The Geostationary Operational Satellite R Series (GOES-R) SpaceWire Implementation

Session: SpaceWire Missions and Applications

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ABSTRACT

The GOES-R program needed a simple high speed data interface for on-board communications. SpaceWire was chosen as the best solution to this need. The British Aerospace (BAE) SpaceWire Application Specific Integrated Circuit (ASIC) was developed under a NASA contract and selected by GOES-R as the model solution for instrument-to-spacecraft communications. The GOES-R project has developed ground support hardware, software, and a Reliable Data Delivery Protocol (RDDP) to meet mission needs. This paper presents GOES-R SpaceWire hardware and software development activities. Also discussed is the SpaceWire implementation and use on the spacecraft.

The GOES-R SpaceWire test card was designed to use the BAE ASIC providing a platform validating this approach to satisfying GOES-R requirements. The SpaceWire test card is Peripheral Component Interconnect (PCI) compliant and operates in a Windows work station and environment. There is on-board memory and all features of the ASIC are available to the user. Primary applications of the test card are spacecraft data system test and evaluation as well as ground support equipment. This test card has been used to prove the concept and functionality of the GOES-R flight data system. Also, the card has been used to develop a Reliable Data Delivery Protocol (RDDP) and verify GOES-R protoflight instrument interfaces.

The GOES-R spacecraft implements a point-to-point instrument-to-spacecraft interface. The RDDP is wrapped around CCSDS Source Packets for full duplex transmission of science, telemetry, command, time, and timing data between the instruments and spacecraft. Details of this development and implementation are presented in this paper.

1. Introduction

The Geostationary Operational Environmental Satellite Program (GOES) is a joint effort of NASA and the National Oceanic and Atmospheric Administration (NOAA).

Currently, the GOES system consists of GOES-12 operating as GOES-East in the eastern part of the constellation at 75° west longitude, and GOES-10 operating as GOES-West at 135° West longitude. These spacecraft help meteorologists observe and predict local weather events, including thunderstorms, tornadoes, fog, flash floods, and other severe weather. In addition, GOES observations have proven helpful in monitoring dust storms, volcanic eruptions, and forest fires.

The benefits that directly enhance the quality of human life and protection of Earth's environment include:

- Support the search and rescue satellite aided system (SARSAT)
- Development of worldwide environmental warning services and enhancements of basic environmental services
- Improvement of forecasting and providing real-time warning of solar disturbances
- Data that may be used to extend knowledge and understanding of the atmosphere and its processes

GOES-N is the first spacecraft in the current GOES-N/O/P series and launched on May 24, 2006 aboard a Boeing Delta IV Rocket.

The GOES R Series (GOES-R) is currently in the formulation phase and follows GOES - NO/P. The first launch is scheduled for the 2012 timeframe [1].

The GOES-R spacecraft uses European Cooperation for Space Standardization (ECSS) SpaceWire [2] for the transfer of sensor, telemetry, ancillary, command data, time code, and time synchronization between instruments and the spacecraft. The GOES-R Project has directed that all data transferred over SpaceWire implement a reliable data delivery protocol. Early in the GOES-R Project development a decision was made to develop GOES-R specific SpaceWire technology to aid in cost and risk reduction. In response to this direction reference hardware and software solutions have been fully developed and verified to be compliant with the SpaceWire standard and GOES-R Project requirements. Intellectual property (IP) developed by this effort is available through the NASA Technology Transfer Office.

2. SpaceWire Test Card

GOES-R instrument-to-spacecraft data rates are between 10 and 100Mbs. Also, error detection and correction, at the source packet level, is needed. In addition to meeting these key requirements, SpaceWire provides a simple interface with minimum cabling. The GOES-R Project set a goal that all SpaceWire computational requirements have a minimal impact on the on-board Single Board Computer (SBC).

