Half-Duplex SpaceWire

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SpaceWire – brief overview

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A point-to-point link technology

- *Supporting multiply-connected, redundant, fault-tolerant networks*

Packet based

Low latency

- *Wormhole routing*

Flow controlled

- *Minimises buffer requirements whilst avoiding data loss*

Low-level error detection and recovery

- *Includes a per-token parity check*
- *Constantly monitors for inactivity (850ns timeout)*
- *Automatic link re-start*

Wide range of speeds

- <2Mb/s to *>200Mb/s over 20m, full-duplex*

Full-duplex operation

Each end of a link sends tokens to the other end of the link

- *Data, control (end-of-packet, flow control), time*
- *If nothing else, NULL*

Continuous activity

- *lack of activity signals error*

Data	Data	Data	FCT	FCT	NULL	NULL	NULL	Data	Data

NULL	NULL	NULL	FCT	NULL	Data	Data	Data	Data

Equal bandwidth in each direction

Application (mis-)match

Some applications are symmetric

- *Data stores*
- *Router-to-router connections (sometimes)*

Some applications are asymmetric

- *Sources of data*
  - *sensors*
- *Sinks of data*
  - *actuator*
  - *data-downlink*

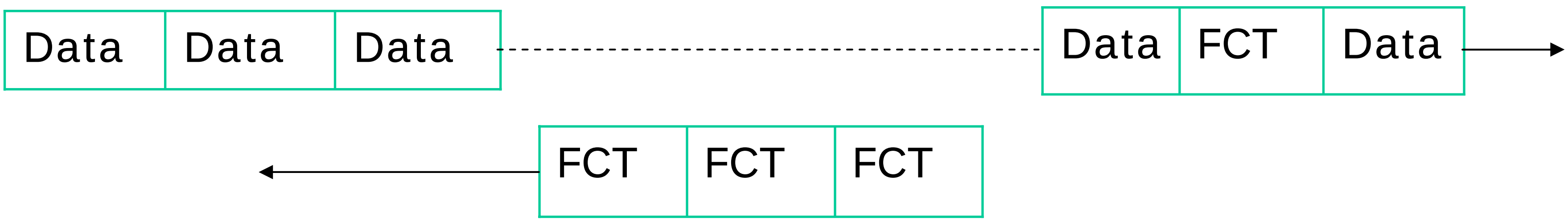
(Why not) Simplex operation

Simplex operation provides a unidirectional data flow

- *Open loop*
  - *No error detection by the data source*
  - *Data source cannot receive re-try requests*
  - *No mechanism for configuration / control of a source*
  - *There is no flow control mechanism to prevent data loss through buffer overflow*

Half-duplex operation

Each end of a link takes it in turns to send data and control



Wires can be re-used

- *We require half the number of wires*
- *Mass may be more than halved*

Operation need not be symmetric but can dynamically adjust to the required asymmetry

The reverse flow is still available for configuration, control, etc.

Half-duplex operation (2)

We need to add a mechanism to swap transmission from end to end – a turnaround

A good time to do this is when the transmitting end can send no more useful (data or control) tokens

- *i.e. when it would send one or more NULL tokens*

Use a single NULL token to change ends

- *Transmitting end sends one NULL token and switches to receive*
- *Receiving end gets a NULL token and starts transmitting*
- *(With care we can control the line during the turnaround period and don't need to resynchronise the receiver)*

Cable requirements and mass

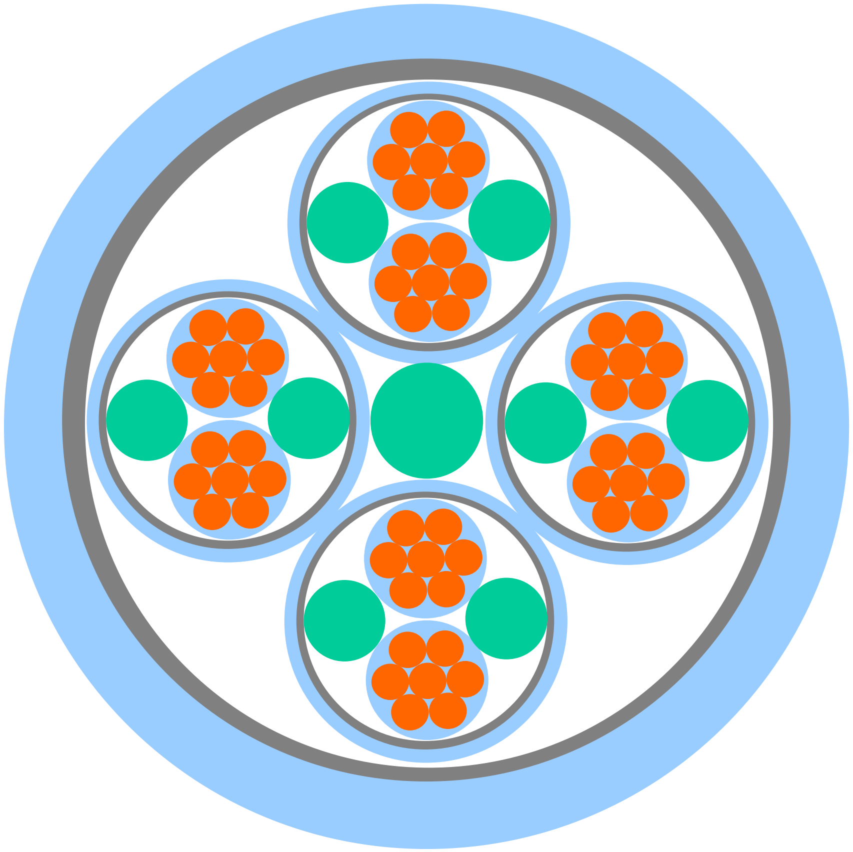
Full-duplex SpaceWire requires 2 (D and S) differential pairs in each direction – with the transmitter and receiver active at the same time.

