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LASER COMMUNICATION SYSTEM

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ABSTRACT

Laser communication system can transmit and receive signal from any audio device. Communication distance is few meters. All components are not critical. Laser communication links in space are attractive alternatives to present-day microwave links. Laser Communication Demonstration Project, a joint project between NASA's Goddard Space Flight Center (GSFC), the Califomia Institute of Technology Jet Propulsion Laboratory (JPL), and the Massachusetts Institute of Technology Lincoln Laboratory (MITLL). The laser Communication (lasercom) flight terminal will be flown on the Mars Telecom Orbiter (MTO) to be launched by NASA in 2009, and will demonstrate a technology which has the potential of vastly improving NASA's ability to communicate throughout the solar system. Laser communication network is introduced that consists of Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geosynchronous Earth Orbit (GEO) satellites. The performance of the satellite laser network can be improved drastically if multiple satellite constellations are used in the architecture. Laser communication allows the real-time transmission of digital data on the basis of the Ethernet protocol; encryption using standard techniques is also possible in accordance with IPv4 and IPv6. Aerial photos, images from covert reconnaissance, radar and uncompressed sensor data can be transmitted to control centers and between mobile units without the risk of interference or interception. The high network capacity offers transmission rates in the Gbit range. The frequency used for laser satellite communication should be selected from bands that are most favorable in terms of power efficiencies, minimal propagation of distortion, and reduced noise and interference effects. Terrestrial systems tend to favor these same bands. So, concern for interference effect between the satellite and terrestrial systems must be made. The optical laser communication system consists of a transmitter uses a laser beam of a wavelength 650 nm as a carrier in free space, and a receiver uses PIN diode as a detector. In both sides Intensity modulation (IM) technique has been used to transmit video signal of a frequency range (0~5) MHz band width. A constellation of low-Earth orbit (LEO) satellites will be used to provide mobile terminals on the ground with Global Multimedia Mobile Satellite System service, which will allow high-speed transmission of information such as image data. Accordingly, we are planning to conduct verification testing of the necessary optical inter-satellite communications technology. Inter-satellite communications: High-speed optical inter-satellite communications (up to 2.5 Gbps) User link connection: Satellite antenna design of 1 user/1 beam User terminal performance: Multimedia communications up to 2 Mbps. Recent years have seen the emergence of a number of international projects for communications, positioning, or Earth-monitoring services using the many Low-Earth Orbit (LEO) satellites (in fact located both in low and medium orbits). Some of these projects have since led to notable practical applications. An example of one such first-generation LEO service may be seen in the US Iridium satellite- telephone system, in which approximately 70 satellites are placed in orbit at an altitude of 700 km for a range of mobile phone services.

KEYWORD
laser communication.

1. INTRODUCTION

Since the early days of laser technology, many countries supported large laser R&D budgets which lead to a rich diversity of systems, ranging from 'laboratory' systems demonstrating the latest non-linear optical technology to eye-safe, low cost laser-ranging binoculars. Traditionally, military interests in laser systems have been concentrated in four general areas: Laser Rangefinders (LRFs) and Target Designators (LTDs), Laser Radars (LADARs), Laser Communication Systems (LCOMs), and Directed Energy Weapons (DEWs). The nature of the interest in laser technology is, for a considerable part, significantly dissimilar for the three military service branches, and this is mainly due to the different requirements (e.g., environmental, weight/size, performance) of systems to be used on land, at sea, and in the air. Although military lasers are significantly different from those which exist in the commercial world, commercial applications of military technologies are also being exploited.

Due to the aim of the present research, in this chapter we will review the fundamentals of the most popular of current airborne and ground tactical laser systems (i.e., LADAR/LRF and LTD), with particular emphasis for the systems currently in service or under development for the Italian Air Force. More detailed information about the relevant laser technologies, and a discussion of various airborne systems applications

An initial hurdle faced by early means of laser communication was the enormous heat generated by pumped laser action. However, in the late 1960's, semiconductor laser was developed and ever since, the possibilities for laser communication have grown. Though developed for carriers, new laser technologies are finding a place in private networks. Recent breakthroughs in wireless technology and the need for a wireless extension of the Internet have increased the demand for faster, higher bandwidth wireless access networks. The two wireless options nowadays are either radio or optical networks. Radio frequency (RF) has been the primary medium of communication for a long period of time. However, in this day and age, the RF spectrum has become congested and may no longer be sufficient for broadband high-speed applications. In addition to this radio communication requires the leasing of frequencies in order to be legally permitted to use them. On the other hand, optical communication is the key to supply the ever-increasing demand for higher bandwidth, without the associated hassles or Interference experienced with radio communication. Entrepreneurs and technologists who know of this are borrowing many of the technologies initially designed for fiber-optics systems and applying them to what is now called Free Space Optical (FSO) communication.

FSO systems run in the infrared (Ir) spectrum, which is at the bottom of the light spectrum. Specifically, the optical signal is in the range of 1 THz (1 Terahertz = 1 trillion Hz = 1,000,000,000,000 cycles per second) in terms of wavelength. FSO is a free space (wireless) technology, meaning that the signal travels in the free space between transmitter and receiver, rather than through a conductor such as a wire or fiber, or through a waveguide of some sort. Another important feature of FSO is that it is unaffected by electromagnetic interference and radio frequency interference, which increasingly plague radio based communication systems. FSO systems are used in disaster recovery applications and for temporary connectivity while cabled networks are being deployed.

In the near future the National Aeronautics and Space Administration anticipate a significant increase in demand for long-haul communications services from deep space to Earth. Distances will range from 0.1 to beyond 40 AU', with data rate requirements in the 1's to 1000's of Mbits/second. The near term demand is driven by NASA's Space Science Enterprise which wishes to deploy more capable instruments onboard spacecraft and increase the number of deep space missions. The long term demand is driven by missions with extreme communications challenges such as very high data rates from the outer planets, supporting sub-surface exploration, or supporting NASA's Human Exploration and Development **of** Space Enterprise beyond Earth orbit.

