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DESIGN AND IMPLEMENTATION OF AN OPTICAL TRANSCEIVER CARD FOR INTRA-SATELLITE COMMUNICATION

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KeyWords
Data transmission, Fiber optics, High speed communication, Intra-satellite communication, FPGA, Optical fiber communication, Optical transceiver, PCB design.

ABSTRACT

Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communications. Fibers are used instead of metal wires because signals travel along them with less loss, and they are also immune to electromagnetic interference. These advantages make it a viable system to be used in various high data rate systems including data communication in intra satellite systems. An optical transceiver converts digital signal to optical data which will be transmitted over the optical fibre and vice versa. To send data as light, it makes use of a light source (LASER or LED) and to receive light pulses, it makes use of a photodiode semiconductor. A PCB consisting of optical transceivers, FPGA, LVDS transmitter, receiver and buffers is designed to establish and characterize optical fiber communication between different subsystems in satellite.

INTRODUCTION

Remote sensing payloads are advancing rapidly, thus demanding an increase in the data rates of high data rate systems like High Definition Cameras, Remote sensing instruments etc. The high speed data links that are used for fast data transfers for aforementioned usage include Low Voltage Differential Signalling (LVDS) and Serializer/Deserializer (SerDes) [5]. A SerDes converts serial data to parallel and vice versa and is therefore used in high speed communications. It reduces the I/O pins and transmits data over a single/differential line. LVDS provides a means of sending data along a twisted pair cable at high speed, with low power and with very good EMC performance. These features make LVDS ideal for satellite on-board data-handling applications [1].

LVDS based interface operates in the 100 Mbps to 1.5Gbps range. The LVDS cables are bulky and although the LVDS cables are said to have good electromagnetic compatibility, they are still susceptible to electromagnetic interferences. The optical fibers have an edge over the conventional LVDS cables because of their light weight, less EMI/EMC concerns and ease of integration. Also, optical fibers support reliably high data rate transmission. Hence, a new technology is being proposed where optical fibers are used as a medium of communication between different subsystems inside a satellite.

To establish and characterize optical fiber communication between different subsystems, a PCB is designed.A reconfigurable and programmable FPGA is incorporated in the PCB card along with data links for LVDS signals and two different kinds of optical transceivers. The main objective of this project work is to develop a hardware model to establish optical fiber communication between subsystems inside satellites. The proposed design is discussed in section II followed by the process of PCB design in section III and hardware testing setup in section IV respectively. The results obtained are discussed in section V.

LITERATURE SURVEY

High-speed interfaces are used for fast data transfers in data communications hubs, wireless base stations, servers etc. The distances vary from a few inches (between ICs or from board to board) up to several meters (between systems). Ground potential differences between driver and receiver are assumed to be less because of the short data link distance [5]. Also, the required common-mode input voltage range of a receiver is commonly limited to a few volts. Industries prefer high speed interfaces. The external noise present in industrial environment couples noise currents. These noise currents help raise the ground potential differences. Data errors and device damages are caused due to the raise in the ground potential differences between bus nodes beyond the common-mode voltage range of bus receivers. This also reduces common-mode voltage to the driver's output offset and assures proper data traffic [5]. Some important requirements for a data link in space applications include low power consumption, sufficient bandwidth to carry the data, electromagnetic susceptibility, low error rate on the link (BER > 10-14), high level of immunity to damage by electro-static discharge, radiation tolerant, low mass and small size, scalable and should support connection within a cold redundant system [11]. Also, the data link should not emit electromagnetic radiation at a level that would interfere with the operation of other systems.

