A Simple Configuration for Replacing Signal Harnesses in Satellites

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A solution to reduce the wired signal harness in a satellite by adapting the RF LAN concept with Code Division Multiple Access (CDMA).

Abstract

A wired signal harness accounts up to 10% of the total dry mass of a satellite and traditionally has been a key design criterion. However, they can lead to the formation of ground loops and often pose a problem by generating Electromagnetic Interference (EMI) if not taken care of. This paper proposes a solution to reduce the wired signal harness in the satellite by adapting the RF LAN concept with Code Division Multiple Access (CDMA). The proposed concept completely eliminates the wired network between subsystems by creating a wireless intranet within the satellite. Latency is reduced since all subsystems can communicate simultaneously.

I. Introduction

In a satellite, all subsystems are connected by a bulky harness and often communications standards like RS-232, CAN-bus, 1553 data bus etc. are adopted for signal transfer among the systems. The physical connection increases the risk of system malfunctioning due to EMI and total failure due to any short circuit. Furthermore, in case of a failure, it is difficult to isolate the faulty system.

New techniques are being considered in satellite design for extending the wireless boundary to the satellite. Unwired applications are highly sought after in many networks that are characterized by numerous nodes designed to enable two-way communications. This calls for exploring the feasibility of developing an unwired LAN using Radio Frequency signals for satellite applications. Interconnecting medium between the subsystems is one of the prime factors in a satellite's mass. Any reduction in mass is of great advantage, even in terms of satellite launch constraints.

An approach is reported in [1] to reduce the signal harness in a satellite with Fractional satellite concept, in that a modularization concept is proposed where the subsystems and components of the satellite are subdivided to form smaller satellites, each intended for their own functionality, and together represents the entire functionality of the satellite. If one sub-satellite is damaged the other sub-satellites can take over, or a new one can be quickly launched. Although increased reliability is reported, the cost and complexity of the satellite is very high, requiring a backup satellite.

Bus standards like Space wire [2] gives good performance with less harness, but the requirement is to completely eliminate the wired harness.

The concept of a wireless satellite bus reported in [3] uses commercial off the shelf (COTS) components such as ZigBee and Bluetooth for multiple access. Although the wired harness has been reduced, latency and speed of the system remains a concern because Bluetooth has a lower data rate and the protocols of ZigBee are more complex.

In this paper, the advantages of RF LAN are discussed in section II. Subsequently, adoption of RF LAN concept to replace the wired signal harness is proposed. Finally, in Section III, the implementation details of RF LAN are summarized.

II. RF LAN

A transceiver operating at a suitable frequency, like ISM S-band, is embedded into each package for sending and/or receiving information/data. The CDMA technique, an optimum multiple access scheme, in performance, is considered for full duplex communication within the satellite. The transceiver consists of a transmitter, receiver and a common conformal antenna. The advantages of RF-LAN compared to traditional architectures are significant:

1) Reduction in mass and volume: Size is one of the main criteria in satellite design. Weight of cables needed for interconnection between various subsystems adds to the dry mass of the satellite. Typical values reported [4] for various satellites are shown in Table 1. In a few satellites, harness mass may even go up to 20% of dry mass.

Satellite	Dry mass (in Kg)	Harness mass (in Kg)	Ratio (%)
Goce	740	60	8
Cluster-2	540	33.4	6.2
Mars express	450	28	6.2
Smart-1	280	22.1	8
Envisat	100	7.6	7.6
Proba	8500	850	10

Table 1 • Harness mass compared to dry mass of the satellite.

Advances in onboard design leads to decreasing the subsystem mass. By employing RF-LAN, the signal harness and the hardware for subsystems interconnection are removed and subsequently, the cost of launch will also be reduced. Typically the proposed concept adds a maximum of 250gms to each package of the satellite.

2) Increased reliability: Reliability is the prime factor considered in any satellite design. All standard signal buses are a sort of physical interconnection viz., cable or optical fiber. If any subsystem fails due to a short circuit, the communication of subsystem is disrupted. With a wireless data handling system incorporated in each subsystem, interconnection between them in terms of wires is completely eliminated, and faults like short circuits no longer exist. In the case of any fault within the subsystem, it occurs independently, without affecting others.

