Delphi Engineering Group's DAQStream Data Recorder Systems for Wideband Data Collection & Playback.

Turnkey Systems Providing:

- Recording and Playback at up to 6 GBytes/s Per Carrier for Multiple Hours.
- Continuous Recording with No Time Gaps.
- Recording of Samples at the Full Rate of Today's Fastest ADCs.
- Scalable System Bandwidth.
- Clock and Trigger Synchronization of Multiple Channels.

Introduction

Delphi's DAQStream data recorders deliver unprecedented high-speed signal collection capability for bandwidth-intensive sensor platforms and applications including: ELINT, SIGINT, ISR, Remote Sensing, and RF Spectrum Analysis. A combination of high sample rate, high sensitivity and continuous sample collection maximize the probability of intercept (POI) and identification for system operators. This paper describes three sample configurations that solve demanding data recording challenges using Delphi's portfolio of high-performance COTS, embedded computing products.

The Delphi DAQStream's industry-leading recording bandwidth is made possible by a unique set of high-bandwidth components, designed to maximize data flow and eliminate bottlenecks. Wideband spectrums digitized by Delphi's Gigahertz (GHz) class of ADC modules are processed by the PC7 Virtex-7 based FPGA carriers, and streamed over PCIe Gen 3.0 channels into an optimized SSD RAID storage subsystem at up to 6 gigabytes per second (GB/s) per DAQStream carrier. Delphi offers a range of GHz class ADC modules for front-end sampling and matching DAC modules for RF playback capability.

Meeting the Modern Spectrum Collection Challenge.

Today's military intelligence analyst faces the challenge of an increasingly crowded signal environment, containing modern low probability of intercept (LPI) waveforms. Typical systems have a bandwidth of 500 MHz or less and require complex schemes to scan or multiplex a wide frequency spectrum in sub-band segments and employ strategies to revisit bands where signals of interest are detected for further data collection and analysis. These schemes require complex and expensive hardware and software, yet remain susceptible to LPI signals due to the effects of time gaps, frequency division, and limited SNR.

As an example, an ELINT system operator often requires the data recorder to collect raw I/Q sample data for off-line computer analysis and playback. They require increased system spectral bandwidth and sensitivity that together challenge data recording bandwidth capacity. An example system with a 500 MHz IF bandwidth sampled with 1 GHz 8-bit ADCs requires 1 GB/s of raw sample recording bandwidth. The need to improve on this for increased POI, requires both faster sampling and more bits which increases the bandwidth load on the recording system. To illustrate, increasing the IF bandwidth to 1 GHz with I and Q sampling of 1.33 GHz at 12-bits requires 4 GB/s of raw sample recording bandwidth. Moving to a dual 2 GHz, 12-bit sampling system would require 6 GB/s of raw sample recording bandwidth.

Additional requirements for these systems may include such functions as: programmable digital down-conversion, spectrum analysis, signal discrimination, demodulation, pulse detection, and pulse descriptor word generation. Performing such numerically intensive processing tasks, at GHz sampling rates, requires the latest in FPGA technology.

