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Paper Session III-C - Ground Based Laser System -Defense at the Speed of Light

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GROUND BASED LASER SYSTEM - Defense at the Speed of Light

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Abstract

The United States and its allies face a potential threat of nuclear attack, intentional and accidental, from not only the Soviet Union but other countries that are developing a nuclear ballistic missile capability. The alarming fact is that the U.S. currently has no defense against ICBM attacks. The Department of Defense and scientific communities have become involved in multidiscipline scientific research in an attempt to develop a formidable defense network that would shield the U.S. and its allies from a nuclear attack. One such system in the concept development phase is the Ground Based Laser system. This system, if developed and deployed, will have the capability of destroying ballistic missiles (negating nuclear ballistic missiles is the objective) whose trajectories place U.S./allied locations at risk. The Ground Based Laser (GBL) system consists of ground and space based assets that are integrated to form a defensive shield against ICBMs. This paper describes the GBL system and how it evolved to the current concept. Also included in this paper are some of the major technology issues that must be resolved for successful deployment and some of the technology demonstrations that have been completed or are in progress.

INTRODUCTION

**** The United States of America - DESTROYED - ****
**** Massive Nuclear ICBM Attack Against the US ****

Even though the United States is the most powerful military nation in the world, there exist no defenses at all against Intercontinental Ballistic Missiles launched towards the U.S.. Our military capability could be destroyed in matter of a few minutes accompanied by a tremendous loss in american lives. It is almost a crime not to develop a capability to defend the US from such an attack. The Ground Based Laser (GBL) is a system, in the development phase, that would have the ability to negate a significant portion of incoming ICBMs.

The development of a Ground Based Laser (GBL) system is dependent upon the threat for which the it must counter, the required effectiveness, technology, estimated deployment time, and of course; cost (cost is a big driver). All of these factors are constantly changing resulting in a variegating GBL system. The evolution of the GBL system up to the current reference concept can be categorized into four periods. Each period is characterized by the threat that the system must meet and the state of technology for the given time period. The system that is current for a particular period is the result of the integration of the threat scenario, prevalent for the given period, and the current technology mixed with an appraisal of future technologies. Throughout all evolutionary periods, the representative system is cost optimized.

PERIOD 1

The system developed during this period was to be considered for far term deployment (phase 3) and had to counter the threat of a massive number of Soviet RVs. These RVs were to be deployed from boosters that were launched in an environment in which the entire force of Soviet boosters were launched at the same time; a spike launch. The methodology enacted to destroy these RVs was to attack them while they were still on the booster in the boost and post boost phase of flight. The system was required to negate a significant portion of the RVs and the most efficient means of accomplishing this goal was to annihilate them while still on the booster. An additional threat that had to be countered were fast burn boosters. It was believed that the Soviets would be able to deploy fast burn boosters by the time the GBL system would be deployed. The additional threat from fast burn boosters is that the boosters burn for a shorter period of time and do not reach an altitude as high as the ICBM boosters in their current arsenal. These boosters will seriously tax the GBL system due to the limited engagement time, on the order of few tens of seconds, caused by the spike launch scenario.

Technology for this period had not progressed enough to determine specific sub-systems that could be incorporated into the over all GBL system. Two candidates for the laser device were selected; the Free Electron Laser (FEL) and the Excimer laser. The Afocal mirror and the Bifocal mirror were the favored candidates for the mission mirror. The Afocal mirror was cheaper to build per satellite and had unlimited beam turning angles capability, but had slower retarget time compared to the bifocal mirror. The bifocal mirror had unlimited beam turning angle capability as well as a shorter retarget time when compared to the afocal. The cost per satellite, however, was more when compared to it's rival afocal mission mirror.

The basic GBL system that was to satisfy the requirements for this period consisted of a moderate power FEL with a wavelength of 0.8 μm. There were to have been many beams in a missile negation battle, each aimed at a large diameter mission mirror which was in a medium earth orbit. The mission mirror would direct the ground emitted laser beam towards a target marked for destruction. The mission mirror would focus the beam onto the target until it was destroyed. The laser beams would have been located at sites placed strategically throughout the world.

