Two key areas for future survivability are Active Defence Systems (ADS) and resilience. ADS sensors fitted to vehicles detect and intercept incoming projectiles; a number of these systems are already in-theatre but it is expected that these platforms will reach maturation over the next decade. In addition, defence forces also expects resilience, whereby a vehicle is able to drive away from an IED attack rather than merely surviving it.

The LEDS (developed by SAAB) is an Active Protection System (APS) that utilises the layered application of sensors and countermeasures to deny threats the ability to effectively attack the platform that it is mounted on. This is achieved under dynamic operational conditions by utilising active signature management, Soft-kill or Hard-kill to prevent the execution of an effective engagement cycle against the protected platform.

Due to the extremely quick responses require, these systems needs to be automated. Typically these systems, in addition to active protection, also contribute to force level situational awareness through a battle management system interface and threat data manipulation.

Figure 52: SAAB's LEDS APS system, showing the LWRs, Active Sensors and munition launcher (left) and installed on a troop-carrier (right).

Sensors typically associated with APS systems are Laser Warning Sensors, Active Radar Sensors, IR Confirmation Sensors and cueing of radar sensors. The soft-kill options consists of multi-spectral smoke, whilst the hard-kill option comprises anti-projectile missies.

2.16 Education & Training as a Preventative Protection Measure

Army's in general have failed to properly assert and emphasize the importance of EW as a force multiplier. Some of the causes and effects of neglecting EW will be argued here, in terms of the lack of "boots on the ground", lack of emphasis on training and lack of resources.

More than ever before, the wars of the 21st century have proven to be reliant on the electromagnetic spectrum (EMS).

When soldiers are asked what, if anything, they know about EW, the recurring response by far is "It's that box in the back of the truck with the antenna." This is not all that EW does and can do. Training exercises typically emphasize the basics of manoeuvre. These tend never to include using multiple resources such as signals intelligence (SIGINT), close air support (CAS) or indirect fire. Leaving out these key force multipliers reinforces the tendency not to use them. EW has to be included in every operation - training or combat - to properly reinforce how to leverage the assets for victory over the enemy.

In order to properly train for EW missions, EW soldiers need to have equipment on which to train, and train against.

Although Electronic Warfare Officers (EWOs) must be highly trained specialists in the integration and implementation of EW concepts, not every soldier needs to an EW specialist, but every soldier should have a basic understanding of what EW can do for them. If officers do not learn about EW as part of their courses, they will never know that it can be used to gain a tactical advantage against the enemy. If soldiers are not introduced to EW, they will not know that it is even an option to employ. It has to be incorporated into all levels of training or else it will never be used to its full potential.

2.17 Conclusion

Despite the fact that most African countries spend a small amount of money on defence procurements, the region has experienced violent conflicts in recent years. This actually means that in several cases the supply of even relatively small volumes of arms to African countries may have had a major impact and that conflicts are of low intensity.

The next-generation battlefield, whether high- or low-intensity, may not appear less busy to the unaided eye, but the number of soldiers and airmen immediately involved and in danger will shrink significantly. Instead of troop-carrying helicopters, manned reconnaissance and close air support aircraft, the battlefield and the air over it will be thickly populated with a few heavily armoured manned vehicles, a lot of robotic ground vehicles, airborne stand-off weapons and both unmanned strike and reconnaissance aircraft.

The reasons for this shift in manpower and tactics is the increasingly lethal nature of a battlefield filled with remotely detonated explosive devices, advanced anti-tank missiles and sophisticated new anti-aircraft missiles with their advanced, electronically scanned, long-range radars.

The weapons used in such combat also will change as defence forces develop new, interlinked electronic warfare systems that can apply non-kinetic fire as easily as they can rain down artillery shells. Perhaps it will even be easier, since non-kinetic and other directed-energy weapons do not require ammunition production, warehousing and transport to the battlefield, as conventional weapons do.

Survivability of aircraft over the modern battlefield is another concern. The amount of reliance that can be placed on the air force has diminished because the air force will be busy attempting to solve the problems of man-portable air defense systems and anti-aircraft fire before they can join the battle. Therefore one trend is to give more capabilities to the tactical levels of the army so that they can conduct more of the mission with less outside help.

One need is to gather persistent intelligence for the tactical mission area, which can be done with assets such as a few advanced sensors mounted on smaller UAVs. In addition, signals intelligence and advanced communications are being designed to bring all the targetable data to a central site at brigade level.

The precision application of effects will be guided by new schemes for fusing intelligence, surveillance and reconnaissance (ISR). There are aspects that are improving dramatically such as connectivity, the quality of information, miniaturization of components and advanced, high-resolution optics and RF sensors that are combined with the ability to link the data and share it. Once you understand the battlespace and what is happening there, you can make decisions about how to deal with it.