DAQStream: Turnkey Data Recorders

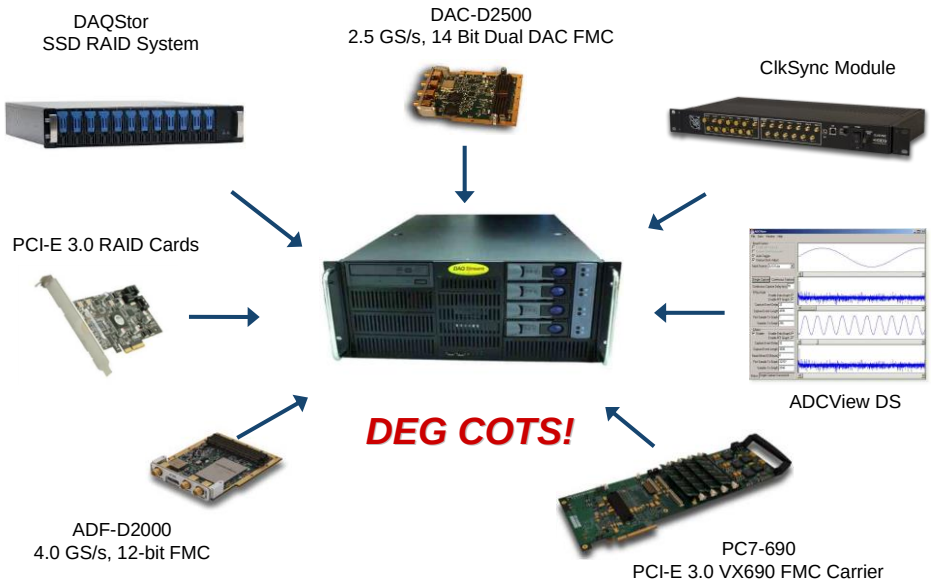

Figure 1: Top-Level Diagram of DAQStream showing Delphi-branded components

The Delphi DAQStream Solution

Delphi's DAQStream wideband data recorders are able to deliver market leading high-speed recording and playback capability through the use of a carefully engineered set of hardware, firmware, software, and interconnect technologies integrated with a validated set of host and storage components. These Delphi products include:

- **PC7**: PCIe Gen 3.0, Virtex-7 FPGA carriers.
- **ADF**: High-speed, high SNR ADC FMC modules.
- **DAC**: High-speed, DAC FMC Module.
- **ADCView DS**: GUI software for DAQStream system control and configuration.
- **ADCStream**: High-efficiency data flow control GUI software.
- **ClkSync**: Module for precise inter-channel synchronization.
- **DAQStor**: Multi-Terabyte SSD JBOD array.

PC7: The engine of the DAQStream system is Delphi's PC7, a PCI Express (PCIe) Gen 3.0, Virtex-7 based FPGA carrier. The PC7 facilitates high bandwidth data flows between each of its two FMC slots and the DAQStream host storage system. The PC7 sets the benchmark for performance and versatility in the embedded PCIe market. Its eight PCIe Gen 3.0 lanes, have sufficient bandwidth to support DEG's fastest ADC modules. For example, configurations with two 2 GHz 12-bit ADCs, four 400 MHz 14-bit ADCs, one 4 GHz 12-bit ADC are all supported. Firmware on the PC7 coordinates multi-GByte streaming data flow between the DAQStream's ADC front-end and system memory, before making high-speed DMA transfers to an SSD RAID storage system. Delphi's PC7 and Mezzanine card combination is the only PCIe FMC Carrier on the market that accommodates two FMC cards on a single PCIe carrier in an enclosed 3U PC Chassis.

ADC & DAC FMC Modules: Delphi delivers the highest performance ADC and DAC FMC modules available in the embedded COTS system marketplace. Designed to maximize analog bandwidth and digital sampling integrity, these VITA 57.1 compliant FMC modules integrate seamlessly with the PC7 carrier to allow uninterrupted flow of full-rate wideband samples to storage. Available FMC Modules include:

- ADF-D2000: Dual 2.0 GHz sampling rate at 12-bits or a Single 4.0 GHz sampling rate at 12-bits.
- ADF-3000: 3.0 GHz sampling rate at 10-bits with 5 GHz Input Bandwidth.
- ADF-Q1014: Quad-channel 1.0 GHz, 14-bit ADC with 2 GHz input bandwidth.
- ADF-Q25: Quad 250 MHz sampling rate at 16-bits with 900 MHz Input Bandwidth.
- ADF-Q40: Quad 400 MHz sampling rate at 14-bits with 1.4 GHz Input Bandwidth.
- DAC-D2500: Dual DACs - 2.5 GHz sampling rate at 14-bits with 2.3 GHz Output Bandwidth.

ADCView Software: ADCView provides DAQStream users with a powerful graphical user interface (GUI) which is used to configure, control and view the real-time performance of the DAQStream system.

ClkSync: With multi-channel wideband recorders, the need for accurate channel synchronization is paramount. Delphi's ClkSync provides clock and trigger synchronization and adjustments for up to twelve ADC or DAC channels from a single unit, and is extendable to multiple ClkSync modules for further channel expansion. The ClkSync is contained in a 1U rack-mountable chassis and provides independent fine grain control of each channel's trigger and clock signals.

DAQStor: Continuous, uninterrupted recording and playback of ADC/DAC samples for multiple hours. Delphi's DAQStor SSD and HDD RAID systems are designed for the most challenging signal recording scenarios. The DAQStor can be configured to record independent IQ channels, at full rate, to RAID for post-processing analysis.

Scalability: DAQstream component sets are designed for easy expansion and replication to increase system bandwidth while maintaining sampling coherency across channels.

