AN ONBOARD PROCESSOR FOR FLIGHT TEST DATA ACQUISITION SYSTEMS

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ABSTRACT

Today's flight test programs are experiencing increasing demands for a greater number of high-rate digital parameters, competition for spectrum space, and a need for operational flexibility in flight test instrumentation. These demands must be met while meeting schedule and budget constraints. To address these various needs, the Boeing Integrated Defense System (IDS) Flight Test Instrumentation group in St. Louis has developed an onboard processing capability for use with airborne instrumentation data collection systems. This includes a first-generation Onboard Processor (OBP) which has been successfully used on the F/A-18E/F Super Hornet flight test program for four years, and which provides a throughput of 5 Mbytes/s and a processing capability of 480 Mflops (floating-point operations per second). Boeing IDS Flight Test is also currently developing a second generation OBP which features greatly enhanced input and output flexibility and algorithm programmability, and is targeted to provide a throughput of 160 Mbytes/s with a processing capability of 16 Gflops. This paper describes these onboard processing capabilities and their benefits.

KEYWORDS

Keywords: onboard processing, bandwidth reduction, data compression

INTRODUCTION

In previous years, flight test data collection systems consisted of low-rate digital data collection in conjunction with banks of voltage-controlled oscillators (VCO's) for higher-rate (e.g. 2kHz) parameters. Though resolution and accuracy of the VCO's was poor, it was possible to telemeter a number of VCO channels (approximately 20) using complex mixer/translator configurations. This provided engineers at the ground station with good visibility into aircraft performance, and allowed cost-effective test point decisions to be made in real-time.

With the advent of all-digital data collection systems, the luxury of telemetering numbers of fairly high-rate parameters became impractical due to bandwidth limitations: 30 parameters at 10,240 samples/second consumes an entire 5 Mbit/second telemetry stream.

In the mid-1990's, Boeing IDS Flight Test in Saint Louis began development of an onboard processing capability to address this issue. When the first-generation Onboard Processor (OBP) was deployed in several F/A-18E/F Super Hornet Engineering Manufacturing Development (EMD) flight test aircraft at Patuxent River, Maryland, it became obvious that an onboard processing capability provided benefits well beyond initial expectations.

FIRST-GENERATION OBP ARCHITECTURE AND AIRCRAFT CONFIGURATION

The aircraft configuration for the first-generation OBP and a simplified internal block diagram are shown in Figure 1. The OBP receives parallel ECL PCM from the input data system, decommutates selected data, processes the data, and sends it to the output data system in a serial format as requested in the output data format.

For the F/A-18E/F Super Hornet Flight Test program, the primary data collection system was the Common Airborne Instrumentation System (CAIS), augmented by the Boeing-developed Digital Data Acquisition System (DDAS) for collection of wideband data. The OBP was configured on various test aircraft in the DDAS-in DDAS-out, DDAS-in CAIS-out, and CAIS-in CAIS-out configurations, depending on the test requirement.

