Implementation of Inter and Intra Tile Optical Data Communication for NanoSatellites

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***Abstract*—The main constraint in the design of small satellites is the available space. AraMiS, a Nanosatellite built by Politecnico Di Torino, employ a novel design approach which is quite flexible and modular. The architecture of the satellite consists of a number of panel bodies called *tiles*. Theses tiles have double functionality i.e. mechanical shape of the satellite and functional design. All tiles consist of solar panels on the external side and data routing, power routing and all the necessary subsystems on the internal side. A number of sensors, actuators and other small modules are present on every tile using a plug and play approach. The communication of housekeeping data of different sensors within a tile and across the tiles, managed by onboard computer, can either be done using wired approach or wireless approach. This work focusses on data communication solutions using infrared optical communication. The communication system largely consists of electronic and optical components. The input data stream from any module is sent through encoder, LED driver and infrared LED at the transmit side and data is available at the receive side through photodetector, amplifier and comparator stages. The channel used for communication can either be free space or glass fiber. An innovative design of placing glass fiber for reliable communication across the tiles has been discussed. The optical light has been guided in certain directions using double surface mirrors. Theoretical and measurement results using a single fiber in light of sight have been calculated and the results are in close comparison with each other. Free space link has also been modeled and the received current at certain positions in the satellite due to a fixed transmitter has been mapped. The only shortcoming of the free space link is that when the payload is present, it becomes very difficult to maintain line of sight between the nodes and complex optics to reflect the light for the transmitters and receivers becomes a major problem. Every tile hosts two tiles processors (MSP430 controllers) which are responsible for communication across different nodes. At the end, this paper has shown some possible schemes for data communication architecture for small satellite using optical infrared light in parallel with the typical wire based solution.**

***Index Terms*— Tile, AraMiS, IRLED**

I. Introduction

THE basic architecture of AraMiS is based on one or more modular *tiles* [1]. These tiles or panel bodies are to be placed on the outer surface of the satellite. Six tiles connect together to form a cube shaped satellite.

The inner part of the satellite is mostly left empty, to be filled by the user-defined payload, which is the only part to be designed and manufactured ad-hoc for each mission. Each tile is designed, manufactured and tested in relatively large quantities. Reuse also allows putting an increased design effort to compensate for the lower reliability of commercial off the shelf (*COTS*) devices, therefore achieving reasonable system reliability at a reduced cost. Each tile can host a number of small sensors, actuators or payloads (up to 16 for each tile).

In [2-3], the authors show some techniques for free space optical communication inside the small satellites. This work discusses the implementation of free space as well as glass fiber based data communication for small satellites.

II. System Overview

Low speed communication link (0.5~1Mpbs) is sufficient for communication of housekeeping data across inter and intra tiles for AraMiS architecture. Fig.1 shows the block diagram of the implemented communication system. The communication system consists of both electronic and optical components. The incoming digital stream is encoded into Return to Zero Inverted (RZI) pattern, where a zero in the transmitted stream is represented by a pulse and a one is represented by no pulse. This RZI pattern is transmitted to the transmission medium in the form of optical light pulses using infrared light emitting diodes (IRLEDs) of different wavelengths with the use of LED driver circuitry. Both free space optical and glass optical transmission media have been implemented for inter and intra tile data communication. The free space medium requires line of sight (LoS) between the transmitters and receivers and hence becomes difficult to implement at times. The receiver block consists of photodiode, transimpedence amplifier and a comparator stage before the data stream is decoded and read by the tile processor for further protocol management purposes. Fig 1 shows the blocks containing optical and electronic components in the system. All the encoding, decoding and filtering stages consists of electronic components while the optical components consists of infrared light emitting diodes, photodiode and guided channel if any.

