SpaceWire and IEEE 1355 Revisited

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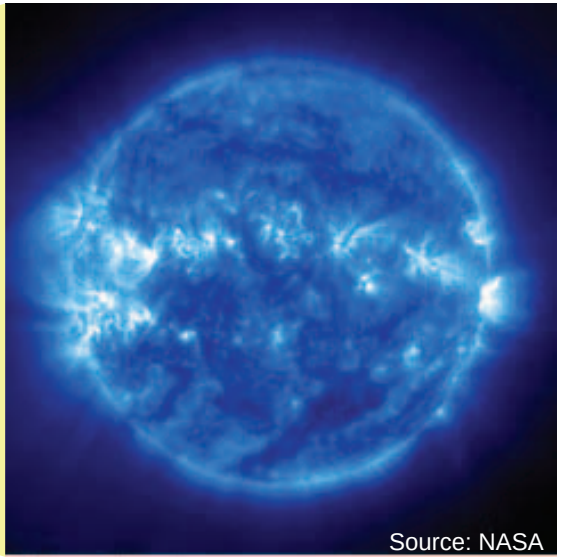
Transputer Links to SpaceWire

- SpaceWire is derived from IEEE 1355
- IEEE 1335 is derived from an improved version of the Transputer Links

Transputers and their Links are flying on many missions

- At least 12 Surrey Satellite missions
- Cluster
- Cryosat
- SOHO
- South African missions
- … we keep hearing of more



- People still excited by the wonder of using Transputers

IEEE 1355 multiple PHYs

The IEEE 1355 standard has multiple versions of three separate signal encodings:

DS Data-Strobe as SpaceWire, but defined for both
- single-ended TTL and
- Differential

TS Three of Six encoding, intended for longer distance than DS, usually over low-cost optical fibre

HS High-Speed encoding (HS) for Gbit/s
- Copper (demonstrated, including routing switches)
- Optical fibre

IEEE 1355 to Space

Of these IEEE 1355 encodings:

DS Several missions are flying with 1355
1355 has become SpaceWire

TS Is flying on at least one spacecraft,
in a low-power copper implementation

HS SpaceFibre has the same goals

The packet structure is identical between these three versions of 1355, and the only change for SpaceWire is Exceptional End of Packet becomes Error End of Packet

IEEE 1355 to SpaceWire

SpaceWire makes several improvements on IEEE 1355

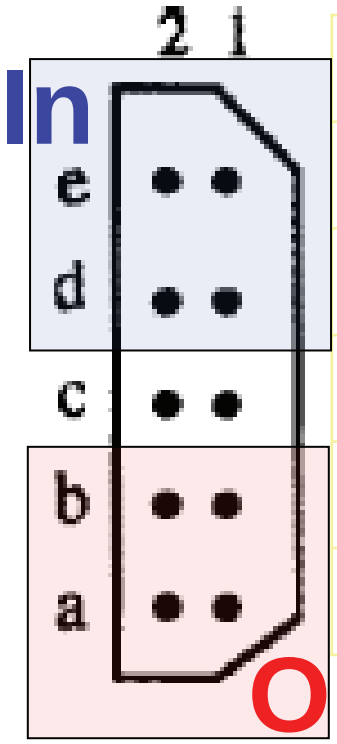
- Initialization state machine
- Time Codes
- Network Layer

But SpaceWire also omits aspects of 1355

- Users are finding some of these are necessary
- And often developing them themselves

We suggest welcoming these improvements and redefining SpaceWire as a family of standards