3) Increased flexibility in the design: Since FPGAs are used to realize the system, designs can be changed even at advanced stages of satellite fabrication and testing.

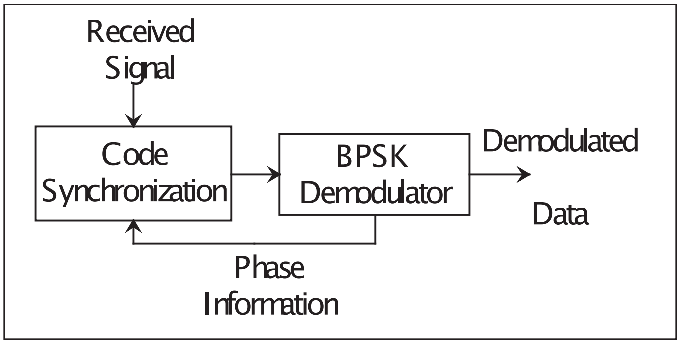
4) Easier upgrading of systems: Since all the systems are independent of each other, a specified subsystem can be upgraded or replaced into without affecting the functionality of the satellite.

5) Reduced latency: The proposed system facilitates simultaneous access using the CDMA technique without complicated protocols, thereby reducing latency.

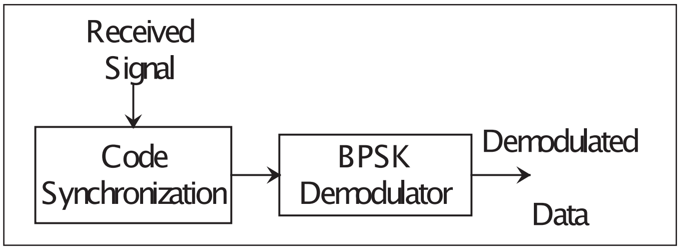
III. Principle of RF-LAN

The Spread spectrum technique is used to transmit data between subsystems. The data to be transferred is spread with a code of a higher rate, though the main requirement of any communication system is to reduce the bandwidth. Unlike conventional modulation and/or TDMA/FDMA techniques, the spread spectrum technique operates over a wide bandwidth even with negative signal to noise ratio. Since the communication is within the satellite, the proper frequency with adequate bandwidth can easily be selected. With spread spectrum, the power requirement is also quite less. Some of the important properties of CDMA [5] are: anti-jamming, interference rejection, multipath tolerance and soft capacity.

The number of subsystems is known beforehand. Based on this, a unique Walsh code of length 64 is assigned to each and every subsystem. Walsh codes are "perfectly orthogonal codes," which means that the dot product of any two Walsh codes is zero. The spectral spreading is done by direct multiplication of input information signal with Walsh code; this technique is known as Direct Sequence Spread Spectrum (DS-SS) [6]. After spreading, the data modulates the carrier with BPSK modulation. All subsystems will receive the transmitted



a. Coherent Code recovery



b. Non-Coherent recovery

Figure 1 • Different recovery loops.

signal, but the receiver with matching Walsh code alone can de-spread the signal.

Conventionally, a received signal is demodulated and de-spread using appropriate code. But in a satellite environment the received signal will have poor SNR. It is, practically, not possible to demodulate the low SNR signal. Hence, the received signal is first despread and then demodulated.

At the receiver, the first primary task [6] is to synchronize the received signal with the transmitter. If the waveforms are not synchronized, insufficient signal energy will reach the data demodulator, leading to erroneous detection. This is known as the code synchronization problem. It takes a two-step approach to overcome this problem. One, code acquisition – gives the initial code phase. Second, code tracking – to maintain the code synchronization achieved in step one.

There are two ways to achieve code synchronization. One – coherent loop – shown in Figure 1a. Second – Non-coherent loop – shown in Figure 1b. Non-coherent loop is considered due to its simplicity.

IV. Architecture of RF-LAN

From a networking point of view, the subsystems can be treated as nodes networked with others. The proposed RF LAN architecture is as shown in Figure 2. Subsystems are interfaced to a wireless module instead of a wired harness. A network can be constructed with simple technologies such as the Star topology where all subsystems communicate with others through a centralized node, or Mesh topology where all the subsystems can communicate without latency.

