MIXED SPACEWIRE - SPACEFIBRE NETWORKS

Session: SpaceWire Standardisation

Long Paper

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ABSTRACT

In this paper the different levels of SpaceWire and SpaceFibre are compared. The mechanisms for data segmentation and virtual channels used in SpaceFibre are explained and it is shown how traffic from standard SpaceWire links can be connected into and be transmitted via a SpaceFibre network. The requirements on mixed SpaceWire - SpaceFibre networks are discussed and the intrinsic features of SpaceFibre which can be used to provide priorities are pointed out.

1 INTRODUCTION

SpaceFibre is aiming to complement SpaceWire and to overcome some of its limitations. While the data rate is improved by a factor more than 10, the cable length can span up to 100m and the cable mass is significantly reduced. In addition SpaceFibre links can provide galvanic isolation. An important requirement from the beginning was to allow for mixed SpaceWire – SpaceFibre networks and to maintain compliance with the protocols and the routing mechanisms as defined in the SpaceWire standard. This compatibility is important to secure the value and to take full benefit of the investments already made into SpaceWire developments.

2 SPACEWIRE – SPACEFIBRE COMPARISON

SpaceWire has been defined by the standard [1] in 2003. Since then plenty of SpaceWire implementations have been made around the world. Interoperability of the designs has been tested and proven in several missions. SpaceFibre is still at the stage of definition and prototype implementations. ESA has conducted a number of activities to define the properties and to make a prototype implementation of the fibre optical elements, the codec and the end to end link. The objective was to trade-off the technical parameters and to verify the feasibility of the implementation. This paper reviews the current status of breadboards and concepts. Note that there might be modifications and further improvements until the successful standardisation of SpaceFibre.

In order to illustrate similarities and differences between SpaceWire and SpaceFibre both are compared at the different levels starting at the physical level.

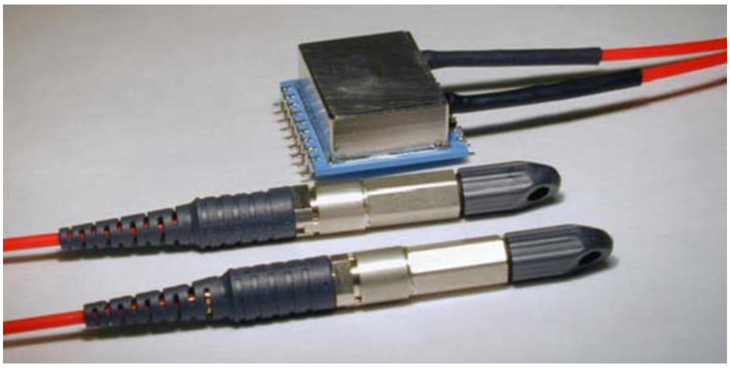

Figure 1: Diamond AVIM connectors and electro optical transceiver breadboard

2.1 PHYSICAL LEVEL

The SpaceWire physical level is defined as a cable with 4 twisted pairs and with the nine-pin micro-miniature D-type connectors. The specified cable assembly is specified to bridge distances up to 10 m.

The SpaceFibre physical level will have two possible implementations. The first implementation is based on optical fibre and second one is based on an electrical copper connection.

A number of optical fibre constructions and implementations where investigated with respect to the requirements on alignment tolerances, bandwidth and radiation sensitivity [2]. The fibre selected after testing a number of options is the Draka MaxCap 300 with is a radhard a laser-optimised graded-index multimode fibre. Radiation tests were performed at a dose rate of 450 Gy/h and with a total irradiation dose of 1000 Gy. The radiation-induced attenuation during this test showed a loss of 7dB for the 100 m of fibre. When transferring this data to the typical dose rates in space the radiation-induced attenuation is expected to be well below 1dB.

A cable around one fibre was designed using an expanded polytetrafluoethylene (ePTFE) buffering system to minimize microbend-induced attenuation changes. The Diamond AVIM connector, which has been already in several space missions, was selected for the SpaceFibre link. For the bidirectional SpaceFibre link connection two of these cables are needed to bridge a distance of up to 100 m.

