Spaceborne Fiber-Optic Data Bus: A Small Satellite Perspective

Dustin E. Rider
Air Force Research Laboratory/ Space Electronics Branch
3550 Aberdeen Ave, Kirtland AFB, NM, 87117; 505-846-9364
Dustin.rider@kirtland.af.mil

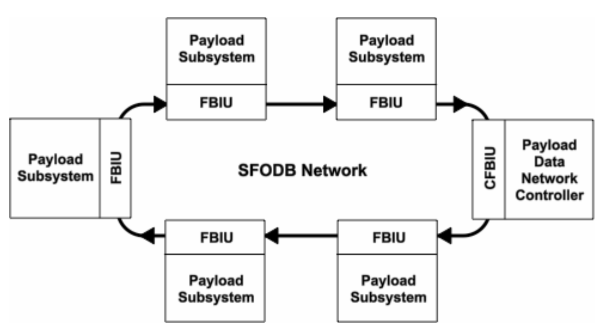
Fred Orlando
Space Photonics Inc.
700 Research Center Blvd, Fayetteville, AR, 72701; 321-258-9392
fjorlando@spacephotonics.com

ABSTRACT

Small-satellite system developers are poised to benefit from yet another technology that was developed with large satellites in mind: standards-based, broadband, on-board payload data networks. Large and small remote-sensing satellite payloads are continuing to advance to higher data rates thereby significantly increasing the demands on on-board networks. The networked satellite payloads include combinations of components commonly found on small satellites: sensors, processors, formatters, storage devices (recorders), broadband downlinks and payload controllers. An effective data-handling network for either type of satellite must support real-time data, must be fault tolerant and must be able to withstand the rigorous conditions of launch as well as the space environment. The Space-borne Fiber Optic Data Bus (SFODB) is the next generation in on-board data-handling networks. Designed specifically to support real-time broadband payload data with precise deterministic latency, it will do for high-speed payloads and small satellites what SAE 1553 has done for on-board command and telemetry systems. That is, SFODB will significantly reduce the cost and time of payload development, integration and testing through interface standardization. The SFODB network is also highly reliable, fault tolerant, and capable of withstanding the rigors of launch and space. SFODB achieves this operational and environmental performance while providing the small size, light weight, and low power necessary for small-satellite applications. SFODB utilizes fiber-optic components for subsystem interconnect, eliminating the need for cable-to-cable and box-to-box EMI mitigation. This paper will describe the SFODB architecture and its benefits for small satellites; the current set of flight transmitters, receivers and protocol ASICs that have been developed; the Development & Evaluation System; and planned component developments by DoD, NASA, and industry organizations.

I. INTRODUCTION

SPACEBORNE FiberOptic Data Bus (SFODB) is a highly reliable, fault tolerant fiber optic network designed specifically to meet the harsh thermal, mechanical, and radiation environments of space remote sensing applications requiring small size and low power dissipation[1]. The SFODB network is implemented as a ring of Fiber Bus Interface Units (FBIUs) interconnected by a fiber optic Physical Plant with a Control Fiber Bus Interface Unit (CFBIU) for network configuration and control[2]. The FBIUs provide the high speed Payload Subsystems with transmit and receive access to the SFODB Network.



The CFBIU provides the network management and data routing functions that allow each FBIU to transport data in one of four methods: dedicated transmit, dedicated receive, tokenized transmit, and ATM Header addressing. The network has an additional Bandwidth Reuse feature that allows the network to operate in a segmented ring configuration. This feature allows a user to multiply the data handling capacity of the SFODB network by the number of ring segments implemented[3].