Fiber optical communication related technology has been very well established for terrestrial applications. In the 90'ies the Defence and Offshore markets were interested in fiber optical harnesses and cable systems. In the beginning of this century various organizations started working with fiber optical harnesses for aircrafts and missiles. During the past years, European Space Agency (ESA) increased its interest for using this technology in orbit. The European Space Agency (ESA) has been working since the late '70s in developing components and systems for inter satellite links and since 2000 for intra-satellite applications [3]. The main drivers for considering Optical Communications in Satellite Payloads are:

- Practically limitless bandwidth (BW)
- Practically lossless propagation in an optical fiber within a spacecraft
- Transparency to any modulation/coding format
- Immunity to Electromagnetic Interference (EMI)
- Lightweight, low volume
- Mechanical flexibility
- Galvanic isolation

The adoption of fiber optics by a mission can be based on one or many of the above characteristics and will have to counterbalance the lack of significant space heritage and the required electro-opto-electronic conversion that involves a power penalty of several dBs in the electrical signal. The introduction of optical communications becomes urgent in cases where current technologies reach their limits e.g. in multi-gigabit transmission. Such applications "push" the introduction of photonic technologies and primarily of fiber optics [3].

In 2009, ESA's approach was to to use the same technology for both intra and inter equipment applications. The selected approach was based on using Vertical Cavity Surface Emitting Lasers (VCSELs) at 850nm, Graded Index Multimode (GIMM) fibers, and PIN detectors. Depending on the data rates to be transmitted Single-Fiber or Parallel Fiber cabling with the corresponding connectors was employed. VCSELs require the least power compared to other laser sources due to their low lasing threshold and being miniature can be integrated in a very small transmitter-Tx. Dispersion is not an issue as the maximum distance is specified to 100 with more typical values to be below than 10 meters for intra-satellite applications [3].

Two kinds of components were introduced in 2012 [1] "SpaceFibre" transceivers (>6 Gbps) and parallel optic transceivers with fiber ribbon cables (4+4 x 10 Gbps), both based on 850-nm VCSEL sources and multimode fibers. The transceivers are expected suitable also for other harsh environment applications.

DESIGN METHODOLOGY

The proposed design is to interconnect different subsystems using optical fibers. Subsystems can communicate with each other over fiber channel within the satellite. Each subsystem consists of a data generation and acquisition unit (implemented in FPGA), an optical transceiver and a fiber optical connector. Optical fibers are used to connect the transceivers of different subsystems. The mode of communication would be over fiber and the data can travel over this medium at greater speed.

In order to achieve communication between the systems, a PCB card is designed for testing optical fiber communication. The core element of the PCB is data generation and acquisition unit which is implemented inside a FPGA, buffers, three optical transceivers, a crystal oscillator, power supply and LDO's. Further, provisions were made to have two optical transceivers of another type, LVDS transmitter and receiver IC's, an LVDS crystal oscillator and RS232 serial port.