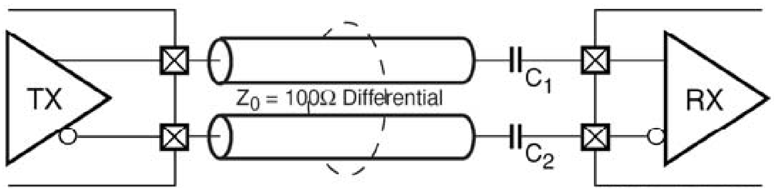

Figure 2: AC coupling of a CML transmitter and receiver

The electrical copper connection has not yet been optimised for space use. During the testing of the breadboard four co-axial cables, two per direction, with SMA connectors have been used. With this a connection was demonstrated over a distance of several decimetres [3]. Other possible copper media like twisted pairs need to be investigated and characterised before making the final choice. An improvement compared to SpaceWire is the introduction of AC coupling (use of DC blocking capacitors in the signal path) to allow common mode voltages differences between transmitting and receiving side. This can enable also hot plug-in capability.

2.2 Signal Level

The Signal Level of SpaceWire is defined by the LVDS specification according to ANSI/TIA/EIA-644. Two LVDS signals per link direction, the Data and the Strobe signal, are sent in parallel. The Data and Strobe coding used allows to encode the clock signal and to recover it on the receive side by simply XORing the Data and Strobe lines together.

For SpaceFibre the Signal Level is defined by the 850-nm laser light with a peak transmitted optical power of 3dBm. In the modular architecture the light is generated and received in an electro-optical transceiver. The electrical interface of the current prototype of this transceiver employs Current Mode Logic (CML) with a typical peak to peak voltage swing of 1.6V and a common mode voltage of 1.25V at 100Ω differential impedance. This CML defines also the signal level of the electrical version of the SpaceFibre link.

The link uses a single fibre per direction because the clock is transmitted together with the data by means of 8B10B encoding. On the receive side the clock is reconstructed by locking a PLL on the transitions of the encoded signal.

2.3 Character Level

SpaceWire knows two types of characters, the data and the control characters. In a data character one eight bit value is encoded together with parity bit and data-control flag using 10 bits. There are four 4 bit control characters defined, the FCT, EOP, EEP and ESC. The ESC character followed by the FCT is defined as NULL control code and the ESC character followed by a data character is defined as Time-Code.

SpaceFibre employs the 8B10B encoding scheme [4] where an eight bit value is encoded using 10 bit. In order to ensure a transition rich signal only the balanced 10 bit codes, which have as may one as zeros, and the codes which have a difference of two between the numbers of ones as zeros are used. For any eight bit value which is not represented by a balanced code there are two 10 bit codes assigned, one with positive and one with negative disparity. The aim is to keep the total number of ones and the number of zeros which are sent over the link equal. In order to achieve this goal the character representation with the best disparity is selected before transmitting. This coding scheme allows to define 12 special characters in addition which can be used for control functions. Among them are 3 comma characters (K.28.1, K.28.5, K.28.7) which contain a unique sequence of ones and zeros only present in these characters. Due to this signature they can be used to align the code boundaries in the continuous stream of ones and zeros.

The data characters and the control information are 32 bit aligned. The control information is sent in form of ordered sets. Ordered sets are 4 characters sequences starting with a comma character (K28.5), the next character determines the type of ordered set while the last to characters can carry two bytes additional information.

There are several types of ordered set defined in SpaceFibre. Those are link-level ordered sets, power management ordered sets, reset ordered sets, flow control ordered sets, framing ordered sets and user ordered sets. Similar to the SpaceWire control characters they are inserted in the data stream at link level to manage certain link functions. The user ordered sets can be inserted in the data stream in addition and are used to implement time-codes or user interrupt functions which can be propagated throughout the network.

2.4 EXCHANGE LEVEL

The exchange level of SpaceWire defines the link initialization, detection of disconnect errors, detection of parity errors, link error recovery and flow control.

In case of a link disconnection or a parity error the SpaceWire link is reset and the connection is restarted after an exchange of silence. This drastic measure interrupts the data flow in both link directions and it reinitializes the character synchronisation and flow control status to guarantee correct operation again.

The flow control in SpaceWire manages the data flow in a way to ensure that the transmitting side is only sending data when the receiving side has sufficient buffer space available. The availability of receive buffer space is indicated to the transmitting side from the receiving side by sending one flow control token (FCT) per every of eight bytes buffer space available.

While the lower levels of SpaceFibre discussed so far where quite different to SpaceWire some important features of the SpaceWire exchange level are maintained in SpaceFibre. The link flow control is one of these features which are maintained and further extended. The higher target speed of SpaceFibre requires that the flow control is operating on larger pieces of data. The 8 characters of 8 bit each per flow control token in SpaceWire are extended to a frame of data of a maximum length of 255 data words of 32 bit each.