Because of the enhanced political content of conflict in a world of instantaneous information, centralized execution will often accompany centralized control. However, in the nonlinear and fluid operating environments that will characterize future battlefields, renewed emphasis on adaptive planning and dynamic operations is necessary.

Precision-guided munitions have emerged as the centrepiece of a new revolutionary style of air warfare. Another advantage stems from the quantity and quality of sensors and their integration into systems and networks. Unmanned aerial vehicles have demonstrated their increasing operational utility, particularly when enabled by advances in satellite guidance and communications, computerized flight control systems and sensor technology.

Irregular warfare caused a paradigm shift in Electronic Warfare, both in the equipment-required capabilities, as well as in the way operations are conducted. EW can no longer operate as a stand-alone entity - it must be closely integrated with the intelligence community this is the most effective way to achieve the desired effect and accomplish proper Battle Management. Interoperability within a force, but even more so for joint and coalition operations, requires proper EM planning and control. It is advisable to move away from a platform centric approach to a net-centric approach and be more mission orientated rather than technology and service orientated.

EW works both ways, and can be used and exploited by both sides. A proper understanding of EW is essential to all warfighters who use the EMS as part of their missions. We need to educate the warfighters, as well as the leaders, in the utilization and vulnerabilities of the EMS. EW is about people firstly, and equipment secondly. EW training must be matched to the operational environment (realism as well as accommodating emerging technologies), and the mix and match of live, virtual and constructive simulation/exercises must be considered.

Future ‘asymmetric and small-scale conflicts’ will drive customer requirements for electronic warfare protection suites. Customers want to buy the best and are looking for very sophisticated EW equipment to protect small numbers of assets from a similarly small number of assets on the opposing side.

Cold War requirements to employ long-range surveillance sensors and suppression of enemy air defence systems to ‘avoid’ enemy weaponry were no longer a priority. Nor are sensors designed to detect enemy radar and laser devices in order to evade potential threats. Instead, requirements are now based on ‘countering’ such threats using defensive aids controllers, directed IR countermeasures, jammers, chaff and flares.

Emerging requirements in the RF EW field include: growth of low-probability-of-intercept radar techniques; operation in complex electromagnetic environments with encroachment into traditional radar bands; use of smaller platforms such as UAVs; and requirements for more coherent countermeasures and more sophisticated EA waveforms.

Navigation Warfare (NAVWAR) is both something on its own thing and a composite of many things. It is not exclusively EW (or EMS Control) or Space Operations or Cyberspace operations or any other mission area concerned primarily with operations in, through or into a particular domain, or awareness of, or superiority within, a particular domain. NAVWAR is both joint and interagency. It is domain agnostic. It is focused on Position Navigation and Timing (PNT) dependency, PNT effects and PNT advantage through offensive and defensive measures.

Current operations clearly show a need for improved mobile communications capabilities connecting the individual soldier, operating at the tactical edge, to the network in order to access critical voice, video, and data network resources. COTS wireless and cellular technologies have matured to the point that tactical employment is now both feasible and affordable. Military investment in cellular technologies will give commanders scalable options for employing their network capabilities in the generating force at posts, camps, and stations, as well as the operating force, in support of all phases of joint operations. The development of this capability will fill current capability gaps while technologies continue to be developed for military communications acquisition programs. Military cellular capabilities will reduce training and administrative functions, and facilitate tactical operations by connecting soldiers to the network with a technology that they are fully familiar. Further integration with combat net radios will maximize warfighter communications capabilities in support of full spectrum operations. This capability will not only thicken the tactical network but also extend the network to lower echelons, both mounted and dismounted.

EW Protection

This entails hardening of own equipment (communication, radar, electro-optical systems, navigation etc.) against intentional jamming by adversaries, but also unintentional interference by own systems – due to their interoperability. Communication examples are cognitive radios, that can sense the environment for interference, and adapt their waveform (frequency, modulation and power) accordingly to ensure communication. Additionally, waveforms that are difficult to detect such as Direct Sequence Spread Spectrum (DSSS), frequency- and time-hopping signals, will also be a harder target for an EA system. On the radar side, Frequency Modulated Continuous Wave (FMCW) and noise waveforms are examples of Low Probability of Detection (LPD) emissions that will make it more difficult to detect, combined with the Low Probability of Intercept (LPI) characteristics of an AESA radar.

Some general pointers for communication, navigation and radar systems to optimize their Electronic Protection capabilities are the following:

- Use as wide an operating frequency bandwidth as possible.
- Carrier frequency selection (in between other types of emitters or out of typical EW system frequency band).
- Employ as much time, frequency and space diversity as possible.
- Use antennas with low sidelobes.
- AESAs have a huge advantage.
- Use adaptable waveforms (cognitive/sense) in terms of frequency, power and modulation.
- Use GNSS augmentation (e.g. WAAS, EGNOS).
- Optimize antenna placements for antenna pattern and screening.
- Implement a proper EM Spectral plan.
- Understand own vulnerabilities.