Figure 3 shows the basic architecture of each node. The operational unit can be any subsystem viz., on board computer (OBC), propulsion system, accelerometers, gyros, magnetometer, control system computational units, thermal control unit, telemetry system, transducers, actuators and sensors like an earth sensor, sun sensor, etc. All the nodes in the subsystem are powered through the concerned subsystem power source.

The implementation details of a node are described below.

A. Transmitter

A simple schematic of the transmitter is shown in Figure 4. The input narrow band message signal is mul-

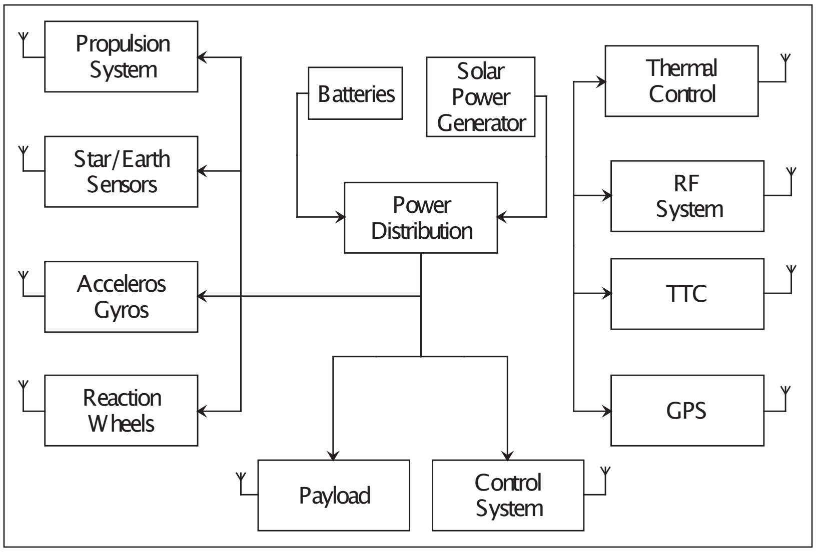


Figure 2 • Wireless LAN architecture.

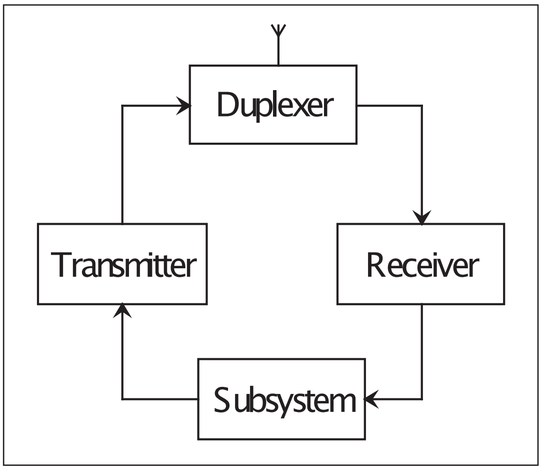


Figure 3 • Basic node configuration for a subsystem.

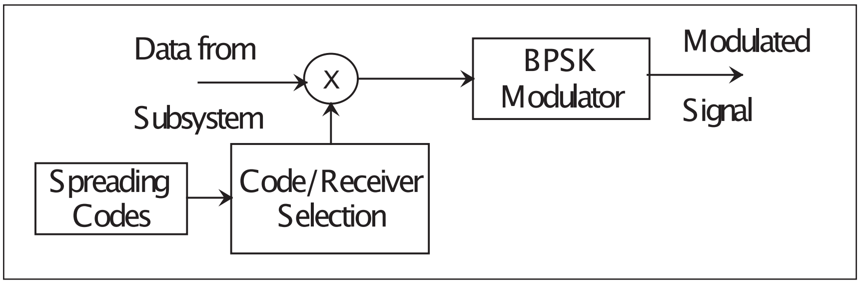


Figure 4 • Block diagram of transmitter.

tiplied by large bandwidth Spreading code of the receiver to which the data needs to be communicated.

The concept is simulated in MATLAB. The information signal is chosen to have a data rate of 100 bps. It is spread with Walsh code at a chip rate of 6.4 Kbps. Figure 5 shows the spectrum of the Walsh code.

Figure 6 shows the Spectrum of Spread signal.

