Problems of Developing Spacewire – Ethernet Bridge and Transferring Spacewire Packages Over Ethernet

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***Abstract*–This article represents a prototype device of the bridge for SpaceWire packet transmission via Ethernet and the implementation of this device. Possible problems in transmission are studied to ensure correct and fast operation of the bridge. The article also presents a comparative analysis of the developing device with modern counterparts and identifies the advantages and disadvantages of each. The variant of the transitional protocol with the function of transferring data from SpaceWire to Ethernet and vice versa is presented.**

I. Introduction

Nowadays space industries in Russia, Europe and North America set demanding requirements for on-board communication systems. In accordance with [1], satellites and piloted spacecrafts require networks with high data transmission rates up to tens gigabit per second for data-handling and computer buses and distances of 50 – 100 m between adjacent nodes. Moreover, the acceptable cable mass is about 30 – 60 g/m and galvanic isolation is necessary.

The drawback of SpaceWire (SpW) technology [2] based on IEEE 1355-1995 [3] and ANSI/TIA/EIA-644 [4] standards consists in the deployment of data-strob (DS) encoding scheme at the physical layer. Thus, the maximum transmission rate in a SpaceWire link stands at 400 Mbit/s, SpaceWire cable has the recommended length of 10 m and comprises four twisted pairs (with whole acceptable mass of 80 g/m).

Due to SpaceWire cable length restriction (10 m) and necessity of connecting the remote segments of SpaceWire network that is able to transfer packets the new solution is needed. The main condition is minimum delay and maximum simplicity. Ethernet and Gigabit Ethernet protocols are the most appropriate technology in this problem.

Ethernet is a protocol that controls the way the data is transmitted over a local area network. An Ethernet LAN typically uses coaxial cable or special grades of twisted pair wires. The most commonly installed Ethernet systems provide transmission speeds up to 10 Mbps. Devices are connected to the cable and compete for access using a Carrier Sense Multiple Access with Collision Detection (CSMA/CD) protocol. Now only fast Ethernet and Gigabit Ethernet technologies are widely used in most LAN networks. The speed rates of fast Ethernet and gigabit Ethernet are correspondingly 100Mbits/sec and 1000 Mbits/sec. Also the cables of the Ethernet are quite cheap and are varied.

In order to enhance SpaceWire link characteristics this paper defines special bridge Spw-Gigabit Ethernet. The bridge is absolutely transparent for the SpaceWire network and can connect two SpaceWire networks into one.

This bridge is used for point-to-point connections. In future the possibility of using the whole Ethernet network can be implemented, but this article is devoted only to the problems of creation the connection the SpaceWire and Ethernet standards using only the link layer.

During subject area analysis the following tasks were allocated:

1) Analysis variants of connection Ethernet-SpaceWire bridge in network
2) Discover and compare modern analogs of developing device
3) Discover and identity problems, that can occur during transferring SpaceWire packets over Ethernet

Fig. 1 shows a prototype of Ethernet-SpaceWire bridge that was developed. On the board is situated FPGA Virtex(1) and ALTERA(2), Ethernet connector(4), Gigabit Ethernet transmitter, SpaceWire connectors(3), test lines and indication (7,6).

This prototype is developed with two different chips – Viretex and Altera. Our developing group is using Virtex.

Our code in Virtex chip is responsible for a work with SpaceWire interface and solves the problem of creating payload for Ethernet frame from SpaceWire Packet and forms SpaceWire packet from Ethernet frame. Altera chip now realize forming Ethernet frames and transmitting/receiving this frames. Ethernet transmitter allows to work on speed 10/100/1000 Mbits/s [2]. In future both Altera and Virtex chips can be used for developing code for different realizations of code for the bridge.

