Study of "Breakthrough Technology" Free-Space Laser Satellite Communication

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***Abstract*-The rising demand for exponential growth in high data rate and effectiveness of satellite communication systems use has drawn the attention of several researchers recently. Universities, NITs and IITs students were developing small satellite projects such as micro satellites in weight of 10 kg to 100 kg within short duration of time and with low cost with breakthrough technologies. The capability and visibility of RF communication between a micro satellite and its ground station is limited time duration for data transfer within less latency. The problems can be overcome by using a geostationary orbit satellite as a "Relay Satellite by using laser wireless communications between a micro satellite and a geostationary satellite. Achieving high data rate transport globally depends on the Inter Satellite optical wireless communication (ISOWC) technology, which combines Inter Satellite Link (ISL) and Optical Wireless Communication (OWC). RF communication system is more depending on type of communication channel used, which has limitations such as atmospheric interference. To overcome the limitations and improving signal quality and bandwidth, an Inter-satellite optical (Laser) wireless communication (ISOWC) system will be widely used to establish communication between low earth orbit (LEO) and geostationary earth orbit (GEO) satellites.**

In this study, we will create an ISOWC between GEO and LEO satellites in order to achieve high data rate transfer between them. The micro satellite in Low Earth Orbit (about 400-600 km altitude) will use ISOWC) laser to communicate with the geostationary orbit satellite which is at the altitude of 36,000 km. Nevertheless, there are a number of issues with ISOWC systems that must be resolved. These challenges are represented by background noise interference, satellite vibration, and misalignment between the satellite's transmitter and receiver. This paper addresses an idea to provide the feasibility study survey of laser communications between micro satellites in LEO and geostationary satellites in GEO. A simulation model to be built for analyzing the performance of laser communications between LEO micro satellites and GEO satellites.

***Keywords— Laser Communications, Micro Satellites, GEO Satellites, Feasibility, Laser Components*.**

I INTRODUCTION

The main goal of this research is towards the study of the inter satellite laser wireless communications systems between a micro satellite in low earth orbit and satellite in geo-synchronous orbit. An inter-satellite Optical wireless communication has been attractive researcher attention because of the growing need for larger capacity and higher speed transmissions. RF and Optical waves are electromagnetic waves and have advantages by using an inter-satellite optical waves in space with reduced mass, power, less volume of equipment and limited of interference for higher data. rates. Inter satellite Communication between LEO LEO, LEO-GEO and GEO-LEO through RF link with omni antenna for high power and laser link with high gain for narrow beam communication.

