International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-1 Issue-3, February 2012

Satellite Communication Networks Performance

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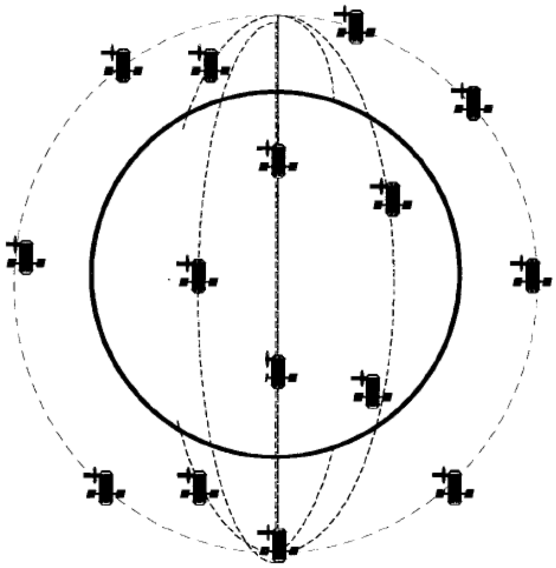
Abstract— A number of serious consortiums develop satellite communication networks. The objective of these communication projects is to service personal communication users almost everywhere on earth. The inter satellite links in those projects use microwave radiation as the carrier. Free-space optical communication between satellites networked together can make possible high-speed communication between different places on earth. Some advantages of an optical communication system over a microwave communication system in free space are 1) smaller size and weight, 2) less transmitter power, 3) larger bandwidth, and 4) higher immunity to interference. The pointing from one satellite to another is a complicated problem due to the large distance between the satellite, the narrow beam divergence angle, and vibration of the pointing system. Such vibration of the transmitted beam in the receiver plane decreases the average received signal, which increases the bit error rate.

Index Terms— Laser communication, optical networks, satellite optical communication, vibrations.

I. INTRODUCTION

Communication from any place to another on earth is an attractive goal. One method to achieve this aim is by networking satellites together to cover the globe. In this method, the information is transferred from the ground to the nearest satellite above and then propagates between the satellites to the satellite above the destination. This last satellite then transmits the information down to the destination. The idea of a satellite communication network is no longer science fiction. Today, a number of serious consortiums develop satellite communication networks. The objective of these communication projects is to service personal communication users almost everywhere on earth. The inter satellite links (ISL's) in those projects use microwave radiation as the carrier. The use of optical ISL's has some advantages over the use of microwave ISL's: 1) smaller size and weight of the terminal, 2) less transmitter power, 3) higher immunity to interference, 4) larger data rate, and 5) smaller transmitter beam divergence angle. The main disadvantage of optical ISL's is the complex pointing system. The complexity of the pointing system derives from the necessity to point from one satellite to another over a distance of tens of thousands of kilometers with a beam divergence angle of micro radians while the satellites move and vibrate. The pointing system compensates the motion of the satellites using the known Ephemerides data. Coupling of satellite mechanical vibration and tracking noise to the pointing system gives rise to vibration of the satellite transmitter beam in the receiver plane. Such vibrations of the transmitted beam in the receiver plane decrease the received signal, which increases the bit error rate (BER). In optical satellite networks, the problem is more complicated because all the satellites continually vibrate randomly.



Satellite communication network.

II. SATELLITE COMMUNICATION NETWORKS - PRESENT STATUS

Today, there are a number of serious consortiums developing satellite communication networks. The objective of these communication projects is to service personal communication users almost everywhere on earth. he amount of money invested worldwide in those projects is assumed to be tens of billions of U.S. dollars. The incentive for this huge investment is the expectation of a growing need for personal communication services (PCS's) unlimited by the coverage of cellular systems. There are two trends for network development: a) using ISL's (space switch) and b) using a ground station for each hop (ground switch).

Using ISL's almost eliminates the dependence on ground stations. This has some advantages: a) less investment in ground infrastructure; b) independence with regard to local telephone companies; c) saving of royalties for terrestrial services supplied; d)

Manuscript published on 28 February 2012.
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prevention of political difficulties; e) channel diversity; f) possible decrease in delay and latency.

The disadvantage of ISL's is the complexity of the system. Some of the satellite communication projects and their characteristics are described.

III. SATELLITE OPTICAL COMMUN-ICATION SYSTEM SCHEME

In this section, we review the basic schemes of the satellite optical communication segments: the transmitter, receiver, and tracking system.

