in the concrete, but conventional revetments will not.

Therefore OCA operations against airfields and aircraft on the ground should include the use of EMP weapons as they offer the potential to substantially reduce hostile sortie rates.

## MARITIME COMBAT AIR SUPPORT USING EMP WEAPONS

As with modern military aircraft, naval surface combatants are fitted with a substantial volume of electronic equipment, performing similar functions in detecting and engaging targets and warning of attack. As such they are vulnerable to EMP attack, if not suitably hardened. Should they be hardened, volumetric, weight and cost penalties will be incurred.

Conventional methods for attacking surface combatants involve the use of saturation attacks by anti-ship missiles or coordinated attacks using a combination of ARMs and anti-ship missiles. The latter instance is where disabling the target electronically by stripping its antennae precedes lethal attack with specialised anti-ship weapons.

An EMP warhead detonated within lethal radius of a surface combatant will render its air defence system inoperable, as well as damaging other electronic equipment such as electronic countermeasures, electronic support measures and communications. This leaves the vessel undefended until these systems can be restored, which may or may not be possible on the high seas. Therefore lofting an EMP bomb on to a surface combatant, and then reducing it with laser or television guided weapons is an alternative strategy for dealing with such targets.

## COMBAT AIR SUPPORT OF LAND FORCES USING EMP WEAPONS

Modern land warfare doctrine emphasises mobility, and manoeuvre warfare methods are typical for contemporary land warfare. Coordination and control are essential to the successful conduct of manoeuvre operations, and this provides another opportunity to apply EMP weapons. Communications and command sites are key elements in the structure of such a land army, and these concentrate communications and computer equipment. Therefore they should be attacked with EMP weapons, to disrupt the command and control of land operations.

Should concentrations of armoured vehicles be found, these are also profitable targets for EMP attack, as their communications and fire control systems may be substantially damaged or disabled as a result. A useful tactic would be initial attack with EMP weapons to create a maximum of confusion, followed by attack with conventional weapons to take advantage of the immediate situation.

## A STRATEGY OF GRADUATED RESPONSE

The introduction of non-nuclear EMP weapons into the arsenal of a modern air force considerably broadens the options for conducting strategic air warfare. Clearly such weapons are potent force multipliers in conducting a conventional air war, particularly when applied to Electronic Combat, OCA and strategic air attack.

The massed use of such weapons would provide a decisive advantage to any air force with the capability to effectively target and deliver them. The qualitative advantage in air capability so gained would provide a significant advantage even against a much stronger opponent not in the possession of this capability.

EMP weapons however open up less conventional alternatives for the conduct of an air war, which derive from their ability to inflict significant material damage without inflicting visible collateral damage and loss of life. Western governments have been traditionally reluctant to commit to strategic air war, as the expectation of a lengthy and costly battle, with mass media coverage of its highly visible results will quickly produce domestic political pressure to cease the conflict.

An alternative is a Strategy of Graduated Response. In this strategy, an opponent who threatens escalation to a full scale war is pre-emptively attacked with EMP weapons, to gain command of the electromagnetic spectrum and command of the air. Selective attacks with EMP weapons may then be applied against chosen strategic targets, to force concession. Should these fail to produce results, more targets may be disabled by EMP attack. Escalation would be sustained and graduated, to produce steadily increasing pressure to concede the dispute. Air and sea blockade are complementary means via which pressure may be applied.

Because EMP weapons can cause damage on a large scale very quickly, the rate at which damage can be inflicted can be very rapid, in which respect such a campaign will differ from the conventional, where the rate at which damage is inflicted is limited by the usable sortie rate of strategic air attack capable assets.[15]

Should blockade and the total disabling of vital industries fail to yield results, these may then be systematically reduced by conventional weapons, to further escalate the

[15] This constraint primarily results from limitations in numbers. Strategic air attack requires precision delivery of substantial payloads, and is thus most effectively performed with specialised assets, such as the F-11, F-15E, F-117A, Tornado or Su-24. These are typically more maintenance intensive than less complex multirole fighters, and this will become a constraint to the sortie rate achievable with a finite number of aircraft, assuming the availability of aircrew. Whilst multirole fighters may be applied to strategic air attack, their typically lesser payload radius performance and lesser accuracy, in the absence of laser designation equipment, will reduce their effectiveness.

pressure. Finally, a full scale conventional strategic air attack campaign would follow, to wholly destroy the hostile nation's warfighting capability.

Another situation where EMP weapons may find application is in dealing with governments which actively implement a policy of state sponsored terrorism, or alternatively choose to conduct a sustained low intensity land campaign. Again the Strategy of Graduated Response, using EMP weapons in the initial phases, would place the government under pressure to concede.

As a punitive weapon EMP devices are attractive for dealing with belligerent governments. Substantial economic, military and political damage may be inflicted with a modest commitment of resources by their users, and without politically damaging loss of life.

## CONCLUSIONS

EMP devices are weapons of mass electrical destruction, with applications across a broad spectrum of targets, spanning 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, OCA and Strategic Air Attack.

Because EMP weapons can cause hard electrical kills over larger area 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 EMP weapons makes their use far less politically damaging than that of conventional munitions, and therefore broadens the range of military options available. This can substantially increase the utility of air power as a political tool.

The doctrine proposed in this paper has included a discussion of the technical, operational and targeting aspects of using such weapons, as no historical experience exists. The immaturity of this weapons technology limits the scope of this discussion, and may 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.

EMP weapons can be an affordable and potent force multiplier for smaller air forces, increasing both their combat potential and political unity in resolving disputes.