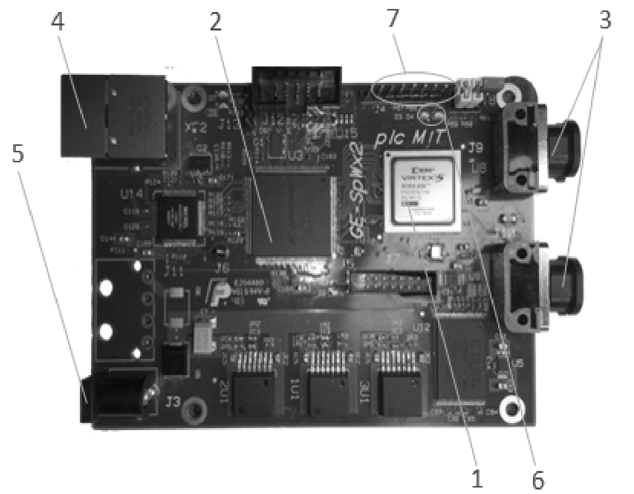


Fig. 1. GigabitEthernet-SpaceWire bridge

FPGA Altera establish connection with network Interface Card of PC or switch and determines speed of the channel. Ethernet frame, comes through Ethernet controller to FPGA Altera where it is processed and CRC removes from frame. Then frame transmits to FPGA Virtex where it analyzes, removes header, forms SpaceWire packet and transmits to SpaceWire macrocell.

When packets from SpaceWire are received they are analyzed and carried in number of buffers while forming the Ethernet frame. Relying on ready-signal from Altera data for Ethernet frame payload transmits to Altera, where frame forms and transmits to the Ethernet network (Fig.2).

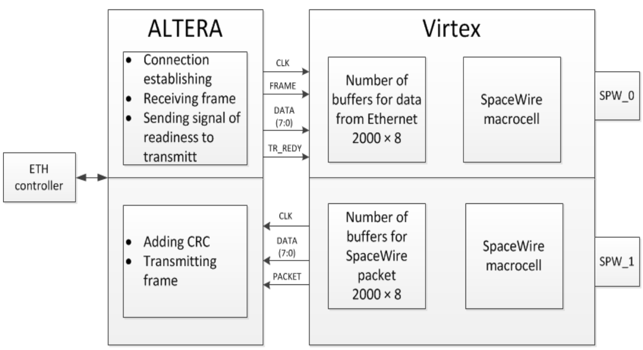


Fig.2. Block diagram of Ethernet-SpaceWire bridge

Different variants of connecting of the bridge prototype to the Ethernet network are presented on Fig. 3:

1) Direct connection of the bridge to the PC
2) Connecting two SpaceWire networks over two bridges with point-to-point connection of the bridge
3) Connecting SpaceWire network, with Ethernet network over Ethernet switches

At this time variant number 1 is realizing. However this variant is point-to-point connection so variant number 2 can be tested also. The third variant of connection is not considered in this article but it is the future purpose of developing and will be considered in the future articles.

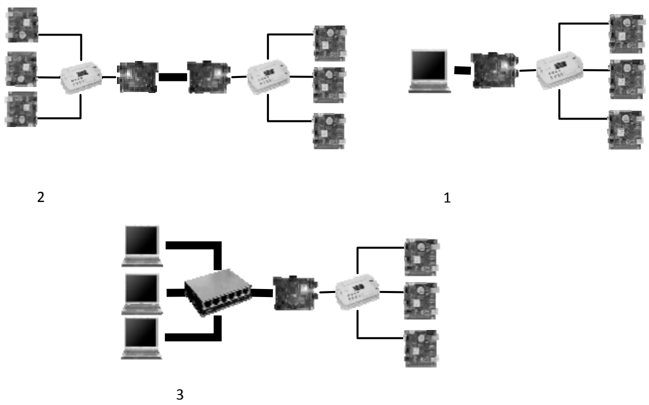


Fig. 3. Variant of connection Ethernet-SpaceWire bridge

II. DISCOVERING PROBLEMS OF ETERNET-SPACEWIRE TRANSFERING

Comparing of the Ethernet frame and SpaceWire packet helps us to analyze the problems that can appear during transmitting data from one network to another. Formats are similar however there are some significant differences. Ethernet frame has fixed length of header (14 bytes), fixed length of payload (46 to 1500 bytes) and at the end of frame there is CRC (4 bytes) as the end of frame [3]. As opposed to Ethernet SpaceWire may have different length of header depending to address type and information that it contains. Data field may be 1 byte or infinitely long. The end of the packet is marker that informs about the end of the packet (eop) or the error end of packet (eep) [1,4].

