

Guide

Space Plug-and-Play Architecture Standards Development Guidebook

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Space Plug-and-Play Architecture Standards Development Guidebook

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Abstract

This document provides a guideline for spacecraft platform, subsystem, and component (including payload) developers for integrating plug-and-play characteristics into spacecraft structures, avionics, and hardware and software components to promote their rapid integration. This guideline will be used as the foundation for Space Plug-and-play Architecture (SPA) standards. The SPA community anticipates adding protocols (e.g., Ethernet as SPA-E) as the PnP capabilities are normalized.

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Foreword

The desire to quickly and reliably assemble spacecraft has been a challenge since the 1960s. In the 1990s the international computer market noted a similar need to quickly and reliably assemble computers and computer accessories. The invention of Plug-and-Play (PnP) capabilities is now assumed for any modern terrestrial computer system. PnP capability is defined in various publicly available technical standards.

It is the purpose of the AIAA to capture, in this Space Plug-and-Play Architecture (SPA) Guidebook and associated technical standards, technical approaches to adapt the various computer PnP capabilities to small spacecraft and the space environment.

This Guidebook provides a general description of a data centric spacecraft model used to form the on-board PnP network. Various views are used to clearly indicate how this works. A common ontology is described to allow for a profile specific Common Data Dictionary (CDD) so that a stable set of terms may exist. Interfaces between devices are described to simplify the implementation of PnP at the device level. Finally, those PnP protocols identified to date are generally described, as are the adaptations needed for space application.

The detailed requirements for each of these topics are listed in the respective AIAA SPA standards listed below.

- SPA Networking Standard
- SPA Logical Interface Standard
- SPA Physical Interface Standard
- SPA 28V Power Service Standard
- SPA System Timing Standard
- SPA Ontology Standard
- SPA Test Bypass Standard
- SPA SpaceWire Subnet Adaptation Standard
- SPA System Capability Guide

At the time of approval, the members of the AIAA SPA Committee on Standards were:

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The AIAA Standards Executive Council (VP-Standards, Laura McGill, Chairperson) accepted the document for publication in November 2012.

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Introduction

This Guidebook provides the introduction to the SPA standard set. The SPA effort is a response to the need for reduced design, fabrication, integration, and test schedules (and therefore related engineering costs) for small spacecraft. The primary goal of SPA is to enable completion of all satellite development phases in days instead of months and years.

With the current technical and standards base, it is common to allocate months in a small satellite development schedule just for integration. This allocation is often repeated recursively at lower levels of decomposition of a large space platform.

Under SPA, computer-negotiated interfaces permit the elements of a complex system to transparently contribute information that accelerates the integration process by reducing or eliminating error-prone human interpretation. Electronic self-configuration/self-organization allows for rapid space vehicle construction. Additionally, the placement of sensors and actuators on the spacecraft is not restricted to specific, predetermined locations. In the terrestrial electronics industry, this capability is called "Plug-and-Play" (PnP). The approach fully supports an à la carte method of constructing arbitrarily complex arrangements of virtually any sensor or actuator type. Self-configuration/self-organization makes the network not only easy to expand and modify, but also robust to component failure from either natural causes or from deliberate attack.

The expected impact of Plug-and-Play goes beyond spacecraft manufacturing to increased manufacturing rates for satellite bus components. Through the production of scores or hundreds of units the economies of scale and the amortization of Non-Recurring-Engineering costs, including iterative design, testing and certification, can fundamentally alter the profitability of satellite fabrication and integration. The result will be faster turns of satellite orders at a lower delivered price and a better profit margin to the manufacturer.

As the SPA concept advances, the set of internalized transport protocols will grow. The initial content of this guidebook will focus on standardization of ontology, the use of xTEDS to establish component (hardware and software) communications interfaces, the logical flow of SPA messages, functions of the SPA network, and the employment of existing data transport standards to form plug-and-play information interfaces. SPA standards complete the architecture with inclusion of physical interfaces.