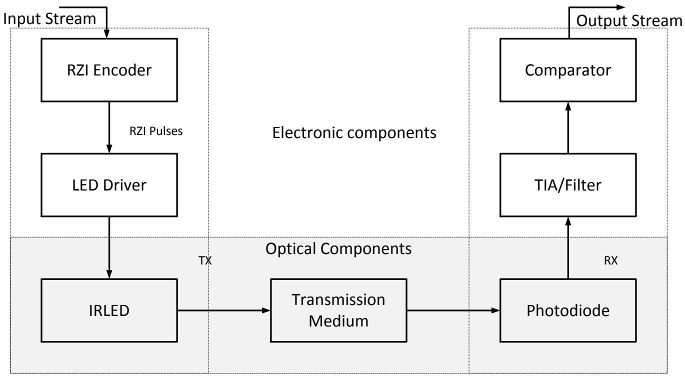


Fig. 1 Communication system overview

III. Glass Fiber Based Communication Architecture

A number of configurations for reliable communication for inter and intra tile communications were studied and the best proposed implementation structure is shown in the Fig 2. For experimental purposes, a no. of glass materials were evaluated for short range communication purposes inside the satellite. *Plexiglass* or *polymethyl methacrylate*, which is a strong, transparent polymer plastic glass showed the best results with respect to the transmission of infrared light in the laboratory conditions. This material has still not being tested in radiation environment. Fig. 2 shows the assembly of six tiles to make a cube structure for AraMiS and possible configuration of glass fiber for inter as well intra tile communication. This configuration is used for communication from one tile to any other tile. Each tile uses four double reflector mirrors placed on different positions at certain angles in front of the junction of every four glass fibres. The proposed configuration uses communication in both ways using two separate channels as shown in the Fig. 2. The reflecting mirrors are placed in such a way that half of the incoming light signal passes straight through and half of it is reflected at right angle to the incident signal. Figure shows the detailed view of the architecture. The only shortcoming of this scheme is that some receiving nodes that are close to the transmitters receive high light intensity while the nodes that are placed much far from the transmitter receive very small amount of infrared light. This needs a receiver with high dynamic range to receive from very small currents up to orders of *nA* to large currents up to orders of some *mA*. A discrete high dynamic range receiver has been designed [4] for this purpose. The mirrors are double reflectors so the transmission can be carried out either way by putting the transmitters at different positions.

