A

Seminar report

on

# LASER COMMUNICATION

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of  ECE

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# Preface

I have made this report file on the topic **LASER COMMUNICATION ,** I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the prepration of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

# Acknowledgement

I would like to thank respected Mr…….. and Mr. ……..for giving me such a wonderful opportunity to expand my knowledge for my own branch and giving me guidelines to present a seminar report. It helped me a lot to realize of what we study for.

Secondly, I would like to thank my parents who patiently helped me as i went through my work and helped to modify and eliminate some of the irrelevant or un-necessary stuffs.

Thirdly, I would like to thank my friends who helped me to make my work more organized and well-stacked till the end.

Next, I would thank Microsoft for developing such a wonderful tool like MS Word. It helped my work a lot to remain error-free.

Last but clearly not the least, I would thank The Almighty for giving me strength to complete my report on time.

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## ABSTRACT

Laser communications offer a viable alternative to RF communications for intersatellite links and other applications where high-performance links are necessary. High data rate, small antenna size, narrow beam divergence, and a narrow field of view are characteristics of laser communication that offer a number of potential advantages for system design. The high data rate and large information throughput available with laser communications are many times greater than in radio frequency (RF) systems. The small antenna size requires only a small increase in the weight and volume of host vehicle. In addition, this feature substantially reduces blockage of fields of view of the most desirable areas on satellites. The smaller antennas, with diameters typically less than 30cm, create less momentum disturbance to any sensitive satellite sensors. The narrow beam divergence of affords interference-free and secure operation.

# CHAPTER 1

# INTRODUCTION

Lasers have been considered for space communications since their realization in 1960. However, it was soon recognized that, although the laser had potential for the transfer of data at extremely high rates, specific advancements were needed in component performance and systems engineering, particularly for space-qualified hardware. Advances in system architecture, data formatting, and component technology over the past three decades have made laser communications in space not only a viable but also a attractive approach to intersatellite link applications. The high data rate and large information throughput available with laser communications are many times greater than in radio frequency (RF) systems. The small antenna size requires only a small increase in the weight and volume of host vehicle. In addition, this feature substantially reduces blockage of fields of view of the most desirable areas on satellites. The smaller antennas, with diameters typically less than 30cm, create less momentum disturbance to any sensitive satellite sensors. Fewer onboard consumables are required over the long lifetime because there are fewer disturbances to the satellite compared with larger and heavier RF systems. The narrow beam divergence of affords interference-free and secure operation.

# 1.1 FEATURES OF LASER COMMUNICATIONS SYSTEM

A block diagram of typical terminal is illustrated in Fig 1. Information, typically in the form of digital data, is input to data electronics that modulates the transmitting laser source. Direct or indirect modulation techniques may be employed depending on the type of laser employed. 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 detectors and signal processing electronics. There are also terminal control electronics that must control the gimbals and other steering mechanisms, and servos, to keep the acquisition and tracking system operating in the designed modes of operation.
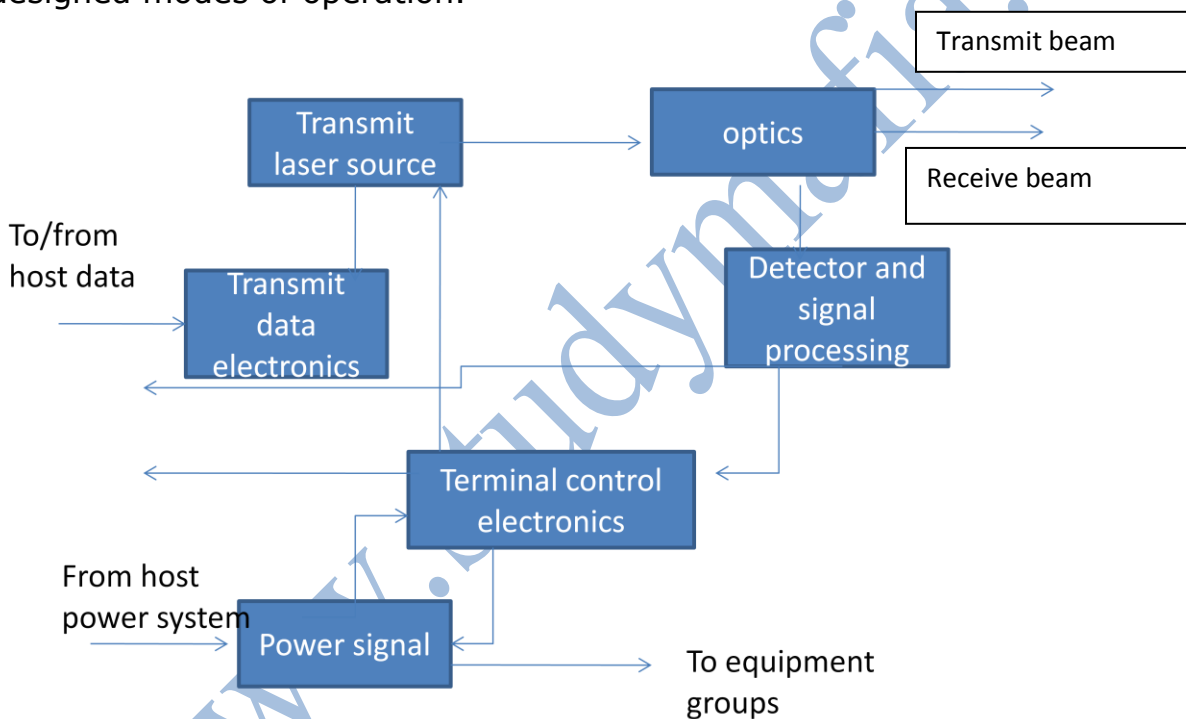