3 Directed Energy Weapons

Directed Energy Weapons (DEW) is one of the relatively new electronic warfare (EW) approaches that have revolutionized certain aspects of EW. DEWs represent a new way to exercise offensive EW against a variety of threats, but must also be countered if used by adversaries.

Directed Energy Weapons are an umbrella term covering technologies that relate to the production of a beam of concentrated electromagnetic energy or atomic or subatomic particles.

Propagation limitations generally focus the practical effectiveness of DEW more towards damaging electronics (e.g. computers and communication systems), sensitive microwave or IR detectors (e.g. radars and missile guidance). The ability of DEWs to operate at the speed of light and their unlimited magazine capability, combined with their scalable effects capability (non-to-highly lethal) make them very attractive weapons.

Present DEWs use either sound, lasers or high-powered microwave (HPM) generators. Lasers generate very narrow beams and one of the considerations involves how these beams are focused on the critical sensor front-ends. HPM systems use wider beams and, hence, are easier to aim. The penetration mechanism for HPM devices are either:

- **Front-door coupling** refers to energy that enters through the antenna of systems containing a transmitter or receiver. Coupling is greatest at the design frequency of the antenna.
- **Back-door coupling** denotes energy that leaks into systems through cables, interconnecting wires, seams in their enclosures, or even non-metallic enclosures. A low frequency weapon will couple well into a typical wiring infrastructure, as most telephone lines, networking cables and power lines follow streets, building risers and corridors.

3.1 Directed Energy Technologies

- Lasers:
  - High Energy (HEL).
  - Low Energy (Dazzlers).
- Radio Frequency (RF):
  - High Powered Microwave (HPM).
  - High Powered Millimetre Waves.
- Particle beams (PB).
- Plasma
- Acoustics.

Although not strictly speaking a Directed Energy Weapon due to its omni-directional nature, Electromagnetic Pulse (EMP) weapons can cause similar effects, and are addressed here as well.

3.2 Operational Effects

Operationally, DEW can be classified in two categories:

- Non-Lethal (against personnel and equipment).
- Lethal (mostly against equipment) - Lethal implies non-zero fatalities.

One of the main advantages of DEW is the fact that the same technology can be scaled from non-lethal to lethal as shown in Figure 53.