This system was adequate to meet the threat established for this stage of its evolution. However, a new type of threat was defined and many technology assessments were conducted that more clearly defined the type of systems that would be used in a typical Ground Based Laser system. These forces combined to move GBL to it's next stage of evolution - period 2.

PERIOD 2

During this period, the GBL was being considered for nearer term deployment and would have to engage a mixed force of Soviet ICBMs. The mixed force of boosters included the current generation of boosters as well as fast burn types. This launch scenario would force the GBL system to deal with a massive number of RVs. A high negation rate was expected due to the increase in mean booster burn time. The policy of boost phase engagement was still considered the most efficient way of destroying warheads. The main differences between the threat for this period and the previous period is that the GBL system was being considered for earlier deployment and the type of boosters the system would engage.

Technology progressed to the point of determining a single candidate for the laser. The leading contender was the Free Electron Laser (FEL). This FEL was selected over the excimer because it had greater efficiency, better atmospheric transmission qualities (a function of wavelength), and was lower cost. The next major decision to be made concerning the laser is whether to use an Induction Linac (IL) FEL or to use a Radio Frequency (RF) Linac FEL.

The second stage GBL system consisted of CONUS located, for reasons other than technological, ground sites with RF FELs at each site. The limited basing of the ground sites reduced Earth coverage to less than satisfactory levels. As a result, a requirement for deploying relay mirror satellites in high earth orbit (HEO) was created. Using the relay mirrors, the laser beams could be directed from the ground site to the fighting mirror in medium earth orbit (MEO). This would restore coverage of the Earth to a satisfactory level. The stage 2 system would have fewer beams in the battle, as a consequence of the reduced threat justified by the mixed booster force, and still achieve high RV negation as required. It was determined that the optimum wavelength for the FEL was 1μm to reduce the effects of atmospheric absorption.

PERIOD 3

The GBL program advanced to this stage of it's evolutionary development on the crest of another threat reduction wave as well as a shortened deployment schedule. It was perceived that the system needed to be able to meet a phase II deployment requirement allowing the integration of the GBL program, along with Kinetic Energy Weapons (KEWs), into an overall Strategic Defense System (SDS) serving with Kinetic Kill Vehicles (KKVs). The threat engagement scenario was a mixed booster force launched in two waves. Fewer number of RVs, as compared to the previous period, was expected as well as a lower RV negation requirement.

The technology side of the house narrowed it's list of possible GBL system elements somewhat. The stronger choice for the laser element was the RF FEL, however, the IL FEL had not been ruled out. The choice for mission mirror was still between one of three options; monocle, afocal, or bifocal.

The points illustrated in the previous two paragraphs led to a representative stage 3 GBL system that consisted of CONUS located ground sites with FELS located at each site. The output of the FELs was to operate at a wavelength of 1 μm for greater atmospheric transmission capability. The beam would be aimed at a relay mirror and, from this point, be directed towards a fighting mirror. This whole operation would be under the control of some type of automated battle manager. The relay mirrors were to be placed in high earth orbits to insure sufficient availability to the ground sites. The mission mirrors were circling the earth in medium earth orbits. Threat requirements and cost optimization led to the criteria of having fewer beams in a particular battle and each of these beams were at a lower power level compared to the earlier versions of the GBL system.

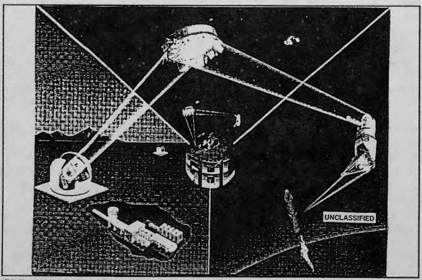
PERIOD 4

Period 4 represents the current stage of the evolutionary cycle of the GBL program. The program is being geared for a phase II deployment and integrated into the overall SDS structure to include serving as a mixed force with KEWs. The threat the GBL system must contend with is a mixed force of Soviet boosters that are launched as fast as possible (compressed launch) using anticipated launch capabilities that will prevail during the GBL deployment and operational period. The GBL must confront a larger number of RVs, as compared to the previous period, but the RV negation requirement is less. An additional mission has been assigned to the GBL program and that is of midcourse target identification. This involves the discrimination of all decoys and RVs in the midcourse phase of the missile and handing over state vectors of the objects to the KKVs.