II. SYSTEM OVERVIEW

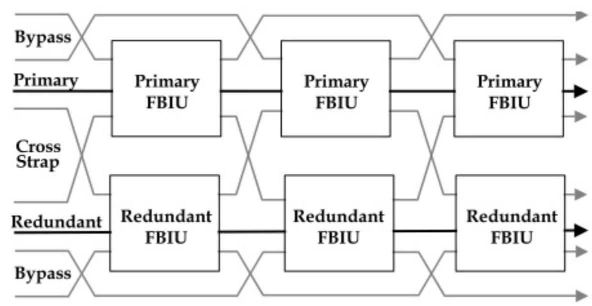
The Ring

The SFOBD is designed to use identical fiber optic interconnects which allows for simple and flexible payload configuration which is ideal for small satellite construction. The basic configuration of the SFODB network is a redundant, cross-strapped, serial ring with a passive optical bypass feature as shown in Fig. 2. This configuration supports four levels of redundancy: an all Primary network, an all Redundant network, a Cross-Strapped partial Primary and partial Redundant network, and the ability to Bypass a subsystem that has completely failed or has been powered off. The network can be setup using up to 127 FBIUs and a CFBIU with a maximum node-to-node spacing of 100 meters. The connectors are typically a multi-fiber cable, multi-pin connectors and specific terminials which are recommended for inter-operability. The Media Dependent Physical Layer is characterized by multimode, graded index fiber with laser diode transmitters and diode receivers operating at an optical frequency in the 1300 nm range[3].

One of the benefits of a ring architecture is the elimination of the overhead associated with burst mode receiver clock synchronization. Burst mode receiver clock synchronization requires each receiver in the network to reacquire bit synchronization between each data transfer; where the SFODB, on the other hand, uses a simple frame format scheme and continuous data transmission to achieve clock synchronization. The FBIU following the CFBIU on the ring is phase & frequency locked based on the frame timing it receives from the CFBIU. Then, the FBIU outputs a frequency locked frame to the incoming data stream delayed by 192 bits. This process is repeated until all FBIUs have locked with the CFBIU generated frame. Next, network setup configuration for the FBIUs is passed to the CFBIU via the spacecraft's control subsystem. Once the configuration is received, the CFBIU sets up and verifies the data transfer configuration for each FBIU. The CFBIU then enables the transfer of data on the ring. During this normal data transfer mode, the CFBIU monitors the operation of the ring & generates periodic reports to the spacecraft T&C subsystem[3].

Usage

Network bandwidth allocation and data routing services are established by the CFBIU based on the configuration setup process described previously. Specifically, the allocation of network bandwidth to the individual FBIUs and the data routing map defining the transfer of data between FBIUs is established by the Control Host using the FBIU data transfer configuration files. These files are generated by the Control Host, downloaded to the CFBIU and used by



the CFBIU to configure the FBIUs accordingly. All network connections are established and broken using this methodology[4]. The following is the typical start up and operational sequence of the SFODB:

Prior to power up, each Control Host and Data Host selects either the primary, cross-strap or bypass transmitter and receiver pair. As spacecraft power is applied to each Control Host and Data Host the host supplies power to one of the redundant CFBIU or FBIU elements. Upon application of power, the CFBIU automatically initiates the network synchronization sequence by the continuous transmission of a Synchronization Frame. As each FBIU in the ring establishes bit and frame synchronization, the FBIU allows the Synchronization Frame to pass through to the next FBIU. The receipt of the Synchronization Frame by the CFBIU signifies that network synchronization is complete. All FBIUs have established bit and frame synchronization and all FBIUs are online and ready to receive configuration commands from the CFBIU. If synchronization is lost during normal operation, the CFBIU automatically initiates this process in an attempt to reestablish network synchronization. Once SFODB network synchronization is complete, the CFBIU sets a flag indicating to the Control Host that it is ready to accept the FBIU bandwidth allocation and data routing tables. The CFBIU is capable of accepting these tables as individual commands from the Control Host or automatically sequencing through these commands in DMA mode. As the CFBIU receives the FBIU configuration tables it transfers the data to the appropriate FBIU using the SFODB Subframe Overhead built into the network's 32-Slot frame. Each time a configuration command is sent to an FBIU the CFBIU automatically polls the FBIU to verify that the command was received and implemented correctly. Once network initialization and the configuration of all active FBIUs is completed, the CFBIU notifies all FBIUs that data transfer may commence. During this normal data transfer mode, the CFBIU monitors the operation of the network & generates statistical network performance reports. While in this mode the configuration tables for any FBIU can be modified. This allows the Control Host to dynamically reconfigure the SFODB network at any time[4].

The satellites that would benefit the most from SFODB are earth observing low orbit satellites typical of those launched by NASA, the European Space Agency, and the Department of Defense. These satellites traverse the earth longitudinally, in a low orbit, at a high velocity, with multiple sensors (optical, infrared, electromagnetic, etc.) and are typically small satellites. The high data rate outputs of these sensors along with the real-time data capturing needs require the characteristics of a SFODB network[5].

