SPACEWIRE: THE STANDARD

Dr SM Parkes,
Applied Computing, University of Dundee,
Dundee, DD1 4HN, Scotland, UK
Tel: +44 1382 345194, Fax +44 1382 345509
email: sparkes@computing.dundee.ac.uk

ABSTRACT

SpaceWire is an emerging standard for high-speed data handling which is intended to meet the needs of future, high-capability, remote sensing instruments. SpaceWire is based on two existing commercial standards, IEEE-1355 [1] and LVDS [2, 3] which have been combined and adapted for use on-board spacecraft. This paper provides a detailed description of the proposed SpaceWire standard. Applications and available integrated circuits and boards are described in another paper [4].

The paper begins with an overview of the requirements for high-speed data links on-board a spacecraft. The SpaceWire standard is then described in some detail. Issues that need to be resolved before the draft standard can be issued to the space industry for comment are highlighted. Finally the current and future work on the standard are summarised.

It should be noted that the information given in this paper is preliminary and likely to change. The intention here is to give visibility of the current state of the standard to European Space Industry and to encourage comment and criticism of the proposed standard.

SpaceWire is the result of the efforts of many individuals within the European Space Agency, European Space Industry and Academia. The ESA Digital Interface Circuit Evaluation (DICE) study, led by the University of Dundee, has tested LVDS with IEEE-1355 and is now drafting the SpaceWire standard document.

AIMS AND APPLICATIONS

SpaceWire is a proposed standard data link intended for use in future high data-rate on-board data-handling systems. The SpaceWire data link is intended to connect sensors, processing elements, mass-memory units and downlink telemetry sub-systems etc., into a unified high-speed data handling architecture.

One of the principal aims of SpaceWire is the support of re-use at both the component and sub-system levels. In principle a data-handling system developed for an optical can be used for a radar instrument by unplugging the optical sensor and plugging in the radar one. Processing units, mass-memory units and downlink telemetry systems developed for one mission can be readily used on another mission reducing the cost of development, improving reliability and most importantly increasing the amount of scientific work that can be achieved within a limited budget.

Integration and test of complex on-board systems will also be supported by SpaceWire with ground support equipment plugging directly into the on-board data handling system. Monitoring and testing can be carried out with a seamless interface into the on-board system. One example of this is the development of sensor simulation systems which provide realistic computer generated data in the same format as the actual sensor across a SpaceWire link [5]. The sensor can be unplugged from the data-handling system and replaced by the simulation system which will provide realistic data to exercise the data handling system during both development and integration and test.

A unified data-handling architecture is essential for cost effective missions in future – SpaceWire will provide the basis for such a high-speed on-board data-handling architecture.

DATA LINK REQUIREMENTS

An overview of the main requirements for a data link for use in space applications are listed below.

- **Data Rate:** A data link shall have sufficient capacity or bandwidth to carry the data for which it was intended. 100Mbaud is an appropriate minimum target for the maximum data rate.
- **Distance:** The data link shall operate over a distance of 10m. This distance is commensurate with the size of a large spacecraft enabling data to be transmitted from one extremity to the other.

- **Scalability:** To meet the data rate requirements of particularly demanding applications it shall be possible to use several links in parallel to increase the data rate accordingly.
- **Error Rate:** The error rate on the link shall be low, better than a BER (bit error rate) of 10^{-12} for the basic link and better than 10^{-14} for a link protected by a higher level error detection protocol.
- **Power Consumption:** The power consumption of the link shall be low.
- **Low mass and small size:** The mass and size of the data link interface and the cable shall be as small as possible.
- **Cold Redundancy:** The data link shall support connection within a cold redundant system, i.e. when part of the system is powered and another part is not powered.
- **EM Susceptibility:** The data link shall not be susceptible to interference from external electromagnetic sources. It should meet the EM susceptibility requirements of most space missions.
- **EM Emission:** The data link shall not emit electromagnetic radiation at a level that would interfere with the operation of other systems. It should meet the EM emission requirements of most space missions.
- **Magnetic Emission:** Magnetic emissions from the data link shall be low – ferrous materials should not be used in the data link components.
- **ESD Immunity:** The electronic devices forming a link shall have a high level of immunity to damage by electro-static discharge.
- **Galvanic Isolation:** It shall be possible to galvanically isolate the data transmission system from the data reception system.
- **Radiation Tolerance:** The components that implement the data link shall be tolerant of radiation.

Detailed requirements are listed in table 1 at the end of this paper.

THE SPACEWIRE STANDARD

Overview

SpaceWire is a full-duplex, bi-directional, serial, point-to-point data link. It encodes data using two differential signal pairs in each direction. That is a total of eight signal wires, four in each direction.

