ODI optics are fast, but the VRT packet structure is also impressive

Author: Larry Desjardin

In October of 2017, the AXIe Consortium, the VITA trade organization, and six companies [announced a new standard] called the Optical Data Interface, or ODI for short. Based on optical links between instruments, instead of electrical links, ODI can stream data up to 20 GBytes/s from a single optical port, with speeds up to 80 GBytes/s through port aggegation. ODI is designed to address challenging applications in 5G communications, mil/aero systems, high-speed data acquisition, embedded systems, and communication research. A good overview of the physical characteristics of this optical interface standard, and the markets it addresses, can be found [here].

ODI links, being a separate pluggable interface, can be placed on any product regardless of form factor. Below is a diagram of a hypothetical recording and playback system that combines any combination of bench instrumentation, AXIe modular instrumentation, and PXI modular instrumentation.

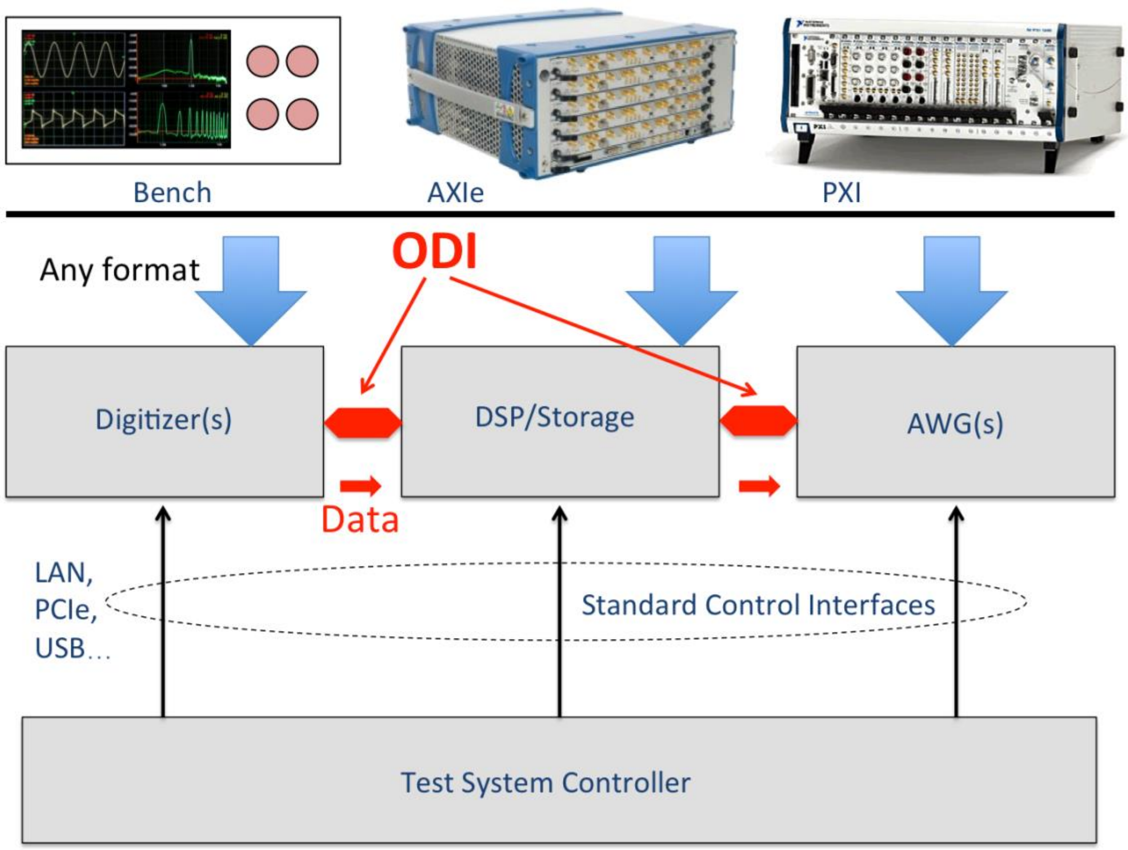

Figure 1 shows a hypothetical storage and playback system using ODI, the Optical Data Interface standard.