The RF FEL, operating at a wavelength 1 μm, has been selected as the laser subsystem for the GBL project. Retargeting capability as well as overall mission satellite constellation cost led to the selection of the bifocal mission mirror as the fighting satellite with the monocle relay mirror as the laser beam relay device.

These facts, which were dominate during period 4 led to the GBL system that is commonly referred to as the current reference concept. The reference concept is described in more detail in the following sections of this paper.

GROUND BASED LASER SYSTEM REFERENCE CONCEPT



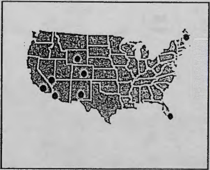
GBL REFERENCE CONCEPT

The GBL reference concept can be divided into two broad segments: the ground segment and the space segment. The ground segment consists of several sites located throughout the Continental United States. These sites are located in such a manner as to insure that the probability of at least one site being operational is sufficiently high, regardless of the national weather pattern. Each site is equipped with RF FELs that operate at 1 μm and are also equipped with fuel storage facilities, laser facilities, personnel and maintenance facilities. Each site will be a fully functional, independently operating facility. The space segment incorporates a multi-functional satellite constellation that provides the capability of directing a laser beam emitted from the ground to a target as determined by a battle manager. The satellite constellation incorporates three types of spacecraft; beacon satellites, relay mirrors, and mission mirrors. The beacon satellite orbits a specified distance from the relay mirror and its function is to transmit a beacon laser to a ground site. This beacon is used by the ground site to determine atmospheric conditions so that the necessary commands can be relayed to the laser's adaptive optics system. The relay mirrors, operating in a high earth molnoyia orbit (HEO), are responsible for directing the energy beam from an active ground site to a designated mission mirror. The purpose of the mission mirrors are to acquire and track an assigned cluster of targets, accept the beam from the relay mirrors and concentrate the laser energy onto the targets. The mission mirrors are of the bifocal type and operates in a medium earth orbit (MEO). The whole operation of the GBL during a hostile engagement is controlled by central battle manager.

The reference concept represents the most current system designed to meet the goals established by the Strategic Defense Initiative Organization (SDIO). These goals state that the GBL system should be deployed during the phase II period and work concurrently with phase I architecture. As a result, RV negation requirements are not as high a they have been in the past, allowing for a reduction in cost while maintaining an impressive missile defense capability. The following discussions present a more in-depth study of the major components that make up the GBL reference concept.

GROUND SITE

The Ground Based Laser system must have ground sites spread out over several locations in order to insure that the probability for a cloud free line-of-sight to a relay mirror is 99%. The optimum areas for these sites is to have them scattered at strategic locations throughout the world. A problem that becomes immediately obvious is the politics involved in having a major US military asset located in a foreign country, as well as providing the extraordinary security that will be necessary to safeguard the sights located outside the United States. The next best option is to place the sights within the continental United States. Several studies have been performed to determine where the best CONUS locations will be for the smallest number of outages throughout the year. The results indicate the ideal areas in the southwest and southeast.



