SPACEWIRE AND IEEE 1355 REVISITED

Session: Standardization

Long Paper

Dr Barry M Cook, C Paul H Walker …

4Links Limited, Bletchley Park, Milton Keynes MK3 6ZP, England

E-mail: [Barry, Paul] @4Links.co.uk

ABSTRACT

The ECSS (European Cooperation for Space Standardization) SpaceWire standard includes a list of changes from the standard from which it was derived, IEEE 1355. Several of these changes are improvements, for example fixing the initialization state machine, adding Time Codes, and adding a network layer. The list in the SpaceWire standard does not include a number of aspects of 1355 that SpaceWire has discarded, yet which are being requested by user missions — sometimes where the need is so strong that the missions are already using adaptations from the SpaceWire standard. This paper considers these user needs, with reference to where they were covered, at least in part, by IEEE 1355. It concludes that as SpaceWire is evolving to include SpaceFibre, it should also evolve in other directions to form a family of standards, all sharing the common link, 'exchange' and packet layers of the 1355/SpaceWire standards.

1 INTRODUCTION AND SCOPE

The IEEE 1355 standard [1] was broader than SpaceWire [2] in terms of the variety of transmission speeds and distances covered and the encoding and physical layers to achieve these speeds and distances. 1355 was less deep than SpaceWire in that it did not include the network layer. What is really important in both 1355 and SpaceWire is the common character alphabet and the separation of the link layer (initialization and flow-control) from the 'exchange' and packet layers.

1.1 MULTIPLE ENCODINGS AND PHYSICAL LAYERS

The IEEE 1355 standard defined a family of three separate encodings to cover different speeds and distances:

- Data-Strobe encoding, from which SpaceWire is derived;
- Three-of-Six (TS) encoding, which is already flying on space missions;
- High-Speed (HS) encoding, capable of transmission through copper or optical fibre at rates exceeding 1Gbit/s, much as is the intention for SpaceFibre [3].

IEEE 1355 Data-Strobe character encoding was identical to SpaceWire except for the EOP2 character (Exceptional End of Packet) which SpaceWire replaced by EEP (Error End of Packet). The electrical signals were very similar to SpaceWire, except that Pseudo-ECL was mature technology in the early 1990s and so was used in preference to the lower-power LVDS which had yet to prove itself.

Three-of-Six encoding was used in IEEE 1355 for low-speed optical fibre connections. The Three-of-Six code takes four bits of data and encodes them into six bits such that each six-bit character has three ones and three zeros. There are 20 such characters, which conveniently gives 16 characters for data plus a further four characters for control. The code uses twelve bits to encode each Byte of data, which is a little less efficient than Data-Strobe encoding that uses 10 bits for each Byte, but the code has some useful advantages. It is DC-balanced over a very short period which means that it can be coupled through transformers or capacitors. The code is very simple when compared with the 8B10B code that tends to be used for Gbit/s links, which means less silicon, reduced power, and that it easier to verify and build.

The High-Speed (HS) encoding of IEEE 1355 allowed for communication exceeding 1Gbit/s, much as SpaceFibre is currently intended. Some choices would be made differently now, ten to twenty years from when they were made for 1355 HS, but the HS links were demonstrated in the early 1990s, including a routing switch.

1.2 SINGLE PACKET STRUCTURE FOR ALL ENCODINGS AND PHYSICAL LAYERS

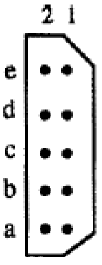
Although IEEE 1355 had several encodings and physical layers, the common threads through them all were:

- Flow-control, with the flow-control unit (Flit) chosen appropriately for the speed and distance;
- A common character alphabet, including 256 data characters plus two EoP characters and the link layer characters Flow-control, and Null. The optical fibre codes also had an init character (‘comma’ in communications terms) that did not occur during normal data transfer, to simplify initialization.
- A minimalist packet structure such that packets are simply delineated by the End of Packet character.

The authors suggest that these threads are the really fundamental aspect of SpaceWire that makes it effective, and that multiple physical layers are to be expected.

2 DATA-STROBE PHYSICAL LAYER

The IEEE 1355 connector was clearly not suitable for use in space, but its pinout and format have certain advantages over the 9-pin Micro-D selected for SpaceWire. The 1355 details are copied from Figure 5.7 and Table 5.9 of the 1355 standard:

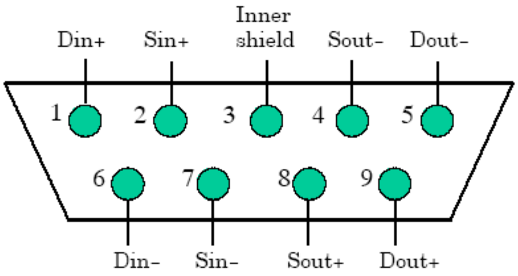


	2	1	
e	DS_DE_data_in_plus	DS_DE_data_in_minus	(Chamfer corners at this side of the connector)
d	DS_DE_strobe_in_plus	DS_DE_strobe_in_minus	
c	No connect or optional power return	No connect or optional power	
b	DS_DE_strobe_out_minus	DS_DE_strobe_out_plus	
a	DS_DE_data_out_minus	DS_DE_data_out_plus	