IEEE Standard 1393 – 1999

The IEEE standard 1393-1999, based on the SFODB, establishes the design requirements for all fiber optic serial interconnect protocol, topology, and media. This standard defines that the network be highly reliable and fault tolerant, thus the configuration shown in Fig. 2 [5].

Real Time Remote Sensing

Aerospace remote sensing data is characterized by synchronous components, common to continuous mode sensors, and asynchronous components, common to event driven sensors. Both sensor types have real time data handling requirements and sensor performance is driving data bandwidth requirements into multiple gigabits per second range. The robustness of the SFOBD makes it ideal to achieve this capability since it can transfer, unformatted data and formatted data packets between FBIUs either synchronously or asynchronously. The format of the packeted data can be either simple 48-byte blocks or fully formatted ATM Cells.

The SFODB standard specifies that the network must be scalable between 200 Mbps to 1 Gbps to allow the network to be optimized for specific spacecraft data throughput requirements[2]. However current implementations provide networks that are scaleable between 100 Mbps and 2.5 Gbps.

Network Configuration and Control

The CFBIU Command Interface Registers (CCIR) allow the transfer of SFODB commands and status between the Control Host and the CFBIU. The CFBIU supports both single command execution and block loaded command execution. The Single Command execution process allows the Control Host to issue a command by writing directly into CCIR-(0-5) and reading out the status of the command execution from CCIR–(6–9). The Block Load Command execution process allows the Control Host to format a series of commands into a predefined block of Control Host memory and directs the CFBIU to execute these commands sequentially using a DMA operation. The status of the command executions are written sequentially into another predefined block of Control Host memory by the CFBIU[4].

Data Routing

Each FBIU provides its Data Host, whether it is a sensor or processor, with full SFODB send and receive data access through two independent interface ports. Both ports are capable of transferring data in either ATM Cell format, 48–byte format or as continuous, unformatted data. Since the Data Host interface is a Dual Port Memory, the data transfer rate between the Data Host and the FBIU is totally independent of the network data rate. That means that a sensor that produces data at a 20Mbps rate can transmit it to the FBIU at 20Mbps rather than being required to transmit burst of data at 1Gbps. The use of the ATM Cell format as the data transfer format on an SFODB network insures compatibility with ATM ground based communications networks and ATM compatible test equipment[2].

The SFODB network uses three methods to transport data across the network and all of these transport methods may be used simultaneously on the same SFODB network.

The Dedicated Transmit/Receive Slot Method assigns (dedicates) one or more slots (packets) of the SFODB frame to a specific set of FBIUs. The FBIUs use these slots to transfer data between each other. With this method the FBIUs appear to be directly connected to each other. This is the same method used by circuit switched networks.

The Token Arbitrated Transmit Method assigns one of more slots of the SFODB frame to a group of FBIUs. These FBIUs use a token passing method to arbitrate for use of these slot(s) to transmit data. This is the same data transport method used by token passing networks

The ATM Header Address Method assigns one of more slots of the SFODB frame to one or more FBIU(s). All data transmitted by the FBIU(s) are multicast transmissions. One or more FBIU(s) on the network are assigned to accept data from these slots based on the ATM packet Header. This is the same data transport method used by packet networks.

III. SMALL SAT ADVANTAGES

Higher Data Rate in Confined Spaces

Transferring data at a gigabit per second rate between tightly packed subsystems, as is the case on small satellites, can be plagued with RFI/EMI problems especially if the on-board sensors are sensitive RF sensors. The use of fiber optic cable to transfer this data not only significantly reduces the weight of the satellite cables and connectors. It also totally eliminates the RFI/EMI problems associated with conventional copper cabling.

Size, Weight, and Power

Since speed is power and power is a precious spacecraft resource, the SFODB data rate can be scaled to meet specific network data throughput requirements. The node-to-node data throughput can be scaled on-orbit between 200Mbps and 1Gbps [3]. This design feature assists aerospace payload designers to address issues of increased bandwidth requirements, while reducing design time, integration and test costs, volume, weight, and power consumption. The SFODB standard assures compatibility of components from different vendors and allows payload designers to select off-the-shelf components instead of having to develop application specific solutions[5].