Based on foregoing we can make a conclusion that additional processing of SpaceWire packet is needed before transferring, Especially if the length of the packet is more than 1500 bytes. One of the ways of processing is dividing packets into parts and supplying these data with special informational bytes that can be placed before SpaceWire data and transmitted in payload of Ethernet frame. Those bytes will inform about number of part and type (eop/eep/Ccode) to the receiving side.

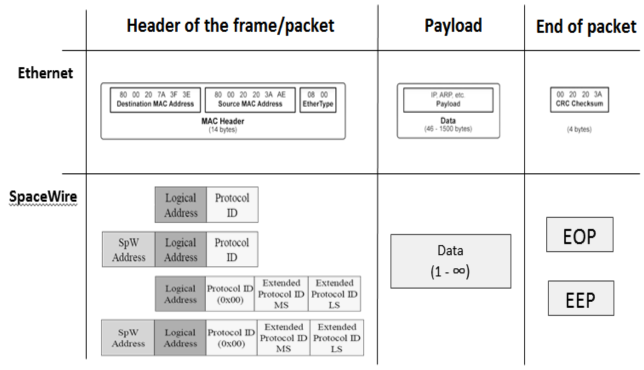


Fig.4. Comparing Ethernet frame and SpaceWire packet

Fig. 5 is the diagram that shows the relation between useful information and transmitting bytes in Ethernet frame and SpaceWire packet.

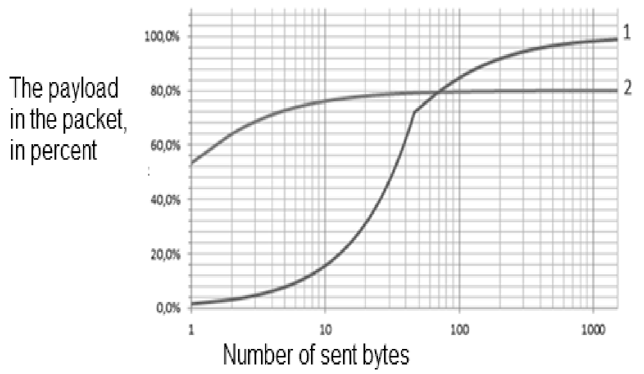


Fig. 5. relation between useful information and transmitting bytes (in percentage) (1 – Ethernet, 2 – SpaceWire)

Chart on Fig. 5 shows that maximum of useful data transfers when data field of SpaceWire contain 30-40 bytes. Usefulness of Ethernet frame at this case is low – 50 % of transmitting bytes. Inflection point on the curve of Ethernet is the result of minimum available bytes that may contain frame payload – 46 bytes. So in case of transmitting 1 byte other 45 bytes of payload will be filled with zeros. Maximum useful data is transmitted over Ethernet when payload of frame contains the maximum number of bytes - 1500 bytes. It shows that bridge developing needs to design transferring rules or protocol, to make this device more productive[9][10].

Based on foregoing following problems can be allocated:

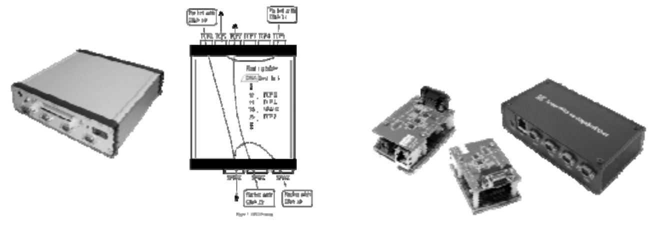
1) Low efficiency in transferring short frames
2) Additional processing of long SpaceWire packets is needed
3) Low efficiency in transferring CCode by separate frames (see item 1)

III. Comparative analysis of similar devices

The main demands to the bridge prototype are:

1) Hardware implementation of the transmitting protocol
2) Usage of physical and data levels of OSI model, not higher
3) Gigabit Speed support. In future – this bridge is supposed to be used with GigaSpaceWire technology

Products of Aeroflex company (Fig. 6 a)[6] and ShimafujiElectric were taken to compare with developing device (Fig. 6 b)[7].



a b

Fig. 6. Ethernet – SpaceWire devices

Table I shows comparative analysis of devices that are similar to developing prototype.