For simplicity of simulation, a 25.6 KHz carrier is assumed. Figure 7 shows the spectrum of the BPSK modulated carrier. In practice, an S-band carrier is used.

B. Receiver

The block schematic of the receiver is shown in Figure 8. Despreading the signal has been done using the Walsh code, first, to increase the SNR for proper demodulation. The despread signal spectrum is shown in Figure 9.

The overall configuration for the transceiver is shown in Figure 10. The received S-band signal is down converted to 10 MHz. Signals coming to and from the FPGA are converted to required form using ADC and DAC, respectively.

The BPSK modulated signal is converted to analog form with DAC and up converted to S-band for transmission.

Carrier for both transmitter and receiver is generated using Direct Digital Synthesizer (DDS). The basic transmitter and receiver blocks are designed in digital domain on an FPGA by coding with VHDL language.

All the modules are integrated on a PCB and attached to each subsystem with the antenna facing outside.

V. Conclusion

A simple concept of using wireless LAN in place of a bulky harness for interconnecting subsystems in a satellite is explained. The main advantage of using RF LAN is decrease in the mass of harness of up to 10%. The architecture of an RF-LAN design based on spread spectrum techniques is presented.

Acknowledgement

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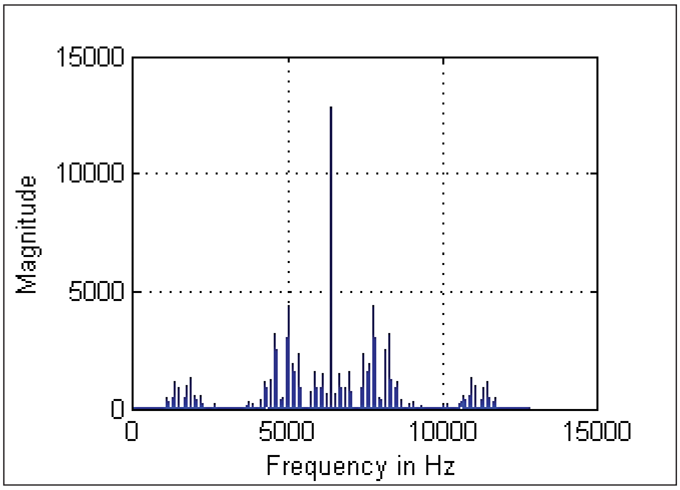

Figure 5 • Spectrum of Walsh code.

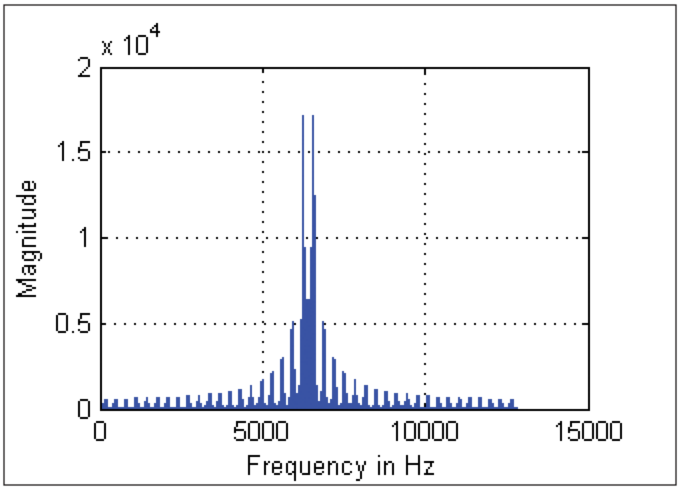

Figure 6 • Spectrum of Spread signal.

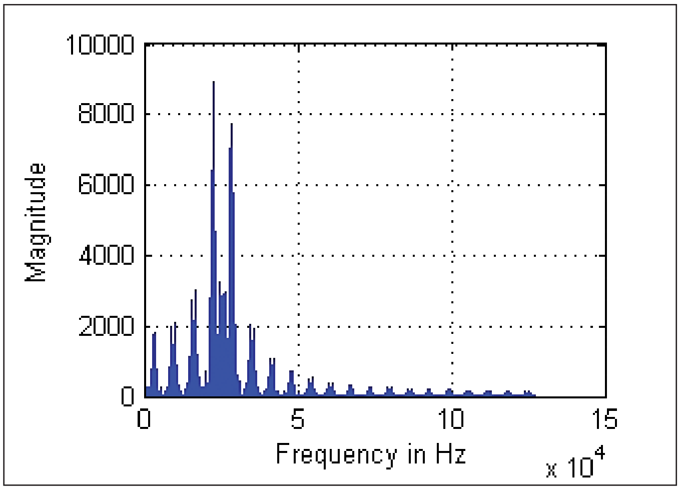

Figure 7. Spectrum of BPSK signal.

