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COMPACT IR LASER FOR CALIBRATION OF SPACE BASED SENSORS

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Abstract

An Er:YAG laser, operating at 2.94 microns, has been developed for in theater calibration of space based infrared sensors. The laser is used to illuminate a spaceborne sensor focal plane from a surveyed ground reference point. The known reference point is compared to the laser position reported by the sensor, and boresight corrections are made. The Er:YAG laser is side pumped by a InGaAs diode array and is tuned to an atmospheric microwindow with an intracavity etalon. This technology is being directly applied to meet Army requirements for enhanced deep strike targeting information supplied to theater weapons systems.

1. Introduction

Battlefield requirements for the next century demand intelligence and warning systems that see deep into enemy territory with a timely feed into theater systems. To answer this need, space based early warning systems are increasingly being used to support the warfighter. These systems, designed and used primarily for strategic warning in the past, are now considered an integral part of theater warning systems that give us the advantage over our adversaries. The Tactical Event Systems (TES) were developed to bring information from space platforms directly into the theater. However, improved sensor accuracies will enhance their value to the theater commander. In its original strategic role, for example, Defense Support Program (DSP) is used to determine where (i.e. what country or region of a country) a ballistic missile launch originated. This translates to allowable uncertainties of thousands of miles. For theater application, however, much better accuracies are required if we are to give our weapons systems a chance to locate and destroy a mobile Theater Ballistic Missile (TBM) transporter-erector launcher (TEL) before it can run and hide.

In this paper we report on the application of an advanced solid state laser that will be used to help meet the Army's battlefield requirements for deep strike targeting. We present a description of the current laser, developed at Lawrence Livermore National Laboratory (LLNL), and discuss warfighter demonstrations to evaluate the utility of in theater calibration to the warfighter. The laser is a tunable Er:YAG, which is side pumped by a InGaAs diode array and generates more than 500mW of output power at 2.94 micrometer wavelength[1]. This compact, environmentally safe laser will be used in conjunction with the Army's Joint Tactical Ground Station (JTAGS) to calibrate infrared sensors on DSP satellites. The "laser boresight calibrator", used in conjunction with JTAGS and other DSP ground stations, will provide the required accuracies for U. S. battlefield offensive systems.

2. The Defense Support Program: Evolving to Support the Warfighter

The DSP satellites, operated by the U.S. Air Force, are in geosynchronous orbit and provide worldwide coverage to detect ballistic missile launches. These satellites were originally designed as a strategic asset, not a battlefield asset. Until the Gulf War in 1991, they were used almost exclusively for strategic warning, i.e., to provide warning of a ballistic missile attack on the United States. In the Gulf War, however, DSP satellites were used to monitor Iraqi Scud missile launches. Information gleaned from DSP was routed from the receiving station in the U.S. back into the theater to offensive systems that would attempt to destroy the mobile SCUD launcher and intercept the incoming SCUD missiles. While the PATRIOT Air Defense systems had limited success intercepting the SCUD missiles, there were no reported kills of a TEL.

The success of DSP in providing warning during the Gulf War lead to the Joint Army-Navy program to build JTAGS, an in-theater capability to receive and process DSP data. This is a necessary step, and will minimize Command and Control timelines used to commit our deep attack and missile defense systems that so critically depend on time to react to the incoming missiles. The JTAGS program recently received approval to begin production of 5 complete systems beginning in 1996. We can do even more to enhance the in-theater capability of DSP and JTAGS by taking advantage of the inherent and, thus far, untapped capabilities of the DSP sensor suite. The in theater laser calibrator will enable us to fully utilize that capability by significantly improving the accuracy of missile launch point and impact point predictions.

3. Increasing the Depth of the Battlefield: Army Requirements

Force XXI promises to provide the Army with the most advanced weapons systems ever seen on the battlefield. Deep strike weapons, like the Army Tactical Missile System (ATACMS), are extending their reach so that "range" may no longer be the limiting factor in their employment. Figure 1 shows a conceptual engagement, by ATACMS, of a mobile Theater Ballistic Missile (TBM) Erector Launcher. The enemy TEL is identified, upon the launch of it's payload, by a DSP satellite, which passes the information along to JTAGS. Eventually, the data works its way to ATACMS or some other Deep Strike system whose mission is then to track and/or destroy the TEL before it leaves the area.

Figure 1. Graphic picture showing (a) TEL moving as ATACMS shoots, (b) TBM intercept, and (c) impact and launch point estimates using DSP data.

There are three key ingredients to success in this mission. They are (1) ATACMS footprint or kill zone, (2) reduced Command and Control timelines, and (3) reduced uncertainties in TEL location. Deep attack systems must have timely and sufficiently accurate target launch point estimation before committing an expensive surface to surface missile (SSM) and to permit selective TEL engagement rather than utilizing the more costly area barrage approach. The launch point circular error probability (CEP) plus the distance that the target can move during the commit and fly out time must be less than the munition footprint (see figure 2).