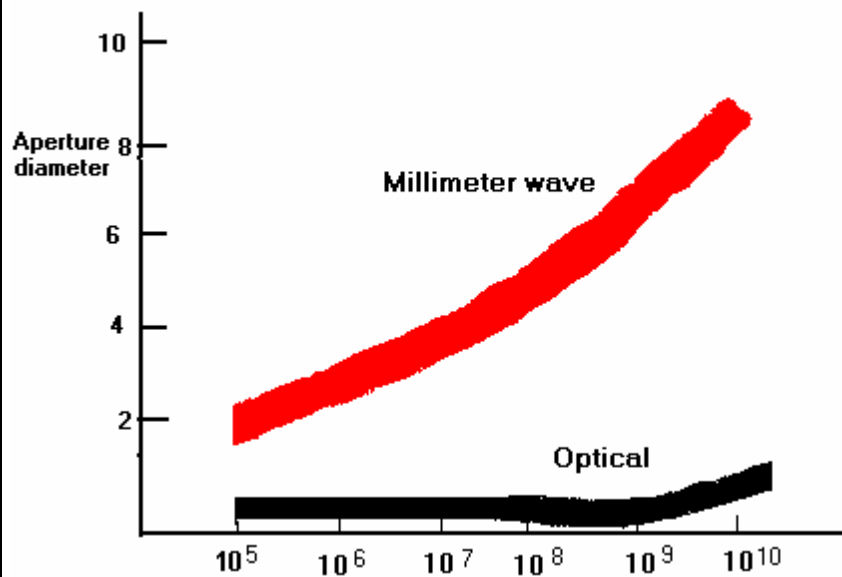Figure 1.1 A block diagram of a typical laser communication terminal.

Fig 1.2 telescope aperture vs data rate

The extremely high antenna gain made possible by the narrow beams enables small telescope apertures to be used. Plots of aperture diameter vs. data rate for millimetre and optical waves are shown in Fig 2. A laser communications system operating at 1 GB/s requires an aperture of approximately 30 cm. In contrast, a 1 GB/s millimetre wave system requires a significantly larger aperture, 2-2.75 m. The laser beam width can be made as narrow as the diffraction limit of the optics allows. This is given by the beam width equal to 1.22 times the wavelength of the light, divided by the radius of the output beam aperture. This antenna gain is proportional to the reciprocal of the beam width squared. The most important point here is that to achieve the potential diffraction-limited beam width given by the telescope diameter, a single-mode high-beam-quality laser source is required, together with very high-quality optical components throughout the transmitting subsystem. The beam quality cannot be better than the worst element in the optical chain, so the possible antenna gain will be restricted not only by the laser source itself, but also by any of the optical elements, including the final mirror or telescope primary. Because of the requirement for both high efficiency and high beam quality, many lasers that are suitable in other applications are unsuitable for long distance free-space communication. In order to communicate, adequate power must be received by the detector to distinguish signal from noise. Laser power, transmitter optical system losses, pointing system imperfections, transmitter and