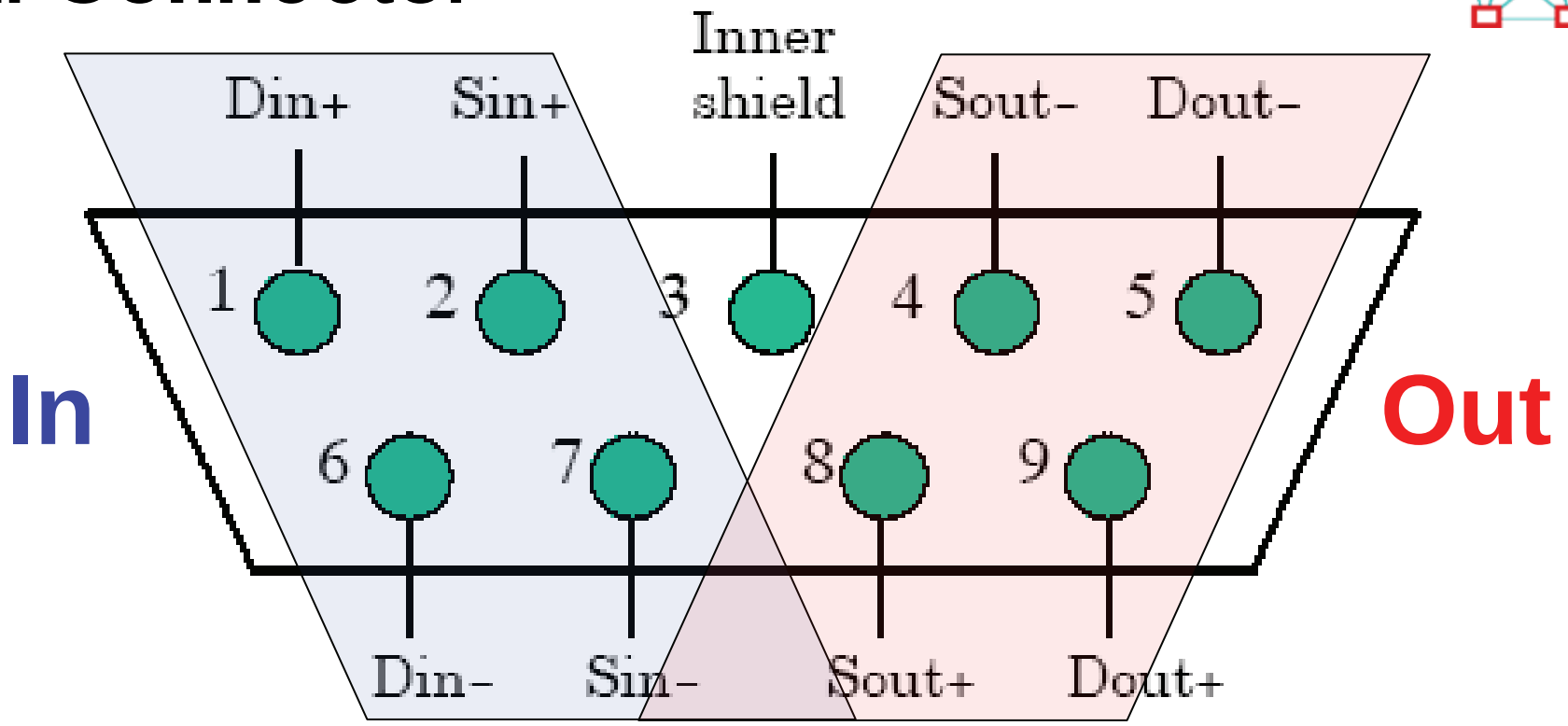
1355 PHY cf SpaceWire: 1: Connector



	2	1
e	D In plus	D In minus
d	S In plus	S In minus
c	NC or power return	NC or optional power
b	S Out minus	S Out plus
a	D Out minus	D Out plus

- The two directions are well separated by the c row of pins, so well balanced, low crosstalk
- The cable can optionally carry power

1355 PHY cf SpaceWire: 1: Connector



- The two directions are NOT well separated
- Pin 7, Sin-, is adjacent to Pin 8, Sout+
- Causes crosstalk, imbalance, and RF emissions

1355 PHY cf SpaceWire: 1: Connector

- For the James Webb Space Telescope (JWST), NASA Goddard needed a long cable run through bulkheads
- So commissioned a multi-twinax connector
  - Much larger than Micro-D
  - Electrically very much better also