2. LASER COMMUNICATION RANGE

We can estimate the range of laser communication system using following equation

$$\text{range} = \sqrt{\frac{(P_\ell \times A \times T_a \times T_o \times 4}{D_s \times \pi \times \Theta^2}}$$

where

range is in kilometers

P_ℓ = laser power

A = area of receiving optics (lens or mirror)

T_a = transmissivity of the atmosphere

T_o = transmissivity of the receiving optics

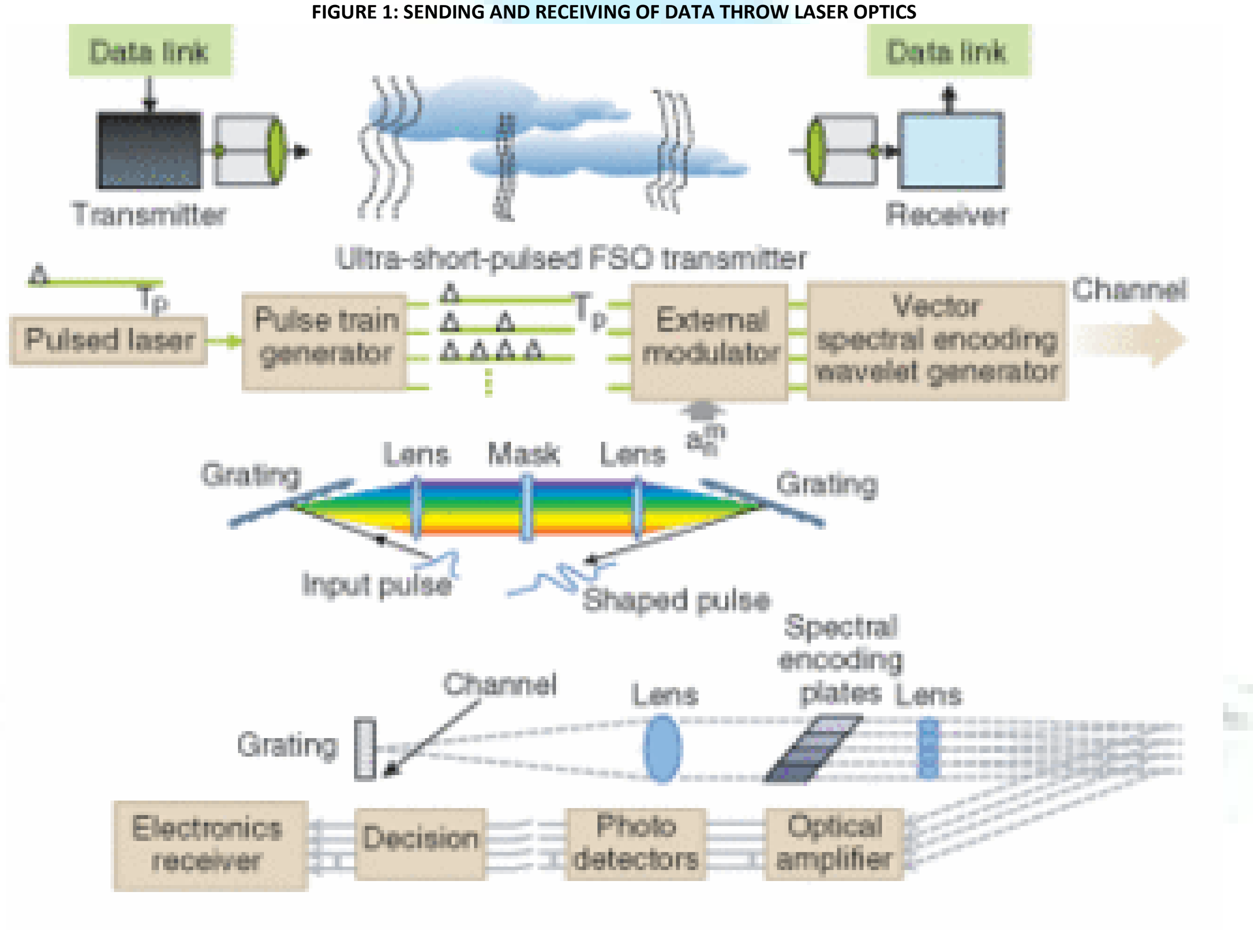
D_s = detector sensitivity (minimum detectable signal)

Θ = beam divergence (in radians)

Above is the equation that helps to find the range between sources to destination. Laser power is important for sending and receiving signal of laser. Area is also important for optical wire or wave.

3. LASER COMMUNICATION SYSTEM TRANSMISSION

FIGURE 1: SENDING AND RECEIVING OF DATA THROW LASER OPTICS



Information typically in the form of digital data is input to data electronics that modulates the transmitting data source. Direct or indirect modulation techniques may be employed depending on the type of laser used. The source output passes through an optical system into the channel. The optical system typically includes transfer, beam shaping and telescope optics. The receiver beam comes in through the optical system and is passed along to the detectors and signal processing electronics. There are also terminal controlled electronics that must control the gimbals and other steering mechanism and servos to keep the acquisition and tracking system operating in the designed modes of operation.

3.1 DATATRANSMISSION OVER SHORT RANGE

TABLE-1: DATA TRANSMISSION OVER SHORT-RANGE DISTANCES

Description	Requirements
Maximum range	5 km, eye safe at 1550 nm
Availability	High (>95%), increase through cell structures
Type of connection	Point-to-point or integrated nodal point
Bandwidth	1 Gbps (higher data rates up to 5 Gbps in development)
Beam readjustment	Not necessary
Compatibility	Compatible with the any other laser communication systems