While the above example is an instrumentation example, ODI may also be used with VPX systems for embedded mil-aero applications.

ODI is based on fiber-optic communication between devices. With this comes increased speed and distance. Each port is capable of sending and/or receiving 20 GBytes/s over the 24-lane fiber-optic cable, 12 lanes in each direction. This is not a theoretical speed that must be reduced for margin. ODI is designed to stream these speeds continuously, without interruption or dropped data.

Higher speeds can be achieved by using multiple ODI ports in parallel through a concept known as port aggregation. By aggregating four ports, gapless speeds up to 80 GBytes/s have been demonstrated.

It's not just speed that is gained by going optical, so is distance. PXI and AXIe designers struggle to achieve the signal integrity needed to span the distance of a backplane. This will most certainly be the case as designers set their aim at PCIe Gen 4. However, ODI allows distances up to 100 meters to be spanned at full speed, not just inches. While applications that require 100 meters may not be common, the robustness of ODI over very long distances means that distance issues completely disappear when connecting within a racked system or to adjacent systems. It also means that as ODI speeds increase with optical technology, the interconnect distances will remain in the range of 10s of meters.

ODI uses VRT Packets

While much has been made of ODI's blazing speed, the packet definition is equally impressive. ODI adopts the VITA 49 Radio Transport protocol (VRT) that is supported by the VITA Standards Organization. The VRT family of standards specify standardized packets and data formats to be used by embedded systems dealing with the creation of radio communications, radar systems, electronic warfare systems, and numerous other RF applications. VRT is designed to work on top of any communication medium. VRT devices communicate by sending VRT packets from one device to another. The packets encapsulate the embedded signal data and metadata.

While VRT has been historically deployed on ethernet buses controlled by general purpose processors, ODI has defined a specific profile of VRT packets that can be executed at hardware speeds between FPGAs. Due to the speeds involved, FPGAs are a neccesity on each side of the ODI optical link. Figure 2 shows the simple block diagram of each device operating over an ODI link. The high speed SerDes (serializer/deserializer) pins of an FPGA connect directly to E/O (electrical to optical) and O/E (optical to electrical) converters, which communicate over the fiber optic cable.

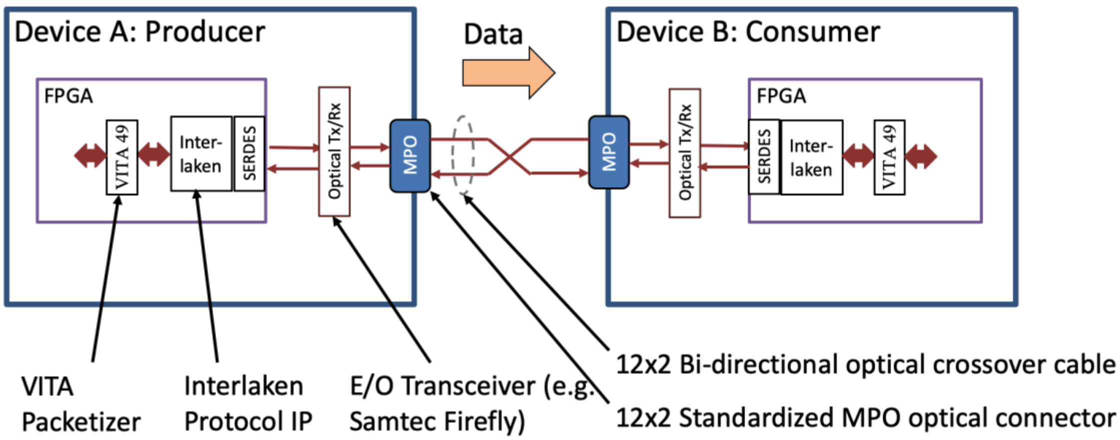

Figure 2 shows the communication link between two ODI-enabled devices. FPGAs are essential at these speeds. ODI has created a specific profile of the VRT packet structure that allows VRT packets to be executed at FPGA hardware speeds.