Upon selection of SpaceWire for instrument-to-spacecraft communications, a search for suitable hardware solutions was completed with the selection of the British Aerospace (BAE) SpaceWire Application Specific Integrated Circuit (ASIC) as the GOES-R reference design. The block diagram of the BAE SpaceWire ASIC is shown in Figure 1. The BAE ASIC is an off-the-shelf heritage part modified to implement the NASA Goddard Space Flight Center (GSFC) SpaceWire 4 port router IP core.

The next step in this process was the design and fabrication of the SpaceWire Test Card. In an effort to minimize cost and utilize one of the BAE ASIC's two PCI ports, the test card is designed to plug into a standard Windows based motherboard. In addition to the on-chip 32 kbyte SRAM, the test card has 4 Mbytes of SRAM and 16 Mbytes of DRAM. Numerous test points and logic analyzer probe attachments are included in the card's design. Custom Windows drivers and support software were developed to make the test card fully operational.

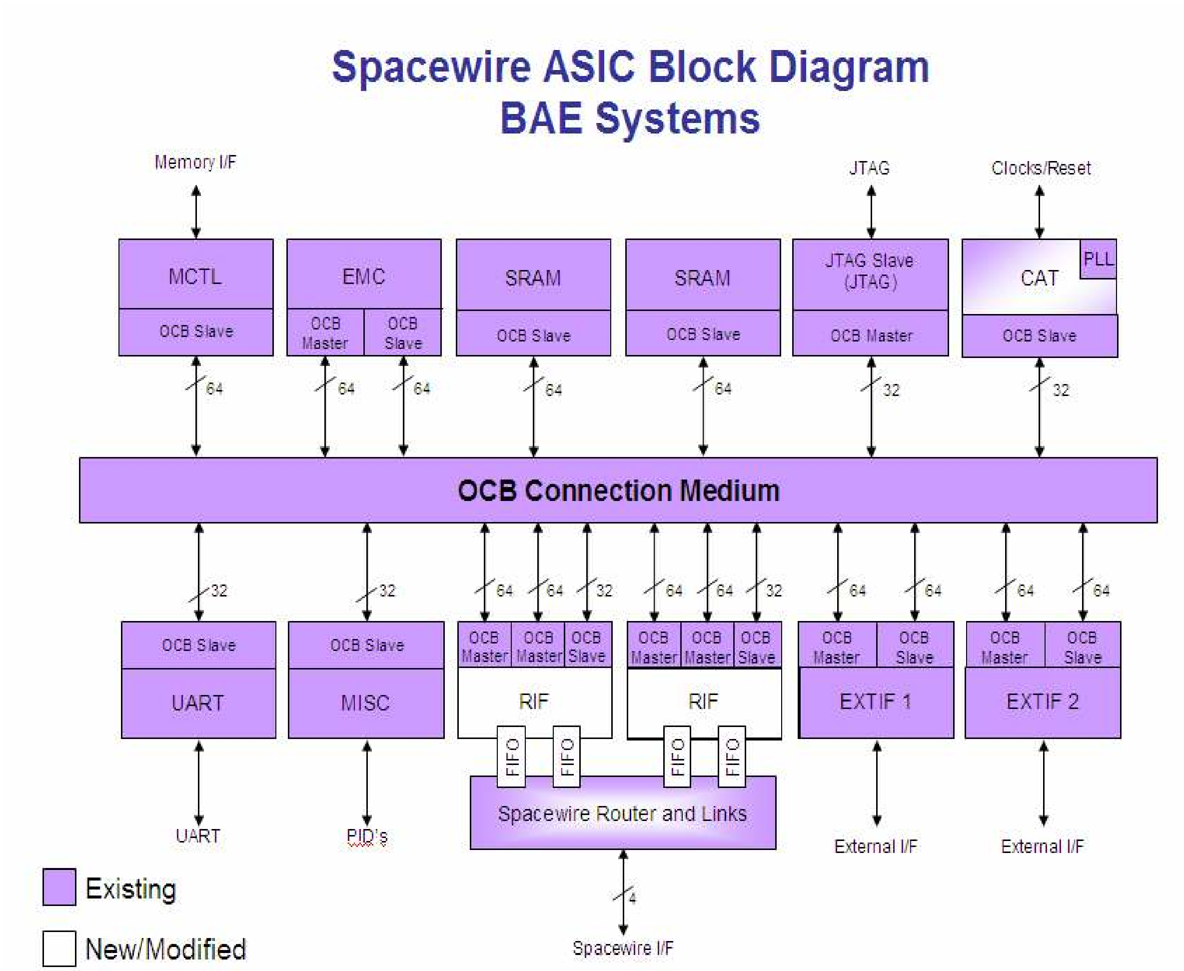

Figure 1. BAE SpaceWire ASIC Block Diagram

Once the test card, motherboard, and support software were fully integrated and tested work began on modelling the GOES-R flight data system. The test card mounted in a test station motherboard is shown in Figure 2. The current flight data system test configuration includes a Command and Data Handling (C&DH) using the test card, another test card based work station simulating a high rate instrument, and two Field Programmable Gate Array (FPGA) based work stations acting as low rate instruments.

Figure 2. GOES-R SpaceWire Test Card in test station

The BAE ASIC has an on-chip embedded microcontroller (EMC). The ASIC based work stations were used to develop EMC software for traffic and error management.

To date, the test card has served in a number of roles and is quite easy to use. In addition to modelling the GOES-R flight data system it has verified instrument interfaces, acts as Ground Support Equipment (GSE) and functions as an EMC software development platform. Plans are in process to incorporate the test card workstation as a "gold standard" for all GOES-R instrument and spacecraft providers.

2. Reliable Data Delivery Protocol Overview