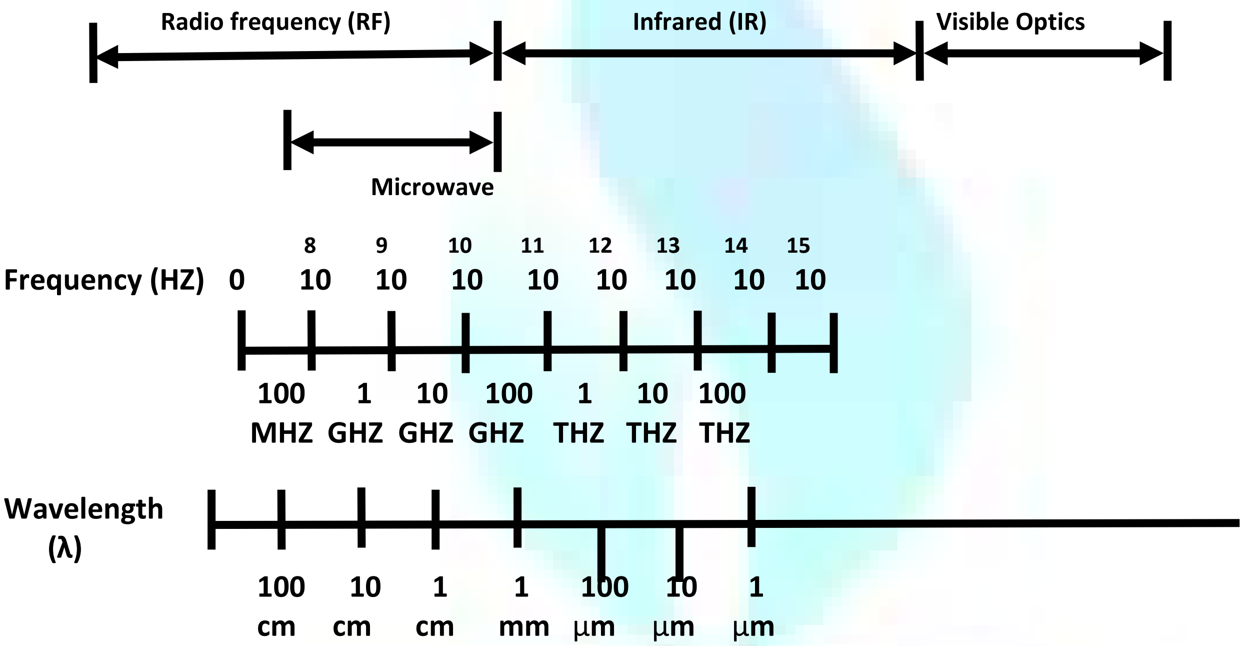
3.2 DATATRANSMISSION OVER MID RANGE

TABLE-2: DATA TRANSMISSION OVER MID-RANGE DISTANCES

Description	Requirements
Maximum range	≥20 km, eye safe at 1550 nm
Availability	Very high (>99%) in good weather conditions
Type of connection	Point-to-point or integrated nodal point, hybrid attachment with RF link as back-up
Bandwidth	1 Gbps (higher data rates up to 5 Gbps in development)
Beam readjustment	Electronic tracking
Compatibility	Compatible with the any other laser communication systems

4. SATELLITE FREQUENCY BANDS

The electromagnetic frequency spectrum is as shown below.



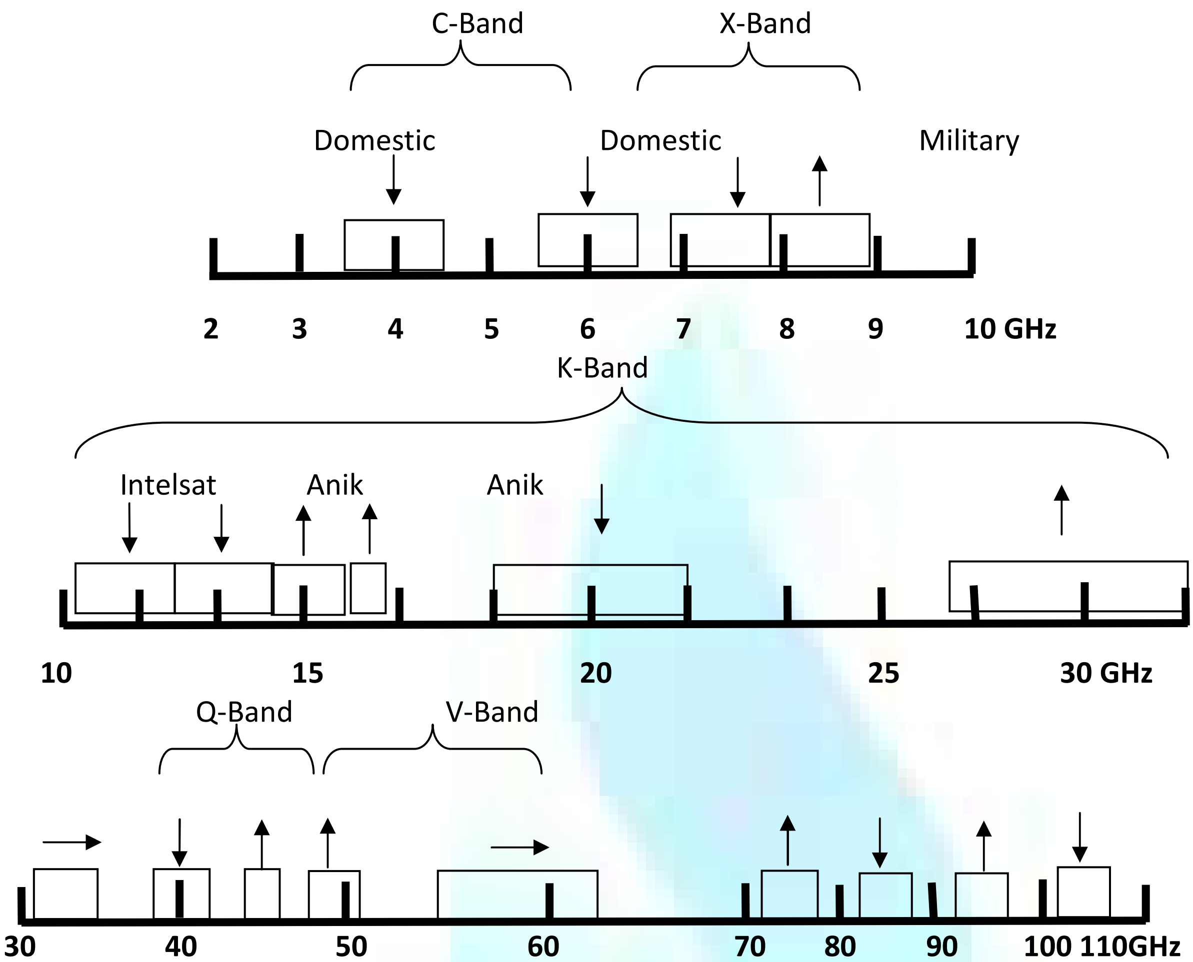
The frequency used for satellite communication should be selected from bands that are most favorable in terms of power efficiencies, minimal propagation of distortion, and reduced noise and interference effects. Terrestrial systems tend to favor these same bands. So, concern for interference effect between the satellite and terrestrial systems must be made.

Satellite use from space must be regulated and shared on a worldwide basis. For this reason, frequencies to be used by the satellite are established by a world body known as the International Telecommunications Union (ITU) with broadcast regulations controlled by a subgroup known as World Administrative Radio Conference (WARC). An international consultative technical committee (CCIR) provides specific recommendations on satellite frequencies under consideration by WARC. The basic objective is to allocate particular frequency bands for different types of satellite services, and also to provide international regulations in the areas of maximum radiation's level from space, co-ordination with terrestrial systems and the use of specific satellite locations in a given orbit. Within these allotments and regulations an individual country can make its own specific frequency selections based on intended uses and desired satellite services.