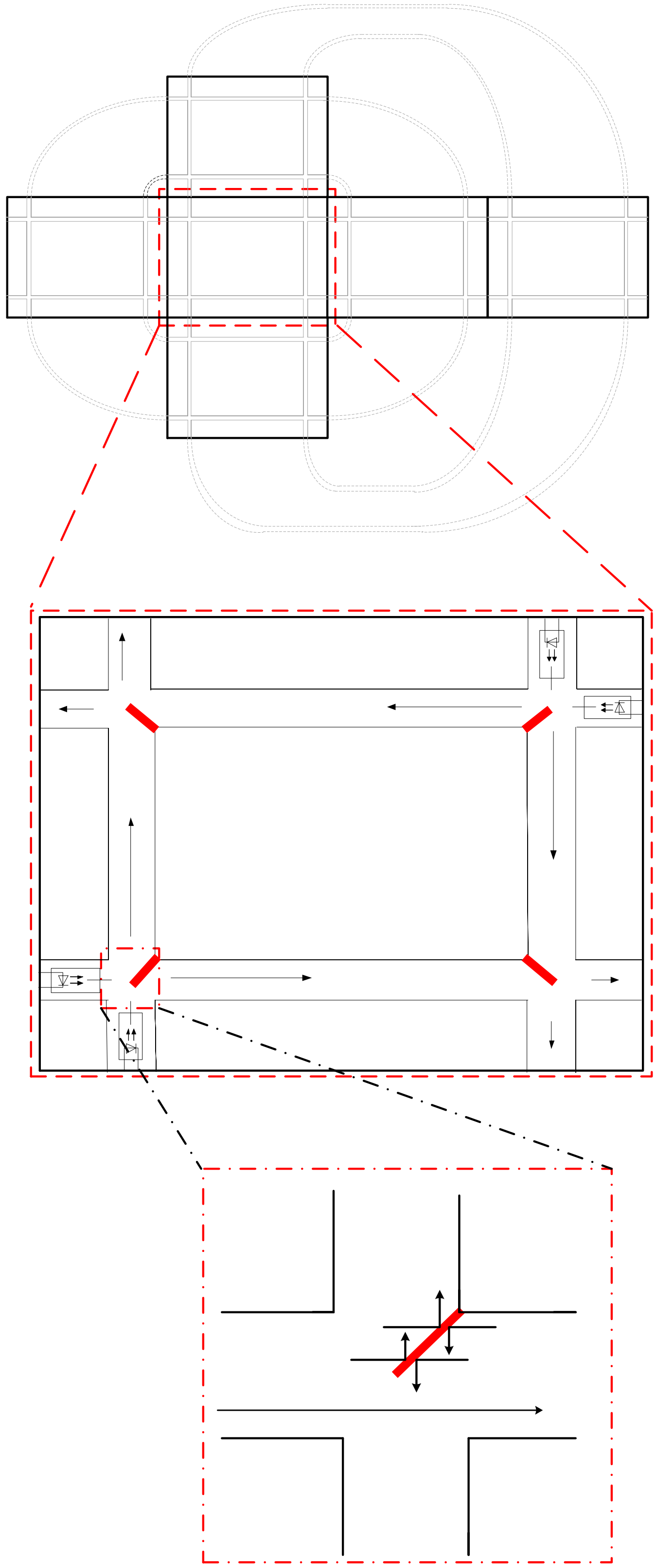


Fig. 2 Architecture of glass fiber based communication showing tles

Many commercial LEDs and photodiodes were evaluated for our design requirement [5-7]. The main parameter in selection of LED is the radiated emitter power in terms of light energy and the amount of current required to generate the desired light energy. The radiated optical power, P_0, is directly proportional to the amount of current flowing through LED, I_{LED}, given by (1).

$$P_o = \eta . VI_{LED} \quad (1)$$

Where η is the optical efficiency of the LED. The theoretical expressions for calculation of transmit and receive optical power and some losses of glass fibre are has been discussed in this section.

The transmitted optical light from the LED is not evenly distributed but distributed in the angular range. Fig 3 shows a typical graph of relative radiant intensity i.e. emitted power versus angular displacement for commercial LED, TSHG8400 [5]. It shows how directional the emitted light is. The narrower the radiation pattern, the more optical energy is concentrated in particular direction.

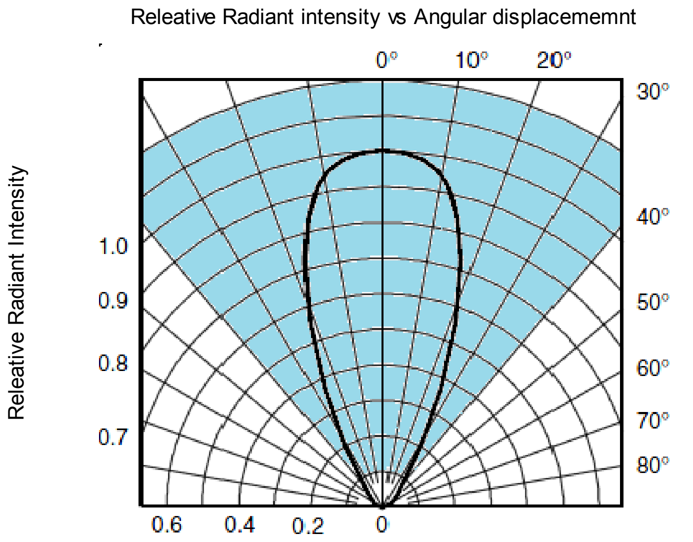


Fig.3 Relative Intensity vs Angular Displacement, courtesy Vishay [5]

The radiation pattern of typical LEDs depends upon the incident power. The beam angle for TSHG8400 [5] is given by (2)

$$Beam\ angle = \frac{Po}{60mW/Sr} \quad (2)$$

The radiation pattern of [5] for 50mW transmit power is 0.8Sr which corresponds to 30° radiant power intensity. The radiant intensity is guided to the glass optical fibre by use of Snell,s law. In order to interface the transmit maximum optical power to the glass fibre, law of refraction is used which relates the indices of refraction n of the two different media to the directions of propagation in terms of the angles to the normal given by (3).

$$\frac{\sin\theta i}{\sin\theta r} = \frac{n_1}{n_2} \quad (3)$$

Where θ_i is the angle of incidence and θ_r is the angle of reflectance. The angles are measured from the normal to the surface, at the point of contact, as shown in Fig 4. The constants n are the indices of refraction for the corresponding media one being air (n_1=1) and the other one glass (n_2=1.5).