It is necessary to ensure that the transmitted signals are not received by the local receiver – we must control Near-End Cross-Talk (NEXT).

Therefore, SpaceWire cables are specified with each differential pair individually shielded and the set of 4 pairs within an overall shield.

The result is a cable with a mass of 80g/m.

SpaceWire Cable



Conductor size:
28awg (7*36awg)

Full-duplex: 80g/m

Cable requirements and mass

Half-duplex SpaceWire requires 2 (D and S) differential pairs in total.

The transmitter and receiver are not active at the same time and NEXT is not an issue.

A much simpler cable can be used.

A suitable cable, with the same conductor size as specified for SpaceWire, has a mass of 26g/m.

SpaceWire Cables

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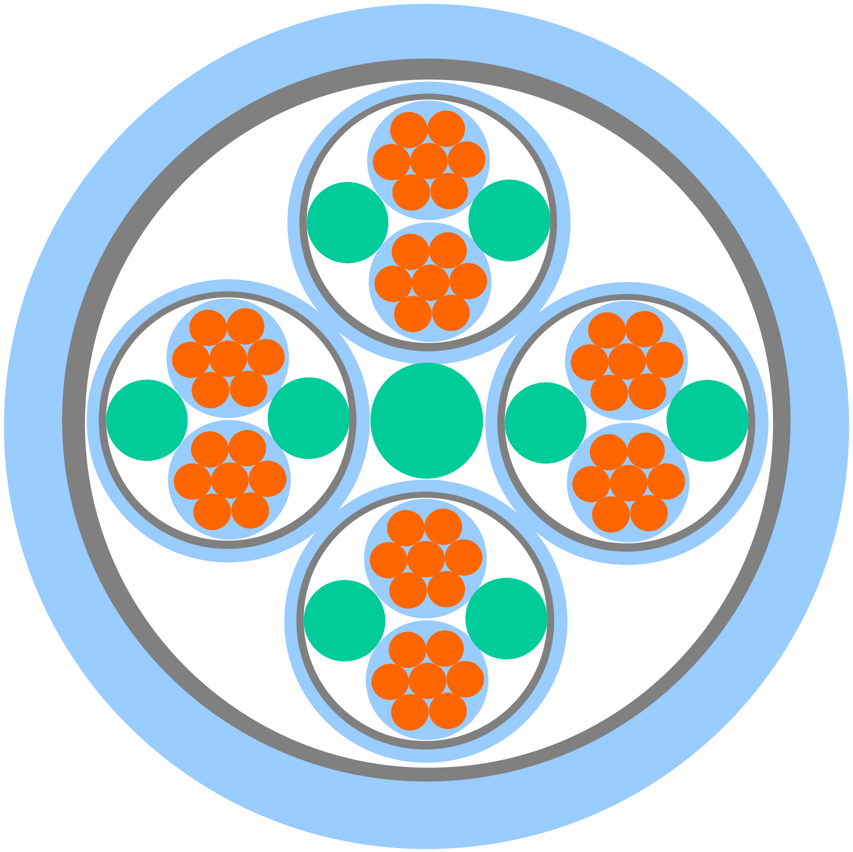

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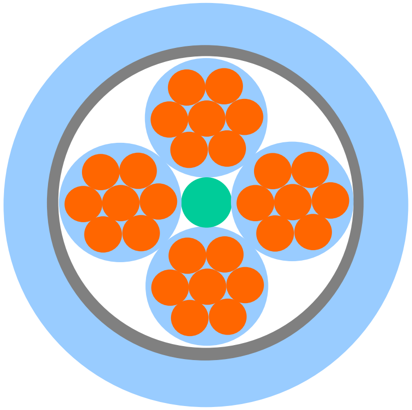

Full-duplex: 80g/m

Half-duplex: 26g/m

Cable capacities

Gore™ already produce a range of aerospace cables configured as shown and intended for Data-Strobe encoding (for IEEE-1394 applications).