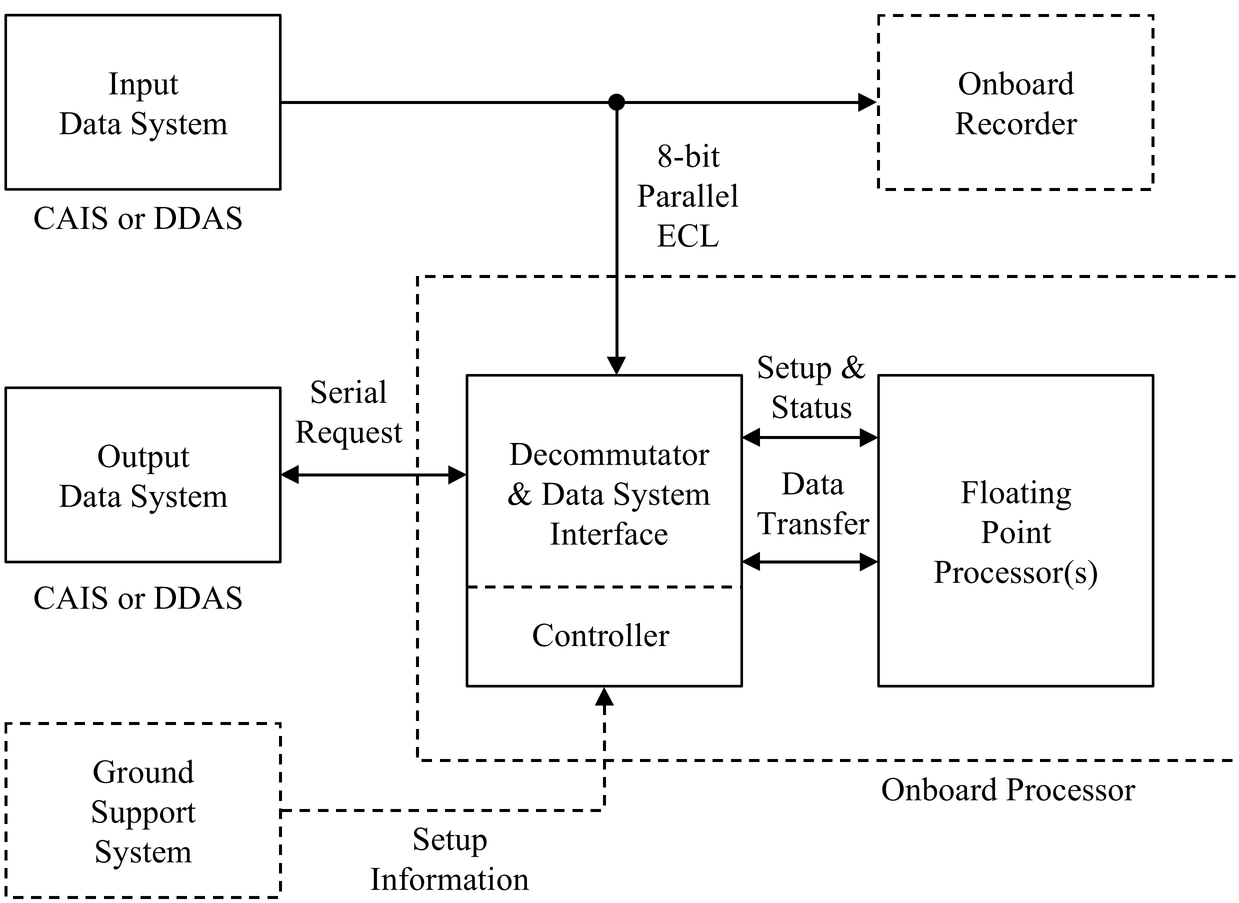

Figure 1. First-Generation OBP Configuration

Referring to Figure 1, the OBP receives input PCM from a parallel 8-bit ECL source that drives the onboard recorder. The decommutator decodes selected PCM words and passes the data to two Analog Devices ADSP-21020 DSP processors. Input data is transferred coherently using a buffer-swapping scheme. The DSPs process the data according to the selected algorithm and send the output data to output buffers that are also coherently swapped. The output data system retrieves data sequentially upon format command in a serial request-response format.

Figure 2 shows the first-generation OBP hardware. Boeing IDS Flight Test developed an OBP for the F/A-18E/F Super Hornet Flight Test Program, which was used as an interface with the Wideband portion of the CAIS data system; thus the unit was identified as the “Wideband CAIS Interface” for that program. Despite the name, however, the OBP is a general-purpose device.