Since the GOES-R Project requires data transferred between the spacecraft and instruments have error detection and correction, a search for a simple protocol was initiated early in the program. Modelling with off-the-shelf protocols indicated they required more computational resources than GOES-R desired. Work then shifted to develop a simple protocol above the SpaceWire packet layer requiring minimal computational resources while providing reliable data delivery. Since the BAE SpaceWire ASIC was already the GOES-R reference hardware solution, the target processor for protocol processing was the on-chip EMC. Software requirement definition and a formal protocol document development activities proceeded in parallel. The end result is the GOES-R Reliable Data Delivery Protocol (RDDP) [3] allowing up to 128 virtual channels, reliable data delivery (RD) mode, and urgent message (UM) mode over a single SpaceWire physical connection. The EMC software meets all protocol and GOES-R requirements with significant margin.

3. Data Reliability

A SpaceWire link bit error rate (BER) is to be 10^{-12} or less [4]. With this BER specification, data transmitted at 100 Mbps results in 1 error every 2.78 hours [4]. Since GOES-R is in constant view of the ground station, on-board sensors provide data around the clock without interruption. If an error occurs about once every three hours then 8 errors happen in a 24 hour period. In a SpaceWire link a data error can result in the loss of a packet. The SpaceWire standard [2] requires clearing the transmit buffer on detection of a SpaceWire link error. This creates an incomplete packet and is discarded by higher level processing. Assuming the largest packet sent over the link is 65 kbytes, a single bit error can cause the loss of approximately 500 kbits. This is a worst case scenario and yields a potential loss of 4 million bits per day, not accounting for orbit-related data loss. Implementation of the RDDP provides a mechanism to eliminate the effects of bit errors.

A process at a higher level than specified in the SpaceWire standard [2] detects data errors and requests packet retransmission. This is one of the two reasons GOES-R developed the RDDP. The second reason deals with implementation of an error management protocol. If the GOES-R Project did not develop the RDDP and impose it on the instrument and bus developers, every developer could potentially provide different solutions to the problem. This is a high cost and risk approach. The RDDP sets the rules for everyone on the project. With the RDDP no developer needs to spend time and money on a solution to the error management problem.

The RDDP complies with ECSS-E-50-12A [2] and functions as point-to-point or in a network. GOES-R made an effort to keep the RDDP from being GOES-R specific and can be used by any organization wishing to do so. The SpaceWire Working Group assigned decimal 238 as the RDDP protocol ID.

