A Plug-and-play Approach Based on the I²C Standard

SPA on a Shoe-string

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Outline

• A space-plug-and-play architecture (SPA)
• International collaboration
• Why SPA-1?
• The mini-PnP/SPA-1 protocol
• Using mini-PnP/SPA-1
• State of mini-PnP/SPA-1 development
• Mission concepts
• Conclusions
A space-plug-and-play architecture (SPA)

- USB interface chip
- plug-and-play component
- driver
- “platform”

- appliqué sensor interface module (ASIM)
- electronic datasheet
SPA as a *brand* of PnP

- Every component is a “black box”
  - Self-describing (using electronic data sheets)
  - Single-point interfaces (power, data, sync)
- Connect them to form a network
- They communicate with messages
- The network understands components and how to put them together automatically (self-organizing)
Benefits of SPA

• Dramatic reduction in system development timeline
  – Simplification of Effort in integration and test
  – Promotion of component and software re-use
• Increase openness and ease of software development (all spacecraft data exposed) – “satellite as a desktop”
• Increased industry competition for components through open intelligent interfaces
• Additional robustness / resilience (a la carte redundancy)
• Late-point additions / graceful accommodation of requirement changes
• Future-proofing: Focus on invention and creation of missions, not the “tyranny of interface”

Learn more about SPA tonight at the Space Dynamics Laboratory!
Where is SPA?

- Interfaces
- Tools
- Components
- Satellites
  - Sounding rocket
  - Orbiting on TacSat 3
International collaboration
Nanosatellite And Pnp Architecture (NAPA)

• USAF and FMV signed program agreement* August 2009

• Primary objectives
  – Harmonize plug-and-play approaches of the two nations
  – Establish joint testbeds for exchange of PnP components
  – Demonstrate interchangeability between testbeds

• Early findings
  – SPA architecture represented common approach
  – Concluded that a “minimalistic” version was needed
  – Led to pursuit of “mini-PnP” technology as joint effort
    • Mini-PnP is a generic plug-and-play technology (similar to USB)
    • SPA-1 is a form of mini-PnP suitable for space

Why SPA-1?

• Nanosatellites are least able to tolerate overhead in interface components
• One size does not fit all...

TARGET FOR SPA-1

SPA-S
75 mm body size
< 1500 mW
< 300,000 kbps

SPA-U (-S option)
50 mm body size
< 1000 mW
< 1000 kbps

size of cubesat face
The mini-PnP (MP)/SPA-1 protocol

• We sought the simplest possible electrical interface – chose I²C (few wires, multidrop, simple state machines, ubiquitous)
• The choice left us “only” to decide what to do above the physical layer
• Many protocols for I2C have been developed (SMbus, ACPI), none “plug-and-play”
• Team jointly created generic (non-space-specific) protocol for I²C (“mini-PnP”) as open source (non-ITAR) protocol (space-qualified version – SPA-1 – created in US would be subject to ITAR)
## MP/SPA-1 Message Format

<table>
<thead>
<tr>
<th>Commands (opcode)</th>
<th>Responses (opcode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self test</td>
<td>Status</td>
</tr>
<tr>
<td>Reset</td>
<td>Data</td>
</tr>
<tr>
<td>Initialize</td>
<td>xTEDS</td>
</tr>
<tr>
<td>Request version</td>
<td>xTEDS &amp; PID</td>
</tr>
<tr>
<td>Request xTEDS</td>
<td>Version</td>
</tr>
<tr>
<td>Request data subscription</td>
<td>Hello</td>
</tr>
<tr>
<td>Cancel data subscription</td>
<td></td>
</tr>
<tr>
<td>Power on</td>
<td></td>
</tr>
<tr>
<td>Power off</td>
<td></td>
</tr>
<tr>
<td>Command</td>
<td></td>
</tr>
<tr>
<td>Time at tone (SCET)</td>
<td></td>
</tr>
<tr>
<td>General call for registration</td>
<td></td>
</tr>
<tr>
<td>Update address</td>
<td></td>
</tr>
<tr>
<td>Ack</td>
<td></td>
</tr>
<tr>
<td>Not Ack</td>
<td></td>
</tr>
</tbody>
</table>
Mini-PnP/SPA-1 Address resolution

- All mini PnP devices have unique global identification (guid)
- Implement address resolution by performing a "general call"
- All devices use 0x11 as an initial address
- Devices become multi-master and "walk up" address space until they find an open spot and claim it
Mini-PnP/SPA-1 Electronic Data Sheet

(xTEDS*) registration

- Mechanism defined to permit the extraction of electronic datasheets from mini-PnP device
- Host parses xTEDS* and registers device services for use by other devices and applications

*xTEDS = eXtensible Transducer Electronic Datasheet*
Mini-PnP/SPA-1 Round Robin communication

- Mini-PnP Implements a Command ("write"), Response ("read"), and General Call as a continuous cycle using a non-weighted round-robin, visiting all known devices and looking for new ones.
Using mini-PnP/SPA-1
Building spacecraft with SPA: you’ll need
components...

..at least one computer...

... and routers / hubs / switches (possibly)
Connect together to form a spacecraft...
State of mini-PnP/SPA-1 development

- ASIMs (US) / RTUs (Sweden) in development
  1. Low cost (~ 30$US) prototype / experimentation modules (mini-PnP)
  2. Pre-flight units (~100$US) cofired ceramic / QFN modules (10mm x 10mm) (quasi – SPA-1)
  3. Flight units (~??US) cofired ceramic / rad-hard / QFN modules (10mm x 10mm ) (SPA-1)

- Other flight units / evaluation units with enhanced features available from AAC Microtec
Radiation Tolerant nano-RTU

- FPGA based
  - 20 kRAD SEU/SEE free using TMR, EDAC, parity and CRC
  - Fully pipelined PIC16 soft core (16F84) with 1 MIPS/MHz
  - In circuit/system programmable
  - Power consumption ~ 20-150 mW
  - PCB version (34 x 34 mm²)
- Interface to low speed devices ~ 100 kbit/s (SPA-1)

**SPA-1 RTU block diagram**
**SPA-1 RTU (MCM)**
**SPA-1 RTU (board version)**
Upcoming Work

• Continued development on mini-PnP and SPA modules and evaluation kits

• Flight project developments
  – RAMPART – mixed network of ASIM/RTU modules to study radiation effects
  – Trailblazer 1.5 – “simple-as-possible” exploratory cubesat (completely SPA-1 based)
  – QuadSat/PnP
System design example (QuadSat-PnP)
Conclusions

• The SPA Plug-and-play architecture offers a new model for rapidly and flexibly building spacecraft through intelligent modularity.

• A joint US/Sweden program ("NAPA") has developed improvements to SPA to allow simple spacecraft components to support plug-and-play.

• The development of the generic minimalist protocol has been described.

• The mini-PnP protocol will be open source / ITAR free, but space adaptation of mini-PnP (referred to as "SPA-1") results in ITAR restrictions (when performed in the US).

• AAC Microtec (Sweden) has created interface modules that implement mini-PnP in rad-tolerant form.

• System design example has been described.