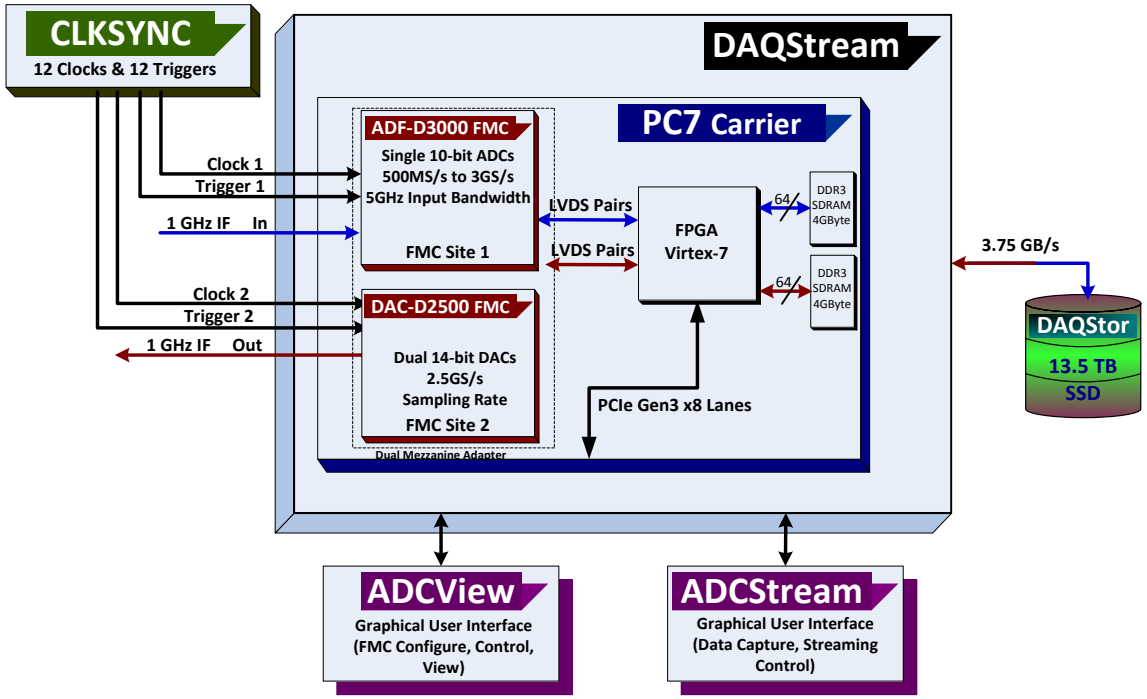

Figure 2: Single Channel DAQStream System w/ADF-3000 and DAC-D2500.

DAQStream System Configuration Examples

This section will describe three real-world examples of turnkey DAQStream configurations. Options range from a simple, lower cost single-band recording system, to a full-coverage multiband recording and playback system with signal processing capability. While this does not represent the full range of available options, it gives the system designer some examples of how they might configure Delphi's DAQStream to meet their application requirements.

Example 1: Single Channel Recorder with Playback: This example illustrates a simple, yet high performance recording system that digitizes a single IF input channel and records the raw samples for offline analysis. This is a complete turnkey system. The customer supplies an IF input, selects the Record button in ADCStream, and the digitized signal is recorded to disk.

Requirements: System has a 1 GHz IF center frequency with a 1 GHz bandwidth of interest and requires to record continuous sample data at or above the Nyquist rate of their maximum frequency extent and 47dB SFDR. Requires one hour of continuous signal recording and playback. Customer has 3 GHz system clock from IF mixer section.

Solution: The 3 GHz, 10-bit, 5 GHz input bandwidth ADC of the ADF-3000 meets the sampling and SFDR requirements. With its digitized samples packed by the PC7, the downstream data bandwidth is 3.75 GB/s. Sixty minutes of continuous recording requires 13.5 terabytes (TB) of storage (3.75 GB/s x 60 sec x 60 min). A single RAID controller and SSD JBOD array can maintain this data bandwidth and capacity.