2.1 CONNECTOR/CROSSTALK

From the above figure and table (copied from the IEEE 1355 standard), it can be seen that the connector had five rows of two pins. Each row except row c was used for a differential pair, with the signals coming in from a cable on rows e and d and out to a cable on rows b and a. Row c could either be left open or could carry optional power and return. In either case there is a significant gap between row b and row d, and so the two directions are separated and near-end crosstalk (or NeXt) is not significant.

The Micro-D (shown with its pinout, copied from Figure 10 of the ECSS standard) has nine pins rather than the 10 pins of the 1355 connector, and the pins are interleaved for mechanical efficiency with the "D" shape. Unfortunately this results in imbalanced coupling between the pins. In particular, while pin 2 (Sin+) is well separated from Pin 4 (Sout-), pin 7 (Sin-) is as close to pin 8 (Sout+) as it is to its pair, pin 2, and so there is crosstalk between these pins. Near end crosstalk between output and input can be a significant problem and in SpaceWire's case, almost the entire contribution to near end crosstalk is in the connector rather than the cable. The imbalance that this crosstalk introduces also results in EMC emissions which, while normally acceptable for CE and FCC regulations, may be undesirable on a spacecraft that needs to receive weak RF signals.



SpaceWire users have recognized these issues. NASA Goddard Space Flight Center has commissioned an alternative connector [4] that is rather larger than the micro-D but which presents much less of an imbalance or discontinuity to the signals. 4Links have described mitigation techniques for the EMC emissions that can be implemented with low-cost components and with negligible additional mass [5].

2.2 CABLE SPECIFICATION

The IEEE 1355 standard specifies parameters for physical components such as cable and connector as normative, and includes informative appendices that give examples of how the specification might be met. So 1355 includes parameters for cable attenuation and crosstalk. The SpaceWire standard omits these important parameters, but includes manufacturing details of how the cable should be constructed. As a result it is not possible, by external examination and test against parameters given in the standard, to determine if a SpaceWire cable will be adequate for its purpose.

2.3 POWER DISTRIBUTION

Like USB, IEEE 1394, and Power over Ethernet, the IEEE 1355 Data Strobe connector included provision for carrying power down the signal cable, using the two pins on Row c of the 1355 connector. During SpaceWire standardization, this was discarded.

AFRL's PnPSat is perhaps unique in the space industry, in taking modularity concepts further than most others [6]. Part of this is to recognize that a satellite needs a data network, a power network, and a test network, and to integrate them into a single connector. They still use Micro-D, but with 25 pins rather than 9 pins.

3 PACKET LENGTH CONSTRAINTS

3.1 MAXIMUM PACKET LENGTH

The T9000 transputer, which was the original source of the technology that has evolved to SpaceWire, had a maximum Payload/Cargo of 32 Bytes. In the IEEE 1355 standard, this restriction was removed and SpaceWire has kept the lack of constraint on packet size.

For point-to-point connections without routing switches, long packets are not a problem. When long packets go through routing switches, they block all the links on their path from carrying other traffic. If the large packet is a low-priority file transfer, and the blocked packet is a high-priority alarm, then the alarm is blocked until the file transfer has completed.

Problems can also occur if packets traverse both slow links and fast links, because the packet duration is determined by the slowest link on the path. One solution to mixing slow and fast links is to place the packets in temporary store-and-forward buffers when there is a change of link speed. But the buffers can only cope with packets that will fit, which imposes the traditional Maximum Transfer Unit (MTU) on packet size.

SpaceWire is still greatly superior to bus or ring topologies and standards, even when these issues are taken into account, because there are normally multiple paths available in a SpaceWire network. And we definitely do not recommend a return to packets as short as 32 Bytes. But it may be that recommendations on packet size (and on the buffering inside routing switches) would prevent unexpectedly low performance resulting from mixed link speeds or large packets. Alternatively, pre-emption of long or slow packets by high-priority packets would retain the freedom while providing the critical performance when needed [7].

3.2 MINIMUM PACKET LENGTH

Both the IEEE 1355 standard and the SpaceWire standard define packets to be:
(DEST) (PAYLOAD) (End_Of_Packet)
although SpaceWire uses the word CARGO instead of PAYLOAD

IEEE 1355 then goes on to say that either DEST or PAYLOAD can be zero length. If both are zero length, then the packet is empty. An empty DEST could be used, for example, between two nodes not connected by a routing switch network; and empty PAYLOAD could be used, for example, as an acknowledgement (it was used this way on the T9000) or as an interrupt or watchdog signal.