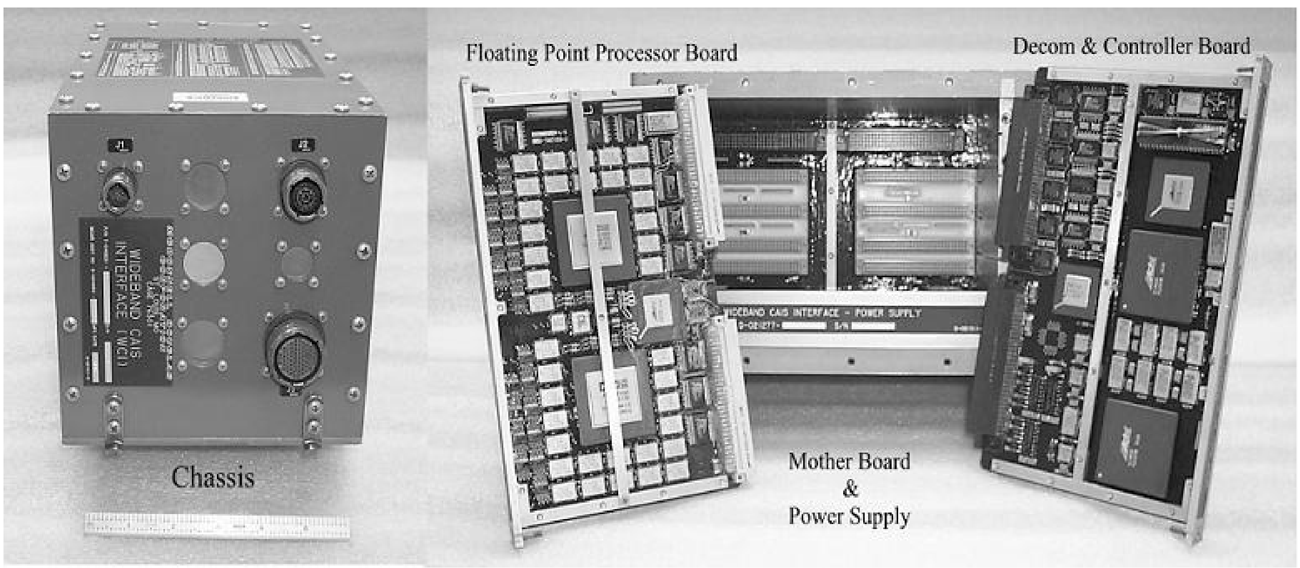

Figure 2. First Generation OBP Hardware

Operationally, the data systems are loaded with formats created from software that generates format loads from a parameter database. An OBP compiler program creates appropriate load files for the OBP, which is loaded via an RS-422 link from the ground support system. Algorithm development is performed in C and assembly code, and DSP firmware is loaded via the ground support system.

FIRST-GENERATION OBP APPLICATIONS AND RESULTS

The initial application used on the F/A-18E/F Super Hornet flight test program was a statistical algorithm, used for noise and vibration parameters. This algorithm provided statistical characteristics in the form of minimum, maximum, root-mean-squared (RMS) and mean. To increase the overall dynamic range, the parameters were high-pass filtered at 2 Hz prior to processing. In one configuration, 62 parameters sampled at three different rates between 5208 samples/second and 39062 samples/second (an aggregate rate of almost 15 Mbits/second) were reduced to 62 min/max/mean/rms groups at 10 samples/second (an aggregate rate just over 39 Kbits/second). This was a reduction on the order of 380 to 1.

Such a significant reduction in telemetry bandwidth allowed characteristics of these parameters to be transmitted in real-time, permitting a substantially enhanced decision-making capability on the part of the technology engineers at the ground station. This capability permitted engineers to determine worst-case flight conditions in real-time, and these test points could then be flown and refined immediately, rather than requiring post-flight processing and additional subsequent flights. The result was a conservative estimate of a 30% decrease of several hundred noise and vibration flights flown on the program, equating to a considerable savings in the tens of millions of dollars, not to mention reducing the risk to the aircraft and aircrew.

Additionally, the ability to assess instrumentation system health in real-time was also greatly improved. Because the instrumentation engineer could identify which parameters appeared to be malfunctioning, an informed decision could be made during the flight as to whether to continue with the flight, or whether the failed instrumentation was critical to the test point. As a result, unnecessary risk to the test vehicle and aircrew was avoided because failed critical parameters could be readily identified in real time.

Another application for the first-generation OBP was a filtering algorithm that provided a decimated version of input parameters. In this configuration, the aircraft was scheduled to perform two different tests, one of which required a group of parameters to be sampled at high rates (2604.2 or 1302.1 samples/second), and the other of which required the parameters to be sampled at 81 samples/second. Telemetering the 157 parameters at the high rate would have consumed approximately 3.9 Mbits/second, which was impractical given other parameter requirements. The OBP allowed this to be accomplished in a telemetry bandwidth around 20 Kbits/second. However, the major savings occurred because the aircraft did not require an expensive one-month layup to reconfigure data collection system pre-sample filters for the 157 parameters: the OBP allowed a single hardware configuration to suffice for both test configurations without reconfiguration.

