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Tactical High Energy Laser

J. Shwartz* **and J. Nugent**
Northrop Grumman Space Technology, S/1040, 1 Space Park,
Redondo Beach, California 90278

D. Card
U.S. Army Air and Missile Defense Program Executive Office, SFAB-AMD-SHO-DF,
Building 5308, Redstone Arsenal, Alabama 35898

G. Wilson
U.S. Army Space and Missile Defense Command, SMDC-TC-D, 100 Wynn Drive,
Huntsville, Alabama 35805

and

J. Avidor and E. Behar
Directorate of Defense Research and Development, Israel Ministry of Defense,
Hakirya, Tel Aviv 61909, Israel

The tactical high energy laser (THEL) is a ground-based stationary laser weapon demonstrator jointly developed by the U.S. Army and the Israel Ministry of Defense (IMoD). Its specific mission was to engage and destroy artillery rockets and similar ballistic threats. By now this demonstrator has shot down 28 artillery rockets and 5 artillery projectiles under a wide range of engagement scenarios, clearly demonstrating the feasibility of using a laser weapon to defend against such threats. Following the success of the THEL program, the U.S. Army and IMoD embarked on a System Engineering and Trade Study (SETS) program to define concepts for a mobile THEL (or MTHEL) that will be a fully operational and militarized laser weapon capable of defending against a wide range of aerial threats, as well as short-range ballistic threats. Several concepts were developed and are being fleshed out and traded to help decide which one will best serve the requirements of the U.S. Army and IMoD. This paper starts with a brief overview of the THEL history and then provides a detailed description of the THEL system. The live-fire tests performed with THEL at the U.S. Army's White Sands Missile Range, in New Mexico, are briefly reviewed, and a MTHEL concept is also described in some detail. The paper concludes with a summary that highlights the significance of the THEL development and test program as a pathfinder for introducing a revolutionary air defense capability that can potentially change the face of the battlefield.

KEYWORDS: Lasers for Air Defense, Laser Weapon Demonstrator, Tactical Lasers

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*Corresponding author; e-mail: joe.shwartz@ngc.com.

1. Introduction

The tactical high energy laser (THEL) program was started in 1996 as an Advanced Concept Technology Demonstration (ACTD), jointly sponsored by the United States and Israel. The initial motivation for the program was the need for a defense against short-range artillery rockets frequently used by terrorists in Lebanon against the northern towns of Israel. The program was initiated in July 1996 by an agreement between President William J. Clinton and Israel Prime Minister Shimon Peres. A Memorandum of Understanding (MOU) that committed both governments to "evaluate effectiveness of high energy lasers in negating the Katyusha rocket threat" facilitated the program start. In just under four years THEL ACTD went from just a concept to a fully integrated laser weapon demonstrator that shot down its first artillery rocket on June 6, 2000. By now the THEL demonstrator has destroyed 28 operational Katyusha rockets in flight, including three two-rocket salvos, and five 152-mm artillery rounds. Some tests included downing both artillery rockets and artillery projectiles in short succession. THEL ACTD is the first full-scale and fully integrated laser weapon demonstrator developed in the United States. It operates in a stand-alone fashion, against real and unaugmented tactical threats in realistic engagement scenarios, clearly demonstrating the effectiveness and utility of tactical laser weapons in the battlefield. Other uses of THEL-like laser weapons are contemplated as well, such as protecting civilian populations and both civilian and military high-value assets. The success of the THEL ACTD program is an important milestone toward the implementation of a laser defense capability to meet current and evolving needs of the United States and its allies.

Following the success of the THEL demonstrations, the U.S. Army and Israel funded a System Engineering and Trade Study (SETS) that was designed to flesh out concepts for an operational mobile tactical high energy laser (MTHEL) that could be deployed to defend high-value assets, civilian populations, and troops. The operational concept for such a system is shown in Fig. 1. The objective of the MTHEL program is to build on the success of the THEL ACTD by providing a smaller, mobile prototype of an operational system. This first mobile system will also serve as a vanguard for future and still more compact laser weapon systems that may be part of the U.S. Army's Future Combat System.