TABLE-3: BANDS AND FREQUENCY

Bands	Frequency
VHF	54 - 216 MHz
UHF	470 - 890 MHz
L	.39 - 1.55 GHz
S	1.55 - 5.2 GHz
C	3.9 - 6.2 GHz
X	5.2 - 10.9 GHz
K	10.9 - 36 GHz
Ku	11.7 - 14.5 GHz
Ka	17 - 31 GHz
Q	36 - 46 GHz
V	46 - 56 GHz

The frequency bands allocated by WARC (1979) for satellite communication are given below.



Allocated satellite frequency bands, WARC 1979

Use of frequencies has been separated into military, non-military, and services has been designated as fixed point (between ground stations located at fixed points on earth), Broadcast (wide area coverage), and mobile (aircraft, ships, land vehicles). Inter satellite refers to satellite cross- links. Most of the early satellite was developed for UHF, C-band and X-band, which required the minimal conversion from existing microwave hardware. The foremost problem is the fact that the available bandwidth in these bands will be inadequate to meet present and future traffic demands. The advantage of using a carrier at higher frequencies is the ability to modulate more information on it.

5. SYSTEM CHARACTERISTICS AND DESCRIPTION

The key system characteristics which when quantified, together gives a detailed description of a laser communications system. These are identified and quantified for a particular application. The critical parameters are grouped into five major categories: link, transmitter, channel, receiver, and detector parameters.

5.1 LINK PARAMETERS

The link parameters include the type of laser, wavelength, type of link, and the required signal criterion, today the lasers typically used in free space laser communications are the semiconductor laser diodes, solid state lasers, or fiber amplifier lasers. Laser sources are described as operating in either in single or multiple longitudinal modes. In the single longitudinal mode operation the laser emits radiation at a single frequency, while in the multiple longitudinal mode, multiple frequencies are emitted.

Semiconductor lasers have been in development for three decades and have only recently (within the past 7 years) demonstrated the levels of performance needed for the reliable operation as direct sources. Typically operating in the 800-900 nm range (galiumarsenide/gallium aluminums arsenide) their inherently high efficiency (50%) and small size made this technology attractive. the key issues have been the life times asymmetric beam shapes, output power.

Solid state lasers have offered higher power levels and the ability to operate in high peak power modes for the acquisition. When laser diodes are used to optically pump the lasing media graceful degradation and higher overall reliability is achieved. A variety of materials have been proposed for laser transmitters: neodyminium doped yttrium aluminums garnet (Nd:YAG) is the most widely used. Operating at 1064 nm, these lasers require an external modulator leading to a slight increase in the complexity and reliability.

With the rapid development of terrestrial fiber communications, wide areas of components are available for the potential applications in space. These include detectors, lasers, multiplexers, amplifiers, optical pre amplifiers etc. operating at 1550nm erbium doped fiber amplifiers have been developed for commercial optical fiber communications that offer levels of performance consistent with many free space communications applications.

There are three basic link types: acquisition, tracking and communications. The major differences between the link types are reflected in the required signal criterion for each. For acquisition the criterion are acquisition times, false alarm rate, probability of detection. For the tracking link the key considerations are the amount of error induced in the signal circuitry. This angle error is referred to as the noise effective angle. For the communications link, the required data and the bit error rates are of prime importance.

5.2 TRANSMITTER PARAMETERS

The transmitter parameter consists of certain key laser characteristics, losses incurred transmit optical path, transmit antennae gain, and transmit pointing losses. The key laser characteristics include peak and average optical power, pulse rate and pulse width. In a pulsed configuration the peak laser power and duty cycle are specified, whereas in continuous wave application, the average power is specified.

Transmit optical path loss is made up of optical transmission losses and the loss due to the wave front quality of the transmitting optics. The wave front error loss is analogous to the surface roughness loss associated with the RF antennas. The optic transmit antenna gain is analogous to the antenna gain in the RF systems and describes the on axis gain relative to an is tropic radiator with the distribution of the transmitted laser radiation defining the transmit antenna gain. The laser sources suitable for the free space communications tend to exhibit a Gaussian intensity distribution in the main lobe. The reduction in the far field signal strength due to the transmitter miss pointing is the transmitter pointing losses. The pointing error is composed of bias(slowly varying)and random (rapidly varying) components.

5.3 CHANNEL PARAMETERS

The channel parameters for an optical inter satellite link (ISL) consist of range and associated loss, background spectral radiance and spectral irradiance. The range loss is directly proportional to the square of wavelength and inversely proportional to the square of the separation between the platforms in meters.

5.4 RECEIVER PARAMETERS

The receiver parameters are the receiver antenna gain, receive optical path loss, the optical filter bandwidth and the receiver field of view. The receiver antenna gain is proportional to the square of effective receiver diameter in meters and inversely proportional to the square of the wave length. The receiver optical path loss is simply the optical transmission loss for systems employing the direct detection techniques. However for the lasers employing the coherent optical detection there is an additional loss due to the wave front error. The preservation of the wave front quality is essential for the optimal mixing of the received signal and the local oscillator fields on the detector surface. The optical filter bandwidth specifies the spectral width of the narrow band pass filter employed in optical inter satellite links. Optical filters reduce the amount of unwanted background entering the system. The optical width of the filter must be compatible with the spectral width of the laser source. The minimum width will be determined by the acceptable transmission level of the filter.

The final optical parameter is the angular field of view (FOV), in radians which limits the background power of an extended source incident on the detector. To maximize the rejection, the FOV should be as small as possible. For small angles the power incident on the detector is proportional to FOV square. The minimum FOV is limited by optical design constraints and the receiver pointing capability.

5.5 DETECTOR PARAMETERS

The detector parameters are the type of detector, gain of detector, quantum efficiency, heterodyne mixing efficiency, noise due to the detector, noise due to the following pre amplifier and angular sensitivity.

For optical ISL systems based on semiconductor laser diodes or Nd:YAG lasers the detector of choice is a p type intrinsic n type (PIN) or an avalanche photodiode (APD) APIN photo diode can be operated in the photovoltaic or photoconductive mode and has no internal gain mechanism. An APD is always operated in the photo conductive mode and has an internal gain mechanism, by virtue of avalanche multiplication. The quantum efficiency of the detector is the efficiency with which the detector converts the incident photons to electrons. The mean output current for both the PIN and APD is proportional to the quantum efficiency. By definition the quantum efficiency is always less than unity. Another detector parameter is the noise due to the detector alone. Typically in a detector there is a DC current even in the absence of signal or background. This DC dark current produces a shot noise current just as the signal and the noise currents do. In an APD there are two contributors to this DC dark current-an multiplied and an un multiplied current.