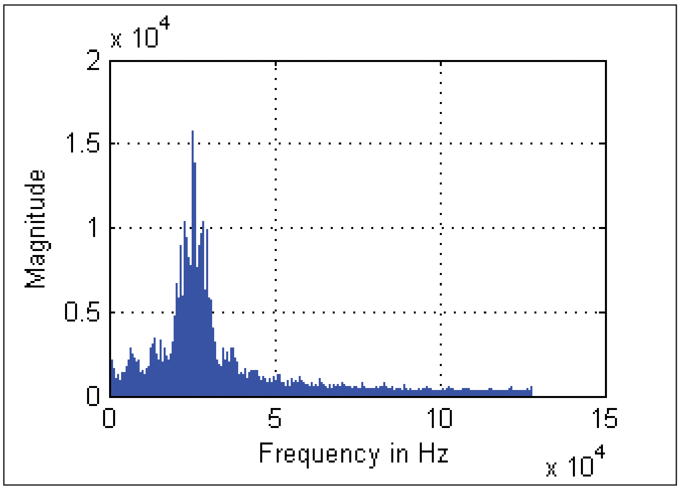

Figure 9. Spectrum of despread signal.

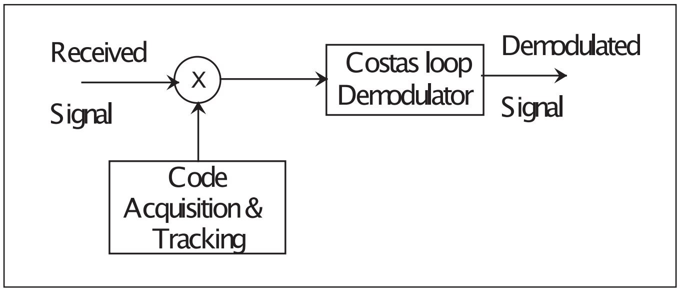

Figure 8. Block schematic of the receiver.

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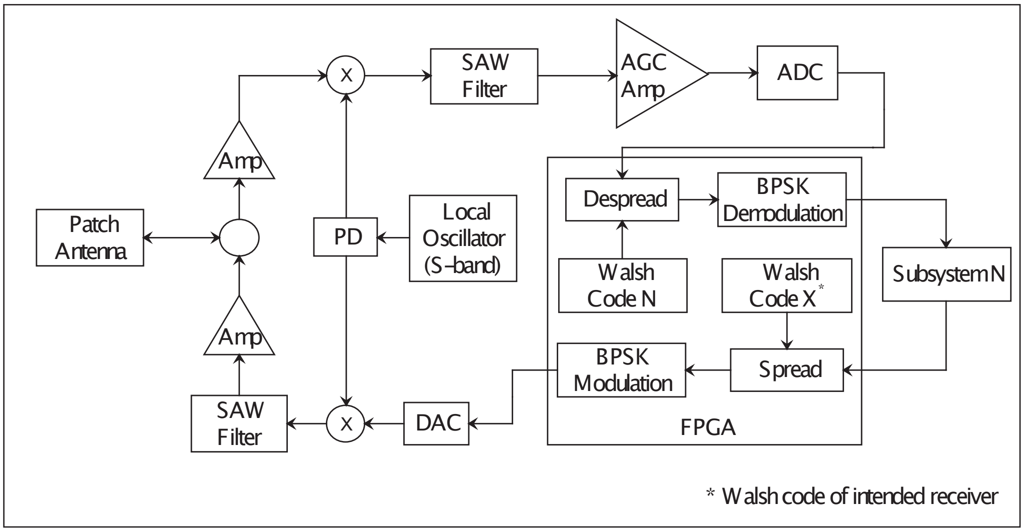

Figure 10. Basic block diagram of the transceiver analog section.