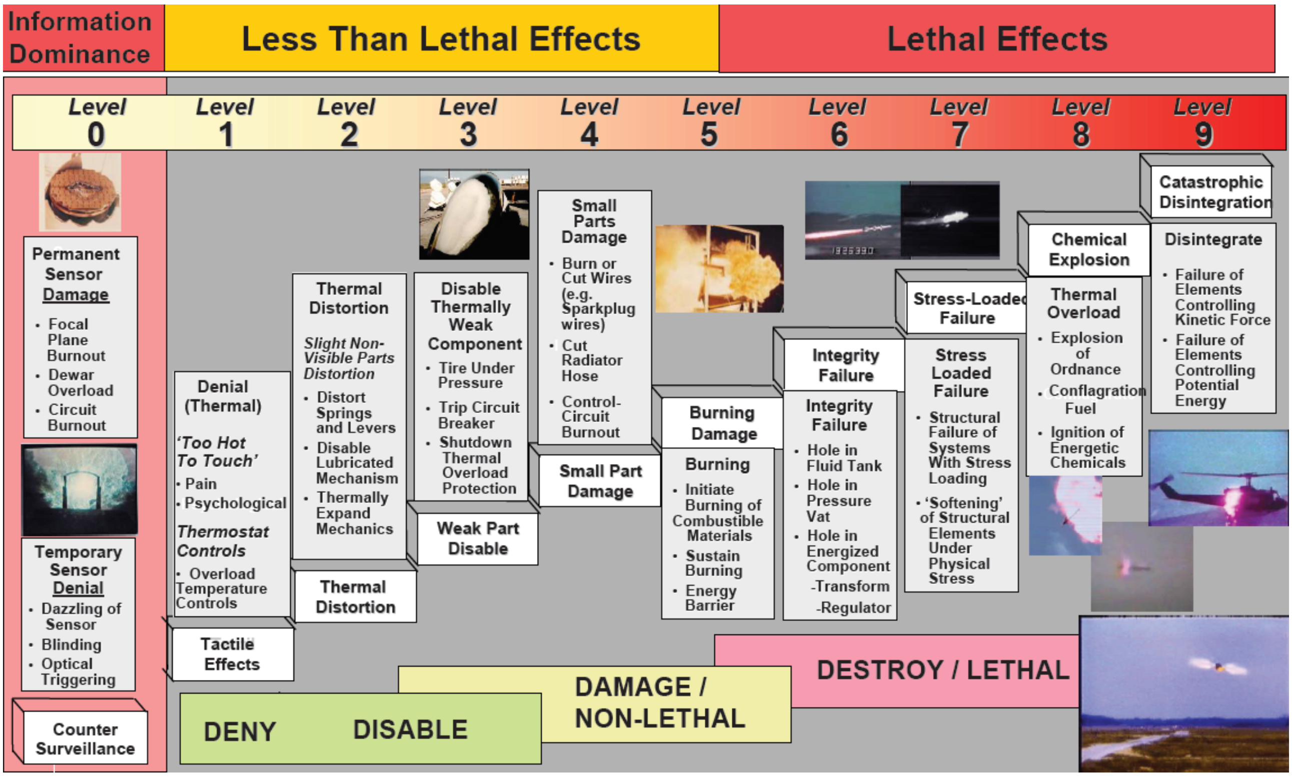

Figure 53: Real-Time Scalable Effects of DEW. [McPheeters - AOC]

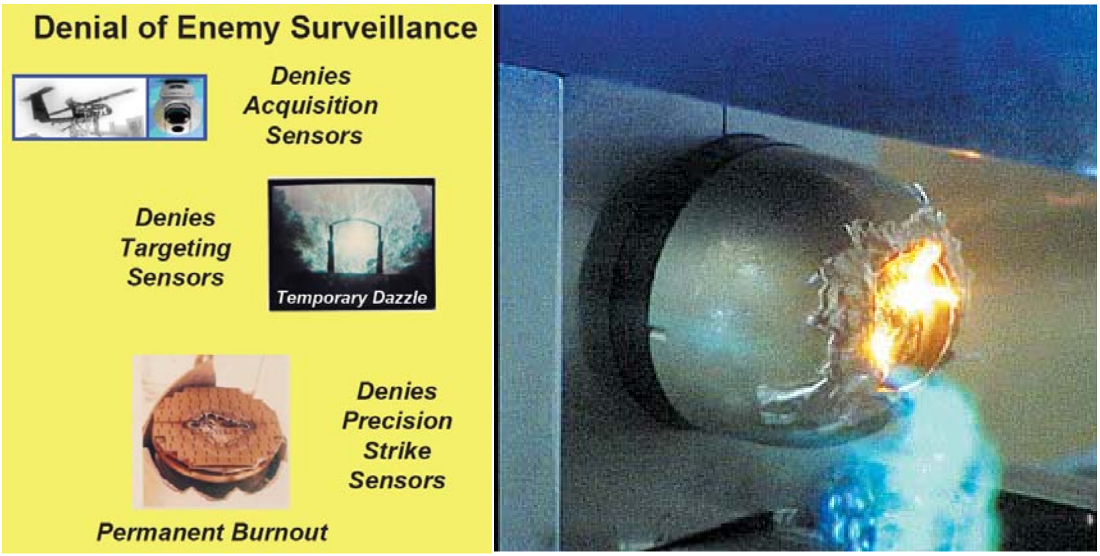

Figure 54: Some of the effects of DEW, showing amongst others a damaged missile seeker antenna on the left and an IR seeker-head on the right. [Lawrence Livermore National Laboratory]

3.3 Non-Lethal Weapons (NLW)

Not so long ago, the effectiveness of a military operation was often measured in terms of number of enemies killed - i.e., the more casualties were inflicted on the other side, the better. Today that is no longer the case. For a whole variety of reasons it is important to keep the killing and the destruction at the lowest possible level, not out of compassion but just in order to better fulfil the task at hand.

In a more general framework, most contemporary military missions are aimed to restore peace and stability, and therefore require the use of means different from traditional weapons. The ultimate political goals of these missions are no longer to be achieved through the annihilation of the counterpart, and therefore rather demand that actions, that are liable to unnecessarily raise the tension to dangerous levels, shall be avoided.

The formulation of appropriate Rules Of Engagement (ROE), whereby every soldier is made to know exactly when he/she can or cannot use his weapon to kill an opponent, is an obvious prerequisite for the deployment of military units in Military Operations Other Than War (MOOTWs). However, even the most stringent and detailed ROEs are hardly enough. In fact, the real risk here in not that a soldier or a commanding officer would act in deliberate breach of the ROEs and use, or order the use of deadly force when they know very well it should not be used, but rather that they would fail to appreciate the real nature of the situation they are facing and the true intentions of the civilians around them. This possibility for tragic misunderstanding is particularly high when the military personnel and the civilians belong to very different cultures with e.g. a totally different perception of the relationship between verbal abuse and physical violence or of the value of human life, which is increasingly the case.