System	Orbit Altitude (km)	Number of Satellites	Inter Satellite Link	Cost Develop. (G$)	Service
IRIDIUM	780	66	yes	3,4	Voice Data (2.4kbps)
TELEDESIC	695-705	840	yes	9	Voice Data (16-2048kbps) special (1,24416Gbps)
GLOBALSTAR	1389	48	no	1.7	Voice Data (9.6kbps)
ARIES	1018	48	no	0.5	Voice Data (2.4kbps)
ODYSSEY	10373	12	no	1.8	Voice Data (9.6kbps)
ELLIPSO	(7846-5000)	6-24	no	0.6	Voice Data (0.3-9.6kbps)

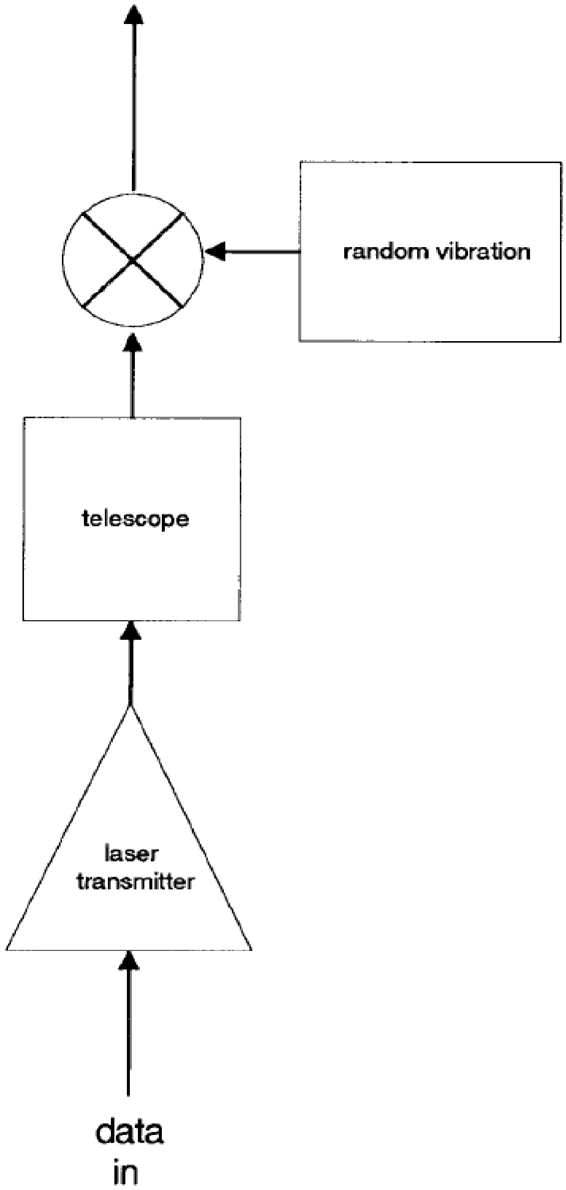
Few Satellite Communication Projects

A. *Transmitter* Scheme

The transmitter model for on–off keying (OOK) includes a laser transmitter, a telescope, and random attenuation (vibration effects). The messages arrive at th input of the transmitter. The transmitter converts electrical signals to optical signals using the laser. The transmitter telescope collimates the laser radiation in the receiver satellite direction.

B. *Receiver* Scheme

The receiver model for OOK includes a telescope, an optical bandpass filter, input insertion losses, an optical amplifier, output insertion losses, an optical bandpass filter, a p-i-n photodiode, an electrical filter, and a decision rule circuit. The receiver telescope focuses the received radiation onto the optical filter. The optical filter prevents most of the background radiation from entering the subsequent stages of the system. The radiation propagates through the optical filter to the optical amplifier. The optical amplifier has losses in its input and output due to reflection and optical mismatch. The radiation from the optical amplifier output is an amplified version of the input radiation but with optical amplifier noise. The optical filter at the output of the optical amplifier prevents part of the amplifier noise from passing.



[Transmitter scheme]

The radiation is converted to an electrical signal by a photodiode. The electrical signal is filtered by the electrical filter. According to the electrical signal amplitude and arrival time, the decision circuit decides the kind of information received.