TABLE I. Comparison of devices similar to developing prototype

Aeroflex [6]	ShimafujiElectric [6]	GigabitEthernet-SpaceWireBridge
Software implementation	Hardware implementation	Hardware implementation
High delays in data transferring due to software processing	TCP/IP protocol introduced	Preparation of new format that will make transferring from SpaceWire to Ethernet and back fast and easy available on hardware
Complexity of device working and additional settings are needed	Is used with connecting to PC	GigabitEthernet support
		High performance due to lack of redundancy

Comparative analysis of described devices shows that they combines in themselves functions of switch and transmits data using TCP/IP and are software implemented. For the combination of two remote networks these devices will complicate work and be excessive.

Based on consideration of the materials work was carried out of protocol developing.

IV. DEVELOPMENT OF PROTOCOL

The simplified version of the data transfer protocol for SpW-Ethernet packets is used.

The packet of Ethernet consists of a destination address, a source address and the EtherType field. We suggest not to change MAC header 14 bytes long. All modifications will be only in the data field, packets of SpaceWire will be located in the field of data, without influencing MAC header in any way (Fig. 6).

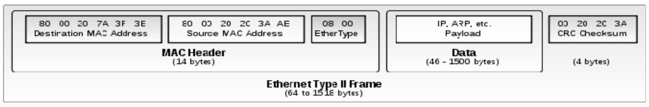


Fig. 7. Ethernet type II frame

There are some problems need to be solved in the transfer of SpaceWire packets using Ethernet:

1) How can the system transfer long SpaceWire packages? SpaceWire package is unlimited, Ethernet packages are limited.
2) How can the system transfer short SpaceWire packages? SpaceWire package's length can be 1 byte, and the Ethernet package contains at least 46 bytes
3) What can the system do if the transfer of an Ethernet package failed, or the CRC code of the package was wrong?

Respectively, the solution of the aforesaid problems is to create a small heading of a package. The heading will contain information containing length of the package, number of the package and type of the package.

The first byte of heading contains information of the package type and the package number. All information occupies 1 byte. The type of a package is coded by the first two bits.

01 – the package comes to an end with EOP

10 – the package comes to an end with EEP

00 – part of a package (the package isn't finished, there will be a further transfer)

11 – CCODE package

Number of a package is coded by remained 6 bits. This number is split in two parts – 4 bits, and 2 bits. Number of a package is 4 bit long and is changed cyclically from 0 to 15. Number of a package changes only if the Ethernet package contains data and a package was transferred completely. The last 2 bits code the number of a slice of a package if the package consists of the several parts.

If the Ethernet package contains only a control code – the number of the package doesn't change (Fig. 8).

Ethernet header	Type, number, part number	Length	DATA	CRC

Fig. 8. Spw packet placed to Ethernet frame

Length of the package will change from 0 to 255. If the package is more than 255 – the number 255 is written. This information is essential to us only if the package small, less than 46 bytes. In any other case – the size of a package is limited by the Ethernet package size(Fig. 9).

Ethernet header	Type, number, part number	Length	Credit	DATA	CRC

Fig. 9. Spw packet placed to Ethernet frame with credit number inside

The receiving side is able to receive the data, if the SpaceWire packet I less than 46 and can detect loss of the packet.

One more problem is the free space in the receiving buffer. If the receiving buffer has no space – there is a possibility of data loss. In this case it is supposed to supply each sending package with additional information on free space in receiving buffer, the quantity of packages of the maximum length which can accept the receiver. The size of this field is 1 byte. Thus, each sending package contains additional information on a condition of the receiving buffer (number of the credits). In case of a long absence of packages – they can be sent using timer.

It is inconvenient to transfer SpaceWire packets[11] directly using Ethernet. First – small packets transfer very ineffective (if the data is less than 46 bytes – it has to be transferred the same 64 bytes). Secondly – big packets can't be transferred directly– the frame of Ethernet is restricted to 1500 bytes. Thirdly – transmission of control codes using one frame in principle is ineffective – 1 byte of data will be transferred by 64 bytes using Ethernet.