The first-generation OBP was also pressed into service to perform simplified loads calculations. In this configuration, the OBP performed a linear weighted sum of several parameters and calculated the mean, min, max, and rms statistical averages. Though this algorithm performed successfully, due to its limitations (for example, it could not apply non-linear or high-order processing) use of this algorithm was abandoned.

The final algorithm used on the F/A-18E/F Super Hornet flight test program was a simple transfer of three high-rate parameters available in the DDAS data collector into the CAIS data collector, so these parameters could be telemetered. This eliminated the complexity of requiring additional rewiring and reconfiguration of the aircraft to measure these parameters with the CAIS system, or to add equipment to telemeter the DDAS output. The result was the elimination of a time-consuming and expensive layup and reconfiguration of the aircraft.

Two notable points should be made with respect to this application: 1) Once the onboard processing capability is present, users identify uses for that capability that are not initially planned. 2)

Especially in a multiple data system configuration, the location of the OBP in the instrumentation system provides the opportunity for a wide range of versatile capabilities beyond the traditional concept of “processing”.

SECOND-GENERATION OBP ARCHITECTURE AND AIRCRAFT CONFIGURATION

Experience with the first generation unit identified a number of areas for potential improvement in OBP performance. An improvement in internal and input/output bandwidth was desirable. An appropriate operating system would isolate the hardware implementation from the application software, considerably improving the ease of application development. Additionally, the second-generation unit is targeted to a wider range of data input and output options (e.g. both legacy and networked data systems, traditional PCM recorders as well as random-access RAID or solid state recorders). With these added capabilities, it was also desirable to improve visibility into OBP operation for hardware and system-level troubleshooting; this could also provide benefits in allowing upgrades or fixes of firmware and programmable hardware without removing the unit from the aircraft.