1 Scope

This Guidebook provides an overview for spacecraft platform (system), subsystem, and component (including payload) developers with spacecraft plug-and-play architectures to promote rapid design, fabrication, integration, and test. Included is an introduction to SPA, providing an informative reference for the uninitiated reader. It also includes a summary of the SPA standards. The standard user is directed to the SPA standards for detailed requirements. In cases where material in this document differs from a SPA standard, the standard will take precedence.

2 Tailoring

Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards. When viewed from the perspective of a specific program or project context, the requirements defined in the SPA standards may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements shall be undertaken in consultation with affected stakeholders, including the procuring authority where applicable.

3 Applicable Documents

The following documents contain provisions which, through reference in this text, constitute provisions of the SPA standards. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

3.1 Normative References

W3C XML 1.0	<i>Extensible Markup Language</i>
W3C XML Schema Part 1	<i>XML Schema: Structures</i>
W3C XML Schema Part 2	<i>XML Schema: Data types</i>
AIAA S-122-2007	<i>Electrical Power Systems for Unmanned Spacecraft</i>
CCSDS 660.0-B-1	<i>XML Telemetry and Command Exchange (XTCE)</i>
CCSDS 850.0-G-1	<i>Spacecraft Onboard Interface Services – Informational Report</i>
ECSS-E-ST-50-12C	<i>SpaceWire – Links, Nodes, Routers and Networks, July 2008</i>
IEEE 1451 Standards family	<i>Standard for a Smart Transducer Interface for Sensors and Actuators</i>

4 Vocabulary

4.1 Acronyms and Abbreviated Terms

6DoF	6-degrees-of-freedom
AIAA	American Institute of Aeronautics and Astronautics
APT	advanced plug-and-play technology
ASIM	appliqué sensor interface module
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials

AWG	American wire gauge
C&DH	command and data handling
CAD	computer aided design
CAS	central addressing service
CCSDS	Consultative Committee for Space Data Systems
CDD	Common Data Dictionary
CG	center of gravity
DNC	does not care
DOD	Department of Defense
DPM	dual ported memory
EDA	electronic design automation
EOP	end-of-packet
EP	endpoint
GPS	global positioning system
GSE	ground support equipment
HWIL	hardware-in-the-loop
HWILS	hardware-in-the-loop simulations
Hz	hertz
I2C	Inter-integrated circuit or Inter-IC bus
I/O	input/output
ICD	interface control document
ID	identification
IGES	initial graphics exchange specification
MKS	meters, kilograms, seconds
NASA	National Aeronautics and Space Administration
OMG	object management group
OS	operating system
OSI	open system interconnect
PC	personal computer
PnP	plug-and-play
PPS	pulse per second
QoS	quality of service
SDA	satellite design automation
SDS	spacecraft data systems
SM-L	SPA manager for the SPA local interconnects
SM-s	SPA manager for SpaceWire protocol subnet

SM-x	SPA subnet manager, where x represents a generic or given technology protocol
SOIS	spacecraft onboard interface services
SPA	Space Plug-and-Play Architecture
SPA-1	I2C
SPA-E	SPA ethernet
SPA-L	SPA local interconnect
SPA-S	SPA SpaceWire subnet
SPA-U	SPA USB subnet
SPA-X	SPA based on generic transfer standard
STEP	standard for the exchange of project model data
TAT	time-at-tone
TB	test bypass
TBI	test bypass interface
UDP	user datagram protocol
uint<n>	unsigned integer, n bits
USB	universal serial bus
UUID	universally unique identifier
XML	extensible markup language
xTEDS	extensible transducer electronic data sheet

4.2 Terms and Definitions

For the purpose of this document, the following terms and definitions apply.

ASIM

a small microcontroller circuit card that provides a logical and physical interface from a non SPA compliant device to the SPA network. The ASIM contains information about the device and its functions and translates between device's native command and data interface to the standard interface as defined in the xTEDS.