Hear more tomorrow

1355 PHY cf SpaceWire: 2: Power distribution

1355, like USB, FireWire and PoE optionally carried power on the signal cable

- Rather crude: diode and fuse protected 5V

SpaceWire chose to omit power distribution

AFRL, for PnPSat, use SpaceWire for modularity

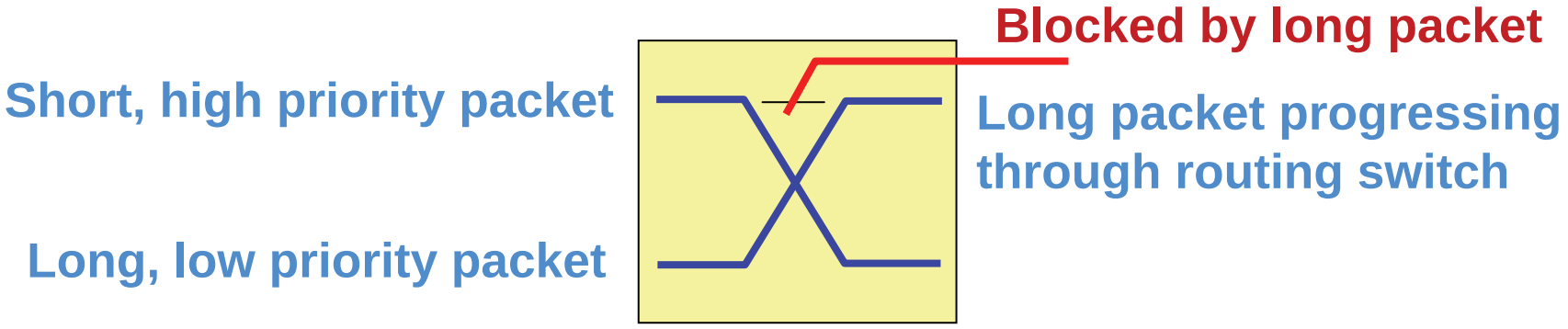
- Realise that modular infrastructure needs three networks:
  - Power
  - Signal
  - Test So integrate all three in a single connector

1355 PHY cf SpaceWire: 3: Cable Specification

- 1355 specifies cable parameters such as
  - Attenuation
  - Crosstalk
  - and describes in an appendix how the cable might be constructed
- SpaceWire does not specify attenuation or crosstalk
  - and it describes as normative how the cable must be constructed
  - It provides no parameters against which a cable can be tested

Packet length constraints 1: Segmenting packets

- The T9000 Transputer had a small packet size with (unlimited length) messages of multiple packets
- SpaceWire removed low-level segmentation
- But long packets can block:



- Segmenting packets could alleviate such blocking
- Pre-emption could also provide guaranteed real-time response

Packet length constraints 2: Zero-length packets

1355 allowed:

- **Zero or more Bytes of Destination/Header**
- **Zero or more Bytes of Payload/Cargo**
  - **Useful for interrupt/watchdog on point-to-point link**
  - **Useful for Ack on routed link**