DAQStream solution system consists of:

- PC7: PCIe Gen 3.0, Virtex-7 FPGA Carrier
- ADF-3000: 3 GHz ADC FMC in FMC Site #1
- DAC-D2500: 2.5 GHz DAC FMC in FMC Site #2
- SSD DAQStor RAID System
- ADCStream Software

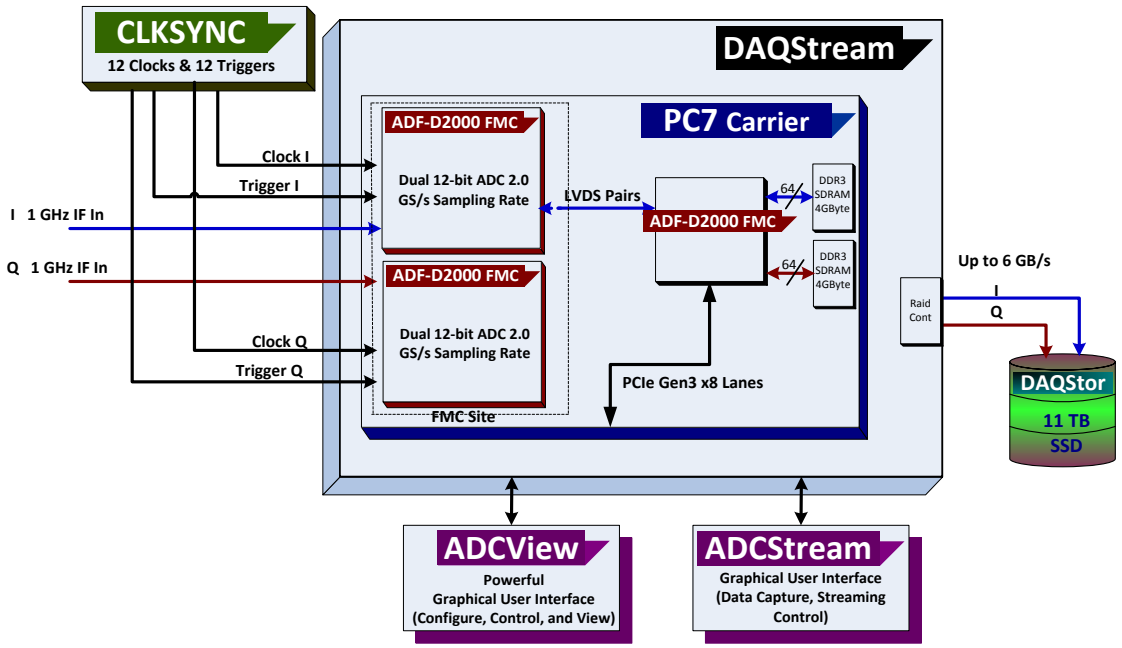

Figure 3: Dual - Channel DAQStream System w/ADF-2000, and One 11 TB JBOD.

Example 2: I and Q Sampling Recorder: With radar and communication signals it is advantageous to represent the signal as a pair of baseband in-phase (I) and quadrature-phase (Q) signals for efficiency of hardware and signal processing algorithms. This requires a synchronous dual-sampling system with precise control of sampling clocks to maintain phase accuracy in the digitized data.

Requirements: System has a 1 GHz IF center frequency with a 500 MHz bandwidth, split into baseband IF, I and Q signals by means of mixers. It is required to record continuous I and Q sample data at the rate of 2 GS/s for sixty minutes. An external trigger is required to synchronize sampling. System must provide I and Q clocks with fine adjustment of the phase relationship

Solution: The dual 2 GHz, 12-bit ADC of the ADF-D2000 meets the sampling requirement. A ClkSync module provides two, 2 GHz clocks with fine-phase adjustments to the ADCs, as well as distributes clock-synchronous triggers. With its digitized samples packed by the PC7 firmware into 1.5 bytes/sample, the downstream data bandwidth is 3 GB/s per channel for a total of 6 GB/s. Sixty minutes of continuous recording requires 10.8 TBs of storage per channel (3 GB/s x 60sec x 60min). A configuration of two RAID controllers and two 11TB SSD JBOD arrays, one each for I and Q data, can maintain this data bandwidth and capacity.

DAQStream solution system consists of:

- Two ADF-D2000 dual 2 GHz ADC FMC
- PC7 PCIe Gen 3.0, Virtex-7 FPGA Carrier
- DAQStream Host Server w/DAQStream Software
- One 11 TB DAQStor SSD RAID Systems
- ADCStream Software