It should further be appreciated that the risk of using lethal force when it should not, is accompanied and paralleled - although this tends to receive far less attention in the media, by the opposite risk of failing to react to a threatening situation until it is too late. Here again, a failure to appreciate the real nature of the situation combined with the commendable desire to respect the letter and spirit of the ROEs may well lead to truly tragic consequences. While the ROEs often state something like "Do not fire until being fired upon", there is a serious risk that if own forces must wait until the opponents start using firearms, then at that point the situation has already degenerated and can no longer be brought back under control. The troops must be given a viable alternative somewhere in between "shouting" and "shooting". This is exactly where Non-Lethal Weapons fit in.

NLWs are designed to protect people and assets, and to prevent entry to important areas and resources. It further enables the protection of friendly forces, influences the actions of potential adversaries and non-combatants without applying lethal force, and it minimises collateral damage. NLWs, if correctly utilised, may effectively neutralise the adversary's personnel or his equipment. Non-lethal weapons leave no immediately visible marks on their victims, but can cause startling psychological and physical destruction.

Crowd control may be obtained by influencing the behaviour and activities of a potentially hostile crowd as well as a rioting mob. NLWs may also be used to target or incapacitate an individual. This capability provides a means to capture specified individuals, such as those inciting a mob to violence or enemy combatants, without affecting nearby individuals.

NLWs can be used to deny personnel access to an area on land, sea, or in the air. This may prove to be a critical capability. Such weapons may create physical barriers by causing discomfort to those seeking to enter the denied area. This capability can be applied to clear facilities and structures of personnel. It will facilitate military operations in urbanised terrain by reducing the risks of non-combatant casualties and collateral damage, while denying enemy advantages in defending a built-up area.

NLWs biggest issue is that of ethics. New bombs can be rushed into service in a matter of weeks, but the process is more complex for nonlethal weapons - it takes years before the debates are resolved, especially for the RF weapons. The development of a truly safe and highly effective nonlethal crowd-control system could raise enormous ethical questions about the state's use of coercive force. If the method used leads to no lasting injury or harm, authorities may find easier justifications for employing them. This verification alone can take many years.

3.4 Particle beam and Plasma Weapons

For the sake of completeness, a short description on the mechanism of operations of particle and plasma weapons are given here.

Particle beam weapons can use charged or neutral particles, and can be either endo-atmospheric or exo-atmospheric. Particle beams as beam weapons are theoretically possible, but practical weapons have not been demonstrated. Certain types of particle beams have the advantage of being self-focusing in the atmosphere.

Blooming is also a problem in particle beam weapons. Energy that would otherwise be focused on the target spreads out; the beam becomes less effective:

- Thermal blooming occurs in both charged and neutral particle beams, and occurs when particles bump into one another under the effects of thermal vibration, or bump into air molecules.
- Electrical blooming occurs only in charged particle beams, as ions of like charge repel one another.

Plasma weapons fire a beam, bolt, or stream of plasma, which is an excited state of matter consisting of atomic electrons & nuclei and free electrons if ionized, or other particles if pinched. Plasma have found many other military applications, specifically in the Electronic Protection field, but no viable weapons have been fielded.

3.5 Lasers

A laser is a device that emits light (electromagnetic radiation) through a process of optical amplification based on the stimulated emission of photons. The term "laser" originated as an acronym for Light Amplification by Stimulated Emission of Radiation. The emitted laser light is notable for its high degree of spatial and temporal coherence, unattainable using other technologies.

Spatial coherence typically is expressed through the output being a narrow beam which is diffraction-limited, often a so-called "pencil beam." Laser beams can be focused to very tiny spots, achieving a very high irradiance. Or, they can be launched into a beam of very low divergence in order to concentrate their power at a large distance.

Temporal (or longitudinal) coherence implies a polarized wave at a single frequency whose phase is correlated over a relatively large distance (the coherence length) along the beam. A beam produced by a thermal or other incoherent light source has an instantaneous amplitude and phase which vary randomly with respect to time and position, and thus a very short coherence length.

Most so-called "single wavelength" lasers actually produce radiation in several modes having slightly different frequencies (wavelengths), often not in a single polarization. Although temporal coherence implies monochromaticity, there are even lasers that emit a broad spectrum of light, or emit different wavelengths of light simultaneously. There are some lasers which are not single spatial mode and consequently their light beams diverge more than required by the diffraction limit. However all such devices are classified as "lasers" based on their method of producing that light: stimulated emission.

A laser can be classified as operating in either continuous or pulsed mode, depending on whether the power output is essentially continuous over time or whether its output takes the form of pulses of light on one or another time scale.

