The Space Congress® Proceedings

1979 (16th) Space: The Best Is Yet To Come

Apr 1st, 8:00 AM

Air Force Space Laser Communications

Charles E. Whited
USAF, Chief, Systems Engineering, Air Force Space Laser Communications Program, Deputy for Space Communications Systems, Space and Missile Systems Organization

Scholarly Commons Citation
Whited, Charles E., "Air Force Space Laser Communications" (1979). *The Space Congress® Proceedings*. 5.
https://commons.erau.edu/space-congress-proceedings/proceedings-1979-16th/session-2/5

AIR FORCE SPACE LASER COMMUNICATIONS

Charles E. Whited, Capt, USAF, Chief,
Systems Engineering
Air Force Space Laser Communications Program
Deputy for Space Communications Systems
Space and Missile Systems Organization
Los Angeles Air Force Station, California 90009

ABSTRACT

In 1970 the United States Air Force created the Space Laser Communications (LASERCOM) Program in order to develop system concepts and component designs for high-data-rate laser communications systems. By 1975, a space-qualifiable engineering model of a one gigabit-per-second spaceborne transmitter had been developed and fully tested. Since then, that transmitter and a brassboard receiver have been used in a laboratory test bed environment to extensively investigate and demonstrate the system capabilities of laser communications systems. The system program has now entered its field test phase. Laser communication systems have potentially unique application to certain satellite-satellite and satellite-aircraft links, whereas application to other communication links will require detailed cost analyses. Some communications links may be most effectively satisfied by a hybrid LASERCOM and radio frequency system.

INTRODUCTION

As the requirement of higher data rates in future communications links becomes apparent, the development of laser communications (LASERCOM) systems becomes inevitable. LASERCOM can be used for satellite-satellite, satellite-air, and, under favorable ground conditions, even satellite-ground communications. In addition to the high data rate advantage of LASERCOM, the narrow transmit beam and narrow receiver field of view provide inherent privacy and jam resistant characteristics. Aircraft to aircraft communication beyond line of sight is another requirement that is easily satisfied by LASERCOM through a relay satellite; further, multiple aircraft simultaneous low data rate reporting via a satellite is possible through current designs and preliminary hardware development.

In the early 1970s, as the Air Force LASERCOM Program started to evolve, the decision was made to develop the system around the Nd:YAG laser. This decision was based on the state of development of the Nd:YAG laser, the ease of modulation using short-pulse modulation techniques, the simplicity of direct detection that can utilize sensitive room-temperature devices, and the overall communications link efficiency as compared with the closest competitor for a gigabit-per-second system, the CO_2 laser. An associated factor in this decision was that NASA was developing a CO_2 system; therefore both concepts could be pursued simultaneously. Subsequent to that decision by the Air Force, NASA terminated its development. A summary of the state of the art in CO_2 laser communications has been provided by McElroy, et al (1).

The purpose of this paper is to provide a general appreciation for the LASERCOM Program as it stands today, to review in layman's terms the status of the technology, and to discuss the airborne flight demonstration, system characteristics, and potential system applications. The technical details of the LASERCOM system as it has evolved over the last eight years and a complete set of references were recently documented by Ross, et al (2).

STATUS OF LASERCOM PROGRAM

In 1971 and 1972 the preliminary component and system design and component development were conducted by the Air Force Avionics Laboratory through both in-house and contractual efforts. In 1973, two contractors, McDonnell Douglas Astronautics Company-East-St. Louis, Missouri, and Lockheed Missiles and Space Company, Palo Alto, California, each built a gigabit-per-second brassboard laser transmitter and receiver. These favorable results led to the development and test in 1974 and 1975 of a space-qualifiable engineering-feasibility model of a gigabit-per-second transmitter built to form, fit, and function by McDonnell Douglas. This engineering feasibility model was the prototype for the transmitter to be built, qualified, and flown aboard a dedicated LASERCOM satellite.

Because of the potential applications and the direction for a space demonstration, the LASERCOM Program Office was moved to the Space and Missile Systems Organization, Los Angeles, California in 1975. The space system development was initiated and the demonstration scheduled for launch in 1979, with McDonnell Douglas under contract to build, launch and demonstrate laser communications between a satellite and a ground station at Cloudcroft, New Mexico. After approximately 18 months, the space demonstration was cancelled because of budgetary cuts at the DoD level, even though no technological or financial problems existed within the LASERCOM Program.