Cabling

The SFODB physical layer transmitters and receivers utilize a 4-fiber, fiber optic cable developed by NASA and DOD. This fiber cable is used for SFODB physical plant connectivity. The cable assembly is qualified for space applications[5].

Reconfigurability

The SFODB architecture implements a failure recovery scheme that uses automated network reconfiguration with graceful degradation versus the classical dual redundancy scheme implemented on current spacecraft [6]. By appropriately selecting the active links, each panel can be operated and verified independently with a Development and Validation System (DAVS) connected across the panel connectors. Failed or inactive subsystems may be individually bypassed. And with the implementation of a redundant CFBIU (SFODB Network Controller), there is no single point failure that will cause the loss of the SFODB network[6].

Standardization

By standardizing the network configuration, the design costs for small satellites are driven down significantly. This also allows for research to be focused in other areas where size, weight, and power can be reduced.

IV. PNP SAT: A SMALL SATELLITE EXAMPLE

PnP Sat Overview

Space electronic systems have evolved gradually over nearly half a century; however, new architectures have seldom been attempted. A conventional spacecraft is typically a hodgepodge of legacy hardware ("it worked before") fastened to new platforms, often requiring extensive additional engineering for each interface. To revolutionize the way we think of satellite design, we are developing the concept of a Plug-and-Play (PnP) satellite. What is a PnP satellite? It is a modular satellite with open standards and interfaces, self describing components, and an auto configuring system that is being developed by AFRL. This combination results in automated system integration and testing, thus simplifying the process. Modular spacecraft structures allow components to be mounted either on the inside or outside on a square grid pattern. The idea of PnP suggests that ease of integration is possible. As it is not normally necessary for a personal computer user to be concerned with the inner workings of common components such as mice and keyboards, Space Plug-and-Play Avionics (SPA) architecture makes it possible for components to carry their own documentation. SPA components carry their own descriptions, referred to as XML-based transducer electronic datasheets (xTEDS). Self-describing components can be used to automatically construct networks. In SPA, devices are "endpoints", connected together through hubs (SPA-USB) or routers (SPA-Spacewire and later SFOBD), and the structure of the network is induced through assembly and automatically inferred by the system. Since the components will have the ability to describe themselves, the components only need to "understand" each other relative to the features or "services" they require of each other. The goal is to have a self monitoring satellite that only needs to talk to the ground for user tasking or as a backup in the event the monitoring capabilities are lost. Another effort being worked on is the tactical user interfaces that allow the user to task a satellite based upon the capabilities of that spacecraft. In the design of a PnP satellite we consider the following:

- the basic substrate or "bones" of the spacecraft upon which all components are attached
- add components that provide robust performance
- add the customizable mission sensors that provide support for war fighter needs

This provides a robust design process using one platform to develop a large array of mission specific satellites. The concept of PnPSat represents an extension of the ideas of small, tactical satellites and modular design approaches, with an infusion of technology concepts that aim to simplify and accelerate the construction of spacecraft[7].

PnP Sat design drivers from a network perspective

This section is not intended to provide an in-depth description of the SPA concept but rather to highlight those features that are design drivers for a SFODB network. First, the panels are mechanical sandwiches with internal cabling, power distribution modules and network interface modules for SPA-USB and SFODB. This drives the mechanical configuration of the SFODB network interface modules since the modules must fit within the mechanical sandwich.

Second, there is a standard set of hinged panels with a standard set of subsystem interface connectors and mounting points on both sides of each panel. This drives the number and mechanical placement of the SFODB network interface modules within each panel; the selection of subsystem interface connectors, the cable routing of the SFODB network, and the cross panel connection method of the SFODB network.

Third, the distribution of 28v power within each panel means that each SFODB network interface module must contain an internal power converter and regulator.

Fourth, the key drivers for the SFODB network are the requirements for self configuring networks with self contained xTEDS interface and functional description files for each subsystem, and the existing SPA-USB network capable of providing SFODB configuration commands, and collecting SFODB health and status[6].

V. CONCLUSION

SFODB provides a robust, high-speed network platform which, with its compact design, is beneficial to all satellites, but is ideal for small satellites in LEO orbit. PnPSat is just one example of the applications possible with this data bus.

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