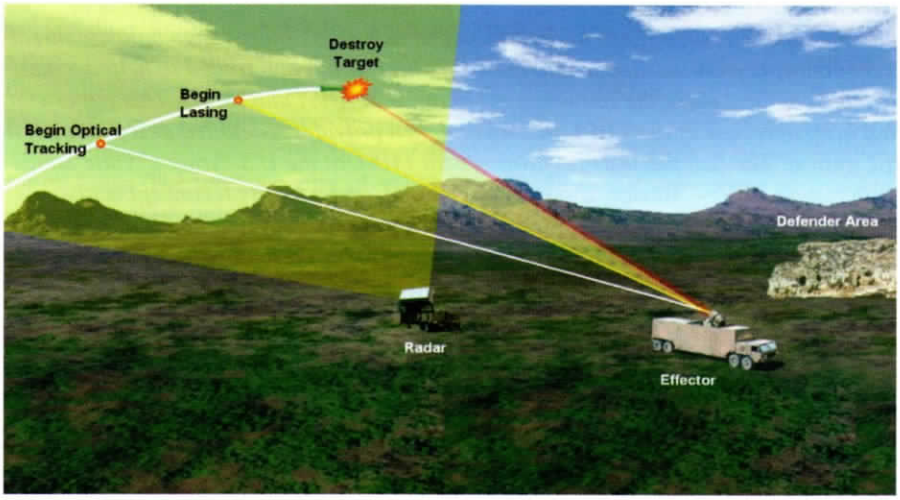

Fig. 1. MTHEL concept of operations.

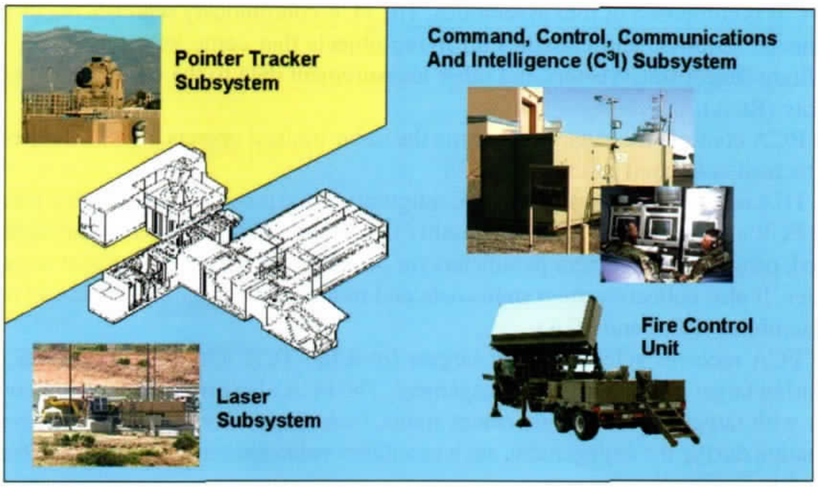

Fig. 2. THEL ACTD configuration.

The key improvements in the new system are significant and include reduced size and weight, improved transportability, reduced setup time, reduced system cost, and increased operational availability.

The MTHEL program will develop, test, and field the first ground-based operational laser weapon prototype. It will enable the war fighter to engage and destroy rocket, artillery, and mortar (RAM) threats and to defeat other air and missile threats, such as unmanned aerial vehicles, cruise missiles and short-range ballistic missiles.

2. THEL ACTD System Description

THEL ACTD is composed of three subsystems: 1) a command, control, communications, and intelligence (C3I) subsystem, that includes a fire control radar (FCR), 2) a laser subsystem (LS), and 3) a pointer-tracker subsystem (PTS). The THEL ACTD radar, used for search, acquisition, and fire control, is part of the C3I subsystem. A layout of the THEL system with photographs of its three subsystems is shown in Fig. 2. A brief description of each subsystem is presented next.

2.1. C3I subsystem

The C3I subsystem controls the FCR, as well as all LS and PTS operations. It manages the complete engagement, searching the extended threat zone, detecting and classifying aerial targets within its range, irradiating and destroying the designated targets, and providing kill assessment as well. Once THEL is ready for operation, it takes only two people to man the C3I and to run the entire THEL system: a commander and a gunner. The C3I is designed to operate in three modes: a) a fully automatic mode, where no human intervention is required, other than visual target identification by the commander (The commander or gunner can intervene to stop fire or skip a target in this automatic mode.); b) a semiautomatic mode, where all functions are performed automatically, except that the commander must manually authorize firing by pressing a fire button; and c) a manual mode, where the commander both designates the target to be engaged and issues the fire command.

The C3I is composed of four assemblies. The FCR continuously searches the threat zone and detects, acquires, and classifies all flying objects that come within its range. It then sends flight-object state-vectors and other measurement data to the radar communications assembly (RCA).

The RCA controls the radar and reports the radar-tracked objects and their state-vectors to the tactical command assembly (TCA).

The TCA sets up the subsystem (C3I) configuration and provides initialization parameters for the FCR and for the fire control assembly (FCA). In addition, it selects the targets to be engaged, provides engagement parameters for the FCA, and determines threat engagement priorities. It also collects system status data and monitors the laser and PTSs and the other C3I assemblies (RCA and FCA).