receiver antenna gains, receiver losses, and receiver tracking losses are all factors in establishing receiver power. The required optical power is determined by data rate, detector sensitivity, modulation formats, noise, and detection methods.
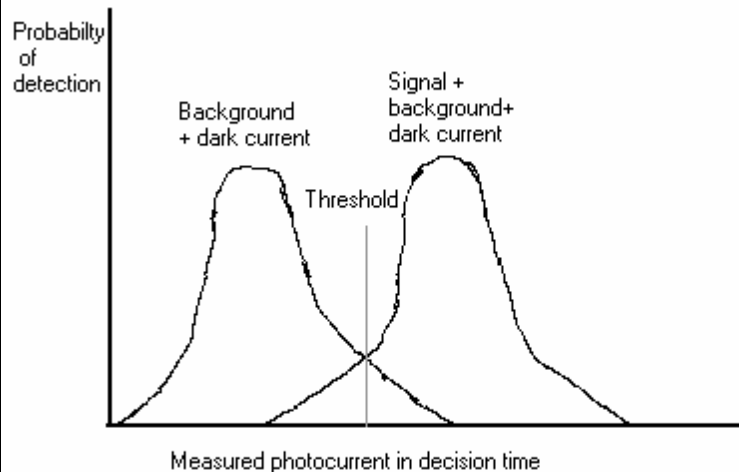


**Figure 3.** Distribution of detection probability Vs. photo current in the presence of signal

When the receiver is detecting signals, it is actually making decisions as to the nature of the signal (when digital signal are being sent it distinguishes between ones and zeros). Fig 3. shows the probability of detection vs. measured photocurrent in a decision time. There are two distributions: one when a signal is present (including the amount of photocurrent due to background and dark current in the detector), and one when there is no signal present (including only the non signal current sources). A threshold must be set that maximizes the success rate and minimizes the error rate. One can see that different types of errors will occur. Even when there is no signal present, the fluctuation of the non signal sources will periodically cause the threshold to be exceeded. This is the error of stating that a signal is present when there is no signal present. The signal distribution may also fall on the other side of the threshold, so errors stating that no signal is present will occur even when a signal is present. For laser communication systems in general, one wants to equalize these two error types. In the acquisition mode, however, no attempt is made to equalize these errors since this would increase acquisition time.

## 1.2 OPERATION

Free space laser communications systems are wireless connections through the atmosphere. They work similar to fibre optic cable systems except the beam is transmitted through open space. The carrier used for the transmission of this signal is generated by either a high power LED or a laser diode. The laser systems operate in the near infrared region of the spectrum. The laser light across the link is at a wavelength of between 780 – 920 nm. Two parallel beams are used, one for transmission and one for reception.



Figure 1.4: MAGNUM 45 High-Speed Laser-Communication Systems (Source:LSA Photonics)

## CHAPTER 2

# 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.

## 2.1 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 fibre 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(gallium arsenide/gallium aluminium 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 aluminium 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 fibre communications, a wide array of components is available for the potential applications in space. These include detectors, lasers, multiplexers, amplifiers, optical pre amplifiers etc. Operating at 1550nm erbium doped fibre amplifiers have been developed for commercial optical fibre 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 is acquisition time, 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.

## 2.2 TRANSMITTER PARAMETERS

The transmitter parameter consists of certain key laser characteristics, losses incurred in the transmitter 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 isotropic 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 pointing is the transmitter pointing losses. The pointing error is composed of bias (slowly varying) and random (rapidly varying) components.

## 2.3 CHANNEL PARAMETERS

The channel parameters for an optical intersatellite 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 platform in metres.

## 2.4 RECEIVER PARAMETERS

The receiver parameters are the receiver antenna gain, the 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 metres and inversely proportional to the square of the wavelength. 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.