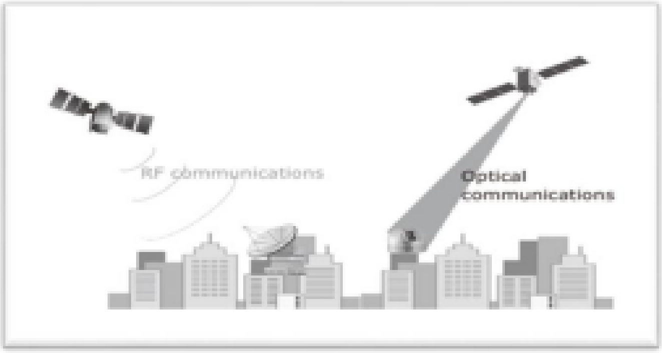

Fig 1. Image of difference in beam s between RF and Optical communication

Fig 1a. Inter-Satellite RF and Optical Communication

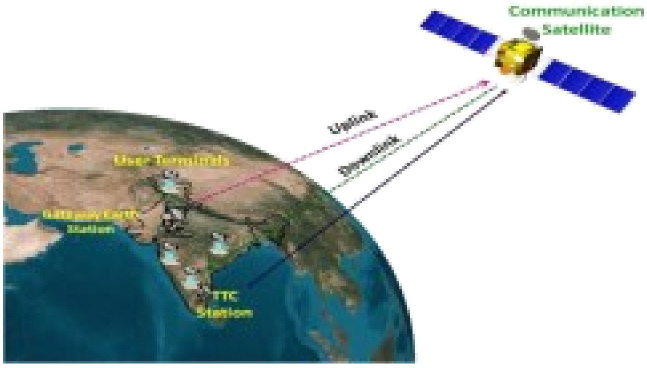

Fig 1b. Image of Satellite RF Communication

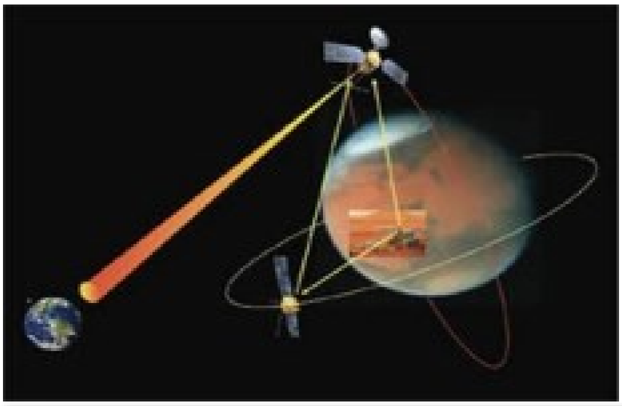

Fig 1c. Image of Inter Satellite Laser Communication

Parameters	**Relay communication via GEO satellite**	**Direct communication to ground station**
Number of communication sessions	~15 (FOV of GEO: 20°)	3-4
Communication duration per one orbit	~ 45 minutes	~ 10 minutes
Amount of data with the same data rate	Bigger	Smaller
Data latency	Almost real time	Long time to wait
Pointing requirement	Stringent	Much loosen

Table 1: Comparison of Optical Communication and RF Communication

A. *Laser Communication System*

The general laser communication systems consist of Transmit module and Receiver module as shown in Fig 2.

Tx module takes an electrical RF input signal and convert it into an optical output for laser transmission. The transmitter module utilizes an Intensity Modulation scheme to convert RF to light, which is transported through an optical fiber into the Optical Receiver.

Rx module takes an optical input and convert it back into an electrical RF output. The Receiver Module converts the modulated light back into an RF signal. Generally, the photodiode is a high impedance current source with an impedance around 2 k-ohms, followed with several amplifiers [2].

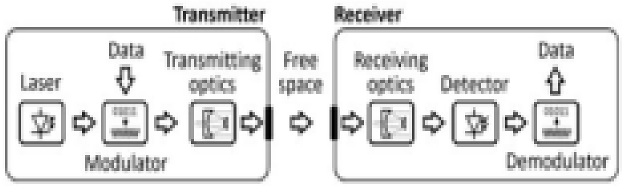

Fig 2. Basic diagram of a generic laser communication system.

B. Optical Link between Ground to Space and Space to Ground:

Replacement of conventional electrical approach by photonic components & systems as shown in Fig 3.

- More compact, lighter
- Cost effective satellites
- Increase of data rates to hundreds of Gb/s to Tb/s
- No frequency authorization requirement
- Secure transmission with reduced beam diameter

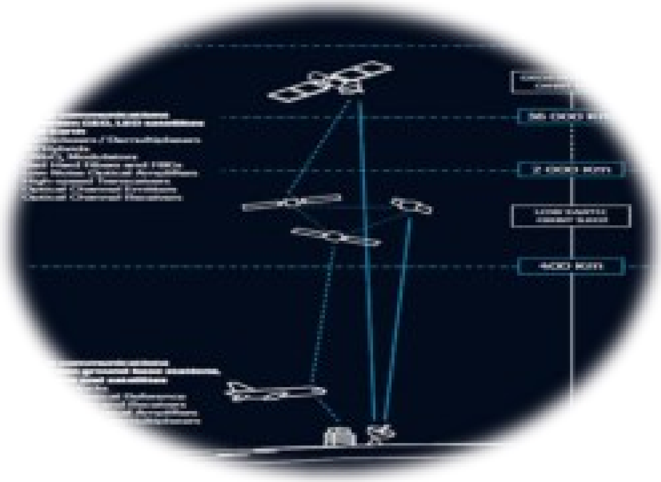

Fig 3. Image of Optical inter-intra-satellite communications between different satellites with different attitudes

The main ideology for choosing this topic is to prove the feasibility study of free space laser communication between satellites and its ground stations.