SpaceWire is based on the "DS-DE" part of the IEEE-1355 standard [1] combined with the TIA/EIA-644 and IEEE-1596.3 Low Voltage Differential Signalling (LVDS) standards [2, 3].

The SpaceWire standard covers the following protocol levels

- **Physical Level:** Defines connectors, cables and EMC specifications.
- **Signal Level:** Defines signal encoding, voltage levels, noise margins and data rates.
- **Character Level:** Defines the data and control characters used to manage the flow of data across a link.
- **Exchange Level:** Defines the protocol for link initialisation, flow control, fault detection and link restart.
- **Packet Level:** Defines how a message is delivered from a source node to a destination node.

Each of these protocol levels will now be described in more detail.

Physical Level

The physical level of the SpaceWire standard covers cables, connectors and EMC specification.

Cables

The SpaceWire cable is illustrated in figure 1. It comprises four twisted pair wires with a separate shield around each twisted pair and an overall shield.

To achieve a high data rate with SpaceWire over distances of the order of 10m the cable must have the following characteristics:-

- Characteristic impedance matched to the line termination impedance (100 ohm differential impedance).
- Low signal-signal skew between each signal in a differential pair and between Data and Strobe pairs.
- Low signal attenuation.
- Low cross-talk.
- Good EMC performance.

Currently 24 AWG wires are specified for the differential pairs. Smaller wires may also be suitable and would provide lower mass and more flexible cables.

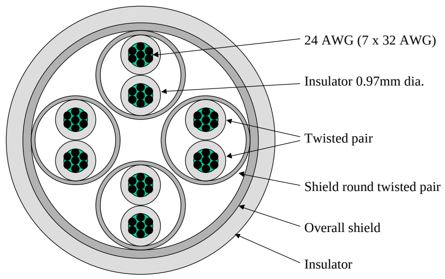


Figure 1. Proposed Cable Construction

Connectors

The SpaceWire connector is required to have eight signal contacts plus a screen termination contact. A nine pin micro-miniature D-type is specified as the SpaceWire connector.

Connectors with flying leads are recommended for connection to a PCB rather than PCB mounting connectors. This is because of the need to control signal-signal skew.

EMC Specifications

The EMC specifications for SpaceWire have been derived from the EMC specifications for the Rosetta [6] and ENVISAT [7] missions. A preliminary EMC specification is given in [8]. Initial EMC testing was performed by Patria Finavitec Oy with support from the University of Dundee. The testing covered:

- Radiated emission, electric and magnetic fields,
- Radiated susceptibility, electric and magnetic fields,
- Conducted susceptibility,
- Electro-static discharge,
- Signalling rate,
- Bit error rate,
- Fault isolation, and
- Power consumption.

SpaceWire is expected to meet all the EMC requirements. It has already been shown to meet many of them [9].

Signal Level

The signal level part of the SpaceWire standard covers signal voltage levels, noise margins and signal encoding.

Signal Level and Noise Margins

Low Voltage Differential Signalling or LVDS is specified as the signalling technique to be used in SpaceWire.

LVDS uses balanced signals to provide very high-speed interconnection using a low voltage swing (350 mV typical). The balanced or differential signalling provides adequate noise margin to enable low voltages to be used in practical systems. Low voltage swing means low power consumption at high speed. LVDS is appropriate for connections between boards in a unit, and unit to unit interconnections over distances of 10m or more.

A typical LVDS driver and receiver are shown in figure 2, connected by a media (cable or PCB trace) with 100 ohm differential impedance.