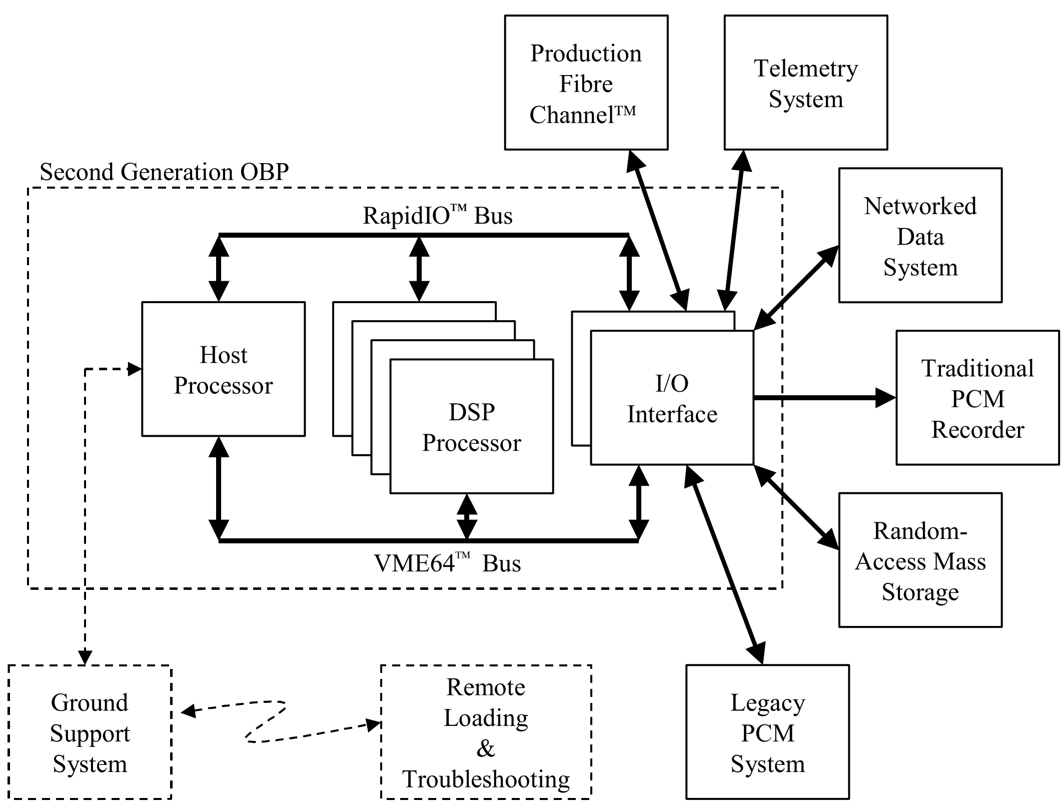

Figure 3. Second-Generation OBP Configuration

As shown in Figure 3, the Second-Generation OBP consists of a host processor (PowerPC™), multiple DSP processor cards (Analog Devices TigerSHARC™, 4 per card), and modular I/O cards, which communicate data via a RapidIO™ bus, with control on a VME64™ bus. The system architecture provides processing and input/output capability that are modular and expandable. The host processor runs an operating system that schedules processing and memory resources to maximize throughput and to allow substantially improved flexibility in the programming of DSP application software. The second generation OBP hardware is shown in Figure 4.

The second generation OBP is currently in development, with planned completion in late 2004. The initial second generation unit will be configured with I/O options to provide a legacy PCM system interface for functional compatibility with the first generation unit, and the initial set of algorithms will match the first generation OBP as well. Ground support loading will be performed through an RS-422 serial interface, but an Ethernet-based link to the host will also be available.

Because of the host operating system, the flexibility of writing DSP application software is substantially improved. Initial capabilities will provide an interface library that will make it possible to write DSP applications in C or C++ without an intricate knowledge of OBP operation. It is subsequently planned to provide a graphical user interface (similar to, or based on, LabView) that will allow technology users to specify input parameters, transfer functions to apply to those parameters (filtering, non-linear operations etc.), and methods to combine those parameters in an arbitrary fashion to create an output parameter or parameters.

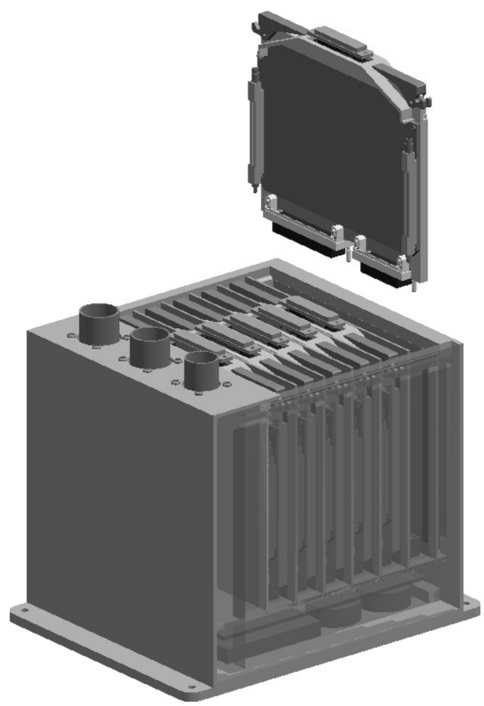

Figure 4. Second Generation OBP Hardware

A comparison of the first- and second-generation OBP units is shown in Table 1.

Characteristic	First-Generation OBP	Second-Generation OBP
Size (inches)	6.8 x 6.9 x 12	7.3 x 7.3 x 8.0
Weight (pounds) {full configuration}	<15	23
Power	+28V @ 1A	+28V @ 2A
Host Processor	8751	PowerPC™ (600 MHz)
DSP Processor Cards	ADSP 21010 (25 MHz) 2 per card	TigerSHARC™ (250 MHz) 4 per card
I/O Throughput (Mbytes/second)	5.0	160.0
Processing Speed {full configuration} Gflops (floating point operations per second)	0.48	16.0
DSP Application development	C and assembly; Very hardware-dependant	- C and C++; simplified programmer interface. - Graphical user interface.
System Troubleshooting & Monitoring	Minimal capabilities	Strong visibility through host via Ethernet and RS-422 interface

Table 1. Comparison of first- and second-generation OBP units

SECOND-GENERATION OBP APPLICATIONS

A number of proposed DSP applications have been created and tested on lab versions of the DSP processor cards, to provide insight into the design of the host operating system and various multi-processing architectures, and to verify that the processors will provide the desired throughput. Third-octave filters and variable-bandwidth power spectral density (PSD) algorithms have been written and verified.

