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BRIEF STATE-OF-THE-ART REVIEW ON OPTICAL COMMUNICATIONS FOR THE NASA ISES WORKSHOP

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Abstract

This is a brief review of the current state of the art of optical communications. This review covers NASA programs, DOD and other government agency programs, commercial aerospace programs, and foreign programs. Included is a brief summary of a recent NASA workshop on optical communications. The basic conclusions from all the program reviews is that optical communications is a technology ready to be accepted but needed to be demonstrated. Probably the most advanced and sophisticated optical communications system is the Laser Intersatellite Transmission Experiment (LITE) system developed for flight on the Advanced Communications Technology Satellite (ACTS). Optical communications technology is available for the applications of data communications at data rates in the under 300 MBits/sec for nearly all applications under 2 times GEO distances. Applications for low-Earth orbiter (LEO) to ground will allow data rates in the multi-GBits/sec range. Higher data rates are limited by currently available laser power. Phased array lasers offer technology which should eliminate this problem. The major problem of cloud coverage can probably be eliminated by look ahead pointing, multiple ground stations, and knowledge of weather conditions to control the pointing. Most certainly, optical communications offer a new spectral region to relieve the RF bands and very high data communications rates that will be required in less than 10 years to solve the communications problems on Earth.

Introduction

NASA interest in optical communications has centered around a number of advantages that optical communications offers. These advantages range from a factor of 10 reduction in antenna size to reduced antenna weight (which also helps improve spacecraft stability and pointing problems), reduced power requirements, a new spectral region to help elevate RF band crowding, higher data transmission rates, and more secure data transmission. Shown in figure 1 is an LEO to telecommunications data relay satellite (TDRS) link comparison of laser communications vs. Ku band communication. From this data it is obvious that optical communications offer some very major advantages over RF communications.

Even though NASA, DOD, Europeans, and the Japanese have planned experiments, very little has been flown in space to demonstrate the technology. A number of aircraft-to-ground demonstrations have been performed. Probably the most sophisticated experimental system to date was planned as the LITE project to fly on the ACTS. However the LITE project has been scratched from ACTS. The good news is that the technology development is continuing. The remainder of this paper will be directed toward the identification of some of the ongoing programs and what organizations are involved as well as a summary of where optical communications stand today and what needs to be developed for the future.

NASA Programs

The major efforts in the development, fabrication, and demonstration of optical communications components and systems have been focused at the NASA Goddard Space Flight Center, Langley Research Center, and the Jet Propulsion Laboratory.

Jet Propulsion Laboratory

Research and development in this area has been directed toward the Deep Space Missions. Current work has been aimed toward the development of coherent communications systems based on diode pumping of Nd:YAG and the development of external modulation techniques. JPL is looking to the future for a 10-year lifetime device with a 2-Watt laser requirement with an external modulator for a 20 MBits/s data rate.

Goddard Space Flight Center

Research and development at this center has been directed toward Direct Detection Light Technology (DDLT) component and system development for the LITE experiment aboard ACTS. The DDLT system would share the Air Force/Massachusetts Institute of Technology/Lincoln Laboratory (MIT/LL) coherent experiment optics and would function when the coherent experiment was in the off mode. Optical communications experiments would be performed between ACTS and the Goldstone, AZ site and the GSFC Greenbelt, MD site as well as to an experimental module called Light Technology Experimental Facility (LTEF) aboard the Shuttle. This DDLT system will utilize the 20-cm optics of LITE, a multiple laser power summer with 200-300 milliwatts power output, and provide direct modulation of the lasers at a 220 MBits/s data rate. GSFC has performed a number of pointing, tracking, and acquisitions systems studies and development programs. GSFC has also addressed the problem of developing long life and stable semiconductor lasers.

Future missions requirements at GSFC are seen to require laser power in the 1-5 watts range and communication data rates to 4 GBits/s to provide communications for all of the upcoming NASA missions. These laser power level and modulation rates will require further development of high power semiconductor lasers.

Langley Research Center

Research and development programs at Langley have centered on the development of laser technology, optical transceivers, and lately the possible use of optical communications with ISES.