Emerging requirements are consistent with this idea. Today's Army is pursuing technologies that will (a) detect enemy weapons platforms on the battlefield, (b) link intelligence and electronic warfare (IEW) and attack systems in near real-time, and (c) increase the accuracy and lethality of our own deep strike weapons systems.

Spaceborne sensors, such as the Defense Support Program (DSP) satellites, serve as our first indication of theater ballistic missile threat launch. They provide (see figure 1) impact point predictions

launch point determinations, and hand-over data to missile defense systems. The accuracy of these sensors can be significantly improved through in-theater calibration using a very bright source (a beacon, i.e. a source that DSP sensors will detect) positioned at a known ground point. The principle of operation is to use the beacon(s) to introduce corrections to a JTAGS calculated target location based on errors from the known beacon location(s).

Such a beacon could be used in conjunction with or as part of the JTAGS, where corrections to the DSP readings can be made in an integrated manner with reduced manpower requirements. The beacon could also be employed at one or more locations within the theater and have a communications link to JTAGS.

4. The Er:YAG Laser

A laser is an obvious choice as the high brightness in-theater calibration source because its narrow beam width permits delivery of high power densities at long ranges. The challenge is to develop a compact laser of sufficient power to reach through the atmosphere into space, and which operates at a wavelength in the sensitive regime of the DSP sensor. The need for laser wavelength selectivity is illustrated in Figure 3 which shows atmospheric transmission microwindows (from a High Trans calculation) and the tuning range of the laser developed for this mission.

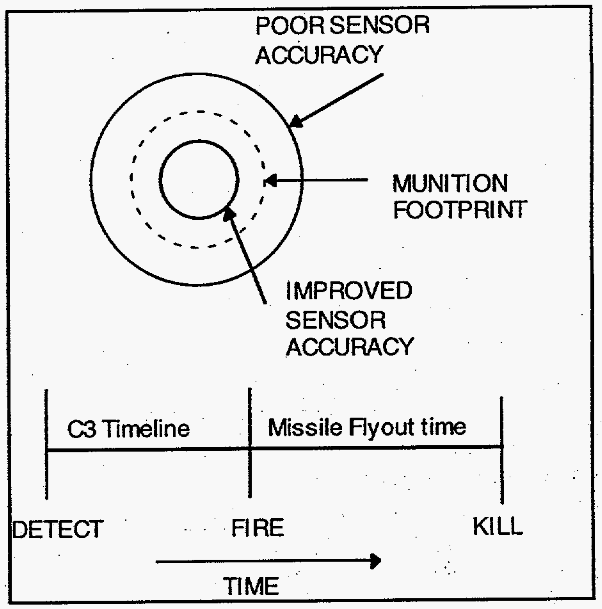

Figure 2. Sensors must provide sufficiently accurate target to allow for the C3 and missile flyout tmes. Improved sensor accuracy buys more time for C3 and missiles

The calibration system of choice uses a pulsed Er:YAG laser developed at Lawrence Livermore National Laboratory (LLNL)[1]. This laser is chosen because it is compact, environmentally safe, and provides sufficient power at a desirable wavelength (figure 3). The laser (figure 4) is side pumped by an InGaAs diode array stack, also developed at LLNL[2], and can generate over 500 mW average power at 2.94 micrometer wavelength in the absence of the wavelength tuning element. Using an intracavity etalon the laser is tunable (with some loss in power) over a 6nm range, allowing it to be operated at a minimum in the atmospheric absorption profile. Before development of this laser, Er:YAG lasers had been end-pumped monolithic devices that were limited to a maximum of 200mW output power.[3]

Much of the difficulty in obtaining higher average power from the Er:YAG stems from the unfavorable lifetimes of the upper and lower laser levels (90 ms and 4.0 ms, respectively[4]), the complex state dynamics, and a low stimulated emission cross section. Quasi-cw lasing is possible for two reasons. Thermal distribution of states among the Stark sub-levels favors lasing at 2.94 mm, corresponding to the transition between lowest sublevel of the upper state and highest sublevel of lower state. In addition, a high concentration of Er^{3+} ions favors cross relaxation between neighboring ions in the lower lasing level, in which the excitation energy of one ion is transferred to another, driving one to ground and the other to a resonant state above the upper lasing level which decays non-radiatively to the upper laser level changing the population inversion by three (figure 5). The higher power required for calibration of space borne sensors was achieved by using high Erbium doping levels (50% Er-doped YAG) to improve cross-coupling between Er3+ ions, and by using side pumping at a total internal reflecting face to maximize coupling between pumped region and the transverse cavity modes. A high power laser diode stack with microchannel cooling is used for efficient, compact laser excitation.[2] The low quantum efficiency of 33% limits the ultimate operating efficiency of the system.