In November 1977 the program was directed to conduct an aircraft-to-ground demonstration by 1980. The redirection was to perform ground and airborne demonstrations of a gigabit-per-second laser communications system; continue the development of selected components for future space applications; demonstrate the inherent system characteristics (high data rate, private and jam resistant); define the necessary interfaces to make the LASERCOM system interoperable with radio frequency communications; and provide for the transition of the developed LASERCOM technology to operational systems.

For the ground-to-ground communications demonstration, the LASERCOM system has been moved from the laboratory environment at McDonnell Douglas in St. Louis, where the engineering feasibility model and brassboard receiver had been undergoing system tests since 1975, to a test site at the Army's White Sands Missile Range in New Mexico. The Range is extremely large, approximately 40 by 80 miles, and has the necessary restricted air space. The particular site (Cowan) was chosen with safety in mind. During both ground-to-ground and air-to-ground tests, the laser beams leaving the boundary of the Range will not have sufficient energy to cause safety problems.

The test/demonstration program at Cowan Site began in September 1978. Communications at one gigabit-per-second along a two kilometer transmission path were almost immediately successful. That path is believed to be the atmospheric equivalent, or perhaps even a worse case, of the anticipated fifty kilometer air-to-ground path, which is itself a worse case approximation of anticipated satellite-ground and satellite-aircraft link applications. This series of tests, which has recently been completed, has demonstrated conclusively that high-data-rate laser communication systems can in fact operate outside of the laboratory in a "real" environment. In October 1979 the initial series of air-to-ground flight tests will be conducted to demonstrate the system's dynamic acquisition and pointing capability. The final flight tests will be conducted in 1980 with the full-up system communicating at one gigabit-per-second along a fifty-kilometer air-to-ground path.

STATUS OF LASERCOM TECHNOLOGY

From its inception, the LASERCOM Program has continuously analyzed in detail the system requirements for high-data-rate communications systems and, more recently, for some lower-data-rate systems also. From these analyses sprang a development program which emphasized the progressive evolution of the necessary technologies, critical components, and operational systems. In particular, significant progress has been achieved in the five most critical technology areas: laser, modulator, detector, electronics, and optics.

During the early phases of the development program, the Nd:YAG laser was selected as having the greatest potential for high-data-rate intersatellite communications applications, although several types of Nd:YAG lasers were investigated initially. Since then, through the cooperative efforts of the Air Force, McDonnell Douglas Astronautics, and GTE Sylvania, both a lamp-pumped Nd:YAG laser and a sun-pumped Nd:YAG laser have been successfully developed and operated.

A space-qualifiable prototype of the lamp-pumped, mode-locked and frequency-doubled Nd:YAG laser has demonstrated output performance of 330 milliwatts (mW), with 400 picosecond pulsewidth, at 500 million pulses per second. The initial goal, to support a 40,000 kilometer link with 6 dB margin was 20 mW output power. The laser pump source, a K:Rb lamp, has been developed and has demonstrated a lifetime (MTBF) of over 5000 hours. An engineering model of the sun-pumped, mode-locked and frequency-doubled laser met its output performance goal of 400 mW power.

The LASERCOM high-data-rate uses an external electro-optical $LiTaO_3$ modulator. Using pulse quaternary modulation, the modulator imposes two bits of data on each pulse, thereby creating a data rate capability of one gigabit-per-second. Pulse quaternary modulation combines pulse position and pulse polarization modulation. Higher rate modulation schemes and higher speed modulators are being investigated.

Since the early 1970s, the LASERCOM Program has pursued several types of detectors with potential high-speed (multi-gigahertz) capabilities. Among those investigated were dynamic and static crossed-field photomultiplier tubes, several types of avalanche photodiodes (APDs), and a hybrid (electrostatic gain stages plus an impact ionization diode anode) photomultiplier tube. The dynamic crossed-field photomultiplier (DCFP) is currently the baseline high-speed detector for the LASERCOM system. DCFPs with 25% quantum efficiency and extremely long lifetimes have been demonstrated. For bit-error-rates down to approximately 10^{-7}, DCFPs are superior in performance to currently available APDs. However, at a bit-error-rate of 10^{-6}, which is the LASERCOM system baseline, recent improvements in APDs show the DCFP is only slightly superior and the APD does offer size, weight, and power advantages. We are continuing the investigation of high-speed APDs.

The development of high-speed and control electronics has been perhaps the least-heralded of the LASERCOM development efforts. In 1973, Motorola Government Electronics Division designed and fabricated brassboard electronics compatible with a one gigabit-per-second pulse-gated, binary-modulation system. In 1975, these electronics were modified for use with the pulse quaternary modulation of the engineering feasibility model. These electronics have been operating successfully in the LASERCOM system test bed for over three years. We are now upgrading and repackaging the high-speed electronics for use in the ground-to-ground and aircraft-to-ground demonstration.