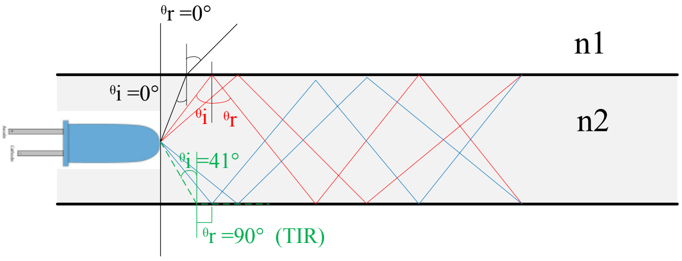


Fig. 4 Optical light guidance in the Fiber

The angle of incidence of light that make sure that all the optical light is guided inside the glass fibre is given by (4)

$$\theta_i = \sin^{-1}\frac{1}{n_2} \quad (4)$$

This expression gives critical angle for which the incident ray does not leave the glass fibre, namely when the angle of reflectance is 90°. Any incident angle greater than the critical angle is consequently reflected from the boundary instead of being refracted. Therefore using equation (4), we guarantee that any light ray of incident angle from 41° stays inside the glass and hence is received by the receiver. This angle is called critical angle where total internal reflection (TIR) takes place. The shaded area in Fig 3 shows the light radiation guided inside the glass fibre as per above calculations. Fig 3 suggests that maximum light emitted by the LED is in between the -40° to 40° therefore most of the light is successfully reflected in the fiber with very small losses.

The received current depend on the input optical power and the responsivity of the photodiode at a certain wavelength. The theoretical expression for received current, $I_{received}$, is given by (5)

$$I_{received} = \frac{Po}{\frac{\pi}{4} * \emptyset^2} * A_{Photo} * Responsivity \quad (5)$$

Where $\emptyset$ is the diameter of the glass fibre, A_{photo} is the active area of photodiode and responsively of photodiode is given in *(A/W)*. This received current has a high dynamic range depending upon the position of the receiver. A novel discrete receiver has been designed to amplify the received current [4]. The receiver consists of two amplification stages, the first being transimpedance amplification stage and second one being the voltage amplification stage. A dynamic comparator stage has also been used. Fig 5 shows the photograph of *glass* with the guided optical light. Reflecting mirrors are not shown in this photograph.

Fig. 5 Photograph showing guided light propagation

Table I shows theoretical and measured values of received current for different values of input radiated optical power. The theoretical results are calculated for *plexiglass* of $\emptyset = 7.5mm$ and using [5] with photodiode of 4mm^2 active area.

TABLE I

S.No	Radiated Power Po(mW)	Responsivity (A/W)	Received current Theoretical (mA)	Received current Measured (mA)	Error (%)
1	10	0.47	0.42	0.39	7.1
2	20	0.47	0.85	0.75	11.7
3	30	0.47	1.27	1.15	9.4
4	40	0.47	1.69	1.55	8.2

IV. FREE SPACE COMMUNICATION ARCHITECTURE

The discrete optical infrared transmitters and receivers were tested for different free space link distances. Fig. 6 shows the received current at different link distances with variable input current. This is a very useful graph for selecting minimum radiated power which makes sure that the receivers receive sufficient optical power for level detection. Since the dimensions of single tile are 16.5x16.5 cm^2, it is apparent from the graph that even a very small forward current is enough for good reception of signal. In case of glass optical fiber based communication, power level for transmitter can be increased if the signal has to travel through multiple reflections.