Every frame starts with an ordered set indicating the start of frame, a virtual channel number and the number of words in a frame. The frame ends with an ordered set indicating the end of the frame and which contains the 16 bit CRC of the data. This CRC is used to verify that the data have been received without error.

For the transport over the SpaceFibre link the SpaceWire packets are split into frames. The first data word in the frame is reserved to indicate if this frame contains the beginning of a SpaceWire packet, the middle of a SpaceWire packet or the end of a SpaceWire packet. It further contains the information on the location of the first valid SpaceWire packet byte in the second word of the frame and the location of the last valid SpaceWire packet byte in the last word of the frame. This is required because SpaceWire packets are not 32 bit aligned and can have a length which is not always a multiple of 4. At the start of the packet padding can occur when the leading path address byte is deleted during routeing by a SpaceFibre router. Due to header deletion the content and the length of the first frame can change and the frame CRC needs to be recomputed.

In contrast to the data characters sent over SpaceWire the SpaceFibre frames can be distinguished by the virtual channel byte. The flow control ordered sets contain a virtual channel byte as well. By implementing separate frame buffers the data flow in each virtual channel can be separated while using a single physical medium [5], [6]. Congestion in one virtual channel does not influence the traffic in other virtual channels and SpaceWire packets in one virtual channel can pass a packet in another virtual channel. Each virtual channel is able to use the complete bandwidth of the SpaceFibre link. Priorities which are controlling the access of the virtual channels to the physical medium ensure that the higher priority channel has always direct access to the link even if the bandwidth is already fully used by other lower priority channels.

In case of a CRC error in one of the virtual channels it is important that not the complete SpaceFibre link is interrupted and restarted as it is the case for SpaceWire. The SpaceWire receive packet is appended by an EEP, the rest of the transmit packet is spilled and the flow control status of the virtual channel is reset.

In case there is no data to be sent over the SpaceFibre link the link is kept busy by sending IDLE ordered sets similar to the NULL characters in SpaceWire. If there is no data frame to be sent in any of the virtual channel an IDLE frame is automatically generated. Idle frames are terminated as soon as a data frame becomes available.

2.5 PACKET LEVEL

The packet level of SpaceFibre is mostly the same as for SpaceWire. The packet starts with SpaceWire address field which contains zero ore more bytes used to route the packet to the target. This is followed by the SpaceWire logical address of the target and the protocol identifier or extended protocol identifier. After this the cargo follows. The end of packet marker is represented by the end of frame ordered set of the last frame of a SpaceWire packet.

2.6 NETWORK LEVEL

At network level SpaceFibre is intended to be fully compatible with the network level of SpaceWire.

3 MIXED SPACEWIRE – SPACEFIBRE NETWORKS

There are a number of different network topologies which could employ a combination of SpaceWire and SpaceFibre links.

3.1 SINGLE SPACEFIBRE LINK

The simplest topology is of course a single SpaceFibre link connecting e.g. a very high data rate instrument with a mass memory. In comparison a network based on SpaceWire links would require several parallel links to provide the necessary bandwidth. Besides the higher data rate the virtual channels in SpaceFibre allow transmitting the instrument telemetry in parallel to the high rate instrument data over the same medium as well as the instrument control information in the other direction. The different data streams of highly different data rate don’t interfere as they are kept separated by the virtual channels in the SpaceFibre link. A SpaceFibre interface device for end nodes could have several parallel interfaces which allow injecting and retrieving very high speed data from different virtual channels with an aggregated data rate only limited by the SpaceFibre bandwidth. In order to allow cross strapping for redundancy reasons such a SpaceFibre interface device should provide two SpaceFibre interfaces.

3.2 SpaceFibre as Back Bone Connection

In some spacecraft the onboard network has to connect clusters of instruments or electronic boxes which are physically placed at different locations. This could for example be the connection between an instrument suite on a mast or detectors in a focal plane with the mass memory, the OBC and the data down link unit. With increased distance the harness mass reduction becomes important as well as the galvanic isolation and robustness against common mode voltage drift. One SpaceFibre link connecting two SpaceWire – SpaceFibre routers could provide a solution for this type of need. In such a case all instruments and electronic units would be equipped with conventional SpaceWire interfaces which are connected to the SpaceWire – SpaceFibre routers to provide the local connectivity between the units. The virtual channels of SpaceFibre can be operated as logical parallel SpaceWire links. It is clear that the bandwidth of one end to end connection is limited by the slower SpaceWire links. A cross bar switch inside the router is able to connect all SpaceWire link interfaces with each other as well as with each of the virtual channel buffers of the SpaceFibre link. The virtual channels are accessed through the router by a path or by a logical address in the SpaceWire packet. To provide basic redundancy such a SpaceWire to SpaceFibre router needs at least two SpaceFibre links in this kind of back bone application.