These offer a range of capacities, for a range of masses:

Wire gauge (awg)	Mass (g/m)	Max length @100Mb/s (m)	Max length @500Mb/s (m)
30	22	21	9
28	26	27	12
26	35	33	18
24	50	45	22
22	63	53	30

Performance

Half-duplex has, at most, half the total performance of full-duplex – but we would expect uni-directional traffic rates to be comparable in both cases.

Half-duplex also has the overhead of turnaround time which will reduce its performance.

Allowing 500ns for each turnaround we can calculate the expected data rates. A fixed turnaround period will have more impact at higher data rates (it represents more bit periods) – hence we show figures for a range of raw bit rates.

Performance

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All figures: Mb/s

Raw bit rate	10	20	50	100	200
Full-duplex Bidirectional	**15.2**	**30.4**	**76.0**	**152.0**	**304.0**
Half-duplex Bidirectional					

Performance

All figures: Mb/s

Raw bit rate	10	20	50	100	200
Full-duplex Bidirectional	**15.2**	**30.4**	**76.0**	**152.0**	**304.0**
Half-duplex Bidirectional	***7.5***	***14.8***	***36.1***	***69.3***	***128.7***

Performance

All figures: Mb/s

Raw bit rate	10	20	50	100	200
Full-duplex Bidirectional	15.2	30.4	76.0	152.0	304.0
Half-duplex Bidirectional	*7.5*	*14.8*	*36.1*	*69.3*	*128.7*
Full-duplex Unidirectional	**8.0**	**16.0**	**40.0**	**80.0**	**160.0**
Half-duplex Unidirectional					

Performance

All figures: Mb/s

Raw bit rate	10	20	50	100	200
Full-duplex Bidirectional	15.2	30.4	76.0	152.0	304.0
Half-duplex Bidirectional	*7.5*	*14.8*	*36.1*	*69.3*	*128.7*
Full-duplex Unidirectional	**8.0**	**16.0**	**40.0**	**80.0**	**160.0**
Half-duplex Unidirectional	***7.3***	***14.4***	***34.3***	***63.6***	***111.4***

Performance

All figures: Mb/s

Raw bit rate	10	20	50	100	200
Full-duplex Bidirectional	**15.2**	**30.4**	**76.0**	**152.0**	**304.0**
Half-duplex Bidirectional	*7.5*	*14.8*	*36.1*	*69.3*	*128.7*
Half-duplex Bidirectional (mass adjusted)	***22.5***	***44.4***	***108.3***	***207.9***	***386.1***
Full-duplex Unidirectional					
Half-duplex Unidirectional					

Performance

All figures: Mb/s

Raw bit rate	10	20	50	100	200
Full-duplex Bidirectional	15.2	30.4	76.0	152.0	304.0
Half-duplex Bidirectional	*7.5*	*14.8*	*36.1*	*69.3*	*128.7*
Half-duplex Bidirectional (mass adjusted)	*22.5*	*44.4*	*108.3*	*207.9*	*386.1*
Full-duplex Unidirectional	**8.0**	**16.0**	**40.0**	**80.0**	**160.0**
Half-duplex Unidirectional	*7.3*	*14.4*	*34.3*	*63.6*	*111.4*
Half-duplex Unidirectional (mass adjusted)	***21.9***	***43.2***	***102.9***	***190.8***	***334.2***

Performance

Half-duplex bandwidth is allocated automatically and may be fully utilised in one direction, the other direction or shared between directions, as the need arises.

Time codes

Are used to broadcast time ‘ticks’ around a network.

Time codes are inserted as soon as possible into a transmit token stream.

In half-duplex operation, that might have to wait until the link end wishing to send the time code is able to transmit.

This potential delay is longer at lower raw bit rates.

- *62μs at 10Mb/s but only 4μs at 200Mb/s.*

Half-duplex operation significantly increases the uncertainty (jitter) of time code delivery times.

Implementation

There is no fundamental change to the principles of SpaceWire, nor is there any change to the user interface.

Only a small change to existing Codec designs is needed to control transmit / receive – after sending / receiving a NULL token.

A Codec able to switch between Normal (full-duplex) and Half-duplex operation appears to be straightforward.

Conclusions

Whilst retaining all the features and benefits offered by SpaceWire – with no change to the user-level functionality or interface ...

Half-duplex SpaceWire offers a unidirectional data rate similar to full-duplex SpaceWire and reduces cable mass by 66%.

Replacing one full-duplex link with two half-duplex links provides a similar bidirectional data-rate, a considerably higher unidirectional data rate, adds redundancy AND reduces cable mass by 37%.