By standardizing on VRT, and defining a VRT profile that can be executed by FPGAs, ODI can deliver not only the high speeds due to the optical links, but also all the advantages of VRT, a signal-oriented packet standard. Some of those advantages include standard data formats, both real and complex, a multitude of timestamp options, packet alignment for port aggregation, and various events and error reporting.

Figure 3 shows the structure of a VRT signal data packet. The packet is very flexible and can be used with any signal type, any number of channels, and any resolution. With only 32 bytes of overhead per packet, and data payloads up to 256 Kbytes in length, VRT offers very high efficiency.

ODI packets are graphically presented as 8 byte words across, and sequential words going downward with time. Eight bytes matches the 64-bit Interlaken word that the physical layer protocol is based on. Interlaken is a chip-to-chip protocol defined by Cisco and Cortina Systems that is available from all major FPGA vendors. It can be used to transport any packet type. ODI uses Interlaken to transport VRT packets. A VRT packet is bounded by the Interlaken Start of Packet (SOP) and End of Packet (EOP) command words, shown in yellow.

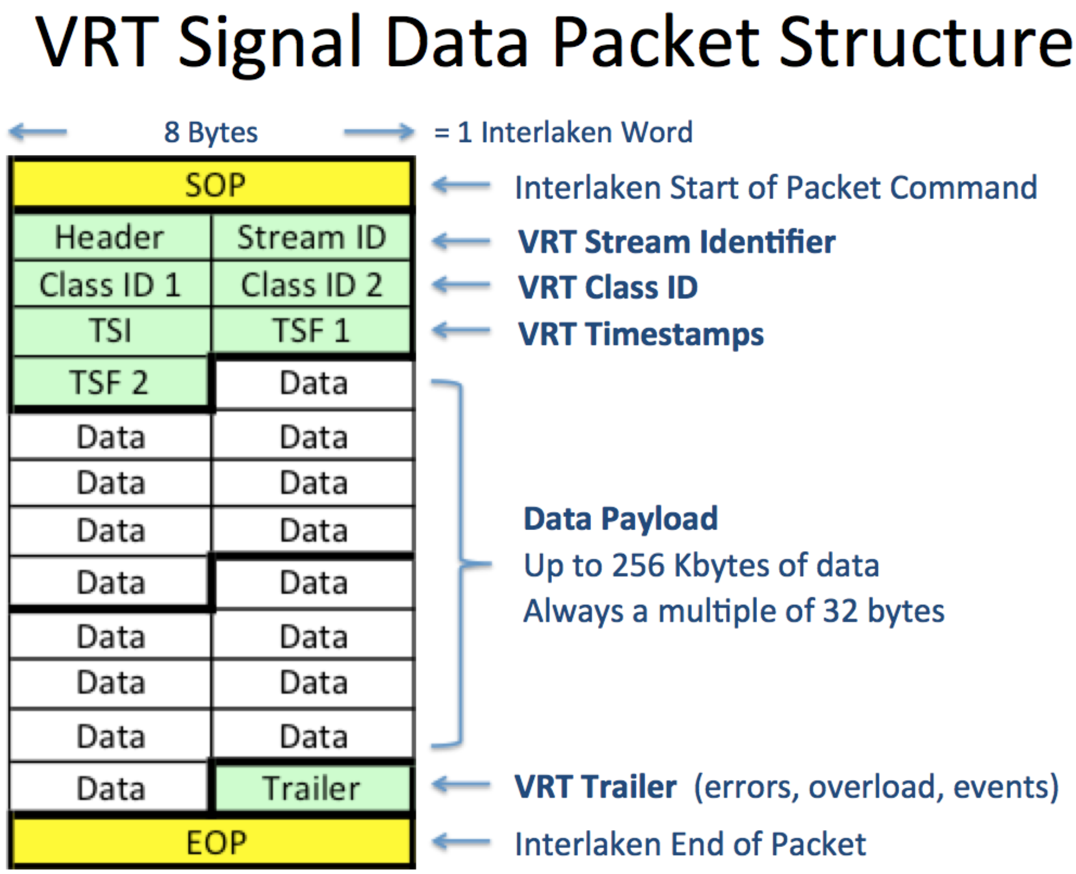

Figure 3 shows the structure of a VRT (VITA Radio Transport) Signal Data Packet. The yellow shows the Start of Packet and End of Packet commands from the Interlaken protocol, part of the ODI physical layer. Green cells denote the Prologue and Trailer of the VRT packet, which carry metadata about the signals being transported, 32 bytes for each packet. The white cells denaote the actual signal data payload, which may be up to 256 KBytes in length. Data is streamed by sending consecutive VRT packets.

Several features come with the adoption of VRT by the ODI standard. The Prologue and Trailer, denoted as green cells, bring new capabilities not available in standard measurement buses. Here is a brief list of the new capability, viewed by examining the packet structure.