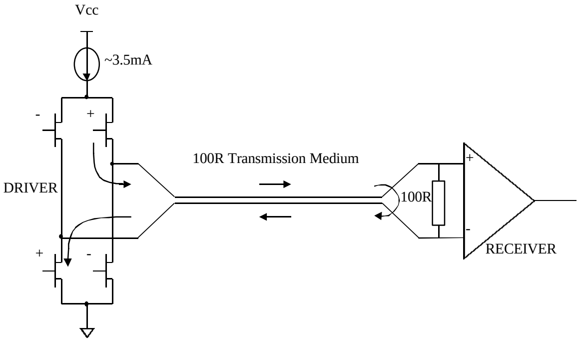


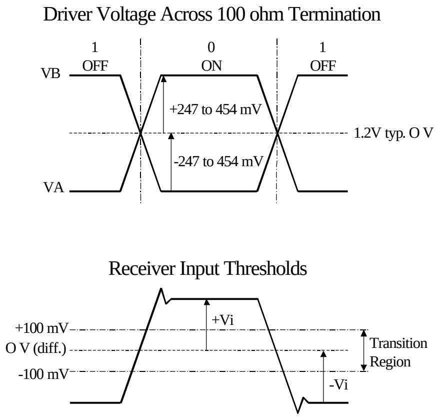
Figure 2. LVDS Operation

The LVDS driver uses current mode logic. A constant current source of around 3.5mA provides the current that flows out of the driver, along the transmission medium, through the 100-ohm termination resistance and back to the driver via the transmission medium. Two pairs of transistor switches in the driver control the direction of the current flow through the termination resistor. When the driver transistors marked “+” in figure 2 are turned on and those marked “-” are turned off, current flows as indicated by the arrows on the diagram creating a positive voltage across the termination resistor. When the two driver transistors, marked “-”, are turned on and those marked “+” are turned off, current flows in the opposite direction producing a negative voltage across the termination resistor. LVDS receivers are specified to have high input impedance so that most of the current will flow through the termination resistor to generate around ±350mV with the nominal 3.5mA current source.

LVDS has several features that make it very attractive for data signalling [10]:-

- Near constant total drive current (+3.5mA for logic 1 and -3.5mA for logic 0) which decreases switching noise on power supplies.
- High immunity to ground potential difference between driver and receiver - LVDS can tolerate at least ±1V ground difference.
- High immunity to induced noise because of differential signaling normally using twisted-pair cable.
- Low EMI because small equal and opposite currents create small electromagnetic fields which tend to cancel one another out.
- Not dependent upon particular device supply voltage(s).
- Simple 100 ohm termination at receiver.
- Failsafe operation - the receiver output goes to the high state (inactive) whenever
    - the receiver is powered and the driver is not powered,
    - the inputs short together,
    - input wires are disconnected.
- Power consumption is typically 50mW per driver/receiver pair for LVDS compared to 120mW for ECL.

The signalling levels used by LVDS are illustrated in figure 3.



Driver Voltage Across 100 ohm Termination

Receiver Input Thresholds

Figure 3. LVDS Signalling Levels

There are two standards which define LVDS

1. TIA/EIA-644 that defines the driver output characteristics and the receiver input characteristics only [3].
2. IEEE 1596.3 Low Voltage Differential Signaling (LVDS) for Scalable Coherent Interface (SCI) that defines the signalling levels used and the encoding for packet switching used in SCI data transfers [2].

One of these two standards will be used to define LVDS for SpaceWire.

Data Encoding

SpaceWire uses Data-Strobe (DS) encoding. This is a coding scheme which encodes the transmission clock with the data into data and strobe so that the clock can be recovered by simply XORing the data and strobe lines together. The data values are transmitted directly and the strobe signal changes state whenever the data remains constant from one data bit interval to the next. This coding scheme is illustrated below in figure 4. The DS encoding scheme is also used in the IEEE-1355-1995 [1] and IEEE 1394-1995 (Firewire) standard [11].

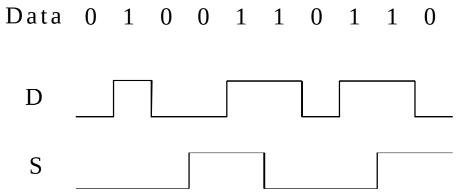


Figure 4. Data-Strobe (DS) Encoding

A SpaceWire link comprises two pairs of differential signals, one pair transmitting the D and S signals in one direction and the other pair transmitting D and S in the opposite direction. That is a total of eight wires for each bi-directional link.

Character Level

SpaceWire employs the character level protocol defined in IEEE 1355-1995.

There are two types of characters:-

- Data characters which hold an eight-bit data value, transmitted least-significant bit first. Each data character contains a parity-bit, a data-control flag and the eight-bits of data. The parity-bit covers the previous eight-bits of data, the current parity-bit and the current data-control flag. It is set to produce odd parity so that the total number of 1’s in the field covered is an odd number. The data-control flag is set to zero to indicate that the current character is a data character.
- Control characters which hold a two-bit control code. Each control character is formed from a parity-bit, a data-control flag and the two-bit control code. The data-control flag is set to one to indicate that the current character is a control character. Parity coverage is similar to that for a data character. One of the four possible control characters is the escape code (ESC). This can be used to form longer control codes. One longer control code is specified which is the NULL code. NULL is formed from ESC followed by the flow control character (FCC). NULL is transmitted

whenever a link is not sending data or control tokens to keep the link active and to support link disconnect detection.

The data characters, control characters and parity coverage are illustrated in figures 5 and 6.