Langley has developed and demonstrated a number of semiconductor lasers for applications to optical communications. This technology has mainly centered on AlGaAs semiconductor lasers with emission in the 50-100 mW range and direct modulation demonstrations to 2 GBits/s. Recent developments have been aimed toward the utilization of phased array lasers to demonstrate multiple watt devices capable of modulation to 5 GBits/s. Other recent efforts have centered on the development and demonstration of a narrow linewidth semiconductor laser in InGaAsP for coherent communication applications.

A joint program with the Air Force has been completed in the area of optical transceivers. This development provided a military family of transceivers up to 1 GBits/s. A second phase of the program currently underway is addressing a high speed transceiver which will operate up to 4 GBits/s.

Langley Research Center has proposed an ISES which utilizes optical communications to downlink data to interactive users of Eos or Space Station data. This system design could utilize existing 20-cm optics, tracking, pointing, and acquisition systems. Implementation of a simple 30-mW laser would easily provide communications rates in the 100 to 1000 MBits/s communications rates. Look ahead and smart pointing systems to alleviate cloud coverage problems and a network of recieving stations interlinked with high speed fiber optic systems would make it a very useful system.

Other Government Agency Programs

The Air Force and Navy support most technology developments in the way of components, subsystems, and systems. Only the coherent optical communications research and development, by MIT/Lincoln Laboratory, part of the LITE experimental system for flight on the ACTS, will be discussed. This project provides the most information available for general use and does not impact DOD restrictions or provide proprietary contractor information.

The original approach for the coherent communications experiment was to downlink to Goldstone, AZ and GSFC at Greenbelt, MD. By utilizing coherent communications, which should have 15 dB better sensitivity than Direct Detection Light Wave Technology (DDLT) there would be a direct comparison of the two optical communications techniques. The coherent design consisted of a 30-mW laser which could be modulated to 220 MBits/s. The laser system was quadruple redundant with an analysis and tuning system. The overall weight was 200 pounds and needed 200 electrical watts. The parts were to be radiation hardened and flight qualified. Perkin Elmer supplied part of the optics and Ball Aerospace part of the point system. No current plans exist for flight. However, a flight version of the system will be available in 1992. This particular system has the best design information available for comparison to other system designs. In addition to the flight system, there was also a ground system design which used 30-cm optics.

Commerical Aerospace Programs

The major commercial companies involved in optical communications component, subsystem, and system development are Martin Marietta, TRW, McDonnell Douglas, Ball Aerospace, Perkin Elmer, Hughes Aircraft Company, GE Aerospace, Spectra Diode Laboratory, David Sarnoff Research Center, and Stanford Telecommunications, Inc. None of these company projects will be discussed because of the many and varied proprietary restrictions. There are a number of government-funded (DOD) projects connected to each company. They range from crosslinks, uplinks, and downlinks systems to a variety of subsystems and component developments. The main conclusion is that there are few major program efforts of such size as the LITE experiment for ACTS.

Foreign Programs

Research and development by foreign countries of which knowledge is available is based on the major efforts of a European project and a Japanese project.

European Program

The European project, called the Semiconductor Laser Intersatellite Link Experiment (SILEX), consists of a contractor team made up of Matra(prime) of France, Dornier of West Germany, Bertin of France, ANT of West Germany, Telespazio of Italy, Selenia of Italy, and Spazio of Italy. The SILEX project consists of two GEO laser communications packages for a '92-'93 launch. This system uses wavelength multiplexed AlGaAs semiconductors with a data relay capability of 480 MBits/s.

Japanese Program

The Japanese project is being put together by a team from the National Space Development Agency of Japan, the Radio Research Laboratory, and the Ministry of Posts and Telecommunications. The project is a GEO-Ground experiment with a 1992 launch and a GEO-GEO experiment for 1996 launch. The project is built for the ETS-6 satellite and utilizes AlGaAs Semiconductor lasers.

NASA Optical Communications Workshop

A NASA optical communications workshop, sponsored by Code RC (Dr. M. M. Sokoloski), was held at Annapolis, Md. on March 28-29, 1989. The major purpose of the worshop was to review optical communications technology with a view toward satisfying future communications needs of the Global Change Technology Initiative (GCTI). A review of the "Mission to Earth" communications requirements was presented along with a view of potential science applications of optical communications technology. A government and industry briefing on optical communications was presented before the workshop sessions.