The FCA receives selected threat targets from the TCA and controls the LS and the PTS during target acquisition and engagement. The FCA also provides the commander and gunner with target data and engagement status, including kill assessment and other target information during the engagement, such as a direct video feed from the PTS and track lock or loss data.

2.2. Laser subsystem

THEL uses a deuterium fluoride (DF) gas laser that has good atmospheric propagation characteristics and a long history of successful development and high-power demonstration. The first high-power DF laser generating tens of kilowatts of radiative power, the baseline demonstration laser (BDL), was built by TRW (now Northrop Grumman Space Technology) in 1973. In 1976, the Navy/Advanced Research Projects Agency chemical laser (NACL) followed and generated hundreds of kilowatts. In 1980 TRW built the Mid-InfraRed Advanced Chemical Laser (MIRACL), a megawatt-class DF laser, and delivered it to the U.S. Army's White Sands Missile Range for field testing. This laser has been the backbone of the U.S. Government's High Energy Laser Systems Test Facility at White Sands, a facility that has been in continuous use since 1984, demonstrating the feasibility of using high-power lasers for various military applications.

In a DF laser, nitrogen trifluoride (NF_3) and ethylene (C_2H_4) are first reacted in multiple, side-by-side, high-pressure combustion chambers using an oxidizer (NF_3)-rich mixture that generates free fluorine (F) atoms. After ignition the combustion-generated F atoms, mixed with combustion by-products and helium (He) diluent, flow into the laser cavity. A mixture of He and deuterium (D_2) is injected into the laser cavity, and DF is generated in an excited state as deuterium reacts with free F atoms. The laser cavity is now ready to produce a laser beam. The stimulated emission of radiation develops in the cavity from a negative branch unstable resonator and emits a continuous-wave collimated laser beam. A negative branch resonator was selected because of its inherent stability and ease of alignment.

The LS is made up of four assemblies: the fluid supply assembly (FSA), the gain generator assembly (GGA), the pressure recovery assembly (PRA), and the laser optics assembly (LOA).

The FSA provides all reactants and other fluids necessary for laser operation. The gases used to generate the lasing action are NF_3, C_2H_4, He, and D_2. In addition, the FSA supplies both the cooling water needed to operate the laser and the hydrogen peroxide (H_2O_2) needed to run the PRA. The FSA is composed of high-pressure tanks, tubing, regulators, fast turn-on/turn-off flow control valves, and sensors. These instruments are needed to monitor and control the various flow circuits and to maintain a safe operating environment. The THEL FSA was proven to be very successful in precisely metering flow rates under very high pressure in a fraction of a second. THEL ACTD has thus demonstrated, for the first time, the rapid turn-on and turn-off of flow controls needed for laser weapon systems using chemical lasers.

The GGA is composed of NF_3 and C_2H_4 combustion chambers, each feeding an expansion nozzle that leads into the laser cavity. Thin cavity injection blades that feed a mixture of D_2 and He into the laser cavity span these nozzles. All the gas and water feed tubes and manifolds that are closely coupled to the laser cavity are part of the GGA. The GGA also includes an F_2 gas generator (F_2GG) that is needed to ignite the NF_3 and C_2H_4 mixture, since this mixture is not hypergolic at normal (room) temperature. This F_2GG is a new development, specifically designed for the THEL laser and, as demonstrated on this program, proven to be a very effective and dependable DF laser igniter.

A PRA is needed since the laser cavity operates at subatmospheric pressure but the laser gases flowing through the cavity must still be exhausted to the atmosphere. The first element of the PRA is a passive diffuser, which recovers the kinetic energy from the supersonic laser cavity flow and increases the pressure of the gas stream. The next element is a heat exchanger that reduces the gas temperature and increases its density, thus reducing the gas volume that needs to be exhausted to the atmosphere. The last element is an H_2O_2-driven ejector pump. Seventy percent H_2O_2 is catalytically decomposed to generate the high temperature and high-pressure ejector driver fluid (steam + oxygen) that produces the pumping effect. This ejector pump raises the laser gas pressure to slightly above atmospheric pressure and exhausts the gas to the atmosphere.

Finally, the LOA is used to extract the laser beam from the laser cavity and to shape it before it enters the PTS. The LOA includes laser mirrors and their supports, a laser optical bench, instrumentation that checks and records the optical bench alignment relative to the laser cavity, vacuum enclosures needed to house all LOA optical elements, and isolation valves that separate the LOA from the laser cavity. All laser mirrors are mounted on sturdy support structures that, once aligned, require little adjustment. The combination of sturdy supports and the negative branch unstable resonator configuration yielded a very stable and robust laser optical system, suitable for test field operations.