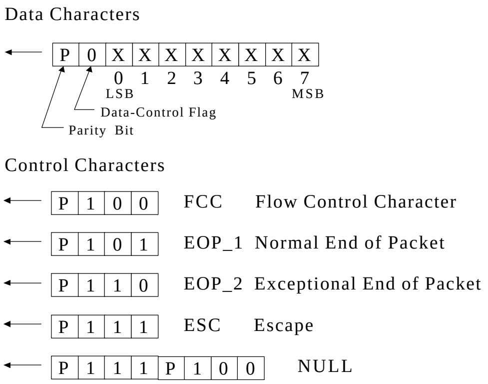


Figure 5. Data and Control Characters

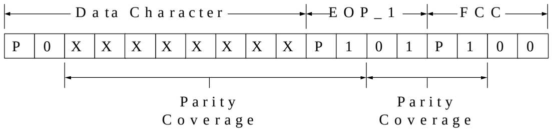


Figure 6. Parity Coverage

Exchange Level

An exchange level protocol is proposed following that defined in IEEE 1355-1995 which provides the following services:-

- **Initialisation:** Following reset the link output is held in the reset state until it is instructed to begin transmission. The link output then starts to transmit NULL characters and the link input is monitored for the reception of a character. Once a valid character has been received on the input then the output can start normal operation.
- **Flow Control:** A transmitter is only allowed to transmit data characters if there is space in the receiver buffer for them. The receiver indicates that there is space for eight more data characters by sending a flow control character (FCC). If multiple FCC's are received then it means that there is a corresponding amount of space available in the receiver buffer e.g. four FCC's means that there is room for 32 data characters.
- **Detection of Disconnect Errors:** Link disconnection is detected when following reception of a data bit no new data bit is received within a link disconnect timeout window (850 nsec). Once a disconnection error has been detected the link attempts to restart (see below).
- **Detection of Parity Errors:** Parity errors occuring within a data or control character are detected when the next character is sent, since the parity bit for a data or control token is contained in the next character. Once a parity error has been detected the link will attempt to restart (see below).
- **Link Restart:** Following an error or reset the link attempts to re-synchronise and restart using an "exchange of silence" protocol (see figure 7). The end of the link that is either reset or that finds an error, ceases transmission. This is detected at the other end of the link as a link disconnect and that end stops transmitting too. The first link resets its input and output for 6.4 usec to ensure that the other end will detect the disconnect. The other end will also wait for 6.4 usec after ceasing transmission. Each link then waits a further 12.8 usec before starting to transmit. These periods of time are sufficient to ensure that the two links are resynchronised and ready to receive data.

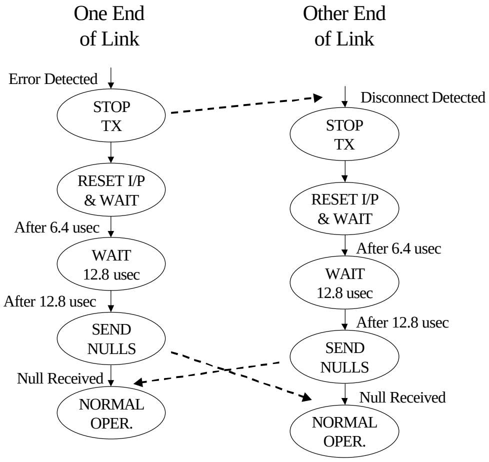


Figure 7. Link Restart

Packet Level

The packet level protocol follows the packet level protocol defined in IEEE-1355. It defines how message is delivered from source to destination. The format of a packet is illustrated in figure 8.

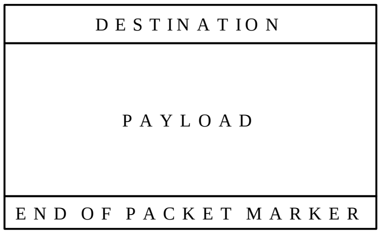


Figure 8. Packet Format

The “Destination” is a list of one or more bytes that represent the destination identity. This list of bytes represents either the identity code of the destination node or the path that the packet will take to get to the destination node.

The “Payload” is the data or message to be transferred from source to destination. The format of payload is not defined by the SpaceWire standard at present although extensions to support fault tolerance are being considered.

The “End of Packet Marker” (EOP) is used to indicate the end of a packet. Two EOP markers are defined.

1. EOP_1 Normal end_of_packet marker - indicates end of packet
2. EOP_2 Exceptional end_of_packet marker - indicates end of packet or an error

The packet level protocol provides suport for packet routing via wormhole routing switches [12].

Higher Level Protocols

Higher level protocols are being considered to support fault tolerance.

CONCLUSIONS

This paper has provided an overview of the proposed SpaceWire standard.

Several issues have to be resolved before SpaceWire can be presented as a draft ESA standard:

1. Provide specification for space qualifiable cable and connectors.
2. Consider high-level virtual channel protocols.
3. Resolve problems with IEEE-1355 start-up/reconnect problems.

These activities are planned as part of the DICE study phase 2. A draft standard will be issued to members of a SpaceWire working group later in 1999 [4].

SpaceWire is set to become an important standard for satellite on-board data handling. It combines appropriate features from two commercial standards with improvements necessary to ensure that it is suitable for many space missions.

ACKNOWLEDGEMENTS

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