## 2.5 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.

## 2.6. 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.

$\alpha = Vt / 150$ μ 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 width 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, the 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.
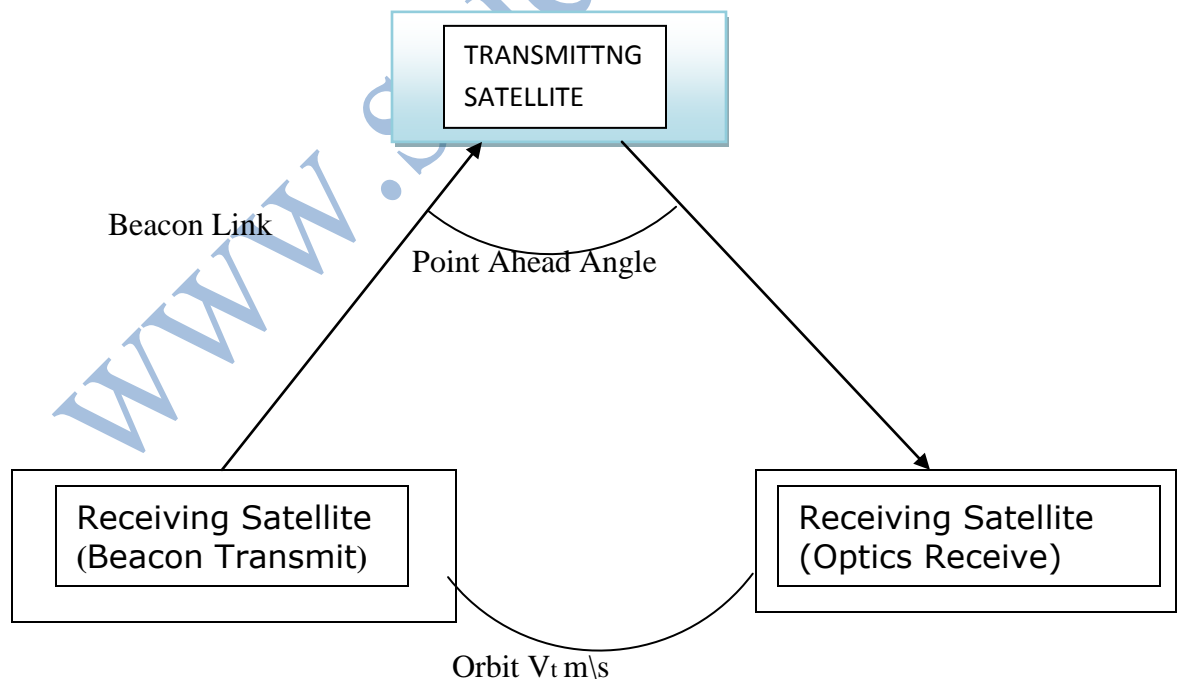
TRANSMITTNG SATELLITE

Beacon Link

Point Ahead Angle

Receiving Satellite (Beacon Transmit)

Receiving Satellite (Optics Receive)

Orbit Vt m\s

FIG 2.1 Required beam widths and point ahead model for optical pointing

## 2.7 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. 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 Gimbals-Only Tracking and Feed-Forward Tracking.

## 2.8 OPTICAL NOISE

Noise characteristics play an important role in laser communication systems. At optical frequencies noise characteristics are significantly different than those at radio frequencies. In the RF domain, quantum noise is quite low, while thermal noise predominates and does not vary with frequency in the microwave region. However,*/ as the wavelength gets shorter, quantum noise increases linearly, and in the laser regime thermal noise drops off very rapidly, becoming insignificant at optical wavelengths*/. Because there is so little energy in a photon at radio frequencies, it takes many problems to equal the thermal noise. The quantum noise is actually the statistical fluctuations of the photons, which is the limiting sensitivity at optical frequencies. However, in optical receivers employing direct detection and avalanche photodiodes, the detection process does not approach the quantum limit performance. For this type of optical receiver, the thermal noise due to the preamplifier is usually a significant contributor to the total noise power. Free space optical communication links, atmospheric turbulence causes fluctuations in both the intensity and the phase of the received light signal, impairing link performance. Atmospheric turbulence can degrade the performance of free-space optical links, particularly over

ranges of the order of 1 km or longer. In homogeneities in the temperature and pressure of the atmosphere lead to variations of the refractive index along the transmission path. This index in homogeneities can deteriorate the quality of the received image and can cause fluctuations in both the intensity and the phase of the received signal.