4 Virtual Channels

The RDDP header destination and source SpaceWire Logical Addresses (SLA) are a data source and sink pair creating a virtual channel. For example: one SLA pair sends telemetry data from an instrument to the spacecraft C&DH. Another SLA pair sends command data from the spacecraft to the instrument. A third pair sends sensor data from the instrument to the spacecraft and so on. In addition, time code messages and time synchronization transfer between the spacecraft and instrument. This is all done over a single SpaceWire physical connection.

5. RDDP Operation

The RDDP accommodates two operational modes RD and UM. All RD packets require an acknowledgement (ACK) from the receiver. All UM packets are fire-and-forget. RD packets must utilize the header sequence number for sliding window, missing packet detection, duplicate packet detection, and packet order processing where UM packets do not. Since simplicity is a driving RDDP requirement, any error condition outside the protocol's management ability causes the RDDP to stop and report this condition to a higher level process. If any packet is regarded as a duplicate it is discarded. Figure 3 shows nominal packet processing with fast ACKs and no errors. Normal data sequencing begins when source and destinations SLAs have been reset and enabled. The source sends a packet and on error free reception by the destination SLA an ACK is sent back to the source SLA. The sliding window is advanced by 1 and the process is repeated.

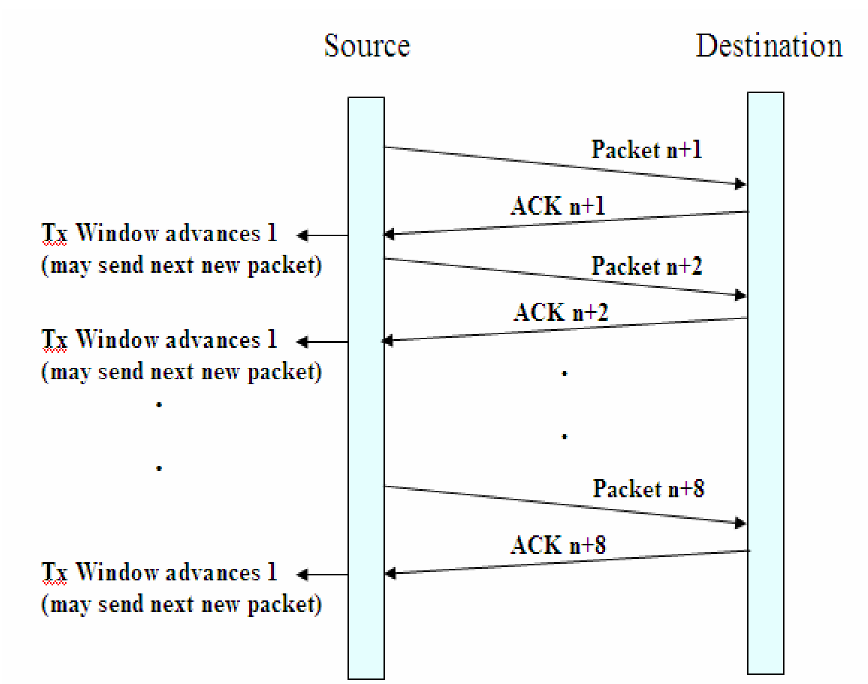

Figure 3. Nominal Operation with Fast ACKs.

Figure 4 is a case where packets are sent in burst mode or due to traffic congestion ACKs are delayed. Simply stated, the source SLA can send up to window size number of packets before having to wait to receive an ACK