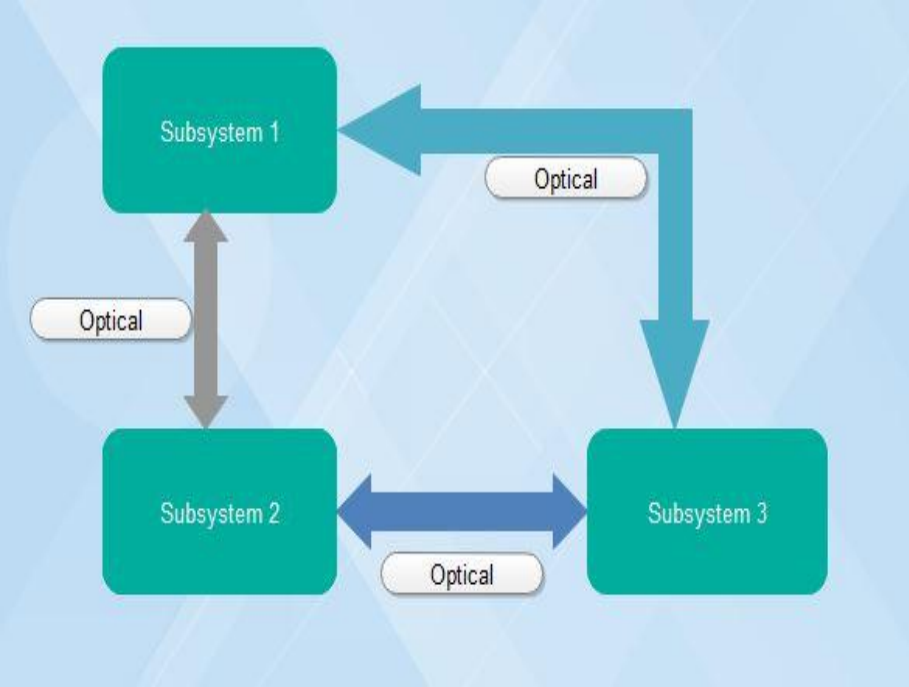

Figure 1: Intra-satellite optical fiber communication design

PCB ARCHITECTURE

A PCB card is designed for testing optical fiber communication between two systems. Core element of this card includes optical transceivers and a programmable FPGA. This card also has LVTH162244 buffer, LVDS TX and RX interface. Radiation and external noise interference to a circuit can be minimized by a well-designed layer stack-up [9]. An 8 layer PCB was preferred, since a 6 layer PCB resulted in an impedance mismatch.

For multilayer PCBs, general layers include ground plane (GND plane), power plane (PWR plane), and inner signal layers. Combined by a type of semi-solid adhesive which is called "prepreg", two or more double-sided PCBs are stacked together to generate multilayer PCB. A dielectric material is a substance that is a poor conductor of electricity, and used as an insulating layer in the PCB build up.

Table 1. Layer Stack-up

1	Signal
	Dielectric
2	Ground
	Prepreg
3	Signal
	Dielectric
4	3.3V
	Prepreg
5	Signal / Ground
	Dielectric
6	1.5V / 5V
	Prepreg
7	Ground
	Dielectric
8	Signal

Features

The following Features were incorporated in the card:

- Proasic P3E3000 Programmable FPGA
- Provision of mounting two different type of Optical Transceivers :
  - Three numbers of FTLF1421P1WCL Optical Transceiver
  - Two numbers of VTT SPFI-003-6G Optical Transceiver
- RS232 serial port communication for commanding and data transfer from PC to card.
- Provision for on Board Crystal Oscillator
- 8 channels of LVDS TX and LVDS RX respectively LVDS Crystal Oscillator – 250 MHz
- 48 LVTH162244 Buffer channels which provide 12 spare inputs and 12 Spare outputs respectively.
- POR circuit and LDO

Block Diagram

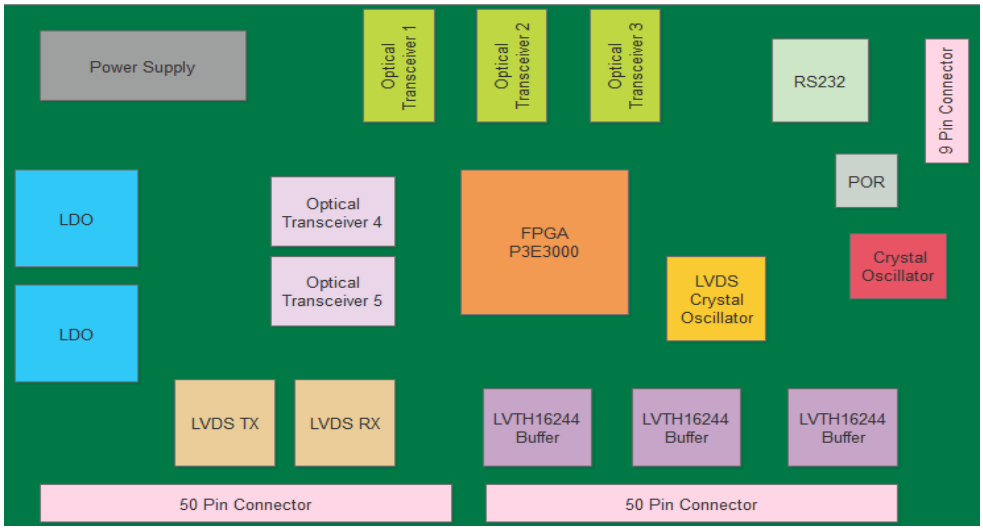

Figure 2: PCB components block diagram

- Power Supply and LDO: The card works at a DC power supplied at 5V. Inside 5V power is fed to the card and LDOs are used to derive 1.5V and 3.3V from 5V. 1.5V is used for FPGA Core. All other logics work at 3.3V. A common ground signal exists for all voltages. The TPS75633 and TPS75615 LDO IC's are used to convert 5V power input to 3.3V and 1.5V respectively.