Application

software package that can be used in a SPA system

Component addressing service

provides blocks of logical addresses to each SPA manager requesting one during topology discovery or component registration; it stores the logical address block, UUID, and physical address of each manager

Component

hardware or software that can be used in a SPA system

Device

hardware item that could be used in a SPA system

Extensible transducer electronic data sheet

machine-readable representation of data provided, messages accepted, services provided, and physical characteristics (e.g., size, weight, and power) for a specific component within a plug-and-play network; xTEDS is conceptually based on the IEEE 1451 standards family

Plug and play

ability to connect a device to the larger system and have the two work together with little or no set-up required (e.g., automated system recognition and data exchange)

Registers

a set of 256 8-byte registers in dual ported memory

Router

a device on a SPA network with multiple ports that may be attached to either another SPA router or a component endpoint

SPA application

a software SPA component

SPA component

an endpoint whose interface conforms to the SPA standards and does not connect to another SPA object via a different port; SPA components are both devices (hardware) and applications (software)

SPA device

a hardware SPA component

SPA lookup service

responsible for accepting component registration and providing data source route information for components requesting a particular type of service (or returning an acknowledgment if the service is not available)

SPA manager

responsible for performing discovery for a particular subnet. It maps incoming packets to the correct SPA endpoint on the subnet, encapsulating the SPA packet with the correct protocol header. In the reverse direction it removes the protocol header and possibly adds a new header conforming to the subnet the packet is about to enter. It is also responsible for topology discovery and reporting within the subnet.

SPA network

an addressable and routable physically connected infrastructure composed of standard SPA transports for the purpose of transporting SPA messages between SPA endpoints and SPA gateways; the SPA network is made available as a SPA service to SPA components through a standard interface

Test bypass host

a test computer that recognizes, configures, and drives the test bypass routers and ASIMs while in a test configuration

Universal serial bus

familiar serial bus used by personal computers, which supports automated enumeration and plug-and-play

NOTE See <http://www.usb.org>

5 Architecture

5.1 SPA Inside a General Space Architecture

SPA sits on top of existing space architecture. SPA uses a federated approach to integrate with existing space architecture in areas such as launch systems and ground systems—those systems are not affected by SPA. In the area of spacecraft systems SPA only affects internal spacecraft aspects; SPA does not affect spacecraft external interfaces. In addition, SPA affects design, fabrication, integration and all aspects of test in a spacecraft lifecycle (see Figure 1). SPA is not intended to affect spacecraft mission operations or end of life, but it can have a positive impact on spacecraft health through the operational phase.

Because SPA does not address spacecraft external interfaces, SPA systems, services, data, and standards are constrained to describe spacecraft subsystems, assemblies, and components at interfaces and the interfaces themselves. It is important to note that SPA sits on top of existing space architecture even within the spacecraft. This replication of the federated approach mentioned previously allows SPA to take advantage of general advances in space systems development without the need to recreate SPA at each turn. Partially for this reason there is an expected connection between general spacecraft architecture and SPA that is not necessarily well defined from a standards perspective. There has been discussion on developing SPA Application Program Interfaces (APIs) to more clearly constrain the connection from general spacecraft architecture to SPA, but as of this publication there is no clear consensus on exactly what such a standard should require.

There are computer/software architecture models that have been applied to space systems. Annex A discusses the OSI model and the CCSDS SOIS model.

5.2 SPA Inside

Different views present themselves within SPA, although the primary view is data-centric. SPA clearly describes specific viewpoints under the architecture. The SPA standards contain requirements primarily related to the following views:

- System View
 - o Physical Interfaces, including mechanical and electrical interfaces are described in the Physical Interfaces Standard (AIAA S-133-4-2013)
 - o Testing capabilities for SPA compliant spacecraft components, used primarily during spacecraft integration, are described in the Test Bypass Standard (AIAA S-133-8-2013)
- Services View
 - o Power is described in the Power Service Standard (AIAA S-133-5-2013)
 - o Timing is described in the System Timing Standard (AIAA S-133-6-2013)
 - o Spacecraft internal computer network establishment and form are described in the Networking Standard (AIAA S-133-2-2013)
- Data-Centric View
 - o The necessary data and data structure for components is described in the Ontology Standard (AIAA S-133-7-2013)
 - o Spacecraft design adaptation of existing space or computer technology protocols are described in the Subnet Adaptation Standards (e.g., SpaceWire Subnet Adaptation; AIAA S-133-9-2013)
 - o Spacecraft internal computer network traffic structure and interaction is described in the Logical Interface Standard (AIAA S-133-3-2013)