The output of the detector is the input to the preamplifier that converts the detector signal current into a voltage and amplifies it to a workable level for further processing. Being the first element past the detector, the noise due to the preamplifier can have a significant effect on the systems sensitivity. The selection of the pre amplifier design and the internal transistor design and the device material depends on a number of factors.

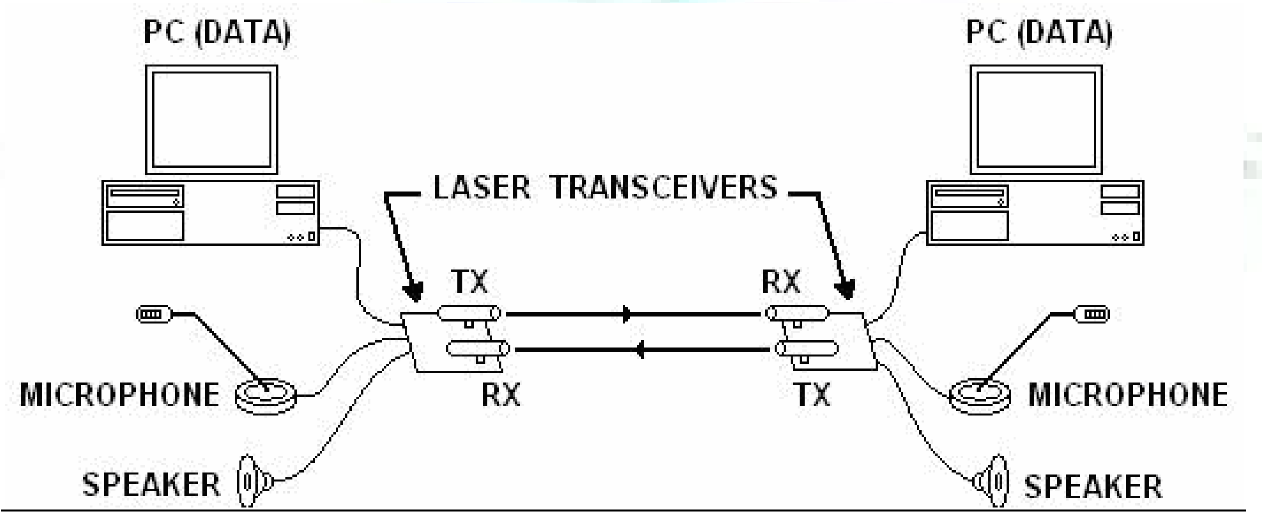
6. A FREE SPACE OPTICAL LASER COMMUNICATION LINK

The free space optical laser communication link developed is comprised of four circuits: the analogue transmitter and receiver, the digital transceiver and the Voice Unit (VU) meter. This combination of circuits will enable line-of-sight (LOS), full duplex voice and RS232-compatible data communication, over a laser beam in free space.

6.1 SYSTEM OVERVIEW

The completed system consists of two transceivers, each capable of simultaneously transmitting and receiving either analogue or digital information. The user has the option to manually select between either analogue or digital information via means of two switches, which control the laser transmitter and phototransistor receiver. This translates to a system where, if necessary, analogue information can travel in one direction while digital information travels in the opposite direction. In normal operation, the system is a full-duplex analogue/digital communicator. The system overview is depicted in Figure 2.

FIGURE 2: SYSTEM OVERVIEW



6.2 THE TRNSMITTER SIDE

The transmitter side is made up of two dedicated circuits that perform amplitude modulation of the laser diode when supplied with either a digital or analogue input signal. The circuits are designed with built-in protection for the laser diode in case the input signal amplitude is too high. As a result, this portion of the circuit is more complex than the receiver side.

6.3 THE RECEIVER SIDE

The receiver side is again made up of two dedicated circuits that perform the demodulation of the analogue signal from the phototransistor. The digital section of the circuit incorporates the MAX232 IC to generate the RS232-compatible signals necessary for interfacing PC and the circuit. In addition to this, there is an onboard VU meter designed to make the alignment process easier and protect the listener from unexpected high pitch sounds during the alignment process.

7. LASER RADAR SYSTEMS

The term radar originated during World War II as an acronym for radio detection and ranging. At that time, it referred to the technique of monitoring reflected, radio frequency, electromagnetic radiation to locate remote objects. Since that time, the basic radar technique has been applied to progressively shorter (and in some cases, longer) wavelengths so that the term radar no longer applies only to systems that operate at radio frequencies. Laser radar is simply radar that operates at optical frequencies and uses a laser as its source of electromagnetic radiation.

Laser radars are commonly referred to as LADAR for laser radar or as LIDAR for light detection and ranging. Ranging is accomplished by measuring the time delay to and from the target. Angular information is obtained from the beam-pointing direction. Laser radars are capable of extremely accurate angular measurement because of the small beam diameters of lasers (on transmit) and narrow fields of view (on receive). On the negative side, the detection and tracking ranges are much shorter than microwave radar because of lower transmitter power and higher atmospheric attenuation.

LADARs usually operate at 10.6 m wavelength in the far infrared and at 1.064 m in the near infrared. The former use CO2 lasers and the latter Nd:YAG crystal lasers, with typical efficiencies of 10% and 3%, respectively. Other available technologies include 1.5 μm "Eye-safe" Erbium doped fibre (Er:fibre) laser and Raman-shifted Nd:YAG lasers. Possible airborne LADAR applications include the following:

- Aircraft guidance (obstacle avoidance and terrain following);
- Tactical imaging systems (surveillance and reconnaissance); and
- Wind velocity measurement (clear air turbulence and severe storm sensors).

The various types of Laser radars and some typical airborne applications are described in Annex A. In the following paragraphs, after a brief introduction to Laser Obstacle Warning Systems (OWSs), a technical description of the Laser Obstacle Avoidance System (LOAS), developed by Marconi-Selenia Communications S.p.A. for the Italian Military Forces and tested by the Air Force Flight Test Centre (RSV), is presented.

8. BEAM ACQUISITION, TRACKING AND POINTING

The use of extremely narrow optical beams for a satellite cross-link introduces obvious beam pointing problems. The transmitting satellite should transmit the narrowest possible beam for maximum power concentration. The minimal band width is limited by the expected error in pointing the beam to the receiver. The pointing error ultimately decides the minimal beam size.