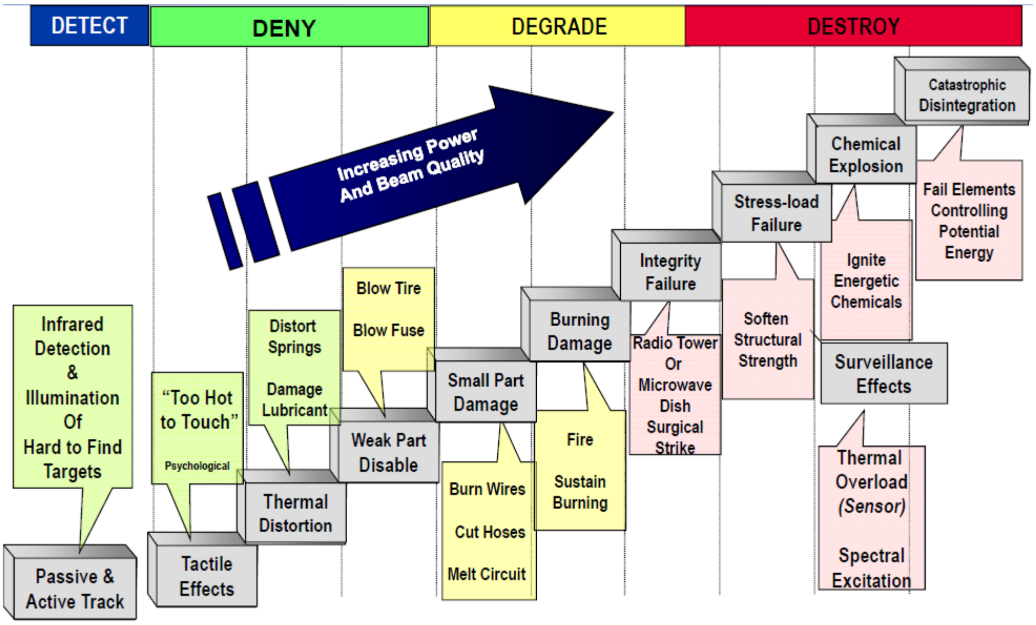

Figure 55: Laser Weapons offer broad-spectrum effects. [Boeing]

Laser-guided weapons can be guided onto a target by reflecting laser energy off the actual target. A non-visible laser which illuminates, marks or designates a target is difficult to detect visually and requires a Laser Warning Receiver (LWR) to perform the detection, warning and possible decoy dispensing. Designation can be from the ground or air, from manned or unmanned platforms.

High power lasers are also being used more frequently as weapons in themselves, destroying Improvised Explosive Devices (IED), missiles and Unmanned Arial Vehicles (UAV). Low power lasers are used to spoof IR missiles (Directable Infrared Countermeasures or DIRCM) and to dazzle human operators and imaging sensors.

Eye-safety will always be an issue where lasers are involved. It must be bourne in mind that a laser is an active device – transmitting energy – and hence can be detected by a Laser Warning Receiver (LWR) and therefore needs to be part of the EMCON planning. Due to the very short response time between first illumination and effector on target for laser guided weapons, the responses are automated, with the resultant burden on interoperability to safeguard own forces and not to waste limited resources like obscurants (smoke).

Three possible ways that lasers can influence electronic sensors are:

- **Saturation:** Saturation can occur in an electro-optical instrument and render the instrument “blind” during the dwell time.
- **Disruption:** Optical systems on vehicles, aircraft and missiles can be disrupted by varying the output power of the laser. The change in incident light causes the auto-gain control of the system to try and optimise the image, causing a cycle of over- and under-exposure.
- **Permanent Damage:** If the power of the laser is high enough, the electronic sensors can be permanently damaged.