3.3 Mixed Networks

The need for very high data rate link is often limited to one or few instruments connected to the mass memory. The other instruments and units have lower bandwidth requirements but they need to connect to the same mass memory or to control the high data rate instruments. A single mixed SpaceWire – SpaceFibre network is capable fulfil these requirements. The SpaceFibre connection between high data rate instrument and the mass memory passes through SpaceWire – SpaceFibre routers. The other instruments and units connect to these routers using normal SpaceWire links. The very high speed and the lower speed traffic is separated through the different virtual channels while it runs over the same medium.

3.4 Pure SpaceFibre Networks

In some applications there is only the need for very high speed interconnections. In this case a pure SpaceFibre based network can be used. Also there the virtual channels can be used to separate different traffic classes like payload data and telemetry or control data.

4 Number of Virtual Channels in SpaceFibre

The maximum number of virtual channels in SpaceFibre is 256. In practice the number of implemented virtual channels will be much smaller. Virtual channels require not only the provision of separate virtual channel buffers but also separate connections to the host system.

In SpaceWire routers the number of ports for path addressing is limited to 31 plus the configuration port. This limitation is inherent to the SpaceWire path addressing scheme and is also applicable to SpaceFibre. There are two ways to overcome this limitation. The SpaceWire standard permits that for very large routers two consecutive path address bytes are used. In the SpaceFibre case the first path address byte could indicate the SpaceFibre link while the second would indicates the virtual channel number. The second possibility is that per SpaceFibre link only a few virtual channels are accessible via path addressing. The other virtual channels would be only accessible via logical addressing.

5 VIRTUAL CHANNEL PRIORITIES AND GROUP ADAPTIVE ROUTING

Each virtual channel can occupy the complete bandwidth of the SpaceFibre link. If two or more connections with a total bandwidth higher than the provided bandwidth of SpaceFibre are accessing the same link some kind of arbitration is needed. One possibility is to assign priorities so that the higher priority virtual channel is granted always direct access. This is a good scheme if there is the need to combine a low rate, low latency traffic and high rate traffic on one link. If there are several concurrent high rate connections a round robin arbitration is preferred. A combination of the two concepts would assign priority levels to the virtual channels and perform round robin arbitration between virtual channels of the same priority.

If these connections are routed thought the same virtual channel the arbitration is provided by the router like in the SpaceWire case. The router can be programmed to provide group adaptive routing among virtual channels of the same priority. This allows for that traffic to the same logical address can take automatic benefit of the availability of several virtual channels.

It should be mentioned that ordered sets used for virtual channel control, time codes or interrupts etc. have always priority over data frames and are directly transmitted in the middle of the current data frame.

The separation of data connections using virtual channels and the possibility to assignment of priorities are important building blocks for controlled qualities of service. The SpaceWire RT protocol will be used to provide the end to end flow control and where quality of service levels beyond priorities are needed.

Figure 3: First prototype implementation of one SpaceFibre link and two SpaceWire – SpaceFibre Routers

6 CONCLUSION

ESA has developed a first prototype implementation in several contracts together with Patria New Technologies Oy, VTT, INO, Fibre Pulse, Gore industry and University of Dundee. The first focus was the development and environmental test of the electro-optical transceivers and the cable based on optical fibre. This effort is continued in a follow-on activity. The second focus was the development of the SpaceFibre CODEC, the SpaceWire – SpaceFibre router and the overall SpaceFibre network concept. The first prototype has been implemented based on Xilinx FPGA using the Rocket I/O as serialiser / deserialiser and as electrical physical layer. A first outline specification [7] has been published and discussed with NASA and US industry in the frame of a SpaceFibre working group. The experience gained will be consolidated and used for the development of a SpaceFibre demonstrator. It is intended to use an Actel FPGA and the Wizard Link [8] as the hardware platform for this coming demonstrator. This will allow to show the feasibility of SpaceFibre links for space flight as both key components are available as qualified parts. Further an IP core of the CODEC will be developed and the necessary documentation to start standardisation will be produced.

7 REFERENCES

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