Pointing error is determined by the accuracy to which the transmitting satellite can illuminate the receiving satellite. This depends on the accuracy to which one satellite knows the location of the other, the accuracy with which it knows its own orientation in space and the accuracy to which it can aim its beam, knowing the required direction. Satellite beam pointing by ground control will not permit the micro radiant beam width projected for the optical link. Determination of the satellite location can be aided by using an optical beacon transmitted from the receiving antennae back to the transmitting satellite.

The transmitting satellite receives the beacon then transmits the modulated laser beam back towards the beacon direction of arrival. The uncertainty in absolute satellite location is transferred to smaller uncertainty in reading beacon arrival direction. The beacon must be trapped in time to provide updated position information. When the beams are extremely narrow there is a possibility that the receiving satellite may have moved out of transmitters beam width during the round trip transmission time. The transmitting satellite should point ahead from its measured beacon arrival direction.

$\alpha = Vt / 150\ \mu$ radians

Where α is the point ahead required and

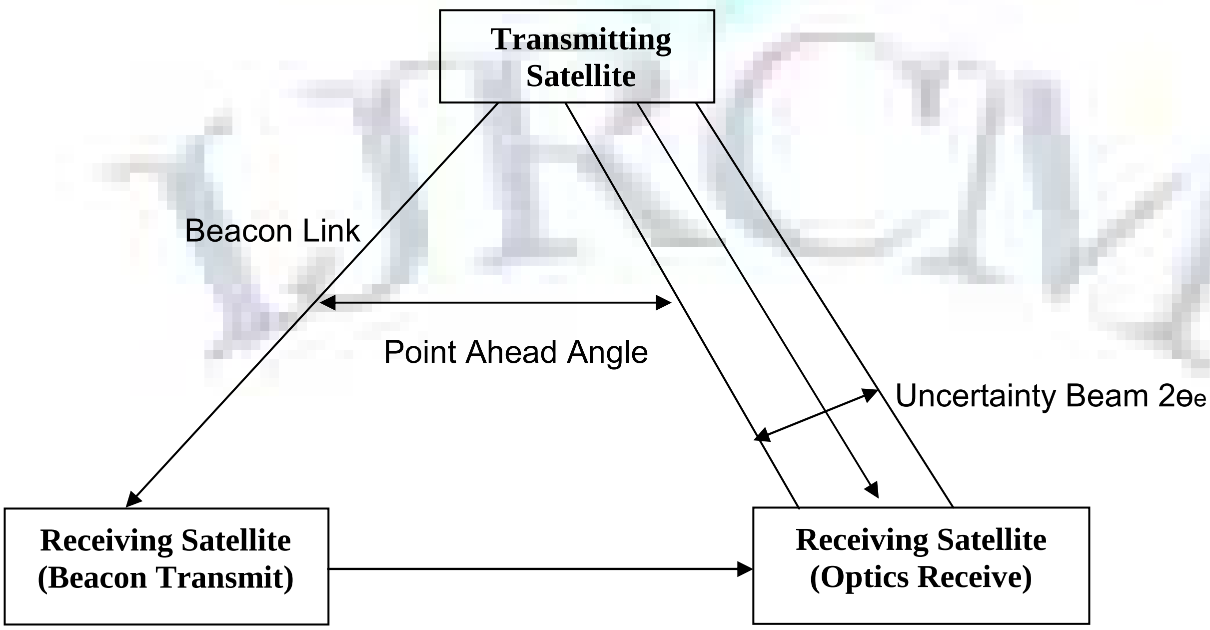
Vt is the tangential velocity of the satellite in m\s.

If this exceeds one half the beam widths the point ahead must be used. This means that the transmitting laser cannot transmit back through the same optics from which the beacon is received. It is independent of the satellite cross link distance.

The use of a beacon modifies the optical hardware on each satellite, since the transmitting and receiving satellite must contain both a transmitting laser and a optical receiver. This means either satellite can serve as a transmitter or an optical data can be sent in both directions. The modulated laser beam can serve as a beacon for the return direction. The receiving optics tracks the arrival beam direction and adjusts the transmitting beam direction. Separate wavelengths are used for optical beams in each direction. If no point ahead is needed, transmit and receive optics can be gimballed together and the laser transmits through receive optics. If point ahead is needed then command control (either stored or received from the earth station) must adjust transmitting direction relative to receiving direction.

In establishing an optical cross link we require the initial acquisition and tracking of the beacon by the transmitting satellite followed by a pointing of a laser beam after which the data can be modulated and transmitted.

FIGURE 3: REQUIRED BEAM WIDTHS AND POINT AHEAD MODEL FOR OPTICAL POINTING



8.1 TRACKING MODES FOR SATELLITE SUBSYSTEMS

Several approaches to tracking have been used in laser communications. Free space laser inter-satellite links require terminal pointing, acquisition, and tracking subsystems that are capable of high speed, high accuracy pointing control for acquisition and tracking to support communication operations. Without the ability to return a beam along the line of sight towards the companion terminal, communications cannot take place. By employing a simple chopper wheel in the optical receiver path, a quadrant avalanche photodiode can be made to track a known stellar object.

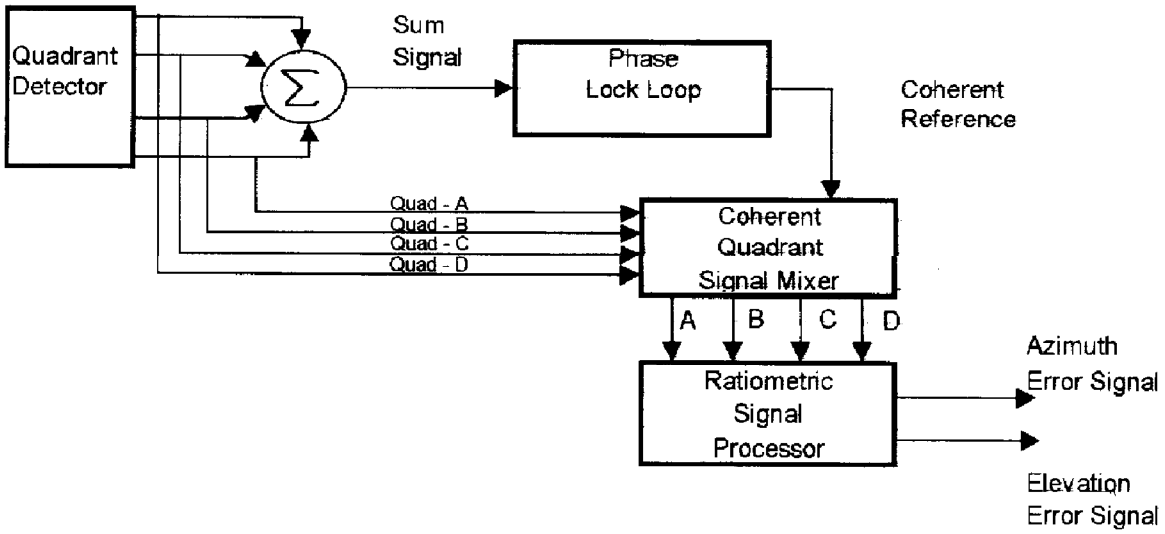
The difficulty in system design revolves around the limited view field and narrow wavelength bands typical of laser cross-link receivers, a typical laser communication pointing and tracking system is nested with a gimbals and fine tracking loop plus the additional forward correction offered by a point-ahead loop. Low-bandwidth disturbances are normally added linearly, while higher frequency disturbances are root-sum squared to achieve an estimate of the pointing uncertainty.