An application for weapon separation image processing was also tested for potential use on a typical tactical development flight test program. In traditional weapon separation testing, a number of high-speed film or video cameras located at various locations on the aircraft monitor the release of stores. These aircraft must return to the ground and the film or video must be processed (a time-consuming task) before the next set of flight envelope test points can be flown. Algorithms investigated for potential use in the second-generation OBP included 1) techniques to identify the centroids of three-dimensional location of targets placed on the stores, and to track these target locations from onboard recorded images and 2) image compression algorithms to allow near real time telemetering of the image data. Simulations were run on lab DSP hardware that demonstrated that the store tracking information could be processed and transmitted back to the ground (based also on typical telemetry link limitations) on the order of 60 seconds after each weapon separation event. Having the capability to make decisions in near real-time while the test vehicle is in the air was estimated to reduce weapons test flights by approximately 25%, resulting in a substantial cost reduction in the millions of dollars for the flight test program, and reducing risk to the vehicle and aircrew.

A technique also proposed involved a NASA-developed algorithm intended to reduce flutter test points, reduce flights required for flutter, and increase the total number of flights per month. This concept took advantage of a software tool that updates an analytical model for the aircraft with real time test data in order to produce post-flight-quality near real time flutter boundary projection. This technique takes input transfer functions computed by the OBP from sine sweeps and compares them to the transfer function predicted by the analysis model. The second-generation OBP, then, would be an enabling technology to make this approach practical.

Another potential application proposed for the second-generation OBP is telemetry bandwidth reduction. Compression of any arbitrary PCM stream pattern may or may not be practical (and is beyond the scope of this paper) but the practical bandwidth reduction already experienced with the first-generation OBP indicates such compression is best achieved by techniques specific to a particular class of data (such as providing low-rate statistical measures for a high-rate parameter).

Because of its modular I/O architecture, the second-generation OBP lends itself to a variety of system configuration applications, such as: 1) a data combiner for multiple PCM streams and/or networked streams, 2) a bridge to link legacy PCM systems with networked data systems and 3) an interface to the aircraft Fibre Channel bus.

A final potential application is to monitor instrumentation system health by taking a “snapshot” of various parameters during a known flight condition (such as a phasing maneuver) that would then be compared against a previous snapshot of that same flight condition. The OBP would then perform an assessment of the health of those parameters and provide an answer in real time. This would allow an informed decision to be made at the ground station in case mission critical parameters were not operating correctly, reducing risk to the aircraft and aircrew.

CONCLUSION

The first-generation OBP has proven to be a valuable tool to provide visibility into aircraft performance that has not previously been available in real time. This visibility has substantially enhanced decision-making by test conductors and technology engineers, allowing tests to be run during one flight that would have previously required multiple additional flights. This results in substantial cost savings, greatly enhanced flexibility in test scheduling, and considerable reduction in risk to the test vehicle and aircrew.

Cost savings attributed to the OBP include not only the savings due to reduced number of flights, but also to reduction in processing costs associated with ground-based processing. This was estimated to be approximately 2000 hours per year for the F/A-18E/F Super Hornet flight test program. The increased visibility into aircraft performance further decreases processing costs by allowing technology customers to identify points of interest for further processing before leaving the ground station.

Experience also indicates that the availability of the OBP as an instrumentation system tool causes new and creative uses to be developed that had not been envisioned during development. These applications have resulted in significant reductions in layup time and aircraft reconfigurations.

The second-generation OBP is expected to provide a substantial increase in internal and external bandwidth and processing capacity, as well as greatly improved flexibility in the development of DSP applications. A graphical user interface, allowing arbitrary combination and processing of multiple parameters is planned.

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