All high-power THEL optics, including both the LS and PTS optics, were produced with very low absorption (VLA) optical coatings on single crystal silicon substrates, which drastically reduce the laser absorption and the heating of these elements and eliminate the need to actively cool them. This is the first time a complete high-energy laser system was built without a single water-cooled mirror. THEL has thus demonstrated that VLA coatings are reliable and ready for high-energy laser applications, allowing a very significant simplification in the design of laser weapon systems by eliminating the need for water-cooled high-power optics.

2.3. PTS

The pointer-tracker element of THEL has a long legacy as well. The first pointer-tracker that was integrated with a DF laser was the Navy pointer-tracker (NPT) developed by the Hughes Company in the early 1970s and integrated into the TRW-built Navy–ARPA NACL in the mid-1970s. In 1978, the integrated NACL–NPT system was used to shoot down TOW (tube launched, optically tracked, wire-command) antitank missiles in midflight. This was the first definitive demonstration of the potential application of high-power lasers as tactical weapon systems.

The THEL PTS is modeled after the NACL NPT. It acquires the designated target from the C3I subsystem and transmits the LS-generated laser beam to the target, while pointing

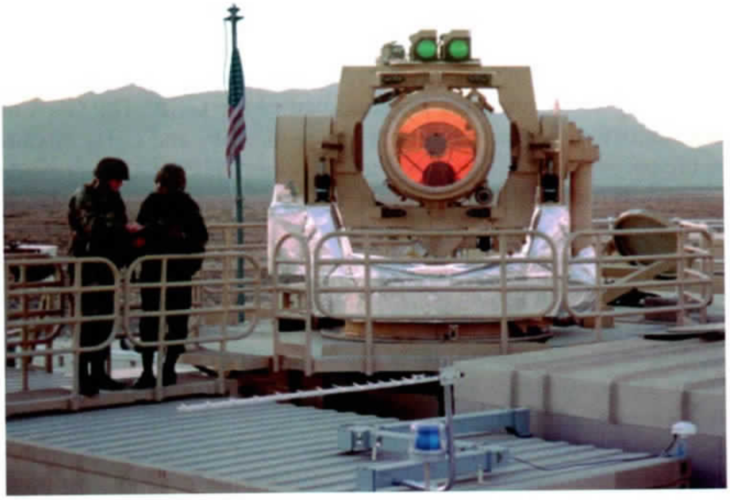

Fig. 3. THEL ACTD laser beam director.

and focusing the beam on the target. The PTS tracks the target with sufficient precision to place the focused laser beam on the desired aim point and keeps the beam there until the target is destroyed. Beam placement and maintenance accuracy required for a successful engagement are on the order of inches, while the target is moving at supersonic speed. The PTS also provides visual target tracking information to the THEL commander and gunner for the final target verification and manual intervention, if required.

The PTS is composed of five assemblies: the beam director assembly (BDA), the beam alignment and stabilization assembly (BASA), the off-axis tracker (OAT), the shared aperture tracker (SAT), and the PTS controller (PTSC).

The BDA accepts the laser beam generated in the LS and expands it in order to improve beam focusing and intensity on-target. The BDA slews to follow the threat target and allows the BASA to point the focused laser beam onto the selected aim point on the target. The BDA can track and point anywhere in the sky with hemispherical coverage, thus turning THEL into a true stand-alone weapon that can address any threat that comes within range. It does so by utilizing a three-gimbal pointing system. A close-up view of the BDA is shown in Fig. 3.

The PTS performs the target acquisition function in a two-step process; once the C3I generates a target state-vector, the PTSC commands the BDA to slew to the target and the OAT acquires the target. The OAT is a wide-field-of-view (FOV), low-resolution IR tracker. The OAT steers the BDA to maintain the target in the center of its FOV, where the SAT can also see it. The SAT is a near-IR, narrow-FOV, high-resolution tracker. When the SAT acquires the target, it takes over the target tracking function from the OAT, selects the aim point on the target, and points the laser beam to the selected aim point. The SAT tracks with virtually no interference in the presence of a high-energy beam. It accomplishes this with a combination of temporal and spectral filtering techniques.

The PTS sensor suite also provides rapid and reliable kill assessment data needed by the C3I subsystem. The reliability and timeliness of these data support the critical retargeting timelines required for salvo handling.

Fig. 4. Firing and shoot down of a two-rocket salvo.