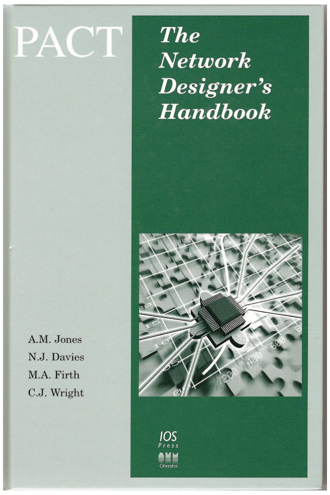
SpaceWire acknowledges that the DEST can be zero, but then goes on to require a minimum cargo of one data character.

In practice, as the SpaceWire standard notes, empty packets can occur as a result of fault conditions, and so they need to be handled. Unfortunately, products are on the market that discard empty packets without updating the flow-control credit, and so suffer from loss of flow-control credit after receiving a number of empty packets.

4 NETWORK AND RELIABILITY STUDIES

4.1 THE NETWORK DESIGNER'S HANDBOOK

Simulations performed on a wide variety of IEEE 1355 networks fed through to a book, 'The Network Designer's Handbook' [8], published in 1997. Most of the networks considered are arrays such as (hyper)cubes, toroids, and Clos networks. On the other hand, most of the SpaceWire networks that are being implemented are less structured than these so that the results may not be directly applicable. In spite of this, there is still much that can be gained from studying the results presented. A brief summary of the sort of information in the book is given in the authors' companion paper at this conference [9]. Those SpaceWire users who are doing their own simulations for architectural modelling may also find that the results inform their network architecture decisions.



PACT

The Network Designer's Handbook

A.M. Jones
N.J. Davies
M.A. Firth
C.J. Wright

IOS Press

4.2 CERN TEST-BED AND RELIABILITY TEST

Further work went into a test-bed for IEEE 1355, with 1024 nodes, at CERN [10]. This was used both to validate the simulation results and to determine reliability. The 1024-node network contained 1344 active Data-Strobe links, of which about a third used differential buffers and 2metre cables, with the others non-differential on printed circuit boards. The results gave a per-link bit error rate better than 9.6 x 10^{-18}.

5 EVOLUTIONS FROM IEEE 1355

5.1 ASYMMETRIC DATA RATE

Some years ago, the authors' company designed an evolution from IEEE 1355 for a consumer electronics application. The application had data flowing mostly in one direction and so had a real need for asymmetric data rates. Other requirements meant that the physical layer was completely different from both 1355 and SpaceWire, but the important 1355/SpaceWire protocols were retained.

Several potential users of SpaceWire have pointed out that their traffic is almost entirely in one direction, and that the harness mass of eight twisted pairs in the SpaceWire cable discourages them from using SpaceWire. One solution is a Simplex mode for SpaceWire, and there is indeed a paper on this topic later in this session [11]. Pure simplex is, however, likely to lose the benefits of flow-control and of being able to control the data stream from within the one network. Much better, we believe, would be a half-duplex implementation [12] of SpaceWire:

- that provides the required unidirectional bandwidth;
- that halves the cable mass;
- that retains the reverse channel for status and control;
- that still has a great deal of compatibility with the SpaceWire standard;
- and that builds on our experience of asymmetric data with 1355.

5.2 COPPER VERSION OF 1355 TS ENCODING FOR FIBRE

The TS Encoding of IEEE 1355, described briefly above, was intended in the 1355 standard to provide longer distance connection than the cabled Data-Strobe version, at similar data rates. A group of collaborators in the space industry realized, however, that the TS encoding, when carried on copper wire, reduced cable mass and power compared with the Data-Strobe version and gave a number of other advantages. We will leave further description to those who did the work (amongst the authors of [13]), but the result is an interface that is logically extremely close to SpaceWire and that is currently flying alongside 1355-Data-Strobe/SpaceWire on successful ESA missions.

6 CONCLUSIONS

While we appreciate that SpaceWire makes many improvements over IEEE 1355, we also recognize that potential users of SpaceWire are deterred by the absence of features that they need, and that some of these features were embodied in the 1355 standard but were deleted from SpaceWire. In a number of cases, including an electrically better connector, power distribution, and the use of the TS encoding, different parties in the space industry have overcome the issues themselves. We welcome their initiatives to improve on the ECSS standard.

There may be other aspects, such as consideration of packet lengths and network topologies — particularly building test-beds for such topologies — where work done ten or more years ago for 1355 will still be of great benefit to many users of SpaceWire.

Evolution of SpaceWire is ongoing, for example with SpaceFibre. Further evolution of SpaceWire such as pre-emption (below the link layer) or reduced harness mass (from a different physical layer), may also be appropriate. As long as it preserves the important layers of IEEE 1355/SpaceWire (the link, exchange, and packet layers), we believe that such evolution should be classed as belonging to an enlarged SpaceWire family, all of whose members share common fundamentals. This larger family could greatly increase the usefulness and hence the penetration and success of SpaceWire within the space industry — and beyond.

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