- Power on Reset (POR): The POR circuit makes sure that every time the card is powered up, the system will start in the same condition. This circuit consists of a capacitor in series with a resistor and a Schmitt Trigger. The resistor and capacitor values should be determined so that the charging of the RC network takes long enough that the supply voltage will have stabilized by the time the threshold is reached [8].
- Clock: The card has a XTAL and an X0 580 LVDS Crystal oscillator. Either the XTAL Crystal Oscillator or the LVDS Crystal Oscillator provide clock to FPGA. The LVDS crystal oscillator used operates at 250 MHz.
- Buffers" LVTH162244 Buffers are unidirectional 16-bit buffers and line drivers which can be also be used as four 4-bit or two 8-bit buffers. Three LVTH162244 buffers are used in this card to provide 16 input signals, 16 output signals and 10 spare input signals to the FPGA.
- LVDS TX and RX: There are two LVDS TX and RX modules mounted on the card which provide 8 LVDS and output channels respectively. A 50 pin connector is used to send and receive signals through these channels.
- Optical Transceivers: An optical transceiver is capable of transmitting and receiving optical fiber data. It comprises of an optical source (LED/LASER), LASER drivers, an optical receiver/ photo detector. Two different kinds of optical transceivers are mounted on this card.

FTLF1421P1xCL Optical Transceiver

- *Small Form factor Pluggable (SFP) Transceiver which provides upto 2.67Gb/s bi-directional data links.*

VTT SPFI-003-6G Transceiver

- *SolidOpto SPFI-003-6G – 6.25 Gbps Fibre Pigtailed Transceiver for Harsh Environment Data Communications. Provides upto 6.25 Gbps full-duplex operation optimised for short distance data communications.*

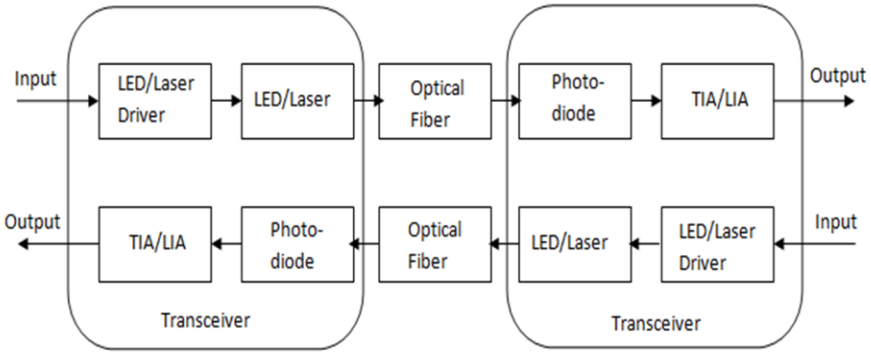

Figure 3: Optical Transceiver block diagram

A fiber optic transceiver is a device that uses optical fibre technology to send and receive data. To send data as light, it makes use of a light source (LED or Laser), which is controlled by the electronic parts, and to receive light pulses, it makes use of a photodiode semiconductor. A Trans-impedance amplifier (TIA) is a current-to-voltage converter. The TIA can be used to amplify the current output of photo detectors and other types of sensors to a usable voltage. Limiting Amplifiers (LIA) strive to provide constant output power.

Component placement plays a vital role. The ease of manufacturing a PCB depends on how well the components are placed. Once the placement is done, the signal traces are connected to match the schematic. The component placement in the top and bottom layer is as shown in figure 4 and 5.