Aside from optical design efforts, optical technology advancements have been sought primarily in the design of optical coatings. This effort concentrates on the ability of various coatings to survive the space environment. Approximately 30 of the most critical coatings will be analyzed. The success of the various technology and component developments is best evidenced by the demonstrated performance of the integrated laser communication system. In the laboratory test bed at McDonnell Douglas Aeronautics-St. Louis, the system operated successfully with simulated intersatellite ranges and with simulated dynamic satellite motion and vibration inputs. Despite the most severe motion inputs, the system repeatedly was able to acquire and achieve tracking within six seconds and to continue pointing with a peak pointing error of only 0.6 microradians for a 5 microradian beamwidth. We anticipate that the results of the ground-to-ground tests and the follow-on aircraft-to-ground tests will confirm this system capability.

NATURE OF FIELD TESTS/DEMONSTRATIONS

Laboratory development and testing are essential to the successful completion of, and confidence in, any communication system; moreover, demonstration of operational capabilities in an operational environment is equally important in the final development of a system. Consequently, in November 1977, the LASERCOM Program Office was directed to initiate a series of field tests and demonstrations to confirm the capabilities of the LASERCOM system in a realistic environment. These tests were initiated in September 1978.

The field test series is divided into six phases, each designed to demonstrate a specific capability of the system as it evolves from a "laboratory" system to a "field" system. The first two phases, just completed, consisted of ground-to-ground tests at the Cowan Site, White Sands Missile Range, New Mexico. The third phase will be an interim flight test, concentrating primarily on the acquisition and handover functions of the system. The fourth and fifth phases will again be ground-to-ground tests, verifying the final integration of the completed high-data-rate system. The sixth phase will be the formal aircraft-to-ground flight test itself, which will be the final field demonstration of the capabilities of the LASERCOM system.

Phase I is essentially a field test of the engineering feasibility model transmitter and brassboard receiver which have been used in the laboratory at McDonnell Douglas, St. Louis. The transmitter and receiver will be located approximately 4.5 meters apart in the Cowan building; however, the communication path will be from the building to a mirror located approximately one kilometer away and return. Phase II was similar to Phase I in terms of the types of tests conducted; however, the receiver equipment was upgraded to enable active acquisition modes. Both phases were highly successful.

In October 1979 the third Phase, the initial flight tests, will begin. For this phase, the high-data-rate transmitter will be integrated aboard an EC-135 aircraft; the high-data-rate receiver will remain at the Cowan Site. This test phase will be the first active field demonstration of the system's ability to acquire, handover, and point in a field environment with real (rather than simulated) dynamic motion of the terminals. Phase IV and V will again be ground-to-ground tests with both terminals at the Cowan Site. During this five-month test series, which begins in January 1980, the terminals will be upgraded to their final field operational condition. In particular, the operation of the completely integrated airborne transmitter will be verified, and the control electronics will be tested.

The final Phase of the series is the formal airborne flight test and demonstration. The complete high-data-rate transmitter will be integrated into an EC-135 and, beginning in July 1980, a four-month series of tests will be conducted to fully characterize the dynamic performance of the LASERCOM system. Characteristics of particular interest will be the open-loop and cooperative acquisition and tracking functions, the two-way communication and ranging functions, and the system's dynamic boresight stability. In addition to the system characteristics, path propagation effects will be observed and analyzed. By the end of Phase VI, the ability of the LASERCOM system to successfully communicate in a "real world" environment will have been demonstrated.

LASERCOM SYSTEM CHARACTERISTICS

Any operational LASERCOM system would be configured to satisfy the requirements of the user, but the currently designed and developed components and packages are the future system building blocks. The basic configuration of these packages and that used for the airborne demonstration is a high-data-rate (one gigabit-per-second) transmitter which includes a command and control receiver (21 kilobits-per-second), a high-data-rate receiver which includes a command and control transmitter, the low-data-rate (100 bits-per-second) wide-area-coverage multiple-access receiver, and a low-data-rate transmitter. These four basic packages will be discussed in this section.

The high-data-rate transmitter has a five microradian beamwidth through a 20 centimeter diameter optical telescope. From synchronous orbit, this results in an 0.1 mile diameter spot on the earth. This small area of illumination makes all communications over this link extremely private.