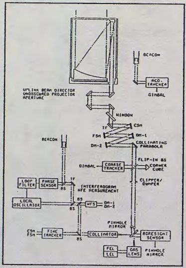
PROPOSED US SITES

RF FEL

Each site will have multiple megawatt class RF FELs operating at a wavelength of 1.06 μm. A Free Electron Laser (FEL) is a device which amplifies short wavelength radiation emitted during the conversion of electron kinetic energy to radiation. The energy conversion occurs in a device called the "wiggler" causing the motion of the electron to oscillate periodically, converting the kinetic energy of the electron to radiation. The RF FEL operates in a master oscillator-power amplifier (MOPA) configuration with the master oscillator being a self-contained FEL. Within the master oscillator, an RF accelerator raises the energy of injected electron "bunches" to the MeV range through a series of coaxitron cavities. The accelerated electrons are applied to the wiggler where the energy of the electron packets are converted to optical pulses and amplified after several passes, or oscillations, through the wiggler assembly. The result is an optical seed pulse, of 1.06 μm, which is applied to the power amplifier. Here, the seed pulse is amplified through a one-pass wiggler by the extraction of the energy possessed by electrons ejected from an rf accelerator (separate from the master oscillator accelerator). The output is an optical beam with a power level on the order of tens of megawatts. This intense beam is passed through a gas lens which expands the beam and focuses it onto to the next optical element within the beam control system.

BEAM CONTROL SYSTEM

The intense laser beam output from the FEL power amplifier, once it passes through the gas lens, begins it's journey through the beam control system (BCS). The BCS performs the critical tasks necessary for acquiring and tracking of cooperative space targets and propagating the beam through the atmosphere to the relay mirror. It consists of the beacon telescope, beam transfer assembly, optical beam steering assembly, the acquisition tracker, and the wavefront aberration compensation device. The initial operation of the BCS is to acquire the cooperative space target, the beacon satellite, and aim the beam director towards the satellite. The acquisition process involves pointing the beam director in the expected position of the spacecraft and acquiring the laser beacon emitted from the beacon satellite. Once this is accomplished, the course and fine trackers fix and maintain precise alignment with the relay mirror. Upon relay mirror lock, the laser beacon is sampled for wavefront errors (WFE) using the WFE interferometer. As the beacon laser enters the atmosphere, the phase-front of the



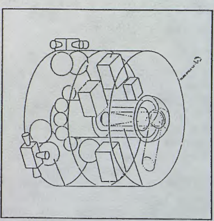
BEAM CONTROL SYSTEM

propagating wave is spherical. While the beam is transversing the atmosphere, the phase-front becomes distorted by the path characteristics of the turbulent and heated atmosphere. The WFE interferometer detects the wavefront aberrations and sends correction signals to the deformable mirrors. These signals alter the surface of the mirror so that WFE compensation occurs by modifying the FEL beam phase-front. The FEL is brought up to full power, passes through the gas lens, travels through the steering optics and phase-front modification optics, and emitted by the beam director. A portion of the outgoing beam is sampled by wavefront sensors so that the phase-front can be compared with the phase-front of the incoming reference beam from the beacon satellite. Any difference is compensated by control signals, originating from the WFE interferometer, sent to the deformable mirrors. Boresight feedback looping is used to insure that the FEL laser beam is centered properly on the relay mirror. The feedback loop consists of sensors in the relay mirror that detects the location of the center of the beam. Control signals are relayed to the ground station that instruct the optical steering mirrors to adjust the beam. The beam director consists of a large primary mirror and an off-axis secondary mirror both of which are attached to a gimbal device.

PRIME POWER

The entire ground site will require a tremendous amount of electrical power. The most attractive option for power generation is to use high speed diesel generators. Other systems under consideration are batteries and superconducting magnetic energy storage devices (SMES). The key issue involved in selecting a suitable power source is the required start up time. It is hypothesized that the start up time will be in the neighborhood of 10 to 20 seconds. Batteries and SMESs can deliver full power in about a second but cost, maintainability, or un-proven technology make these power sources less attractive compared to HS diesel generators.

The preceding sections have described the major systems incorporated within the ground site. The major systems that comprise the space segment of the GBL system will be described in the following sections.