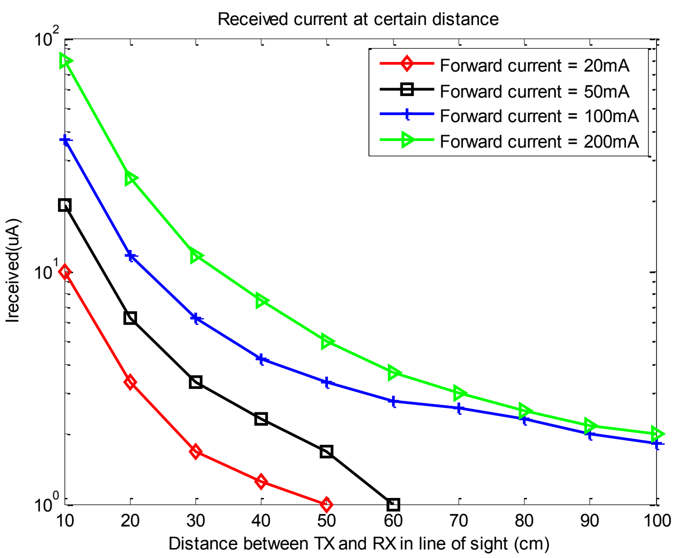
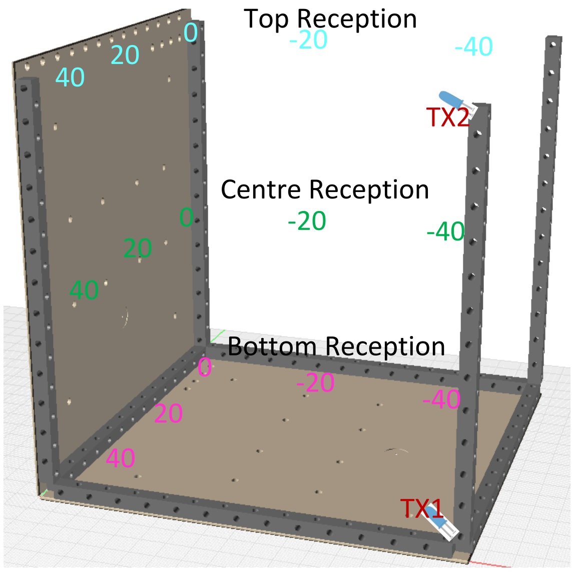
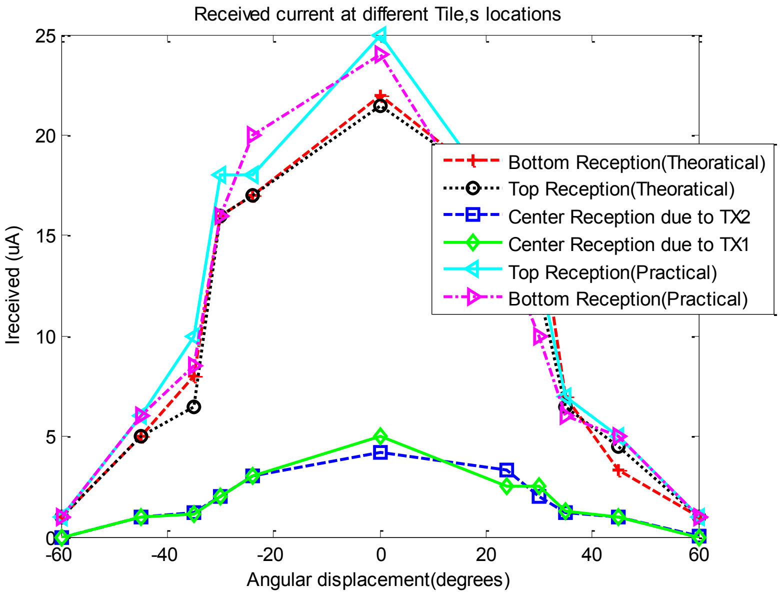


Fig. 6 Received photocurrent for certain distances

Fig. 7 shows a possible scheme of implementation of free space communication across the tiles. Two transmitters, *TX1* and *TX2* are used for test purposes as shown in the Fig.7 (a). The receivers are placed at different angular positions and the resulting received current is plotted in the Fig. 7(b). Transmitter *TX2* is placed on the top position and the *TX1* is placed on the bottom position. The figures show certain possibilities of reception due to both transmitters either at top, centre and bottom.



(a)



(b)

Fig. 7 Reception at different positions due to transmitters

Fig. 8 shows two transmitters and receivers placed according to the proposed scheme for practical measurement of received currents.

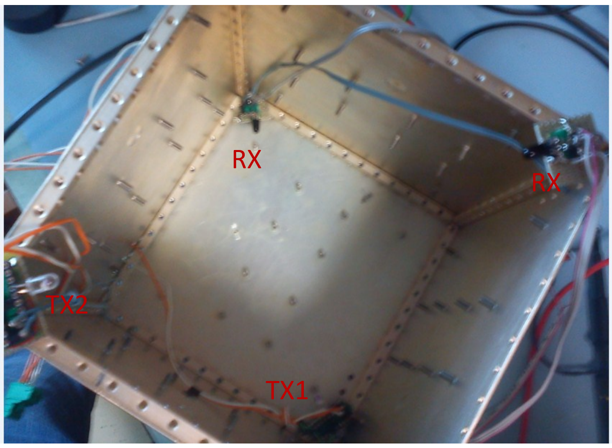


Fig. 8 Photograph of Transmitter and receivers for practical measurement

The results of these practical measurements are in close comparison with the theoretical results and shown in Fig 7 (b).

V. CONCLUSION AND ACKNOWLEDGMENT

In this paper, we have shown some data communication structures using free space and glass fiber. The proposed optical communication systems will be used along with the other wired communication approaches for more flexibility. The authors are thankful to Mr. Jie Zhou for his valuable support during the tests.

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