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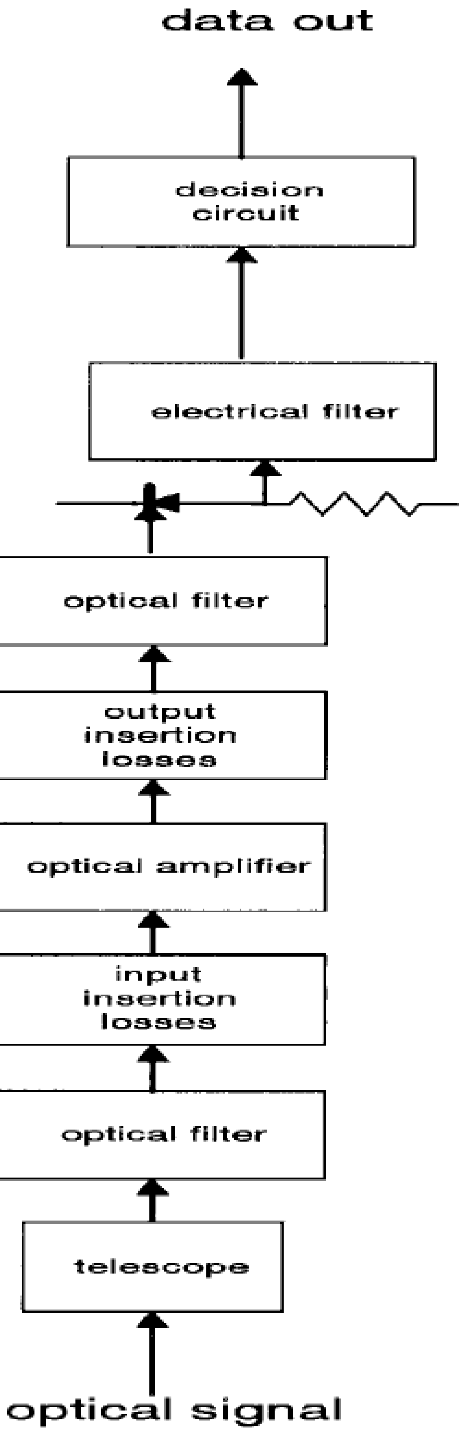
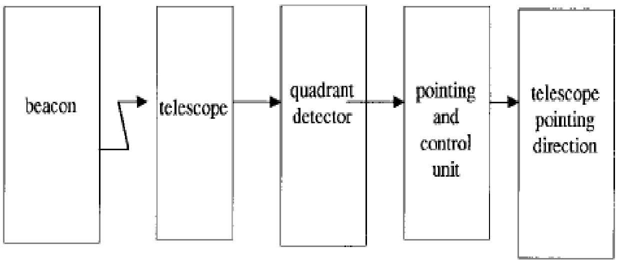


[Receiver scheme]

C. Tracking System Scheme

To establish optical communication between two satellites, the line of sight of their optics must be aligned during the entire time of communication. To meet this requirement, the satellites use the Ephemerides data (the position of the satellite according to the orbit equation) for rough pointing and a tracking system for fine pointing to the other satellite. The basic and popular method of tracking between satellites includes use of a beacon signal on one satellite and a quadrant detector and tracking system at the other satellite. The fine elevation and azimuth angle of the pointing system evaluates pointing direction from the output signal of the quadrant detector. In below Fig., we see the main components of the tracking system. The radiation from the beacon on one satellite is received by the telescope on the other satellite. The telescope focuses the received radiation onto the quadrant detector. The pointing and control unit calculates the telescope pointing direction according to the quadrant detector signal.



[Tracking-system scheme]

IV. COMPARISON BETWEEN MICROWAVE AND OPTICAL ISL'S

Comparisons between the microwave and laser technologies involve many considerations. In below table , we present some of the possible criteria for satellite communication segments. The important factors for satellite communication are mass, size, data rate, and power consumption. The optical link is better than the microwave link according to such factors. The main disadvantage of optical links is the lack of knowledge, subsystems, and experience from previous projects (technologies without history).

[Qualitative Comparison Between Optical and Microwave Links]

Characteristic	Optical link	Microwave link
size	smaller	larger
mass	smaller	larger
power consumption	less	more
bandwidth	wider	narrower
development cost	huge	almost zero
immunity to interference	more	less
orbit population	more dense	less dense

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Some researchers made quantitative comparisons between RF (23 and 60 GHz) and optical links for various satellite communication scenarios at data rates of 25 and 360 Mb/s. The results of the comparison for present technology are that the optical payload is found to be at least 50% lighter and the prime power and size are functions of the data rate and distance between the satellites. For data rates of 100 Mb/s and above, laser cross links are generally considered to be lighter, smaller, and of lower power consumption than RF links.

