Scalable SpaceWire Backplane System based on uTCA

Takayuki Yuasa - JAXA/ISAS

Co-authors:
Tadayuki Takahashi (Japan Aerospace Exploration Agency - JAXA)
Masaharu Nomachi (Osaka University, Japan)
Makoto Ioki (Japan Space Systems, Japan)
- Many subsystems; attitude, power, communication, and mission instruments.
- Necessity of common well-defined data transfer interface between subsystems.
- Several interfaces have been widely used:
  - MIL-STD-1553B, CAN bus, RS422 ...

- All above provide maximum data transfer rate no more than ~10Mbps.
- Improvements in mission instruments, such as high resolution camera, high data rate detector, and high performance processor, pushed standardization of faster common data transfer interface.
- SpaceWire is a new standard.
- Spacecraft-oriented data transfer interface by European Space Agency (ESA) and European Consultation of Space Standard (ECSS).
- Peer-to-peer, bidirectional link over 4 LVDS pairs.
- Provides 2-200Mbps and network with routers/switches.
- PLL is not necessary (i.e. suit for space-qualified FPGAs).
- Small logic footprint (~10k gates).
- Already used in many spacecraft missions.

Layers

- Physical level: LVDS and Data-Strobe encoding.
- Character: 8-bit Data/Control characters.
- Packet:
  <Routing Address>
  <Protocol ID>
  <Cargo>
  <EOP>
- Network:
  - Path addressing
  - Logical addressing

See also http://spacewire.esa.int/
- Higher speed, redundancy, and modularity compared to shared bus type systems.
- Can work with mission-specific dedicated signals.
- Space-qualified SpaceWire interface chips and routers have been developed and used in orbit.

![Spacecraft onboard network with SpaceWire diagram](image)
The ASTRO-H Space X-ray Observatory

- JAXA-NASA-ESA collaboration.
- Scheduled to be launched in 2014.
- 14 m (length), 2.7 ton.
- 4 X-ray telescopes observe the high energy universe.
Real network diagram incl. redundant system.

~110 physical connections, 10 external routers, and >40 internal routers

50 Mbps in the Bus
10-25 Mbps in the Mission
Why SpaceWire Backplane?

**Simplification of development and ground test**

- Many tests and debugs...
- Test of onboard SpaceWire network can involve more than 20-30 subsystems (interconnected with SpaceWire). Cabling can be a big problem.
- Test bed that allows rapid integration can reduce man-hour needed for tests.

**Requirements**

- Crate (or subrack) that collects multiple SpaceWire modules, i.e. processor and FPGA boards.
- Rugged mechanical support.
- Good power supply and grounding.
- Good cooling.
- Commercial availability (reduced test cost).
- 100 Ω transmission line for SpaceWire.

We selected \(\mu\text{TCA}^{\text{TM}} + \text{AdvancedMC}^{\text{TM}}\).
AMC = Advanced Mezzanine Card

- Mezzanine for Advanced TCA board.
- Any protocol with LVDS can be used for backplane connection.
  => SpaceWire (4 LVDS pairs)
- Form factor ~ 180mm x 74mm comparable with 3U Euro Card.
### AMC Signal Allocation

#### Port = Tx + Rx = 2 LVDS pairs

<table>
<thead>
<tr>
<th>Connector Region</th>
<th>AMC Port #</th>
<th>Signal Conventions</th>
<th>Non-redundant MCH Fab #</th>
<th>Redundant MCH Fab #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Side</td>
<td>1</td>
<td>AMC2 1000BASE-BX</td>
<td>A</td>
<td>1/A</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>AMC2 1000BASE-BX</td>
<td>2/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>AMC3 SATA/SAS</td>
<td>B</td>
<td>1/B</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td>C</td>
<td>2/B</td>
</tr>
<tr>
<td>Fat Pipe</td>
<td>5</td>
<td>AMC1x4 PCI Express</td>
<td>D</td>
<td>1/D</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>AMC4x4 SRIO</td>
<td>E</td>
<td>1/E</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>AMC2 10GBase-BX4</td>
<td>F</td>
<td>1/F</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>G</td>
<td>1/G</td>
</tr>
<tr>
<td>Extended Fat Pipe</td>
<td>9</td>
<td>AMC4x4 SRIO</td>
<td></td>
<td>2/D</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td>2/E</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>AMC2 10GBase-BX4</td>
<td></td>
<td>2/F</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td></td>
<td>2/G</td>
</tr>
<tr>
<td>Extended Side</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extended Options</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### AMC Signal Allocation

#### 4 SpaceWire links using Fat Pipes (basic/extended).

<table>
<thead>
<tr>
<th>Connector Region</th>
<th>AMC Port #</th>
<th>Signal Conventions</th>
<th>Non-redundant MCH Fab #</th>
<th>Redundant MCH Fab #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Side</td>
<td>1</td>
<td>AMC2 1000BASE-BX</td>
<td>A</td>
<td>1/A</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>AMC2 1000BASE-BX</td>
<td>B</td>
<td>2/A</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>AMC3 SATA/SAS</td>
<td>C</td>
<td>2/B</td>
</tr>
<tr>
<td>Fat Pipe</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td><strong>SpaceWire 1</strong></td>
<td>D</td>
<td>1/D</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td><strong>SpaceWire 2</strong></td>
<td>E</td>
<td>1/E</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td></td>
<td>F</td>
<td>1/F</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td></td>
<td>G</td>
<td>1/G</td>
</tr>
<tr>
<td>Extended Fat Pipe</td>
<td>9</td>
<td><strong>SpaceWire 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td><strong>SpaceWire 4</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extended Side</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Options: Basic, Fat Pipe, Extended*
uTCA backplane - 12 AMC slots version

- Collects AMC modules in a normal uTCA crate (or subrack).
- Crate-controller modules (MCH) interconnect links from individual AMC modules.
- Below is the default backplane topology for SpaceWire connections.