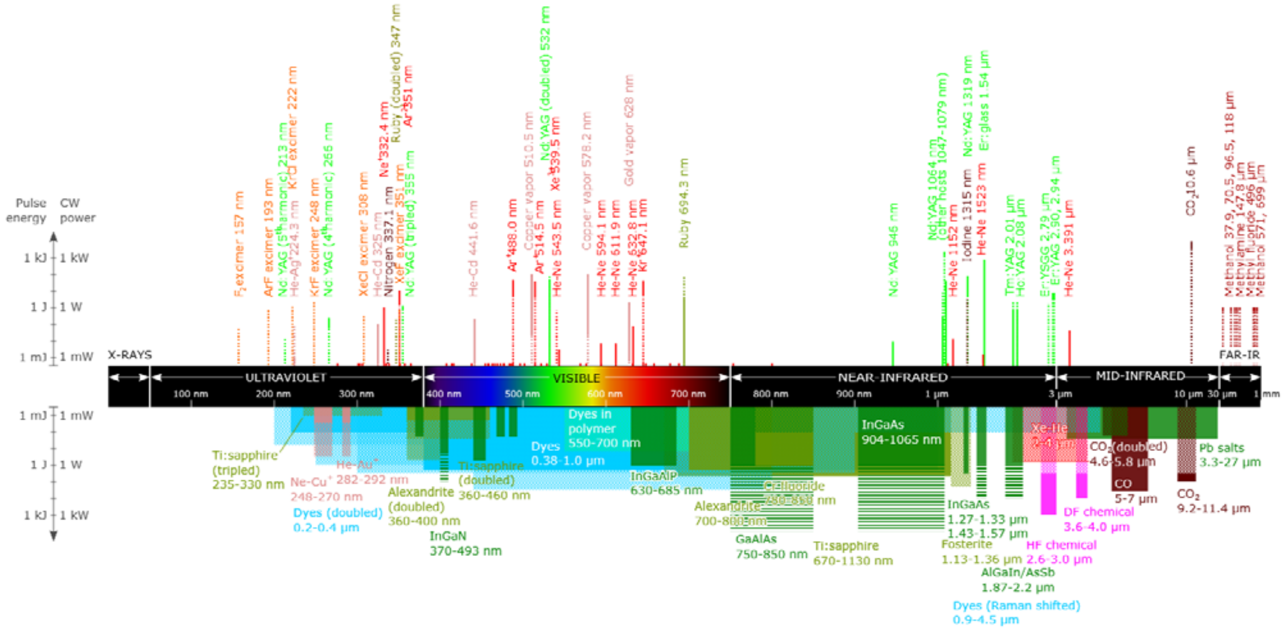

Figure 56: Wavelengths of commercially available lasers. Laser types with distinct laser lines are shown above the wavelength bar, while below are shown lasers that can emit in a wavelength range. The colour codifies the type of laser material.

3.5.1 High Energy Lasers

High Energy Lasers (HEL) systems of interest are based upon six different types of lasers: gas dynamic, pulsed high-energy electrical molecular and atomic, excimer, chemical optically pumped gas, solid state (including fibre lasers), and free electron. The development of new approaches for energy transfer, efficient mixing of chemical reactants, scaling of present systems to higher power design of waveforms, and more efficient propagation of beams through the atmosphere are currently the main focus.

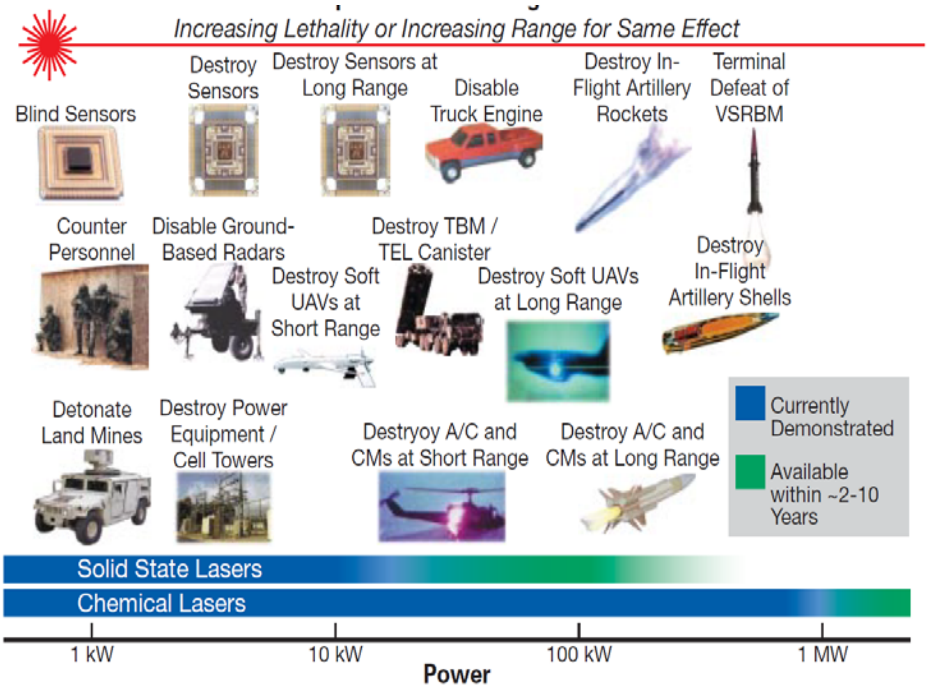

Figure 57: Power required to affect targets of interest. [Northrop Grumman 2005]

3.5.2 Problems and considerations

Blooming: Laser beams begin to cause plasma breakdown in the air at energy densities of around a megajoule per cubic centimetre. This effect, called "blooming," causes the laser to defocus and disperse energy into the atmosphere. Blooming can be more severe if there is fog, smoke, or dust in the air.