The total pointing error is the contribution of the bias and the random term's. Tracking systems can be divided in two distinct categories. The first category involves those systems that derive the track information from communication signals. The second technique set concerns those systems that use a separate laser beacon to track. The first technique to track signals is dc tracking. The term is used to describe tracking the laser source by integrating the received amplitude-modulated signal over a large number of cycles or pulses. Commonly, an integrating type of detector such as CCD, which will be optimized to the track bandwidth, would be used to track the beam. With dc tracking, the drawback is the susceptibility to optical background, especially point sources in the field of view (FOV). DC tracking is not recommended because unique discrimination is not possible without very narrow line width filtering of the signal.

A second technique for tracking a communication signal is pulse tracking. This technique is used when the communication source is also a pulse waveform but can be used also as an independent beacon channel. With pulse tracking system, each pulse is detected with the receiver threshold and uses this information to generate a high-bandwidth tracking error signal from the track quadrants. Pulse tracking has a high-bandwidth receiver front end to effectively detect very short pulses. In the dc system, the bandwidth is dependent upon the communication system, pulse width and pulse rate.

Another technique of tracking systems that derives a track signal by squaring the communication waveform to generate a tracking signal is Square-Law Tracking. This technique can be used most effectively when a single quasi-CW modulated source is used for communication. Squaring the incident signal waveform at twice the signal bandwidth generates a harmonic signal. This harmonic signal can then be phase-locked and used to generate the quadrant track errors. One inconvenience with this technique is that the track signal is twice the communication bandwidth and the tracking system is more dependent upon the data rate. Figure below shows this type of tracking system.

FIGURE 4: TYPE OF TRACING SYSTEM



Tone tracking involves transmitting a separate tone beacon via an additional laser source or modulating the tone into the communication waveform. In this type of modulated tone, the frequency does not interfere with the message content of the communication waveform. If a wavelength separation is available it could involve a separate detector.

By using coherent waveform techniques, spatial inter satellite tracking can be achieved. Coherent techniques use the high front-end local-oscillator gain to compensate for downstream noises. There are others approaches to track a system using Non conventional Tracking Techniques like Gimbal-Only Tracking and Feed-Forward Tracking.

8.2 SPATIAL INTER SATELLITE TRACKING

The use of optical frequency for communications has several advantages such as high, bandwidth, lower power requirements, and smaller antenna size, minimization of spurious background, privacy, and jam-resistance. The selection of beam width and field of view is not inhibited by aperture size, wavelength, and surface quality, but by the ability of the communication terminal to acquire, point, and track to a compatible accuracy.

9. ADVANTAGES OF LASER SYSTEMS

Laser communication systems offer many advantages over radio frequency (RF) systems. Most of the differences between laser communication and RF arise from the very large difference in the wavelengths. RF wavelengths are thousands of times longer than those at optical frequencies are. This high ratio of wavelengths leads to some interesting differences in the two systems. First, the beam-width attainable with the laser communication system is narrower than that of the RF system by the same ratio at the same antenna diameters (the telescope of the laser communication system is frequently referred as an antenna). For a given transmitter power level, the laser beam is brighter at the receiver by the square of this ratio due to the very narrow beam that exits the transmit telescope. Taking advantage of this brighter beam or higher gain, permits the laser communication designer to come up with a system that has a much smaller antenna than the RF system and further, need transmit much less power than the RF system for the same receiver power. However since it is much harder to point, acquisition of the other satellite terminal is more difficult. Some advantages of laser communications over RF are smaller antenna size, lower weight, lower power and minimal integration impact on the satellite. Laser communication is capable of much higher data rates than RF.

The laser beam width can be made as narrow as the diffraction limit of the optic allows. This is given by beam width = 1.22 times the wavelength of light divided by the radius of the output beam aperture. The antennae gain is proportional to the reciprocal of the beam width squared. To achieve the potential diffraction limited beam width a single mode high beam quality laser source is required; together with very high quality optical components throughout the transmitting sub system. The possible antennae gain is restricted not only by the laser source but also by the any of the optical elements.

In order to communicate, adequate power must be received by the detector, to distinguish the signal from the noise. Laser power, transmitter, optical system losses, pointing system imperfections, transmitter and receiver antennae gains, receiver losses, receiver tracking losses are factors in establishing receiver power. The required optical power is determined by data rate, detector sensitivity, modulation format, and noise and detection methods.

Following is the major Advantage of the laser communication systems
1. The narrow beams guarantee high spatial selectivity so there is no interference with other links.
2. High bit rate enables them to be applied in all types of networks.
3. Optical band lies outside the area of telecommunication offices; therefore, a license is not needed for operation.
4. The utilization of quantum state transmission promises long-term security for high-value data.
5. Short size and small weight corresponds to easy integration to the satellite body.

For reliability improvement number of new methods is applied:

1. Photonic technology
2. Multi beam transmission
3. Wavelength and space division
4. Beam shaping
5. Auto-tracking system
6. Microwave backup
7. Adaptive optics
8. Polygonal (mesh) topology

10. DISADVANTAGES OF LASER SYSTEMS

Following is the major disadvantage of the laser communication systems

1. Availability of Free-Space optical (FSO) link depends on the weather
2. FSO link requires a line of site between transceivers
3. birds and scintillation cause beam interruptions

11. DEVELOPMENT OF CONSTITUENT TECHNOLOGIES

To date we have conducted research into the basic concepts and feasibility of a next-generation satellite mobile system as well as investigation of the constituent technologies. We have also studied satellite visibility factors and quality of service regarding handover and delay characteristics. Based on our results, we have made recommendations as to the optimum satellite constellation: a circular orbit at an altitude of 1,200 km; an orbital inclination of 55°; ten orbital planes; and 12 satellites per orbital plane (120 in total).