3. THEL ACTD Summary of Test Results

The first shoot down of an artillery rocket by THEL ACTD occurred on June 6, 2000, a scant four years after the start of the program. This would be remarkable enough for any weapon demonstration program but was even more so for this fundamentally new type of weapon.

Many additional rocket intercepts have occurred since then, both against single rockets and against salvos of two rockets. Figure 4 depicts the firing and the shoot down of a two-rocket salvo. The system was completely autonomous in these tests, performing all necessary weapon functions from target detection and tracking to target kill and kill assessment. One test was labeled a "surprise attack" since the commander and gunner had no prior knowledge of the timing of the attack or where it was coming from. The THEL ACTD tests mapped out the performance of the system over a wide range of engagement parameters and demonstrated that a laser weapon can engage and destroy artillery rockets under realistic operational attack scenarios. Engagement parameters of major interest, which were systematically explored in these field tests, include the engagement range, the required laser dwell time on target to cause target destruction, the elevation angle of the engagement, the target slew rate, and other engagement parameters important for an operational system. Through these tests, a comprehensive performance map was developed and used to validate our laser weapon mission performance model. This validated model will be invaluable for gaining insight into the design of the next-generation THEL system, which most likely will be a mobile THEL weapon system prototype (see MTHEL Concept Description, Sec. 4).

On November 5, 2002, THEL ACTD was used to shoot down artillery projectiles in midflight (Fig. 5). This was the first time ever that an artillery round was knocked out of the sky after it was launched. Four additional artillery projectiles have been engaged and destroyed in midair since November 2002, and plans are now underway to engage other tactical aerial threats. By the end of calendar year 2002, THEL had engaged and destroyed 28 artillery rockets and 5 artillery projectiles.

What may be just as important is that THEL has been out in the field and operational now for nearly three years, offering a wealth of information on system environmental compatibility, reliability, availability, and maintainability in the harsh New Mexico desert environment. The operational and maintenance data collected, like the performance data, will be of great value in defining the requirements and the design of MTHEL.

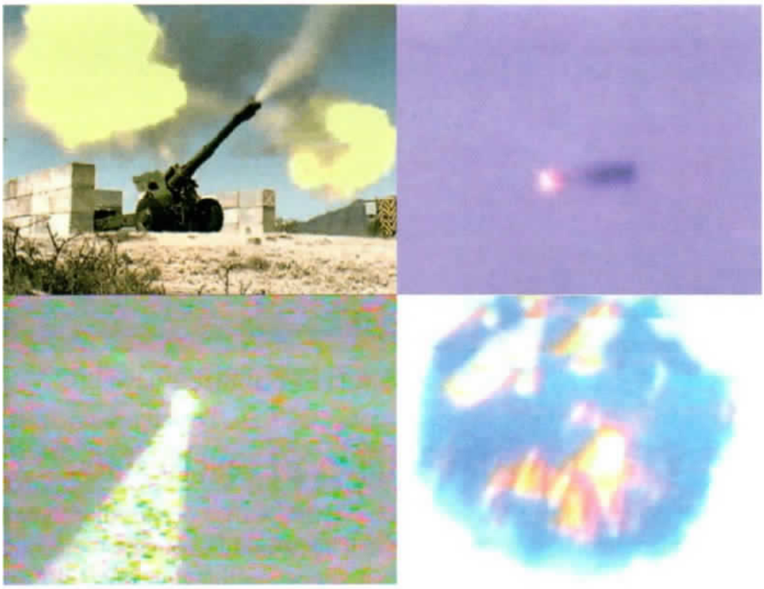

Fig. 5. Firing, lasing, and shoot down of an artillery projectile.

4. MTHEL Concept Description

MTHEL will be a tactical laser weapon system similar in many ways to THEL ACTD but with capabilities that go well beyond those of THEL ACTD. It will be designed to negate a broad set of short-range air and missile threats. The threats that MTHEL must address include unmanned aerial vehicles, cruise missiles, short-range ballistic missiles, artillery rockets, artillery projectiles, mortars, and air-to-ground munitions. Other uses may be defined as the system is developed and as its capabilities are further explored. One such new application may be homeland defense against airborne threats.

Initial concepts for MTHEL were generated during the MTHEL SETS funded by the U.S. Army and the Israel Ministry of Defense (IMoD) in 2001. One of these concepts is shown in Fig. 6 as an artist's concept. A key driver in the MTHEL concept definition was the desire by the U.S. Army and its ally, Israel, to produce an operational weapon in the shortest possible time. Consequently the decision was made to use well-validated technologies, such as those used in THEL ACTD. A significant engineering effort will still be required, however, to make MTHEL more compact and mobile and to militarize it so that soldiers in the field could use it.