The high-data-rate receiver consists of a 62 centimeter diameter optical telescope (to collect a portion of the transmitted energy) and high speed detectors and receiver electronics (to resolve the time delay and polarization of the incoming data stream). In this manner, the two bits of information contained in each pulse are resolved. The field of view of the receiver telescope is 100 microradians, which requires an earth-based jamming source to be within a two mile diameter spot on the earth to jam the high-data-rate uplink from a ground or airborne platform to a synchronous satellite. On the other hand, orbital jamming of signals between low earth orbit and synchronous or nonsynchronous and synchronous satellites would be only intermittent at best because of orbital kinematics. A jammer could rendezvous with either the transmitter or receiver, but would be required to have precision pointing, tracking and stability equivalent to the LASERCOM system to be an effective jammer and would be clearly a one-for-one trade-off.

The command and control transmitter serves as the beacon laser for the closed-loop acquisition and tracking function of the LASERCOM system. This laser is a less than one watt Q-switched Nd:YAG system that generates 3000 pulses-per-second of 1.064 micron wavelength light. The modulation scheme, known as pulse interval modulation, varies the time position of each pulse relative to the previous pulse into one of 128 distinct time intervals or bins. This then uniquely designates a 7-bit word by each pulse and provides 21 kilobits-per-second from the 3000 pulse-per-second laser. Pulse interval modulation allows discrimination between nonsignal photoelectrons (jamming, background, or internal) and authorized data streams. This temporal discrimination is achieved by optical pulse gating techniques that are uniquely applicable to the short-pulse low-duty-cycle modulation formats (Ross, et al (2)).

The command and control receiver is an integral part of the high-data-rate transmitter package and serves as the receiver for the beacon laser. This receiver package collects the beacon energy incident on the 20 centimeter high-data-rate transmitter telescope and focuses it on a quadrant-array of avalanche photodiodes. This quadrant-array serves not only as the command and control receiver but also as the acquisition and tracking detector assembly. Fine pointing is achieved through the use of torque motor beam steering mirrors mounted at critical locations in the optical path. The inner loop of the tracking system has a 300 Hertz response which allows the system to track to less than one microradian peak to peak.

The low-data-rate (100 bit-per-second) transmitter and wide-area-coverage multiple-access receiver are designed to provide transmission from airborne platforms through 2.5 centimeter optics to a 31 centimeter receiver telescope. The receiver telescope directs the incoming signals onto a focal plane array of avalanche photodiodes. Current designs call for a 10 by 10 element array with associated electronics to process up to 15 simultaneous signals per element giving not only the 100 bit-per-second message but also the geographical location of the signal source to within the accuracy of selected grid coverage.

The transmitter consists of a 5 watt Q-switched Nd:YAG laser providing 10 pulses-per-second of 1.064 micrometer wavelength light. The modulation scheme is again pulse interval modulation but with 1024 time intervals and thus providing 10 bits of information per pulse and yielding 100 bits-per-second from a 10 pulse-per-second laser.

The weights, power requirements, and optical telescope diameters of typical packages are shown in Table I. These characteristics are based on current hardware design and actual components that have operated in the laboratory. Projections of weight, power, and size reductions based on future improvements have not been made, nor have prototype systems been built except for the high-data-rate transmitter engineering feasibility model. The synergistic effect of placing a high-data-rate transmitter and receiver together on a satellite for relay purposes should be to reduce both the weight and power for the transceiver to less than the additive weight and power of individual transmitters and receivers. These reductions would be possible because of shared components and functions.

Although the current LASERCOM system is designed for one gigabit-per-second, lower or higher data rates may be incorporated into the design as the requirements dictate. The one gigabit-per-second is not an upper limit on data rate. Through optical multiplexing a 4 gigabit-per-second system is achievable with today's technology; if the need existed, a 2 gigabit-per-second modulator could be developed over the next two years, thus providing an 8 gigabit-per-second system in the 1981 time frame.

POTENTIAL LASERCOM APPLICATIONS

The potential applications of laser communications systems are virtually unlimited, but those currently being considered by the Air Force Program Office are primarily military in nature. Table II lists the inherent characteristics of the LASERCOM system and some of the potential applications. Three specific classes of applications (low-data-rate, intermediate-data-rate, and high-data-rate) will be addressed here.

The low-data-rate transmitter and wide-area-coverage multiple-access receiver have direct applications to the report-back function when periodic one-way communication is required from a large fleet of aircraft to an airborne command post via satellite relay. The system currently in design would allow a 5000 by 5000 kilometer region to be covered by a 10 by 10 element array. Each element could process up to 15 simultaneous signals and would have a field-of-view of approximately 500 by 500 kilometers. The total processing capacity would be 1500 simultaneous report-back messages.