II LITERATURE SURVEY

Survey related to free space laser communication between satellites and satellites to ground station is discussed: Presently free space laser satellite communication becomes more and more popular in Europe and other countries. Development is under progress in India. Many researchers and space agencies have demonstrated various techniques and approaches for break through communication technologies for inter-satellite c0mmunication and data relay.

In the ***year 2005***, Europe, European Space Agency (ESA) was a primary driver in the development of laser communications and successfully demonstrated the Laser communication between SPOT-4 (Micro satellite in LEO) and ARESMIS (GEO satellites in GEO orbit) and in turn SPOT-4 satellite transmitted its data through ARTEMIS to its ground station.

In the ***year 2007***, USA and Germany have successfully demonstrated in setting up a laser data link between NFIRE satellite (USA) and TerrSAR-X satellite (Germany).

In the **year 2013**, NASA, USA jointly demonstrated the laser communications and transmitting data from lunar orbit to earth. In the ***year 2019***, Japan (JAXA) developed first optical link between satellite in LEO (OICETS) and satellite operates in GEO and transferring of its data to the ground station (earth) through GEO (ARTEMIS) satellite.

To study the feasibility of breakthrough technology free space laser communication between LEO & GEO satellites systems. The literature suggests that laser communication can provide reliable communication for transfer of high data between satellites and ground stations.

Overall, the literature on free space lase communication systems suggests that they have potential applications in a variety of satellite fields, including ground to space, LEO-LEO, Space station to ground via GEO satellite feeder.

III Methodology and Parameters

The block diagram describes the purpose of building this proposed systems methodology.

Generally, the capability of communication between a micro satellite in LEO and a dedicated ground station is limited in terms of the time duration for communication and data latency. A micro satellite in LEO can only communicate with a ground station at most several times per day and the duration of each communication window is only up to 10 minutes [7]. In LEO satellite, the period for one orbit of a micro satellite is ~ 90 minutes and the micro satellite cycles around the earth about 15 times per day. To overcome the problems raised in micro satellites in LEO, a Geostationary Orbit satellite can be used as a relay station for the micro satellite and laser will be used as the carrier between micro and GEO satellites in Fig 4.

The scope of this research is focused on feasibility study of breakthrough free space laser technology to be developed by private space industries for satellites communication shown in Fig 5.

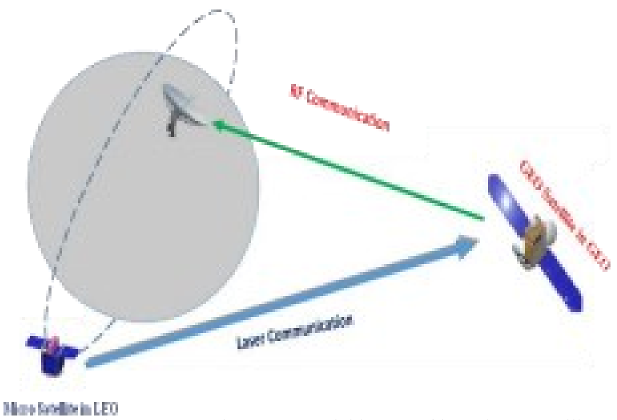

Fig 4. Proposed System model image of laser inter-satellite communications between Micro & GEO satellites

Fig 5. Author Imagination of laser inter-satellite communications between Micro & GEO satellites

Free space laser inter-satellite communication with an optical communication system on-board of satellite and laser as the carrier helps to solve almost of problems of RF communication in LEO satellite to ground stations. Laser communications will not be interrupted between LEO and GEO since there is no cloud and atmosphere in the space [4].

A. Optical acquisition and Tracking Technology

In free-space laser communications in space, the laser beam plays two roles [10]. Optical acquisition and tracking technology are necessary to establish this link.