Guided by these objectives, the MTHEL SETS concluded that MTHEL should be a DF laser, just like THEL. The reasons for this are many, but chief among them is the maturity of this technology. The risk is lowest with this type of laser, particularly considering the limited range of viable laser candidates that exist today for integration into a near-term weapon prototype. DF is still one of the simplest high-power lasers (the other being HF) developed to date. The technology for generating the gain medium is not much different from what is required to power a gas or liquid rocket motor. Little electrical power is required. The laser power generation is provided by the reaction of NF_3 and C_2H_4. The cooling requirements are also minimal. Most of the waste heat generated while powering the laser (which can

Fig. 6. MTHEL concept.

be substantial, since the efficiency of all high-power lasers is much less than 100%) is convected out of the laser by the same gas medium that generates lasing. DF lasers are also capable of continuous operation for tens of seconds to even hundreds of seconds as long as there is enough fuel to feed the laser cavity. Yet another motivation for choosing DF is a recent development by Northrop Grumman Space Technology that allows rapid and low-cost fabrication of a DF laser gain generator that is two times more fuel efficient than the gain generator built for THEL ACTD and will therefore require only half the fuel for producing the same energy. This design is also nearly three times volumetrically more efficient than THEL ACTD, allowing for the same power generation from a laser cavity that is one-third the size of what was used on THEL ACTD. It can be said that this new development in DF laser gain generator design enables the significant laser size reduction required for going from THEL ACTD to MTHEL.

With a mature, proven, and practical laser power source in DF technology along with the PTS and C3I technology baseline from THEL ACTD, the MTHEL program has a firm foundation to address some of the other challenges that will emerge as this revolutionary weapon is employed to address new battlefield missions. Some of the challenges are efficient and effective target processing of large raids (especially RAM), integration of the soldier into the weapon system, doctrine and tactics for employing DE technology against new missions, and providing the fine aim point designation and maintenance especially with complex targets. The MTHEL program, using DF, can be a vanguard for solving these and other issues that are independent of the laser power source.

The SETS activity suggested several design solutions. For example, the basic design of the PRA is the same, but diesel fuel and oxygen will be used instead of hydrogen peroxide (H_2O_2) to reduce storage volume and improve safety. The weapon's magazine—storage fluids for both the PRA and the gain generator—is kept on a separate movable platform (Fig. 6). Although not shown in Fig. 6, our design concept allows two fuel magazines to connect to the laser platform simultaneously, one on each side. This modular arrangement facilitates field replacement of empty magazines, ensuring that one magazine is always connected to the laser, ready to fire. Leaving the basic weapon emplaced in its operation location and replacing only the magazine significantly increases the magazine depth available to the weapon and allows for a flexible arrangement of vehicles when transporting the system into theater.

While THEL ACTD was designed to be a single stand-alone weapon, MTHEL units will be deployed in multiple units and will support each other. Having multiple weapons fighting as a team provides opportunities for design simplification as well as new design challenges. One example of a simplification is in the gimbal design. Since THEL ACTD had to fight alone, it had three gimbals to point the beam-directing telescope. This provided hemispherical coverage and eliminated the small "dead" volume right above the beam director (also known as gimbal lock zone) that a two-gimbal system has and where targets cannot be tracked because of finite gimbal authority. With more than one weapon deployed to protect a certain asset, MTHEL units will be used to cover each other's dead zones, and a simple two-gimbal telescope will suffice. This will significantly reduce the weight, size, complexity, and cost of the three-gimbal system associated with the THEL ACTD telescope.

For the BMC4I system, managing a short-timeline air battle against large threat raids with multiple weapons and multiple sensors provides new challenges beyond the simple single-weapon, single-sensor THEL ACTD system designed for modest threat raids. These challenges fall along several dimensions. Communications is one example. Our design calls for use of a wireless tactical communication system. Having a wireless system supports the rapid march/emplacement times required for MTHEL to be operationally effective. Such a system must be compatible with deployed tactical communication systems and allow interoperability with legacy and emerging air defense systems. Disseminating sensor-derived information and interweapon coordination data during a large air battle will stress the data throughput of such a wireless network and demand a BMC4I design that employs throughput-management logic at all nodes that ensure efficient use of the existing throughput capacity.

The analysis of potential BMC4I architectures has considered a loosely coupled decentralized approach that will provide the warfighter a system that is robust—free of single points of failure—and fluid in responding to a variety of deployment configurations. This concept is depicted schematically in Fig. 7. Even if sophisticated weapon-target-pairing logic is needed to optimally negate large complex raids, that logic can be potentially distributed among the weapon elements.