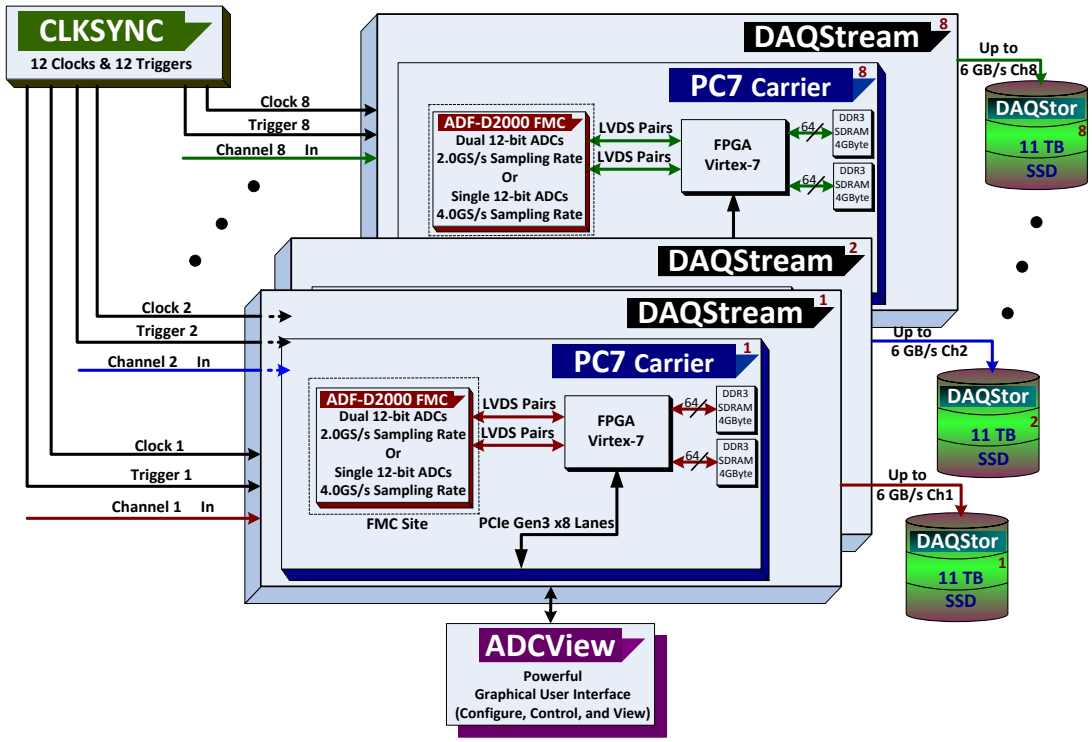

Figure 4: 2 - 18 GHz Recording System.

Example 3: Multi-Channel Recorder: An effective method to increase system bandwidth without losing POI is to build multiple parallel IF sub band channels that simultaneously sample different parts of the spectrum. In this example we show how to build a multi-channel recorder to cover a typical 2 - 18 GHz radar spectrum.

Requirements: System must record the entire 2 - 18 GHz spectrum with no band-stepping or time gaps. Sub-bands must be as wide as possible to reduce complexity and cost of the IF system. All samples must be synchronous to one sampling clock and sampling trigger. It is required to record continuous sample data for one hour.

Solution: The spectrum is divided into eight sub-bands that each cover a 2 GHz band of the full spectrum. The 4 GHz, 12-bit ADC of the ADF-D2000 (Dual Edge Sample Mode) meets the sampling and SNR requirements (a dual 2 GHz option is available for I and Q sampling). A ClkSync module will provide eight, 2 GHz clocks with fine phase adjustments to the ADCs, as well as distribute eight clock-synchronous triggers. With its digitized samples packed by the PC7 firmware into 1.5 bytes/sample, the downstream data bandwidth is 6 GB/s per sub-band channel for a total of 48 GB/s. Sixty minutes of continuous recording requires 22 TBs of storage per channel (6 GB/s x 60sec x 60min). A configuration of two RAID controllers and two 11TB SSD JBOD arrays for each channel can maintain this data bandwidth and capacity.

2 - 18 GHz DAQStream solution system consists of:

- One ClkSync Module with 8 Clocks and Triggers
- Eight ADF-D2000 4 GHz ADC FMC (Dual Edge Sample Mode)
- Eight PC7 PCIe Gen 3.0, Virtex-7 FPGA Carriers
- Eight DAQStream Host Servers w/DAQStream Software
- Sixteen RAID Controllers and 16, 11 TB JBODs

Summary: Delphi Engineering's DAQStream delivers high-data rate recording with a scalable system architecture. The DAQStream's proven design and advanced recording technology, along with a simple yet powerful GUI, provide market leading data recording and playback capability for mission-critical applications. Contact Delphi today and learn how a DAQStream system can help you meet your program goals.