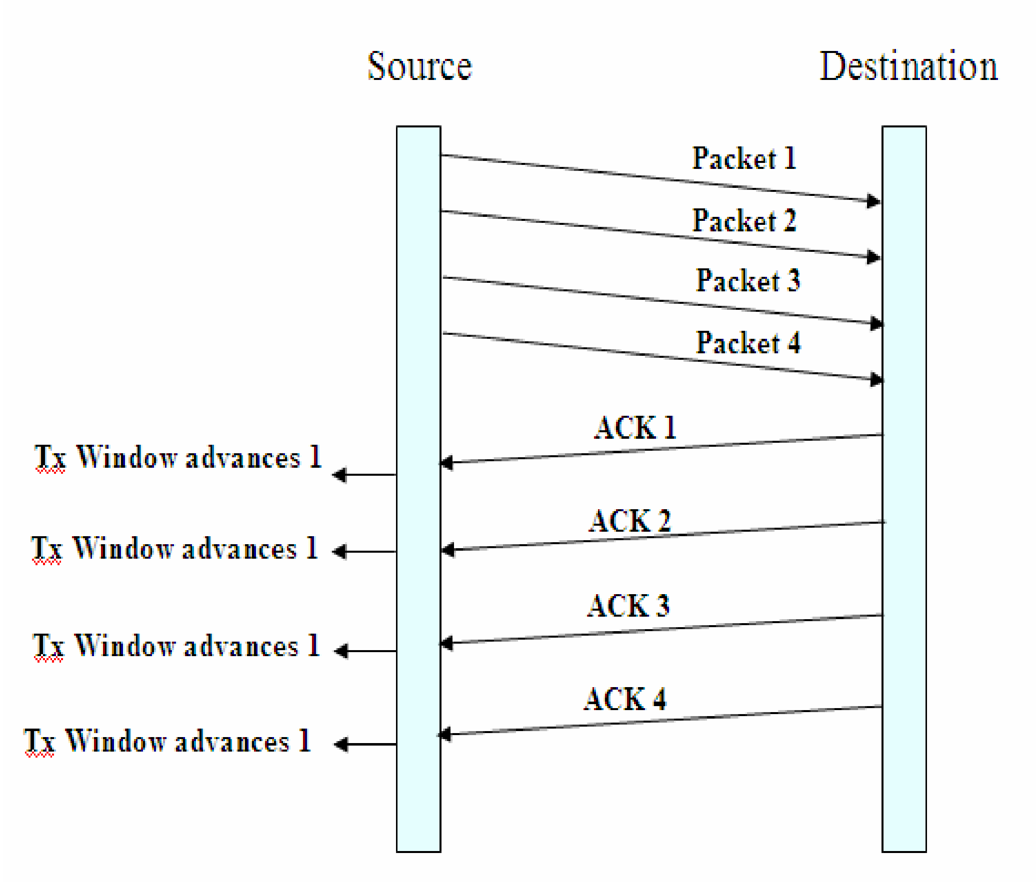

Figure 4. Burst packets or Slow ACKs

Figure 5 shows a case where the window size is set to 4 and the ACK for packet 2 is not received by the source SLA. The source window cannot advance beyond the number of contiguous ACKs received. The source SLA waits the timeout period and resends packet 2. If the ACK for packet 2 is received, the window is advanced and the virtual channel is clear to send the next set of packets. If the ACK for packet 2 is not received after the timeout period, the retry counter is incremented.