LASERCOM is a viable option along with SHF or EHF for future strategic report-back applications because of the lightweight (50-100 pounds), small optics (2.5 centimeters), and low power requirement (360 watts) for the aircraft terminal. The low-data-rate package also has application as the method of call-up for the high-data-rate system that could be used on a time sharing basis. While the high-data-rate receiver is receiving traffic from one source, another user within the large field of view of the wide-area-coverage receiver could send a 100 bit-per-second message requesting to transmit some high-data-rate traffic. Within a predetermined priority, the high-data-rate receivers would swing over to the calling platform and use the multiple-access receiver position information and transmitted data to perform the initial acquisition and tracking. In laboratory simulation of 40,000 kilometer links, the average acquisition time between high-data-rate users has been 6 seconds.

The intermediate-data-rate system (18-21 kilobits-per-second) has application to many aircraft-to-aircraft two-way links via a satellite relay. This type of laser communications link would be very effective for beyond line-of-sight communication between two airborne platforms. Studies that are currently underway through the Air Force Program Office will help identify which airborne links could be satisfied by laser communication in the future operational systems.

The high-data-rate system has very clear applications to intersatellite links where various sources of traffic can be received, combined, and relayed in a common data stream. At each receiver node the data could be reprocessed as necessary for further dissemination. For example, the data could be transmitted earthward via a laser communications downlink or via radio frequency signal. The final processing or use of the data at its ultimate destination would, of course, be dependent upon the user's application.

SUMMARY AND CONCLUSION

Although it may be somewhat revolutionary in concept, laser communication has nonetheless evolved steadily since the early 1970s. Even though systems have not yet been fully field tested, the technology developments to date have been most noteworthy in many areas. The forthcoming LASERCOM field tests and demonstrations should provide that final level of confidence necessary prior to the development and acquisition of general systems. Laser communications technology has reached its maturity, but further advancements may be expected as system requirements continue to be defined and refined. This paper has addressed a broad range of applications of laser communications systems; however, this is not intended to suggest that a laser vs radio frequency would always favor the laser systems. Rather, we may anticipate that laser systems will be merged into appropriate areas of total communications community, expanding our total communications capability.

REFERENCES

1. McElroy, J. H., N. McAvoy, E. H. Johnson, J. J. Degan, F. E. Goodwin, D. M. Henderson, T. A. Nussmeier, L. S. Stokes, B. J. Peyton, and T. Flattan, "CO_2 Laser Communication System for Near-Earth Space Applications," Proceedings of the IEEE, Vol. 65, pp. 221-251. 1977.

2. Ross, M., P. Freedman, J. Abernathy, G. Matassov, J. Wolf, and J. D. Barry, "Space Optical Communications with the Nd:YAG Laser," Proceedings of the IEEE, Vol. 66, pp. 319-346. 1978.

TABLE I. LASERCOM SIZE, WEIGHT AND POWER BASED ON CURRENT DESIGN

PACKAGE	FUNCTIONS	WEIGHT LBS	POWER WATTS	ANTENNA DIA., CM.
Space				
HDR XMTR.	1 Gbps; 21 Kbps Laser Rcvr; Ranging	300	300	20
HDR RCVR.	1 Gbps; 21 Kbps Laser XMTR; Ranging	250	250	62
LDR RCVR.	100 bsp Multiple Access Rcvr	55	60	31
Aircraft				
HDR XMTR.	1 Gbps; 21 Kbps Laser Rcvr; Ranging	230	550	20
HDR RCVR.	1 Gbps, 21 Kbps Laser Xmtr; Ranging	245	500	62
LDR XMTR.	100 bps Open-Loop Report Back	50	360	2.5
Ground				
HDR RCVR.	1 Gbps; 21 Kbps Laser Xmtr; Ranging	2000*	1500	62

HDR = High Data Rate 1 Gbps or Submultiples

LDR = Low Data Rate

*Self-Sufficient Trailer is 7000 lbs

TABLE II. LASERCOM INHERENT CHARACTERISTICS AND POTENTIAL APPLICATIONS

INHERENT CHARACTERISTICS	POTENTIAL APPLICATIONS
Jam-Resistant	JCS Airborne Command Post/ Satellite Links High-Data-Rate Relay
Security	SAC Looking Glass/Satellite Links
Survivability	ADCON E-3A/NORAD Links Via Satellite
Covertness	Call up of High-Data-Rate Package SIOP Report Back
High Data Rate	TAC AWACS/Satellite Link
Small Size, Weight, Power	AFSC Satellite Control Satellite AFSC Satellite Test Center II