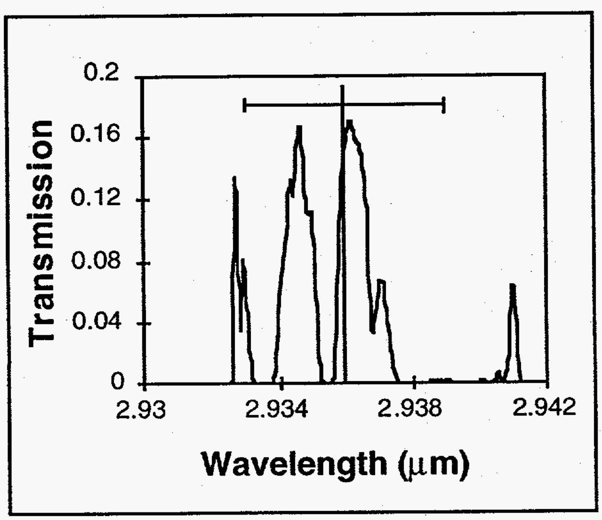

Figure 3. Representative atmospheric transmission and tuning range of Er:YAG laser.

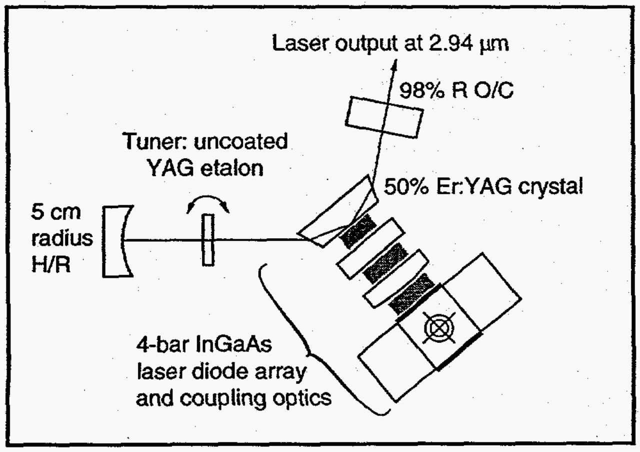

Figure 4. Schematic of Er:YAG laser developed for the LLYNX-Eye calibration system.

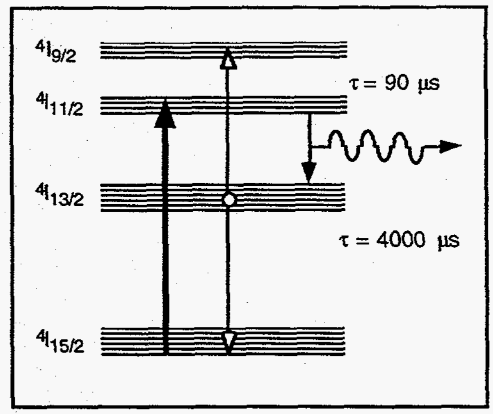

Figure 5. Energy levels in Er:YAG crystal (not to scale). The upper laser level is pumped directly from the ground state. The lower laser level undergoes cross-relaxation, driving one ion to the ground state ad the

5. Warfighter Demonstration in 1996

The Army Space & Strategic Defense Command is working on a Joint project with the Air Force, Navy, and DOD Counterproliferation Office to conduct a series of field calibration exercises using the LLNL LLYNX Eye system (figure 6). LLYNX Eye is a prototype system, consisting of the laser beacon, a computer-controlled pointing and tracking system, and a GPS receiver. The exercises include calibrating the DSP satellites in a realistic field environment with JTAGS. These exercises will provide information relating achievable accuracies to frequency of calibration and beacon location. The results will also be used to determine software modifications for DSP ground stations and to evaluate the utility of the in-theater laser boresight calibrator on the battlefield.

Figure 6. LLYNX Eye Prototype System

6. Future Developments: The Super Laser

If in theater calibration proves to be a cost effective approach to enhancing warfighter capabilities, a user friendly ruggedized prototype calibration system will be developed and provided for JTAGS pre-planned product improvement (P3I) evaluation.

Higher laser power will improve the robustness of the prototype system and expand possible applications. The current limit to output power is strong thermal lensing which occurs along the pump face due to the high absorption coefficient (14 cm^{-1}). Current efforts toward increasing output power are directed at shaping thermal gradients by cooling through the pump face and redesigning the laser cavity to better accommodate the residual thermal lens. Another possibility includes the use of multiple gain elements in the laser cavity. Also under investigation is a hollow fiber waveguide to deliver power to the tracking system from an off-board laser head.

7. Summary

The Er:YAG laser is being applied to battlefield requirements that demand improved target location data in order to fight and win the deep battle. Preliminary tests have shown that that laser boresight calibration can significantly reduce target location errors for satellite data. A series of laser boresight calibration tests are being conducted in 1996 to quantify the calibrated satellite accuracies and to evaluate the benefits of placing the calibrator in-theater with JTAGS.

Acknowledgments

This project represents an excellent example of how cooperation among government agencies can lead to direct and useful application of technologies to support the Warfighter. Our thanks and appreciation is extended to the United States Air Force DSP Project Office, and the U.S. Space Command for their support for this program.

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