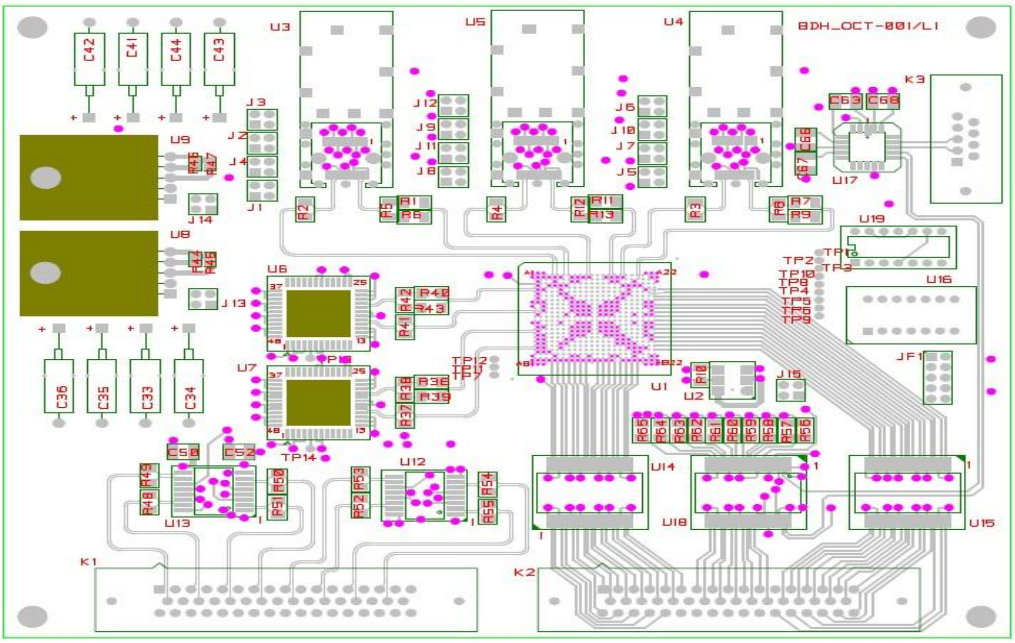

Figure 4: Top layer marking of PCB

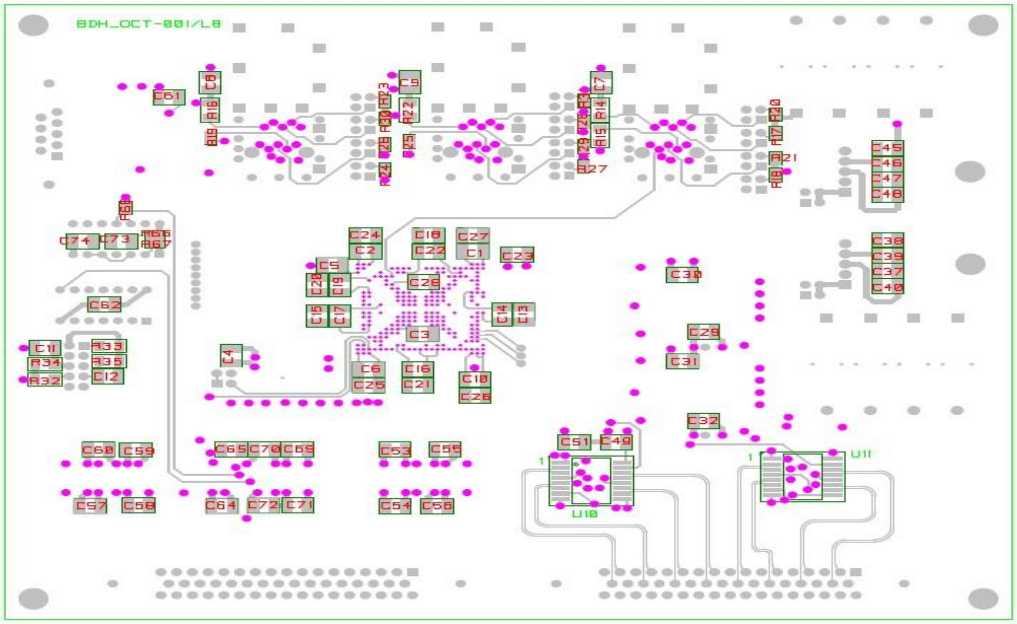

Figure 5: Bottom layer marking of PCB

DEMONSTRATION TEST SETUP

The possible test setup for the proposed idea is discussed in this section. A development board with the provision for Small Form Pluggable (SFP) connectors for optical cables is used along with another PCB that is designed as a part of this project work. The FPGA present in the board will be programmed to generate different data patterns used for simulation. The development board also has an option to receive data from a PC. The data is transmitted with 4 bit to 5 bit (4B5B) encoding along the optical fibre which terminates at the optical transceiver placed in the PCB. The features of the PCB designed are already discussed in the previous section. 4B5B encoding technique solves the clocking problem at the receiver by assigning each block of 4 consecutive bits an equivalent word of 5 bits. For decoding of data, same technique is used in the reverse manner, where the 5 bit words are mapped to their corresponding 4bit data. The FPGA in the PCB performs decoding of data received. The hardware test set up connection is depicted well in the figure 6.

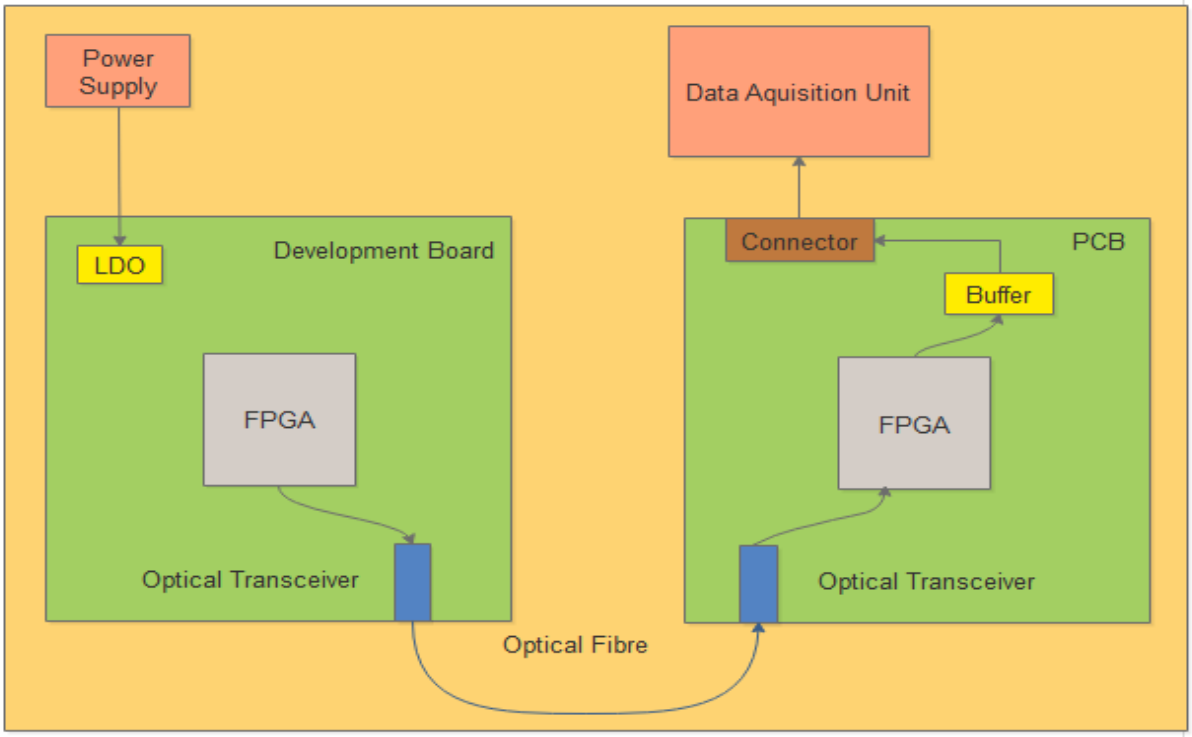

Figure 6: Demonstration plan.