Another feature of the design is preferential engagement. While destroying every enemy target that enters the shield is desirable, economics suggests that an absolute shield against a large threat would be costly. Cost of weapons and munitions to intercept RAM raids will be significantly higher than the cost of corresponding threat RAM munitions and delivery mechanisms. Moreover, RAM arsenals are too abundant and proliferated, making it feasible for a potential enemy to "overwhelm" an absolute defense shield. The key to addressing this issue is recognizing that not every RAM target poses the same level of threat; in fact, in many situations, some fraction of a RAM attack can be allowed to fall with little or no risk of casualties or damage to the defended asset. When preferential engagement is implemented, casualties can be minimized by determining—through a careful assessment of sensor data—the most threatening targets to prioritize for engagement.

The role of the soldier will be a key design consideration for MTHEL as it was for the THEL ACTD system. Automation is required to respond quickly to complex air battle, but the soldier is an essential part the system. Depending on doctrine and rules of engagement,

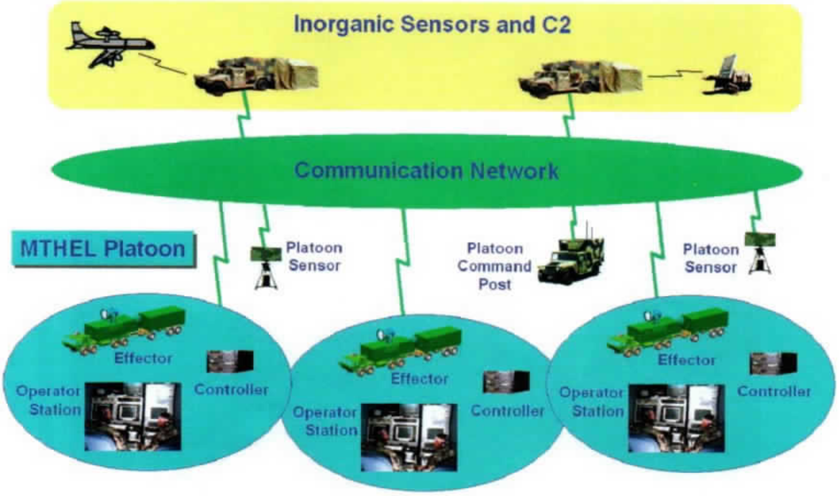

Fig. 7. Possible integration of a MTHEL platoon into the U.S. Army's air defense system.

a soldier "in the loop" may be required for every mission. Further, relative to automated algorithms, the soldier can have a better heuristic, macroscopic understanding of the air battle and its context, an understanding that might indicate a different course of action. The system design must meaningfully integrate the soldier into the engagement decision process with as little impact on the timeline as possible.

MTHEL will address critical shortfalls in the current U.S. air and missile defense capabilities. No system today can stop short-range ballistic missiles, rockets, artillery rounds, and mortars. Yet, in a conventional conflict, these threats cause the most casualties. Furthermore, since rockets and mortars are used by many terrorist organizations, a weapon that can counter such threats is a high priority, especially in Israel. Both the IMoD and the U.S. Army therefore support the development of this new transformational weapon system.

The fact that the U.S. Army committed to fund the MTHEL development in the 2003–2007 timeframe manifests this support. Similarly, Israel has frequently stated the intent to share the cost of MTHEL development. With funding in place, a MTHEL prototype can be built in four to five years, leading to a shoot-down demonstration in the 2007–2008 time frame. Following its development, the system will undergo an extensive series of operational tests to resolve issues of doctrine, tactics, and procedures. A production capability could be developed in parallel, leading to an initial operational capability by 2010 or 2011.

5. Where Do We Go from Here?

Beyond MTHEL is a development path for an even more mobile tactical laser weapon system by reducing the size of MTHEL so that it is placed on a single high-mobility vehicle. An artist's conception of such an "objective THEL" fighting vehicle is shown in Fig. 8. This system will be designed to move with the force, provide first-line battlefield protection against a variety of air threats, and possibly "shoot-on-the-move." Significant technology advances will be required to move from MTHEL described previously to such an objective MTHEL.

Fig. 8. Future objective MTHEL concept.

6. Conclusions

THEL ACTD demonstrated that lasers are effective for defense against artillery rockets and projectiles. Some key technical issues had to be resolved first in order to demonstrate such effectiveness. One was the need for very precise beam pointing. The laser beam must be pointed at a specific aim point on a small target at range. Another issue was how to deal with the short timelines of threats. A tactical laser system must detect, acquire, track, destroy, verify kill, and retarget, all within a very short timeline. These and similar issues were all addressed and resolved on the THEL ACTD program, leading to successful artillery rocket and artillery projectile shoot-down demonstrations under a wide range of rocket attack scenarios. THEL has thus demonstrated that even a robust threat such as an artillery projectile can be destroyed by laser irradiation.