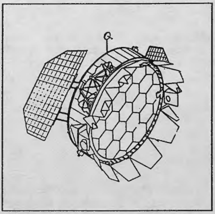
BEACON SATELLITE

BEACON SATELLITE

The function of the beacon satellite is to transmit a low power laser beam through the atmosphere to the ground site. The purpose of this beam is two-fold; to serve as a guide for the beam director tracking mechanisms and to provide atmospheric refractive index information to the groundsite wavefront sensor. The satellite orbits a few hundred meters ahead of the relay mirror. The actual fly-ahead distance is determined by the product of the round trip distance from the satellite to the ground at the speed of light and the satellite speed. Although nuclear power was considered as a means of supplying primary power, solar power was selected as the primary power source.

RELAY MIRROR

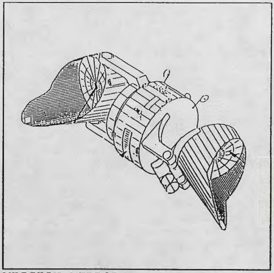
The primary mission of the relay mirror is to direct the ground originating laser beam towards an active mission satellite. The relay mirror will be of monocle configuration consisting of individual controllable mirror segments assemble together to form a large circular mirror. Beam relay angle is controlled by a combination of spacecraft slewing and mirror segment tilt adjustments. The satellite is pointed by simultaneously viewing alignment beacons from the ground site and the mission mirror and comparing them an on board steering beam splitter corner-cube system. This pointing system is called the Optical Alignment angle Locator (OPAL). Upon an error in the alignment beacons, the relay mirror is course aligned by slewing using Control Moment Gyros (CMGs) and the fine alignment is achieved by segment tilt. Fine alignment of the segments is achieved using grazing incidence interferometry (GII). Primary power will be supplied by a battery/solar array system. The relay mirrors will be in a molnoyia orbit with a period that will allow the necessary access time required by the ground stations to insure an adequate defensive posture.



RELAY MIRROR

MISSION SATELLITE

The mission satellite, sometimes referred to as the fighting satellite, will acquire, track, and point the incoming laser beam to a designated target. The mission mirror also has the capability to "clean up" the outgoing laser beam. The mission mirror is of bifocal configuration with an off-axis beam expander for the receiver and transmitter assemblies. The spacecraft is composed of three main sections; receiver, turntable, and the transmitter. The receiver accepts the laser beam from the relay mirror, propagates it through the turntable, and focuses the beam onto a target. Alignment between the receiver and the relay mirror is accomplished using HEL sensors and a laser beacon emitted from the relay mirror. Course alignment is accomplished by capturing the incoming laser beacon from the relay mirror while fine alignment uses beam walk sensors and HEL intensity sensors. The transmitter is aimed at the



MISSION MIRROR

target using a complicated acquisition, tracking, and pointing system. The type of ATP system that will be used is still a much debated topic and a discussion of each of the candidates is a subject for another paper. As the HEL beam is transmitted towards the target, a small portion of the beam is sampled by the outgoing wavefront sensor (OWS). The light is diffracted into the OWS by holographic optical elements (HOEs) for determination of the outgoing beam quality. Any wavefront aberrations are corrected for by sending the appropriate control signals to deformable mirrors located within the optical path. Internal beam alignment is accomplished using incoming and outgoing wavefront sensors as well as steering mirrors. Beam pointing is accomplished by spacecraft slewing, transmitter pointing, and optical steering. Optical steering is accomplished using a combination of course and fast steering mirrors. Batteries and solar cells will provide power for continuous operations supported by high density fuel cells for peak power requirements. The mission mirrors will be in circular orbits with the necessary parameters to insure that adequate global coverage can be maintained at all times.

The preceding paragraphs presented a top level description of the GBL system reference concept. To delve deeper into the system would require much more space than what is allocated for this paper. The elements just described are of the necessary systems required to deliver a beam to a target. A summary description of the beam path states that the laser beam is generated from an RF FEL and aimed at a relay mirror. The relay mirror directs the beam to an active mission mirror which in turn directs the laser to a target. The beam path, from ground to target, contains many elements which serve to degrade beam quality and promote beam deterioration. As a result, about 20% of the beam first emitted from the FEL is available for target destruction. Before the GBL system can go into full scale development, many technologies must be demonstrated. In the next few paragraphs, a brief synopsis will be presented that highlights some of the technology demonstrations that have occurred and some that are planned.