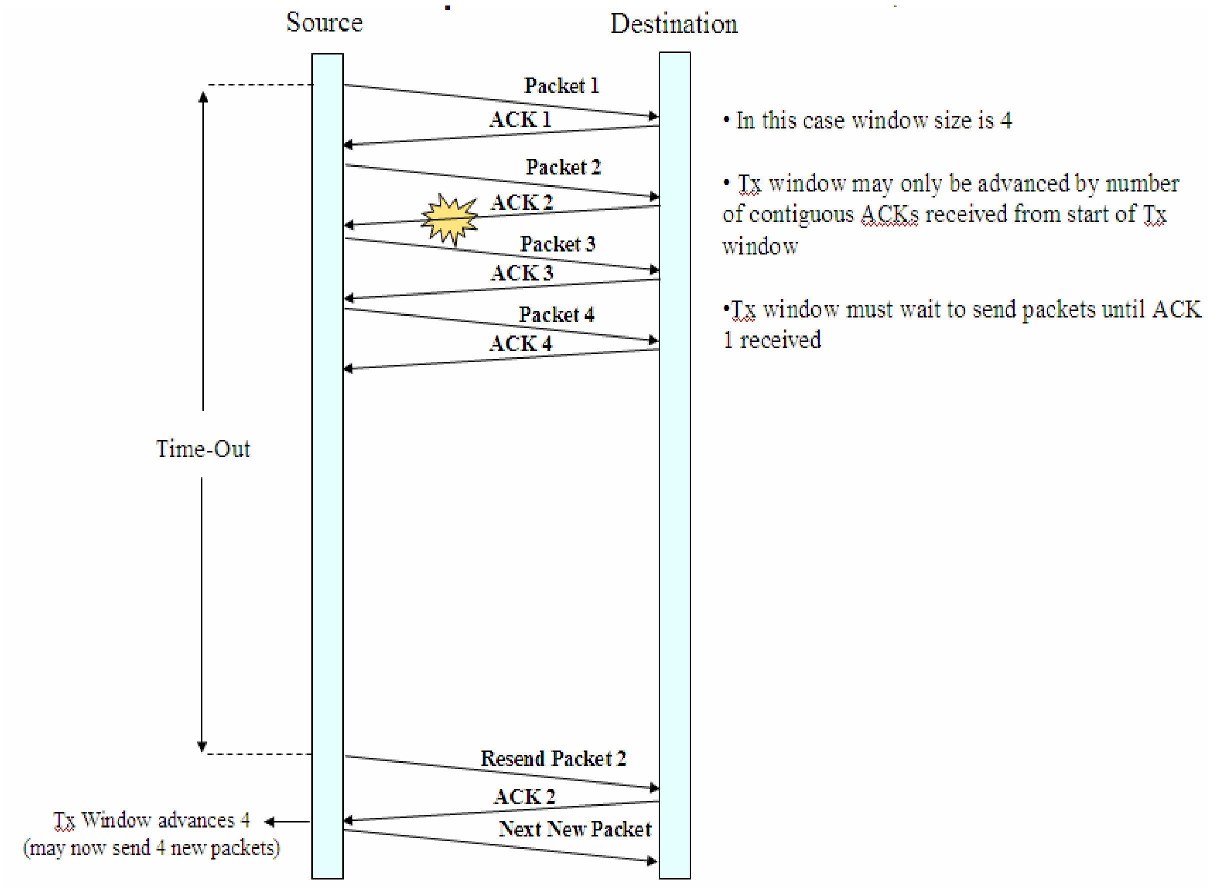

Figure 5. Destination SLA Fails to ACK Packet #2

6. GOES-R

The GOES-R C&DH serves as the hub for all data received by and sent from the spacecraft. The C&DH implements Consultative Committee for Space Data Systems (CCSDS) recommendations for both packet telemetry and telecommand communications. Multiple X-band and S-band services provide the space-to-ground and ground-to-space communications. Standard CCSDS packet multiplexing and Transfer Frame error coding are implemented on the communications links. The technology for moving uplink and downlink data between the on-board communications equipment and the C&DH is not yet known. The current state of the GOES-R Project has not moved completely into the implementation phase. Most instruments are under contract while the spacecraft procurement is still in process. It is not known if the use of SpaceWire beyond the instrument-to-spacecraft data interfaces will expand to other bus subsystems.

7. References

1. “GOES-R Web Page”, National Aeronautics and Space Administration Goddard Space Flight Center, http://goespoes.gsfc.nasa.gov/goes/project/index.html.

2. European Cooperation for Space Standardization, Standard ECSS-E-50-12A, “SpaceWire, Links, Nodes, Routers and Networks", Issue 1, European Cooperation for Space Data Standardization, February 2003.

3. NASA Goddard Space Flight Center GOES-R Project, “GOES-R Reliable Data Delivery Protocol”, 417-R-RPT-0050, January 2007.

4. S.M. Parks, SpaceWire Working Group, “SpaceWire: Serial Point-to Point Links”, Space Engineering, ECSS-E-50-12, January 2000