Header. The header denotes the type of packet being sent, and its length. This article focuses on Signal Data Packets, but VRT also allows Context Packets and Control Packets. Context and Control packets can occasionally send metadata about the signal, such as its RF and IF frequencies, bandwidth, and amplitude. ODI-2 defines how any packet in the complete taxonomy of VRT packets can be transported and executed.

Stream ID. The most common ODI application is the transmission of synchronous single–channel or multi-channel sample data from one device to another. This is called a stream. In most applications, a single stream is sufficient, as all data is synchronous. Streams can contain thousand of channels, if necessary, or just one. These streams are each identified by a unique Stream ID (identification) number. Stream ID is retained when data is stored, so the entire sequence can be recreated when played back to an ODI-capable signal generator. Stream ID is also used during port aggregation to associate the ports together as one large data pipe. Finally, Stream ID identifies one stream from another, allowing multiple, asynchronous streams to be transported across the same ODI link.

Class ID. Class ID (identification) plays a key role in interoperability, as it specifies the data formats to be used in the data payload. The ODI-2.1 Data Format standard uses an algorithmic approach so the Class ID unambiguously determines the number of signal channels, complex or real numbers, binary or floating point, the length (number of bits of resolution) of each data sample, and the packing method. ODI-2.1 also allows for a method to include events on a sample by sample basis, when indicated by the Class ID. These may be trigger signals, markers, overload detection, or any of a number of different event definitions. Everything is included in the Class ID fields to completely determine the meaning of the data payload, even between vendors.

Timestamps. This is a very important aspect of ODI, and is without parallel in other measurement buses. ODI embraces the VRT timestamp capability, where the absolute time of the first sample is specified in the Integer Timestamp (TSI) and Fractional Timestamp (TSF) fields. Though timestamps are optional in ODI, they bring new synchronization capabilities between devices. ODI allows UTC, GPS, and free running sample counts as timestamps.