The solution can be simple - transfer several SpW packets in one Ethernet frame. However, it is necessary to make new descriptor part in the data part of the Ethernet frame which describes type of SpW packet in Ethernet frame.

We have already described the header (descriptor) of the packet. We will make slight changes:

Four types of descriptors are slightly changed (size is 1 byte). Descriptors will be located before a SpW part of packet (Table II).

If the SpW packets are small (up to 64 bytes), they are packed directly to the data field with the descriptor.

TABLE II. NEW DESCRIPTORS

Descriptor	Description	Comments
01 LLLLLL	Packet (or part of a packet) which ends with EOP	LLLLLL– length of a packet (L+1). Maximum length of the packet is 64
10 LLLLLL	Packet (or part of a packet) which ends with EEP	LLLLLL– length of a packet (L+1). Maximum length of the packet is 64
00 LLLLLL	Intermediate packet	The part of a packet, the size is from 1 to 64 bytes
11 XXXXXX	Special Symbol	XXXXXX – type of special symbol, 6 bits

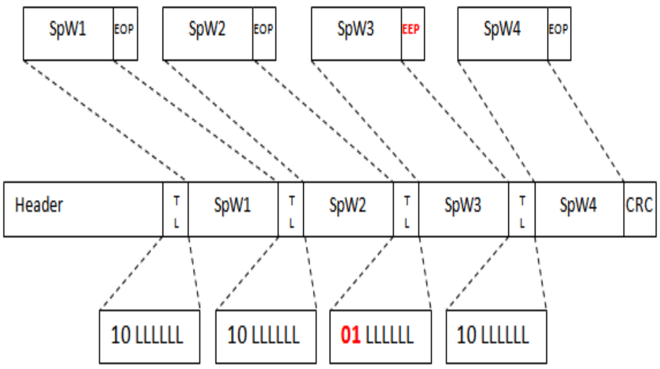


Fig. 10. Several SpW packets placed to Ethernet frame

Thus – 4 small SpW packets are transferred in one Ethernet frame (Fig. 10).

If SpW packet has more than 64 bytes – they are split to the smaller packets and are transferred the Ethernet frame (Fig. 11).

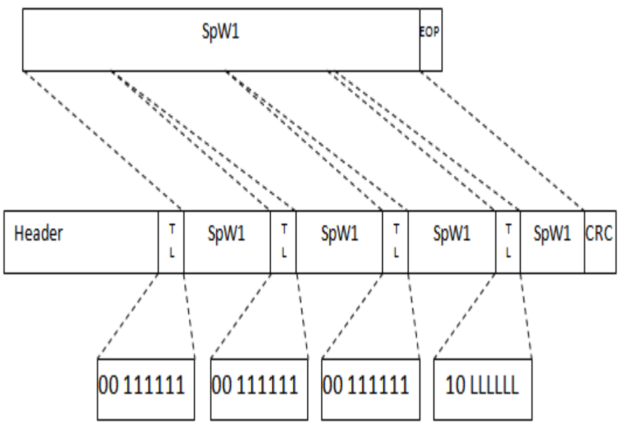


Fig. 11. Big SpW packet placed to Ethernet frame

For transmission of control codes special TL codes are used.

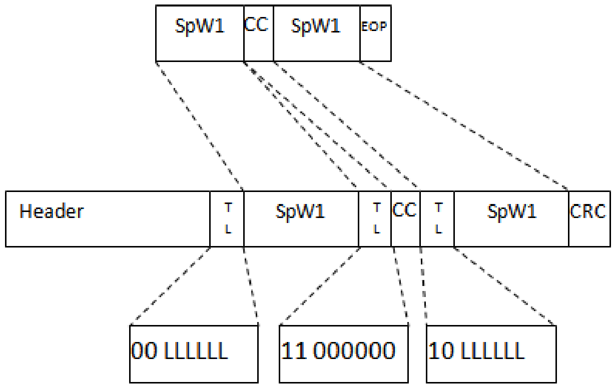


Fig. 12. SpW CCode placed to Ethernet frame

Thus, at first the part of a packet with the TL 00 code and length of this part of a packet is located. Then there is TL 11000000 code designating that there is a CCode. Then – the rest of the packet with a code and its length. It is possible to transfer several codes CC in one frame of Ethernet.