- Establishing a link
- Laser as a carrier wave for communications.

Information on the locations of the two communicating satellites can be predicted to a certain degree using orbit calculations.

Optical Capture Operations: The laser beam is first scanned in the expected direction of the communication partner satellite. The partner satellite detects that laser beam.

Optical Acquisition Operations: Sensor is used to determine the exact location or position of the other satellite and emits a laser beam in that direction.

An algorithm for the acquisition and tracking of the communication partner satellite with certainty in a short period of time.

As a result of both satellites performing these operations, the satellite will eventually track the laser beams from the other satellite and continue to lock the laser beams. Fig.6 shows an image of a spiral scan between a satellite in geostationary orbit (GEO) and one in low earth orbit (LEO).

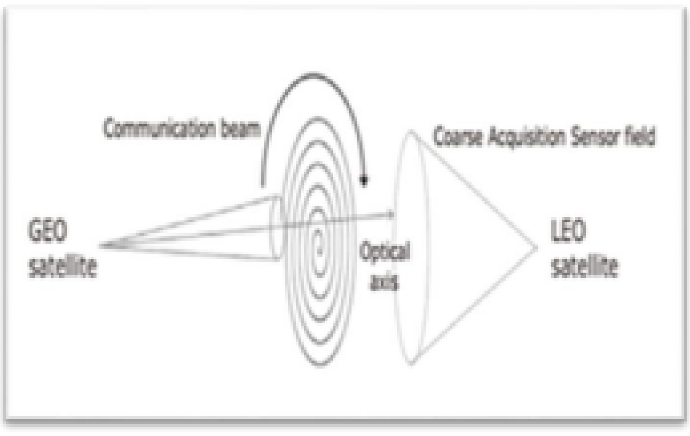

Fig 6. Image of spiral scan during acquisition between LEO and GEO satellites

B. *Data Collection*

The size of both transmitting and receiving antennas in laser communications are much smaller than in RF communication. The link budgets for RF systems in Ka band and an optical link of a GEO-LEO distance of 42,000 km.

Hypothetically case of the link budgets for RF systems in Ka band and an optical link of a GEO-LEO distance of 42,000 km and how the parameters of both links vary in terms of their characteristics. Considering an examples of link budgets for RF systems (Ka band) and an optical link at λ=1.55 μm at a bit rate =2.5 Gbps with a GEO-LEO distance of 42,000 km.

Parameters	**RF Systems (Ka)**	**Optical System**
Transmit power	50 W, 17 dBW	10 W, 40 dBm
Frequency	32 GHz	193 THz
Wavelength	9.4 mm	1.55 m
Tx antenna diameter	2.2 m	10.2 cm
Tx antenna gain	*55.1 dBi*	*109.3 dB*
Feeder/Tx loss	-3 dB	-2 dB
EIRP/ Strehl ratio	69.1 dBW	-0.4 dB
Pointing loss	-0.3 dB	- 3 dB
Beam divergence	0.25 deg	19.3 rad
Path loss	-215.0 dB	-290.6
Rx antenna diameter	2.2 m	10.2 cm
Rx antenna gain	55.1 dBi	106.3 dB
Feeder/Rx loss	-2.1 dB	-2 dB
Receive power	-93.7 dBW	-42.4 dBm
System noise	29.6 dBK	NA
G/T	23.4 dB/K	NA
Noise density	-199.0 dBW	NA
C/N_0 /Receive sensitivity	105.3 dBHz	90 photons/bit
Required C/N0 / Required power	102.0 dBHz	45.4 dBm
Link margin	**3.4 dB**	**3 dB**

Table 2: Comparison of link budget for RF and Optical Communication Systems

IV SYSTEM DESIGN AND REQUIREMENTS

The micro satellite moves around the Earth at the altitude from 500-1000 km (LEO orbit) while the height of the orbit of the GEO terminal is about 36,000 km (GEO orbit) [1]. The main satellite subsystems are shown in Fig 7.