These fluctuations can lead to an increase in the link error probability, limiting the performance of communication systems. Aerosol scattering effects caused by rain, snow and fog can also degrade the performance of free-space optical communication systems. The primary background noise is the sun. The solar spectral radiance extends from the ultraviolet to the infrared, with the peak in the visible portion of the spectrum. Atmospheric scattered sunlight, sunlit clouds, the planets, the moon, and the Earth background have similar radiances; the sun's radiance is much higher and a star field's much lower. A star field is an area of the sky that includes a number of stars. If one were able to look only at an individual star, one would find brightness similar to that of the sun; but a star field as a whole is composed of small point sources of light, the stars in the field, against a dark area having no background level. The background is reduced by making both the field of view and the spectral width as narrow as possible. For direct detection systems, narrow field of view spectral filters on the order of 20A*(2 nm) are typical. Heterodyne systems will enable further reduction, but with a increase in terminal complexity. However, some systems can be signal-quantum-noiselimited, rather than background-limited, without having to resort to heterodyne detection.

## 2.9 AN EXAMPLE

Here we give a simple example of hoe the parameters just described are used in link analysis to design a laser communications system capable supporting a full duplex 10 Mb/s geosynchronous orbit crosslink. The detailed link analysis is not covered in this article but employs the entire element described above. To size the system, however, a link analysis for the communications function was performed. The source peak power requirement, 3 dB of the system margin, was determined to be 0.6 W. A semiconductor laser diode beam combiner is assumed for the transmitter source employing four lasers at 150 mW each. A 5 in aperture was determined to produce a beamwidth compatible with the fine-track pointing budget of 4.0 mrad. The pointing budget was determined by assuming a tracking system employing both fine-steering mirrors and a gimballed telescope. The transmitter and receiver optics efficiencies are representatives of nominal values achievable totally in similar systems. The peak received signal power was determined to be 1.64 nW from the assumed parameter values given.

The diode laser source is modulated directly in a Manchester modulation format by changing the drive current to the diodes. The link employs a rate ½, constraint length 7 convolution code with Viterbi decoding and hard decisions. This permits the link to operate at a higher channel symbol error rate (0.014), but still produce a decoded bit error rate of $10-6$ . The code employed yields approximately 2 dB of coding gain for direct detection laser communications link. A quadrant APD was selected as the detector because of its compactness, high reliability, and high sensitivity (compared to a PIN photodiode). The desired communications signal was obtained by summing the four quadrants. It is assumed that 0.6 W of laser power is adequate to support the acquisition and track functions. This example is representative of a typical laser communications system for satellite applications.

## 2.10 APPLICATIONS

Depending on the climatic zone where the free space laser communications systems are used, they can span distances up to 15 km at low bitrates or provide bitrates up to 622 Mbps at shorter distances. The systems are protocol transparent allowing transmission of digital computer data (LAN interconnect), video, and voice over IP, multiplexed data, or ATM. They are suitable for temporary connectivity needs such as at conventions, sporting events, corporate and university campuses, disaster scenes or military operations.

## 2.11 ADVANTAGES AND DISADVANTAGES

Free space laser communications links eliminate the need for securing right of ways, and buried cable installations. As the equipments operate within the near infrared spectrum, they are not subject to government licensing and no spectrum fees have to be paid (according to Art. 7 in [3] requires only the use of the frequency spectrum below 3'000 GHz a licence). Additionally, since no radio interference studies are necessary, the systems are quickly deployable. The narrow laser beamwidth precludes interference with other communication systems of this type. Free space laser communications systems provide only interconnection between points that have direct line-of-sight. They can transmit through glass, however, for each glass surface the light intensity is reduced, due to a mixture of absorption and refraction, thus reducing the operational distance of a sys-tem. Occasionally, short interruptions or unavailability events lasting from some hours up to a few days can occur. 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.

## CONCLUSIONS

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.

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