RESULTS

The hardware results of data transmission and reception through optical fiber between two PCB's having optical transceivers on each of them is shown in this section.

Figure 7: PCB after component mounting

Figure 7 shows the PCB after component mounting and the hardware connection of the development board and the PCB linked by an optical fiber cable is shown in figure 8 below. The optical transceiver on the development board is connected to another transceiver on the PCB through an optical fibre.

Figure 8: Hardware setup for testing

Once the card is powered on, input data is given by the FPGA. Different Data Patterns were generated to test the system performance like up-counter, down-counter, random values etc. The input data patterns were made into frames using some communication protocol frame format. It was then encoded using 4B5B technique and then converted to serial data within the FPGA. The serial data goes to the optical transceiver which converts the electrical data into digital and transmits the serial data through the optical cable. The transceiver on the PCB card that was designed, receives the serial data and converts it back to electrical form.

The serial data is converted to parallel data and decoded using the 4B5B decoding technique in the FPGA of the second card. The protocol header, sequence number and the inter-frame gap is removed and only the message is retrieved. The 8 bit parallel data is then sent to the LVTH162244 buffer. The output of the buffer is taken out through the 50 pin connector. This is then given to a Data Acquisition unit which reads the output and saves it in a text file. The data transmitted and received were both compared and found to be same. This indicates successful transmission and reception of data. The text file image of the transmitted and received data in hexa-decimal format is shown in figure 9.

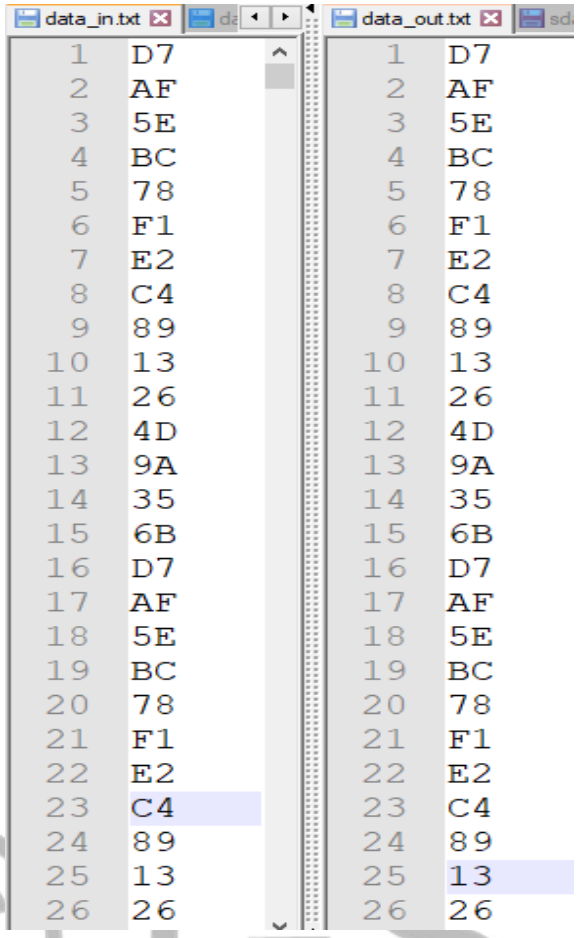

Figure 9: Message sent and received

Conclusion

The concept of optical fiber communication is well understood through literature survey. With a purpose of increasing the data rates being handled on-board, optical fibre communication was chosen. The proposed concept of using optical fiber communication between intra-satellite subsystems is a new approach for high speed intra-satellite communication.

A multilayer PCB was designed and fabricated to establish optical fiber communication between different subsystems in a satellite. The results shown in the previous section indicates successful transmission of data. Optical fiber communication between two subsystems was verified through increment counter data and random data generation. This project finds its application in intra-satellite communications between different subsystems especially high data rate links.

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