![SpaceWire link (4 per AMC)]
Example of commercial backplane product

Double-height 12-AMC-slot uTCA Backplane from Schroff
- Used for the ASTRO-H SpaceWire network integration test in 2011.

<table>
<thead>
<tr>
<th>Front slots</th>
<th>Rear slots</th>
</tr>
</thead>
<tbody>
<tr>
<td>MicroTCA specification PICMG MicroTCA.0 R1.0</td>
<td>PICMG Physics WG1 (MTCA.4)</td>
</tr>
<tr>
<td>2 x MCH slots Single/Double Full-size</td>
<td>12 x RTM slots Double Mid-size</td>
</tr>
<tr>
<td>12 x AMC slots Single/Double Mid-size</td>
<td>4 x PM slots Single/Double Full-size</td>
</tr>
</tbody>
</table>

- Two redundant hot-swap fan trays with EMMC for AMC and uRTM cooling in push-pull configuration.
- Air Flow: bottom front air intake, top rear air exhaust

Chassis dimensions:
- Width: 19” Rack mount
- Height: 9U
- Depth: 373.30 mm

![12 AMC Slots]

MCH+Router

MCH+Router
We have developed a modified uTCA-like backplane for smaller systems. SpaceWire links to redundant-MCH are flipped to non-redundant-MCH. i.e. 1 MCH+Router handles at most 24 SpaceWire links from 6 AMC modules. Affordable for small experiments, university groups.

Product from UBER Corp., Japan. (with Osaka U. and JAXA)

Compact and cheaper.
Available SpaceWire AMC modules

- For SpaceWire network integration test of JAXA’s ASTRO-H satellite, Mitsubishi Heavy Industry, Japan, developed CPU board and General-purpose FPGA board based on the SpaceWire AMC concept.

AMC SpaceWire CPU Board  AMC SpaceWire FPGA Board

- Generic SpaceWire I/F Board, SpaceWire-to-GigabitEther, and MCH+Router modules are available from Shimafuji Electric, Japan (support from Japan Space Systems/MEXT).

MCH+ SpaceWire Router  SpaceWire-to-GigabitEther
Deployment

- We have used SpaceWire uTCA Backplane in the ASTRO-H SpaceWire network system test in 2011. (ASTRO-H = space X-ray observatory)
- Mission instrument electronics were simulated using AMC modules enclosed in a crate/subrack.
- SpaceWire links between FPGA and CPU boards are interconnected via the backplane.
- The backplane system greatly simplified cabling and test configuration.
Deployment

- We have used SpaceWire uTCA Backplane in the ASTRO-H SpaceWire network system test in 2011. (ASTRO-H = space X-ray observatory)
- Mission instrument electronics were simulated using AMC modules enclosed in a crate/subrack.
- SpaceWire links between FPGA and CPU boards are interconnected via the backplane.
- The backplane system greatly simplified cabling and test configuration.
Deployment

- We have used SpaceWire uTCA Backplane in the ASTRO-H SpaceWire network system test in 2011. (ASTRO-H = space X-ray observatory)
- Mission instrument electronics were simulated using AMC modules enclosed in a crate/subrack.
- SpaceWire links between FPGA and CPU boards are interconnected via the backplane.
- The backplane system greatly simplified cabling and test configuration.
Deployment

- We have used SpaceWire uTCA Backplane in the ASTRO-H SpaceWire network system test in 2011. (ASTRO-H = space X-ray observatory)
- Mission instrument electronics were simulated using AMC modules enclosed in a crate/subrack.
- SpaceWire links between FPGA and CPU boards are interconnected via the backplane.
- The backplane system greatly simplified cabling and test configuration.
Future prospects: Space-qualified SpaceWire Backplane

- The present uTCA-based SpaceWire Backplane is aimed for ground tests.
- Space-qualified SpaceWire Backplane has been actively discussed in the SpaceWire Working Group led by ESA/ESTEC.
- Looking for a space-qualified, high-density, high-speed connector. Comments are welcome!

- Seamless transition from ground prototyping to real space components.
- Lower development cost, more frequent chance to launch.
- Paradigm may shift: Piggy-bag satellite => Piggy-bag SpaceWire Backplane module!
Summary

- For simplifying development/test of spacecraft onboard network, SpaceWire Backplane system was developed based on uTCA and AMC.

- Default and modified backplane topologies are commercially available for 12 and 6 AMC-slot crate, respectively.

- Several kinds of SpaceWire AMC modules are also available.

- Space-qualified SpaceWire Backplane is planned for standardization, aiming at easier spacecraft integration and space experiments.
Backup slides
SpaceWire AMC Modules from Shimafuji Electric

- Generic SpaceWire FPGA Board
- SpaceWire-to-GigabitEther
- SpaceWire Traffic Generator
- MCH+SpaceWire Router (28port)
Example system