There can be a situation when it is necessary to finish the Ethernet packet and to send it incomplete (the data field less than 46 bytes). The incomplete packet (in this case – because of the emergency transmission of CCode) will be carried out as follows (Fig. 13).

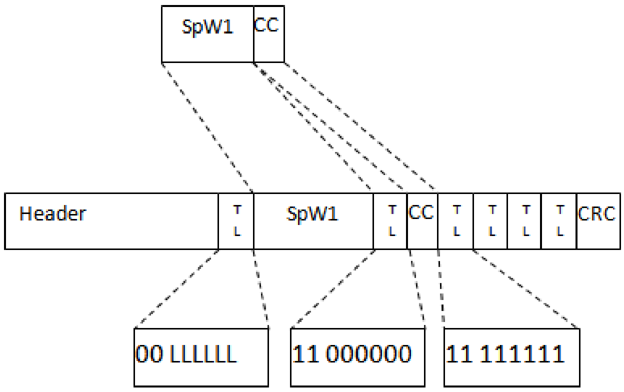


Fig. 13. Incomplete SpW packed placed to Ethernet frame

The packet comes to the end, and the missing packet achieves the special TL code equal 11 111111. Thus the packet can be transferred before it will be full. The quick transfer is not the only CCode needs to be transferred to the network. The necessary conditions, under what circumstances the packet of Ethernet shall go to a network, are:

1) The packet exceeded some value of length of a packet

Here everything is clear – the packet was created with a certain length, it is necessary to send it to an Ethernet network (normal work)

2) The SpaceWire packet ended with EOP or EEP, and the new packet came or CCode haven't arrived for a long time

This is a normal situation, when one of the SpaceWire datalink has transferred all data and no more data is expected. This can be implemented using timer.

3) It is necessary to send CCode

The special CCode came and the packet must be sent to the network quickly. This situation can be also implemented using timer. The second variant – two timers can be used. First timer we will use as global, second is local. Global timer is set to the init value when the special CCode is received from SpaceWire network. Local timer is set to its init value. Local timer init value is less or equal to global timer init value. When the new special code is received – local timer is set to init value again, and global timer is not touched. Several CCodes can be transferred in one packet (if they came before the end of the global timer). The packet is sent in two situations – the local timer comes to zero (no new CCodes has come from Spw network), or the global timer comes to zero (the CCode is maximum time late). The init values of timers can be conFig.d due to each CCode and even be set to zero (the CCode is very urgent and must be sent immediately).

The main disadvantage of the composite Ethernet packet is the rising of the latency of the SpaceWire packets, because the first SpaceWire packets of the Ethernet frame can wait for a significant period of time, especially if the packets are small. For reducing the latency several several variants can be used:

1) Not using the maximum of the Ethernet frame – frame can be reduced
2) Reducing the init value of timer if the last packet was received with the EOP
3) Reducing the init value of CCode timers – the packets will be transferred quicker

It is necessary to continue the research of the protocol from different positions, such as – latency, speed, errors and special situations with CCodes.

V. CONCLUSION

As the result of the work we can say that the SpaceWire protocol can be transmitted using the Ethernet network. The main problem of the prototype bridge is the latency. Even if we are using the simple protocol – buffering the SpaceWire protocol and the use of CRC in Ethernet protocol are greatly increasing the latency of transmitting of SpaceWire packets.

Our prototype bridge is working on two low levels of the OSI model, thus making it simplier than the devices, using protocols of the higher levels such as TCP/IP. Similar devices are excessive in functional and complex in work. Manville developing prototype can provide transition data with less delay and maximum simplicity of connecting and work.

Considered variants of communication need different approaches in realization of the bridge and demand additional researches. Future realization of the protocol of the bridge depends on future investigation.

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