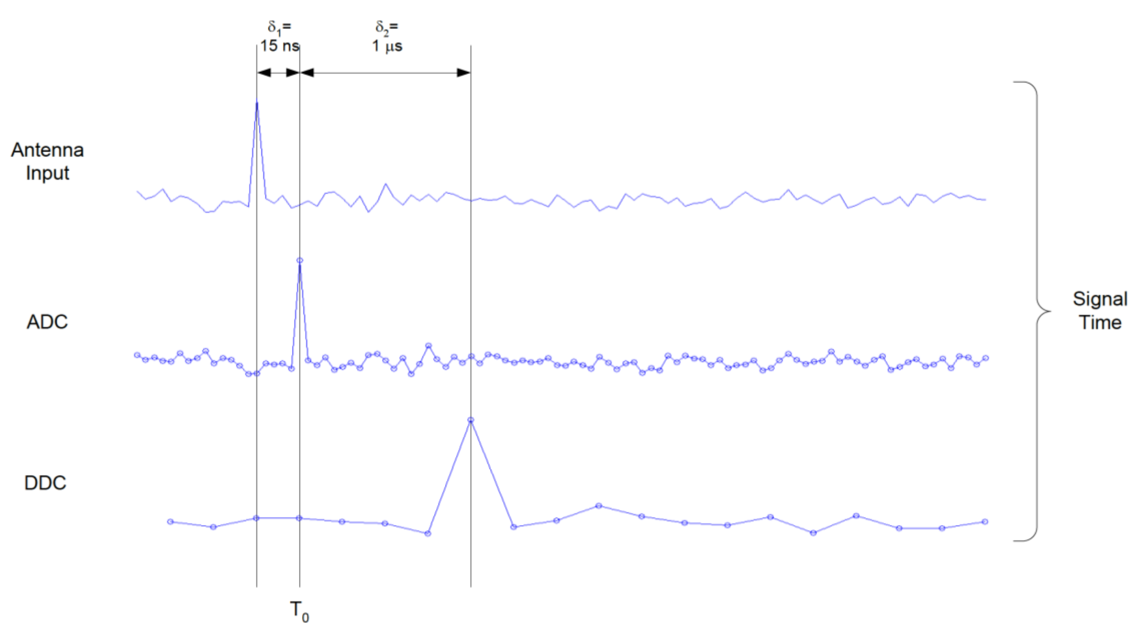

Figure 4 above shows how signals may occur at different points of the measurement system. Timestamps allow the alignment of signal data, even when it comes from different devices. Applications such as beamforming require precise time matching of data, which can be achieved through the VRT timestamps. Image courtesy of VITA 49.2.

Trailer. All ODI Signal Data VRT packets end with a trailer. This allows to identify events that occurred during the data stream, such as an overload or loss of AGC lock.

Data Payload. The flexibility of the VRT data payload is a key reason ODI embraces VRT. As mentioned in the Class ID paragraph above, nearly any combination of signal channels, data formats, and packing methods may be used. ODI-2.1 specifies the mandated and permissible formats. 8-bit and 16-bit data handling is required by all devices, but a device may use any resolution in-between. Real and complex data is supported, as well as channel counts from 1 to 8192. These resolutions match well with the speeds delivered by ODI. Longer data sample lengths and floating point representations are also allowed.

Embedded Applications

While ODI was conceived by players in the electronic test market, VRT was invented by VITA for embedded applcations. This expands the possible applications for ODI beyond electronic test to include embedded applications such as those found in mil/aero avionics. ODI's adoption of VRT allows new synergies.

First of all, embedded designers can use VRT over the ODI interface for very high speed data communication. VITA 66 defines standard optical ports, typically deployed on a VPX backplane. ODI is compatible with the VITA 66 definition, and could be deployed as the optical interface between VPX modules, carrying standard VRT packets. Additionally, the alignment of data packets and formats between measurement applications and embedded applications will lead to synergies in the design and development of embedded systems, as instruments and processing units can directly interface with the optical links of the embedded systems. This will enable critical measurement and processing functionality early in the development process.

Summary

ODI is different from all other test and measurement buses. It is a high-speed point-to-point interface that carries real-time signal data. The speeds, data formats, and timestamps are optimized for wide bandwidth multi-channel data, as found in 5G, radar, electronic warfare, and other RF applications. Its data bandwidth exceeds that found in standard electrical interfaces, and it can be cabled up to 100 meters between devices. Ports can be configured in parallel for more speed, and there is a roadmap to more per-port speed to come. It has standardized data formats that are both, general purpose and ideal for software defined radio applications. It changes the measurement system paradigm from connecting analog signals between instruments, to connecting digital signals between measurement devices, processors, and storage systems. It is as applicable to embedded systems as it is to measurement systems.

ODI is literally a ray of light to address challenging new measurement and embedded applications. The complete set of ODI specifications can be found on the AXIe website at http://axiestandard.org/odispecifications.html