Following are examples of the main constituent technologies we have developed in this project to date. Some of these technologies have potential in a wide range of applications in addition to their use in satellite mobile systems.

11.1 DEVELOPMENT OF SATELLITE-MOUNTED EQUIPMENT FOR ACCESS TO THE GROUND

High-efficiency amplifiers offer potential for use in satellite mounted phased array antennas. Eschewing conventional materials, we constructed a new type of power amplifier using a gallium nitride semiconductor. To study the feasibility of mounting the amplifier on a satellite, we then conducted environmental evaluations, such as testing of the amplifier's radiation resistance and dispersion properties.

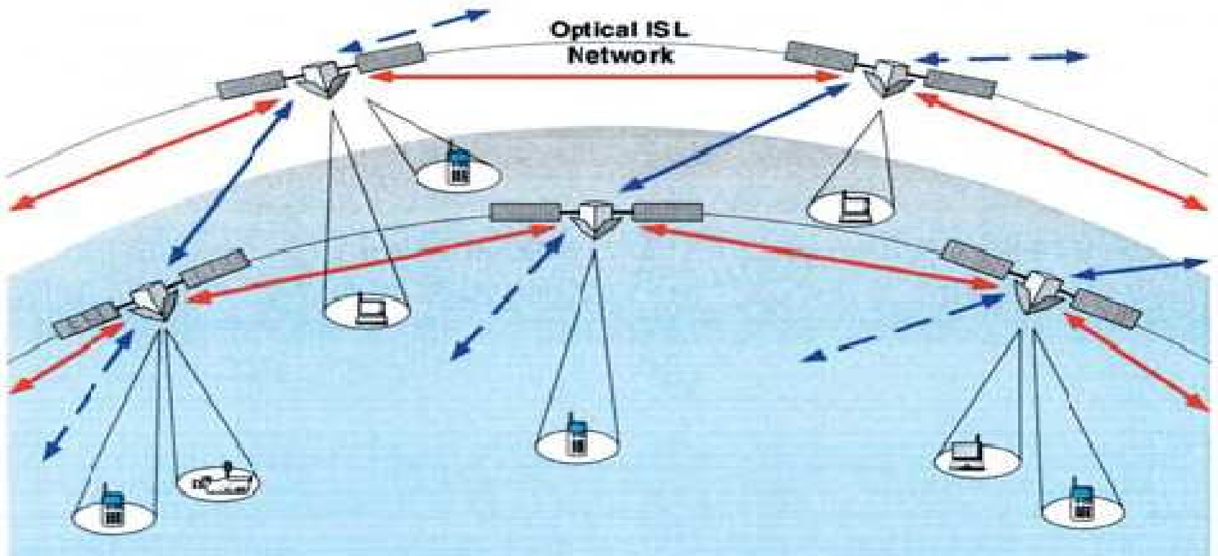
11.2 INTER-SATELLITE COMMUNICATIONS TECHNOLOGY

We developed an optical antenna and a transmission evaluator for an "optical inter-satellite" communications terminal. This compact and lightweight terminal achieves single-wavelength data transmission at 2.5 Gbps. We also carried out partial prototyping and evaluation of the satellite-mounted system including a control/processing circuit and a finely sensitive acquisition and tracking sensor module/mechanism featuring a receiving collimator fiber assembly.

11.3 GROUND-SATELLITE NETWORKING TECHNOLOGY

We developed a ground-satellite network simulator that is compatible with ground-based communications systems; the device simulates multimedia communications via satellite.

FIGURE 5: NEXT-GENERATION LEO COMMUNICATIONS



A constellation of low-Earth orbit (LEO) satellites will be used to provide mobile terminals on the ground with Global Multimedia Mobile Satellite System service, which will allow high-speed transmission of information such as image data. Accordingly, we are planning to conduct verification testing of the necessary optical inter-satellite communications technology. Inter-satellite communications: High-speed optical inter-satellite communications (up to 2.5 Gbps) User link connection: Satellite antenna design of 1 user/1 beam User terminal performance: Multimedia communications up to 2 Mbps.

12. CONCLUSION

The implementation of any of these systems in an inter-satellite link will require a substantial development effort. The strengths and weaknesses of the various types of lasers presently available for laser communications should be carefully considered. Based on existing laser's characteristics, the GaAlAs system, especially the full-bandwidth, direct detection system is the most attractive for inter satellite links because of its inherent simplicity ant the expected high level of technological development. The system and component technology necessary for successful inter satellite link exists today.

The growing requirements for the efficient and secure communications has led to an increased interest in the operational deployment of laser cross-links for commercial and military satellite systems in both low earth and geo-synchronous orbits. With the dramatic increase in the data handling requirements for satellite communication services, laser inter satellite links offer an attractive alternative to RF with virtually unlimited potential and an unregulated spectrum.
Compared to existing stationary satellites or LEO satellites (providing communications services now experiencing a notable slowdown in demand), the next-generation LEO satellite system offers superior multimedia communications features. This new system offers high-capacity transmission despite its globally unparalleled small size. Further, technologies discovered in the course of system development will likely find commercial application in many fields other than satellite communications, including areas involving national security, global environmental measurement, and resource exploration. Notably, the development of a next-generation LEO satellite system was selected as part of the Millennium Project.
A full-duplex, combined analogue and digital FSO Laser Communication Link was successfully designed and implemented. It was also possible to obtain experimental data from the designed system, which proved to be very useful and informative.
The results of testing and experiments created new areas within this study's scope that can still be explored. Recommendations for future developments of the FSO laser link are based mainly on alignment and focusing systems to improve performance, in addition to the use of laser diodes specifically designed for modulation.
FSO technology is ready for utilization as terrestrial links, mobile links and satellite links.

1. Importance of high bit rate and security for high-value data.
2. Possibility of integration in global wireless communication network.
3. Optical communication in deep space between Mars satellite and Earth station is in preparation (MTO, Mars Telecommunication Orbiter).
4. Terrestrial links are a suitable technology for the "last mile" solution in the frame of access network.
5. The utilization of the FSO links is requested namely in situations where the use of an optical cable is impossible and desired bit rate is too high for a microwave links.
6. FSO links are flexible, simple and full-value (in terms of quality of transmission) license-free instrument of network communication technologies.

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