TECHNOLOGY DEMONSTRATION

An RF FEL has not been developed that demonstrates FEL performance that can be scaled to power levels greater than 1 MW. Some critical technology issues that effect the development effort are obtaining the required beam quality necessary at high powers, jitter control, the efficiency of the master oscillator and power amplifier, optics power tolerance, optical guiding, accelerator performance, and electron beam injector performance. Each of these issues can be decomposed into components with developmental problems associated with each. The are some major technology demonstration programs in existence that have attempted or will attempt to tackle some of these critical issues. Some of the organizations involved in technology experimentation are Boeing, Rocketdyne, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Stanford and Duke University. Recent breakthroughs include the first successful FEL oscillator run with a laser driven cathode, first all FEL MOPA configuration was demonstrated, as well as a series of successful specific laser components technology demonstrations. The US Army Strategic Defense Command's Ground Based Free Electron Laser Technology Integration Experiment (GBFEL-TIE) will provide technology for the further development of the FEL. Future work includes studies of the salability of the major components that will be integrated into the RF FEL so that weapons class power can be obtained. A major problem with further studies is funding.

The number of ongoing optics experiments are numerous but three important ones for GBL are the Large Active Mirror Program (LAMP), Large Optics Demonstration Experiment (LODE), and the Large Optical Segmentation (LOS) program. The Large Active Mirror Program is a completed program which proved successfully that a large deformable mirror can be produced. The diameter of the deformable mirror constructed under this program was 4 meters. The topic that has to be addressed, concerning LAMP, is the scalability of the mirror to the size necessary for GBL as well as designing a mirror to handle the necessary power loads. LODE was an experiment to demonstrate beam control operations as well as wavefront correction. A small (compared to the needs of GBL) beam expander was constructed similar to the ones that will be used with the GBL system. LOS is a successful technology demonstration program that involved the construction of a 4 meter mirror segment. A group of these mirror segments will be assembled together to form a large primary mirror for use with the GBL system.

Testing of the feasibility of a satellite to reflect an incident laser beam, originating from a ground site, to a geographically separated ground target is one of the missions of the Relay Mirror Experiment (RME). Initial experiments have already been conducted with success. The future of this program is threatened because of the familiar funding shortage.

A major "show stopper" for the GBL program are the issues concerning the propagation of a high power laser beam through the Earth's atmosphere. Some experiments under way to deal with this problem are the Scaled Atmospheric Blooming Experiment (SABLE) and the Low-Power Atmospheric Compensation Experiment (LACE). SABLE involves the conducting of atmospheric propagation experiments to investigate phenomena affecting the correctability of thermal blooming and turbulence by adaptive optics. LACE is an atmospheric compensation experiment that will measure beam characteristics of a laser beam after it passes through the atmosphere. These measurements will be compared to theoretical predictions to validate a myriad of models used to predict the behavior of the atmosphere.

CONCLUSION

This paper has described the evolution of the proposed technological marvel called the Ground Based Laser System. A careful study of the GBL evolution reveals that the overall design of the system is fairly constant regardless of the threat against which GBL would have to counter. A top level description of the current concept was presented and some basic conclusions can be formulated about the GBL. The Ground Based Laser weapon system is a high power system that would be capable of negating a significant number of ICBMs launched against the United States, thus preserving our warfighting capability as well as saving the lives of millions of people. A further solidification of our warfighting capability would take place by adding the anti-satellite role to the original mission of the GBL system. By pursuing this option, millions of dollars could be saved as a result of the reduction of redundant research being conducted in this field. The Ground Based Laser system will be an awesome weapon system. However, more research needs to be conducted so that the technology, that will optimize the proposed capabilities of the system, may be conducted. It is imperative that more funding be approved so that the system can be deployed in the near future. We have already seen the deterrent capability of the system while it is still in the development phase...imagine the power that an actual, working system will portray to any potential aggressor.