The workshops were split into three sessions: Laser Technology, Systems Technology, and Science Benefits. The laser technology working group concluded that semiconductor lasers with good lifetime existed with power outputs up to 35 mW. Semiconductor lasers with power outputs up to 100 mW are available but with questionable limits on their lifetime. By power multiplexing a system of lasers with reasonable life, 200 mW power output was achievable with modulation capability to GBit/sec data rates. Within the next 3-5 years phased array lasers, Nd:YAG lasers, and Master Oscillator Power Amplifier lasers should offer in excess of 1-watt power ouput at high modulation rates.

The Systems Technology Working Group foresaw that optical communications systems at 1 MBits/s at 2 times GEO and that 220 MBit/s systems at 1 times GEO were currently available. Technology needs were high power lasers/amplifiers, modular highly integrated packaging, better acquisition and tracking systems, and novel approaches to reducing the weight of the optical systems. Reasonable systems are available by 1991 whereas higher data rate systems will be available for deployment in the 1996-98 timeframe with technology fixed by 1991-93.

The Science Benefits workshop concluded that global wind sensing, water vapor measurements, gravity field mapping, planetary sciences and fundamental theories such as gravitational wave detection would be possible through the use of optical communications systems and associated technology.

ISES Optical Communications

The ISES optical communications system could be easily achievable on an LEO mission such as Eos or Space Station Freedom. The optical communications system could implement a direct detection systems approach and utilize a 20-cm optic system with a 30-mW AlGaAs laser which could be modulated up to a multi-Gibits/sec data rate while maintaining a signal margin. Pointing, acquisition, and tracking systems of the type developed by Ball Aerospace would satisfy the system's needs. Electronics of the LITE type developed by MIT/LL would be a model for the systems. For GEO-GEO and GEO-Ground communications, either a coherent communications system such as that built by MIT/LL or a DDLT type design such as that built by GSFC would provide a 200-300 MBits/sec data rate. Any higher data rate requirements would require a higher power laser which requires greater lifetime than is currently available. These types of laser devices should be available in the 1991-92 timeframe. A ground station design could utilize 20- to 30-cm optics depending upon data rate for communications and be of the type being developed by MIT/LL.

The item that will mean most to the success of optical communications is the ability to communicate to a variety of ground stations located throughout the United States. Therefore a point ahead capability to direct the optical beam to a clear cloud free location is imperative. This will require a computer with knowledge of the weather pattern and a selection alogrithm to assure a clear communications path. With the advent of expanding high data rate fiber optics communications routes by a number of communications companies, the problem of directing data to the user is no longer a problem.

Summary

Optical communications systems can do the job at higher data rates than achievable in the RF domain. Near-Earth systems requirments are ready. What needs to be done is to qualify the optical communication system for use in space. A satellite for proof of demonstration of optical communications needs to be available.

Optical communications systems require longer ranges such as those from GEO orbits, and data rates higher than 200 MBits/s require higher laser power. This technology is advancing more rapidly in the past four years than previously thanks to DOD funding. Multi-GBits/s data rates for communications are a reality for optical communications systems. The electronics to drive and sense the signals are available.

What needs to be done is to utilize more systems development such as in the ACTS - LITE optical communications to drive out and develop optimized systems. Lighter weight hardware with further reduction in system power would be the major goals. System packaging and space qualification of the hardware are also major requirements. Adequate funding has not been directed toward solving needed flight hardware systems demonstrations.

Optical communications is a super data rate channel for the transfer of data and informations. It is past ready for experiments and demonstrations. What needs to be done is to properly implement the available technolgy into an acceptable demonstration to prove the viability of optical communications.

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LINK COMPARISON

LASER VS. Ku BAND

LINK CHARACTERISTICS

- o 300 MBPS DATA RATE
- o 10E-5 BIT ERROR PROBABILITY (UNCODED)

	LASER	Ku BAND *
LEO TRANSMITTER POWER	0.25 WATTS	10 WATTS
LEO ANTENNA DIAMETER	7 INCHES	12 FEET
TDRS ANTENNA DIAMETER	10 INCHES	16 FEET
LINK MARGIN	6 DB	6 DB

*FROM TDRSS USER'S GUIDE, REVISION 4, JANUARY 1980

Figure 1. Low Earth orbiter to TDRS link comparison of laser communication versus Ku band communication.