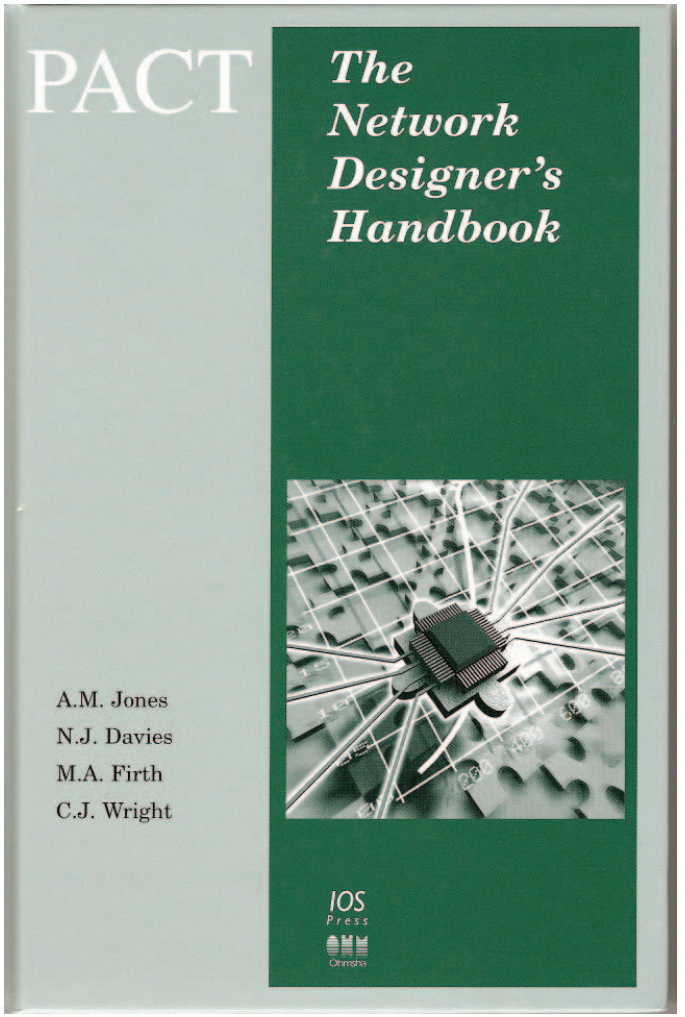
SpaceWire removed option of zero-length Cargo/Payload

- **SpaceWire designers knew they should not be sent**
- **But in fault conditions, zero length packets can be received**
- **Products exist that lose flow-control credit when they receive zero-length packets**

Simulation and testing of IEEE 1355

4Links®

- The Network Designer's Handbook
  - Based on Opnet simulations of many networks
- Backed up by CERN who built and performance tested a network with 1024 nodes
- The CERN network was also used for reliability testing, achieved BER better than 9.6×10^{-18}
- This work is still available to benefit the SpaceWire community



Evolutions from IEEE 1355
1: Asymmetric Data Rate

Some years ago a consumer electronics application needed

- The simplicity and functionality of IEEE 1355
- A completely different physical layer (PHY) from 1355
- Data flowing mostly in one direction

We delivered a PHY that could be used half-duplex yet retained all the benefits of 1355/SpaceWire protocols

Much SpaceWire traffic is mostly unidirectional

- Simplex halves cable mass but loses the return channel
- Half-duplex halves the cable mass, while retaining the reverse channel, flow control, and SpaceWire protocols

Evolutions from IEEE 1355 2: 1355 TS: 3 of 6 encoding

The 1355 TS version used a 3 of 6 code

- Six-bit symbols, with three bits zero three bits one
- Alphabet of 20 symbols, 16 for data, four for control
- 16 data symbols encode four data bits
- Two data symbols per Byte

Extremely simple to code and decode

DC-balanced over every symbol

Low-power Copper PHY implemented

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and flying on Rosetta

Conclusions 1

- IEEE 1355 was not a failure, it was just 10 years ahead of its time, and SpaceWire users can still benefit from it
- The space industry has benefitted greatly from its bold moves into Transputers and then into 1355/SpaceWire
- SpaceWire makes several improvements on 1355
- But potential users of SpaceWire are deterred by the absence of features, some of which were in 1355

- The important common quality of both 1355 and SpaceWire is in the link layer and the simple packet structure — these must be retained

Conclusions 2

- **Evolution of PHYs, such as 1355-TS, SpaceFibre, the JWST connector, the PnPSat power distribution and half-duplex are inevitable: they should be welcomed**
- **Further evolution below the link layer, such as pre-emption, will overcome system issues that are inhibiting SpaceWire's penetration, even in space**

- **These should be seen as a larger family of SpaceWire standards, all of which preserve the important link and packet layers of 1355/SpaceWire**
- **This larger family will increase usage of SpaceWire, to the benefit of this community and of the world at large**