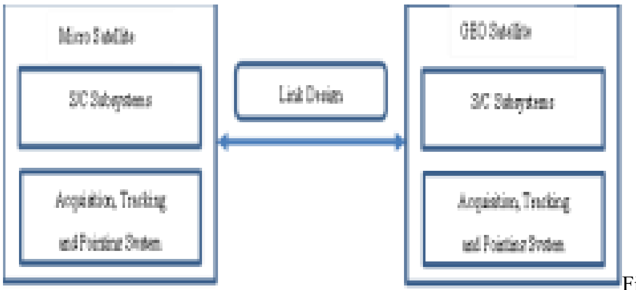

Fig 7. Design of the communications system between micro and GEO

A. System requirements and Assumptions

In communication between the micro satellite and the GEO satellite, two crucial parameter requirements for the systems are

- Bit Error Rate (BER) requirement
- Pointing requirement.

The required BER is $10^{-6}$for any successful laser free space communications.

Assumptions made that the data rate of laser communications from the micro satellite to the GEO satellite is 300 Mbps which is approximate to the best speed of radio communication for micro satellites currently. The wavelength of laser is 1.55 μm and the aperture of the telescope will vary in range of 35 cm to 45 cm for GEO satellite. The link requirements for communication between the micro satellite in LEO and the GEO is shown below.

SN	**Parameters**	**System Requirement& Assumption**
1	Date Rate	300Mbps
2	Link (Slant) range	40,000 km
3	Average BER	Asymmetrical Duplex Link 10^{-6}
4	Pointing accuracy	Several μrad
5	Tx o/p Power	<10 W
6	Tx aperture	>10 cm
7	Link budget margin	≥ 3 dB

Table 3: Link requirements of LEO-GEO Communication

Analysing communication between a transmitter and a receiver by using a link equation for any communications system [11]. In laser communications between the micro satellite and the GEO satellite, the signal delivering is expressed in the equation.

$$Pr = Pt\ Gt\ Lt\ LR\ Gr\ Lr \quad (1)$$ where

P_r = Receiving signal power (dB), P_t = Transmitted optical power at the output of the transmit antenna (dB),
G_t = Effective transmitting antenna gain (dB), L_t = Efficiency transmitter loss (dB), LR = Free space range loss (dB),
G_r = Receiving antenna gain (dB), L_r = Efficiency loss associated with the receiver (dB)

Calculation of Link Budget for Free Space Laser communication of LEO-GEO satellites as shown below.

SN	**Parameters**	**Data**
1	Transmit Power	2 W, 33 dBm

2	Frequency	1.93 THz
3	Wavelength	1.55μm
4	LEO Tx antenna diameter	5 cm (0.05 m)
5	LEO Tx antenna gain	103.5 dB
6	Distance (Slant range)	40,000 km
7	Path Loss	~ -290 (dB)
8	GEO Tx antenna diameter	35 cm (0.35 m)
9	GEO Tx antenna gain	117 dB
10	Receiver Power	-44.1 dBm
11	Receiver sensitivity (photon/bit)	90
12	Data rate	1Gbps
13	Required Power	-49.4 dBm
14	Link Margin	~5.3 dB

Table 4: Calculation of Link Budget for LEO-GEO Communication

V Results and Discussions

To evaluate free space laser communication link performance, the actual satellite signal was used for testing with Radio Frequency over Fiber (RFoF) system at ground system setup which is similar of laser communication link in free space. The graph represents the results optical communication link behaviour or performance shown in Fig 8. The input satellite signal was passed through RFoF system (optical fiber link) and the output shows a nominal signal without any loss as expected from fiber link.

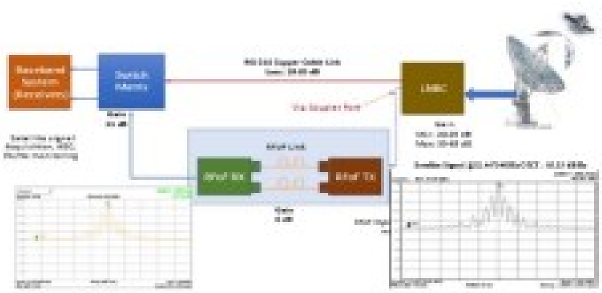

Fig 8. Image of Satellite Signal Acquisition through-RFoF system

Fig 9 graph shows satellite signal AGC, E_b/N_o measurements recorded by using spectrum analyzer between satellite ground station (Earth station) to Base-band system through RFoF (Radio Frequency over Fiber) system link.