Evaporated target material: Another problem with weaponized lasers is that the evaporated material from the target's surface begins to shade.

High power consumption: One major problem with laser weapons (and directed-energy weapons in general) is their high electric energy requirements. Existing methods of storing, conducting, transforming, and directing energy are inadequate to produce a convenient hand-held weapon. Existing lasers waste much energy as heat, requiring still-bulky cooling equipment to avoid overheating damage. Air cooling could yield an unacceptable delay between shots.

Beam absorption: A laser beam or particle beam passing through air can be absorbed or scattered by rain, snow, dust, fog, smoke, or similar visual obstructions that a bullet would easily penetrate. This effect adds to blooming problems and makes the dissipation of energy into the atmosphere worse. The wasted energy can disrupt cloud development since the impact wave creates a "tunnelling effect".

Lack of indirect fire capabilities: Indirect fire, as used in artillery warfare, can reach a target behind a hill, but is not feasible with line-of-sight DEWs. Possible alternatives are to mount the lasers (or perhaps just reflectors) on airborne or space-based platforms.

3.5.3 Example Systems

The best known example is the US Airborne Laser (ABL) Program - a massive missile-killing laser housed in a 747 freighter. The laser plane includes a "megawatt class" high-energy chemical laser designed to shoot down Inter-Continental Ballistic Missiles (ICBMs). The laser targets the missile's fuel tank, taking advantage of pressure and velocity to "unzip" the rocket, rendering it powerless during its initial flight. Once the wall is weakened, it is actually the internal pressure and aerodynamic forces that destroys the missile.

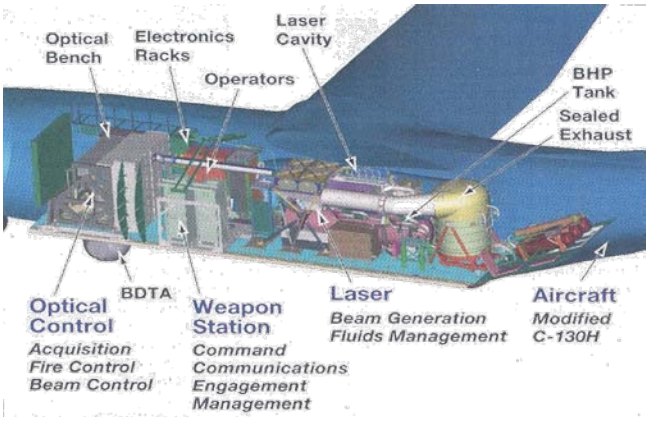

Figure 58: The USAF ABL (left) and the ATL 12,000-pound integrated laser module installed in a C-130 (right).

Another HEL system is the Advanced Tactical Laser (ATL), a concept for airborne ultra-precision strike missions that uses a high-energy laser weapon mounted in a tactical aircraft to engage stationary or moving ground targets. On-board visible and infrared surveillance and acquisition sensors provide the weapon operator scene images of increasing resolution for finding, identifying, and engaging targets. The entire weapon system is envisioned as a package of several self-contained modules that can be installed or removed from the aircraft in a few hours.

The ATL has been installed in a C-130 aircraft and has demonstrated its ability to engage tactical targets from a moving platform at ranges of approximately 10 kilometres.

The Advanced Tactical Laser can place a 10-centimeter-wide beam with the heating power of a blowtorch on distant targets for up to 100 shots - it can slice through metal from a distance of 9 miles.

The Advanced Tactical Laser can provide powerful capabilities for both lethal and non-lethal ultra-precision engagement of threats with little or no collateral damage. This is often critical in urban environments and congested chokepoints that are vulnerable to terrorist activities or insurgent operations. Operated from a ground, sea or airborne platform, ATL offers the ability to place a precisely calibrated energy pulse on a target from either close in or from a standoff distance of several miles. While the ATL provides a laser weapon that can be used for lethal warfare when warranted, the ATL can also affect less-than-lethal engagements that can help control high-risk situations for both military and humanitarian purposes. The ATL uses a Chemical Oxygen Iodine Laser (COIL) of 100 to 300 kW of optical power.

The outermost cruise missile engagements occur at 20 km, where laser dwell times of five seconds are required for each kill. At shorter ranges, the dwell times are reduced. One target is destroyed for each dwell period, and a few seconds are allocated for re-targeting between shots. An ATL will generally operate below most of the clouds. For missile defence, the ATL works best at altitudes around 10,000 feet. However, it can operate down to about 2,500 feet; below which the operational range becomes too short to be useful.

Two other high energy laser systems of interest are shown in Figure 59.

Figure 59: The US Army's HEL Technology Demonstrator (left) and the Tactical High-Energy Laser (THEL) (right).