From an operational standpoint, THEL has proven that the technical, performance, and support issues of an integrated, stand-alone laser weapon system can be resolved. Furthermore, for nearly three years, THEL at the White Sands Missile Range has provided tremendous insight into the field operations and maintenance of a laser weapon system. The experience gathered from THEL will be invaluable in streamlining the development of the MTHEL weapon prototype.

MTHEL extends the capability of THEL ACTD in several key dimensions: 1) by making the system lighter and smaller, MTHEL facilitates deployment to a theater of operations and enhances mobility once in theater; 2) by negating a larger variety of targets, MTHEL greatly enhances its utility to the war fighter; and 3) MTHEL will fight in integrated teams, enhancing its force-on-force capability. MTHEL will be the vanguard of tactical directed energy weapons, paving the way for other such weapons on the transformed battlefield of the future.

The Authors

Joel M. Avidor received his B.S. in Aeronautical Engineering from the Technion, Haifa, Israel, in 1965, and his M.S. and Ph.D. in Aeronautics and Astronautics from the Polytechnic

Institute of Brooklyn, Brooklyn, NY, in 1968 and 1971, respectively. During his stay at AVCO Everett Research Laboratory, Everett, MA, 1971–1977, he worked as a principal research scientist in developing high-power CO_2 lasers. From 1977 to 2000 he was with Soreq NRC, Yavne, Israel, active in developing lasers and laser-based systems. Since 2000, Dr. Avidor has been the Israeli program manager of the joint U.S. Army/IMOD MTHEL (Mobile Tactical High Energy Laser) Weapon System program.

LTC Eliezer (Eili) Behar received his B.S. in Mechanical Engineering from the Technion, Haifa, in 1992. LTC Behar has been a member of the IDF since 1983. He served in the Israel Air Defense SHORAD battalions in various command positions until 1997. He then became the Israel THEL ACTD program office representative to the United States. In 2000 LTC Behar became the Head of System Branch in the Israeli MTHEL PO.

LTC Dennis Card, Ph.D., received his B.S. in Chemical Engineering from the University of Missouri–Rolla, in 1985. He received his M.S. and Ph.D in Physical Chemistry from Pennsylvania State University, University Park, in 1997 and 2000, respectively. He has conducted research in laser-matter interactions with mass spectrometers coupled to a femtosecond laser to understand the phenomenon of Coulomb explosion. At the U.S. Military Academy's Photonic Research Center, he used photoacoustic spectrometers to explore dimerization of gases. Since 2001, LTC Card has been involved with the MTHEL program as the deputy and now as the program manager. He is a member of ACS, AAAS, Sigma Xi, and AUSA.

Dr. John Nugent is currently the Deputy Program Manager for the Mobile Tactical High Energy Laser program for Northrop Grumman Space Technology. He has worked on air defense systems for 20 years, the last 7 of those years in the area of directed energy weapons for air defense. Dr. Nugent was part of the team that developed THEL ACTD. He holds a doctorate in physics from the California Institute of Technology. His undergraduate degree is from MIT, also in physics. Dr. Nugent is a member of the DEPS, AIAA, and Sigma Xi.

Dr. Josef Shwartz received his B.S. degree in Aeronautical Engineering from the Technion, Israel Institute of Technology, in 1961, and M.S. and Ph.D. degrees from MIT, in 1966 and 1968, respectively. From 1968 to 1975 he taught college and conducted research on electrical discharge lasers. Dr. Shwartz has been with Northrop Grumman Space Technology (NGST, then TRW) since 1975, working on development of high-power lasers. He was the Program Manager of the Nautilus Project that demonstrated, in 1969, that a high-power laser can shoot down a rocket in midflight. He is presently the NGST MTHEL Program Manager.

Gerald Wilson is the Lead Engineer for the ZEUS Program managed by the U.S. Army Space and Missile Defense Command. The ZEUS program, a self-contained high-energy laser system integrated on an up-armored HMMWV, is currently deployed. Previously, he was the Program Manager for MTHEL, THEL ACTD, and NAUTILUS efforts. Wilson has more than 29 years of professional experience in directed energy technology research and development, Naval Tactical Missile and Aircraft weapon system development, and in-service support. Wilson earned a B.S. degree in aerospace engineering from the University of Florida. He is a graduate of the Naval Aviation Executive Institute.