V. SATELLITE MECHANICAL IMPACTS AND VIBRATIONS

In this section, we review most of the vibration and impact sources in satellite technologies. Due to these mechanical impacts, the satellite transmitter beam to the receiver satellite vibrates and the communication system performance is degraded. Measurement of satellite vibrations has been performed onboard the OLYMPUS and LANDSAT satellites. The review is divided into two parts. The first describes external sources and the second describes the internal source of vibrations and impact. Such vibrations and impact propagate to subsystems onboard satellites and may cause disturbances for satellite subsystems, such as laser communication segments.

A. External Sources

Major external sources are listed in below table. Satellites can be destroyed by colliding with meteorites. If the satellite collides with micrometeorites, the collision can cause vibrations and impact in the satellite structure. When a satellite circles the earth, the radiation levels on it change according to its relative position with regard to celestial bodies such as the earth, moon, and sun. These changes of radiation level cause gradients of temperature on the satellite structure, which cause structure deformations. Due to cycling of the satellite movement, elastic forces of tension and bending are created. Another source of vibrations are in homogeneities of gravitational force through the satellite orbit (such as solar and lunar gravity, earth oblateness effects, the earth's central gravitational field, and ellipticity of orbit).

B. Internal Sources

Some internal sources cause vibrations in laser communication. Their range and duration are listed in below table. These results were measured on the OLYMPUS communication satellite by the ESA and are presented here only as an example. It is expected that in future satellites, the characteristics of vibration sources may change due to changes in design requirements. From this table, it is easy to understand what vibrations cause for each operation of mechanical systems. The strength and duration of the vibration are determined by characteristics of the subsystem. In practical LEO satellites, the solar array drive mechanism and antenna-pointing mechanism adapt their directions in order to optimize their performance.Consequently, vibrations are expected over most of their operation times. In below Fig., we see a plot of a simulation of vibration power density function for a laser communication system as a function of the mechanical frequency. The important points in this figure are the vibration limits at very low frequencies and the number of peaks included in the spectra. These peaks can relate to the operation of subsystems onboard the satellite, such as gimbal rate control jitter and gimbal position control jitter. The peak jitter can be filtered using appropriate stop-band filters.

[External Vibration Sources]

No.	Source
1	solar radiation pressure
2	thermal bending
3	micro-meteorite impacts
4	solar and lunar gravity
5	earth oblateness effects
6	ellipticity of orbit
7	effects of initial conditions
8	elastic forces of tension and bending
9	earth's central gravitational field

Summarizing this section, the vibration sources are various and are caused by internal and external mechanisms. Some of these vibrations and impacts may propagate into satellite subsystems, such as the laser transceiver, and cause disturbances in their normal operation modes.

[Internal Vibration Sources]

Event	Range [mg]	Duration [ms]
background	1	-
waveguide switch	80	14
solar array drive mechanism	3	56
thruster operation	33	30
antenna pointing mechanism	3	3600
gyroscope noise (navigation system)	-	-

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VI. RESULTS

This paper deals with the effects for satellite optical communication networks. Real-time applications such as video conferencing, medical imaging, and multimedia from any point on earth to any other point can become a reality if optical communication networks are implemented. This review points out that even low values of vibration amplitudes in each satellite can dramatically decrease the performance of the network. Consequently, even low vibration amplitude should not be neglected in any satellite design. It is important to understand that the performances of satellite attitude-control systems determine the satellite's vibration level. This new attitude system includes sensors (such as gyros, a global positioning system, a star tracker unit, a horizon sensor, an angular displacement sensor, accelerometers, and a quartz rate sensor) and filters (such as Kalman and complementary). The analysis and synthesis of the effects of vibrations on optical receiver and heterodyne communication systems are not included in this review due to its limited scope and length. It is our hope that this review can be the basis for future analyses and syntheses of satellite optical communication networks.

ACKNOWLEDGMENT

Mrs. Anubhuti Khare one of the authors is indebted to Director UIT RGPV Bhopal for giving permission for sending the paper to the journal. Manish Saxena is also thankful to the Chairman, Bansal Institute of Science & Technology Bhopal for giving permission to send the paper for publication. We would also like to thanks our colleagues for supporting us.

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