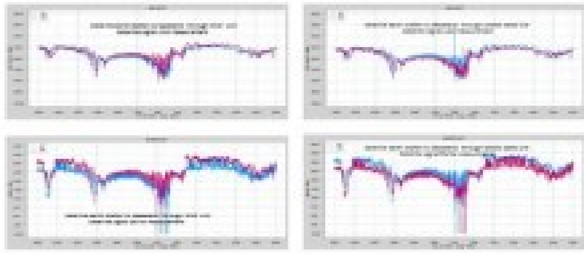

Fig 9. Image of Performance Comparison RFoF and Coaxial cable Link

VI Simulation and Analysis

The main objective of this simulation is to verify the communication link between the micro satellite and the GEO satellite. A model of the laser communications link from the micro satellite to the GEO satellite is built by using the free trial version of opti-system simulation software shown in Fig 10.

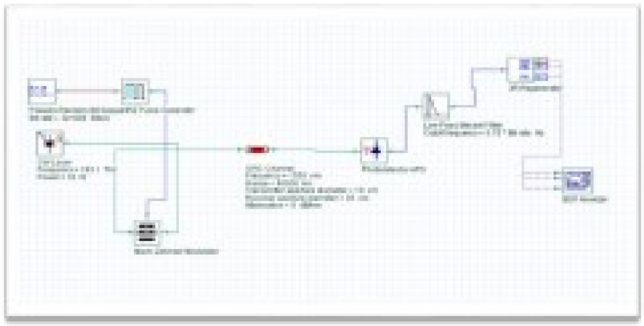

Fig 10. Layout of the link simulation

In the communication link, the transmitter includes a pseudorandom bit sequencer generator (PRBS), which represents the stream of data that will be transmitted, non return-to-zero (NRZ) modulator, which will be encode the stream of data, continuous wave laser and a MachZehnder modulator, which is an optical modulator whose functions are to vary the intensity of the light source according to the output of the NRZ pulse generator.

The Optical Wireless Communication (OWC) channel represents for the propagation environment between the two satellites. The receiver is an avalanche photodiode that receives the optical signal and converts it into electrical signal, low pass filter (LPF), used to filter out the unwanted high frequency signals and 3R regenerator, which is used to regenerate the electrical signal corresponding to the original bit sequence.

Considered the OWC channel is between an optical transmitter and optical receiver with 5-10 cm optical antenna at micro satellite and 35-45 cm antenna at GEO satellite and the transmitter and receiver gains are 0 dBm. Optical efficiency assumed is equal to 0.9 and no attenuation due to atmospheric effects between the two satellites

Laser/Optical communication link simulation in free space environment was not feasible by simulation software tool, instead of that, RF over Fiber (RFoF) systems has been used to simulate optical link performance in ground for satellite signal. Satisfactory results were achieved through RFoF systems for received satellite signal which is same behaviour in space for optical communication link performance.

VI Conclusion

This paper gives an idea to research in laser communication for free space laser communication and provide the feasibility study of laser communications between the micro satellite and the GEO satellite. The overall design of the communications system which includes the micro satellite, the GEO satellite, and the communication link between them. The system design, requirement and link budget calculation were done based on assumed data for laser and RF communication for comparison purpose. A model of the communication link between the micro satellite and the GEO satellite to be built and verification is being done by using the simulation software.

The goal of this paper is to bring out the feasibility study of designing the communications system between a micro satellite and a GEO satellite.

VII Future Work

The above system technology can be useful for satellite communication field, preferably for laser inter or intra satellite communication in free space and ground A set of full-scale demonstrations of high-speed laser satellite communication links is needed as the next step for optical communications in space in order that the future needs of intersatellite communication can be met with appropriate technologies.

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