The new ODI optical bus is fundamentally different from all other test and measurement buses

By Larry Desjardin, Modular Methods

In October of this year, the AXIe Consortium, the VITA trade association, and six companies announced a new instrumentation standard called the Optical Data Interface, or ODI for short. The companies endorsing the standard were Conduant, Guzik, Intel, Keysight, Samtec, and Xilinx.

ODI shatters conventional distance and speed records. Based on optical links between instruments, ODI can stream data up to 20 GBytes/s from a single optical port, with speeds up to 80 GBytes/s through port aggegation. 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. In October, I wrote gave a brief technical overview of the ODI standard, which you can read here. In this column I will dive deeper, and show some of the unique aspects of ODI that don't exist in other instrument buses.

ODI differs from other test and measurement buses (LXI, GP-IB, AXIe, and PXI) in some very interesting ways. These include:

- Speed and Distance
- Data vs. Control
- Port Aggregation
- Point-to-point vs. Bus
- Standardized Data Formats
- Timestamps

In this article, I will describe how the above features differ from those found in other buses. Since ODI can be used with all other buses, I will describe how that is done as well. Finally, I will describe how ODI can be used well beyond test and measurement, and into embedded applications.

Speed and Distance

The most obvious difference is that of the physical layer. 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.

Contrast that to GbE (Gigabit Ethernet), the most common interface for LXI instruments. GbE is capable of about 0.11 GBytes/s in optimal conditions. 10GbE will bring this to 1.1 GBytes/s. Even the modular standards of PXI and AXIe, with their blazingly fast PCIe (PCI Express) connections, are constrained. Their throughput becomes a straightforward calculation of lane width to each slot, multiplied by the generational speed of the PCIe fabric. Figure 1 shows the maximum theoretical throughput of each of the modular systems compared to ODI. Furthermore, the modular systems need to have those figures de-rated by 20% for realistic values, while the ODI systems support their headline speeds.

	Bus Speed (GBytes/s)					
	PXIe: (PCIe x8)	AXIe: (PCIe x16)	ODI 1-port	ODI 2-port	ODI 4-port	
PCIe Gen2	4	8	20	40	80	ODI-1 (14.1 Gb/s)
PCIe Gen3	8	16	40	80	160	ODI-1.1 (28 Gb/s)

Figure 1 shows the theoretical top speeds possible to each PXI or AXIe slot, and that for ODI interfaces. ODI-1 shows current ODI speeds today, ODI-1.1 shows the value as the optical rates double in the next generation.

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 essentially 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.

Data vs. Control

Another key difference is that ODI is a data interface only. Control is executed over a device’s native control bus, as shown in Figure 2 below.

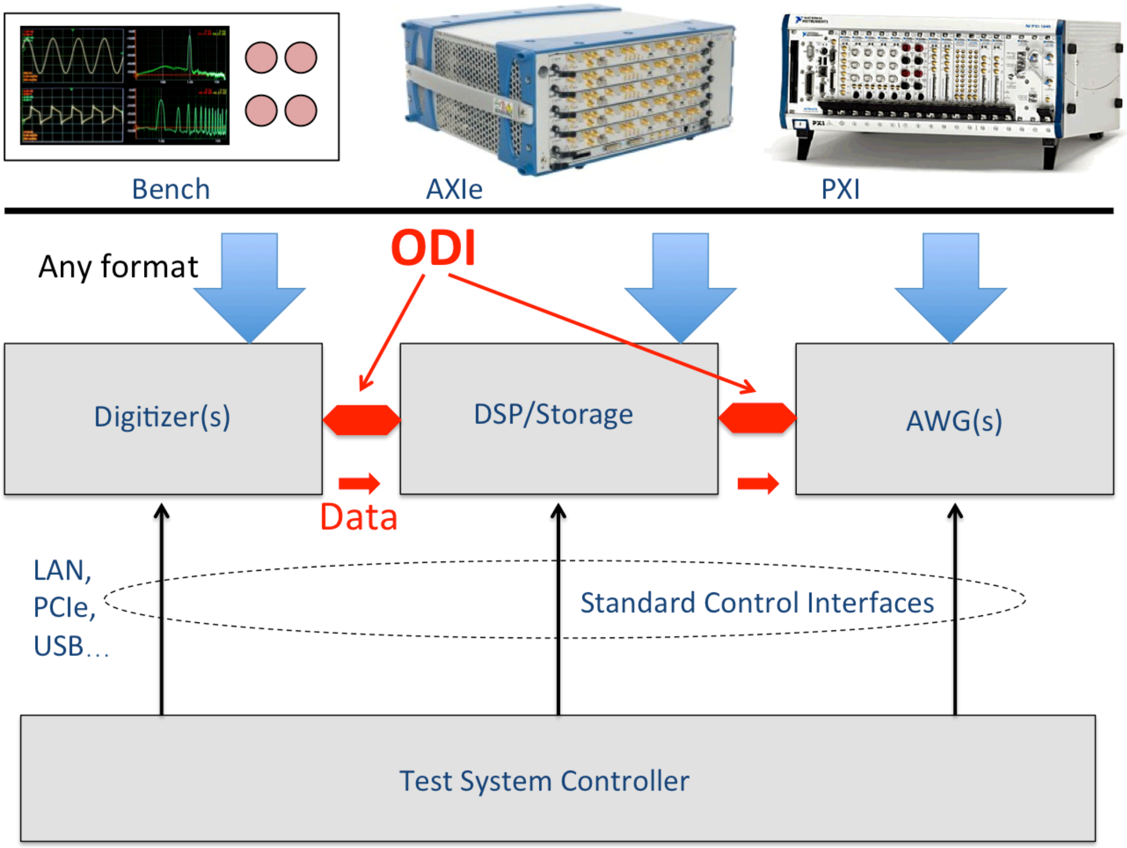

Figure 2 shows a hypothetical storage and playback system using ODI, the Optical Data Interface standard. Since ODI is a pluggable interface, any product can become ODI-enabled, regardless of form factor. The devices are controlled through their standard native interfaces, typically LAN or USB for a traditional instrument, and PCI Express for a modular instrument. Data is streamed over the separate ODI link.

Segmenting control from data has many benefits. One is that current instruments, regardless of form factor, can be enhanced to include ODI capability. The control functions of today's instruments remain the same, though extended for ODI-specific commands. Only an ODI optical port needs to be added.

However, the key benefit may be that, by removing control traffic from the data interface, uninteruptable high-speed data rates can be guaranteed. There is no sharing of bandwidth with the control commands, and no random interuption of data traffic when commands occur.

This may be a good time to add that the most recent VITA 49 specification, VITA 49.2, does allow for some limited control functions to occur. Since ODI adopts the VITA 49 packet structures, this capability will be included in the future.

Port Aggregation

Another difference is that ODI speeds increase proportionally to the number of ODI ports used. For example, a 4-port device can send data at 80 GBytes/s, four times the nominal bandwidth of a single port. This could theoretically be the case with PXI or AXIe products as well, as multi-slot devices could access the fabric from each slot. However, to the author's knowledge, this has never been deployed, and certainly wouldn't be the case for LAN-based instruments. However, port aggregation is a key feature of the ODI specification. Figure 3 shows a system configuration where four ports are aggregated to quadruple the bandwidth.

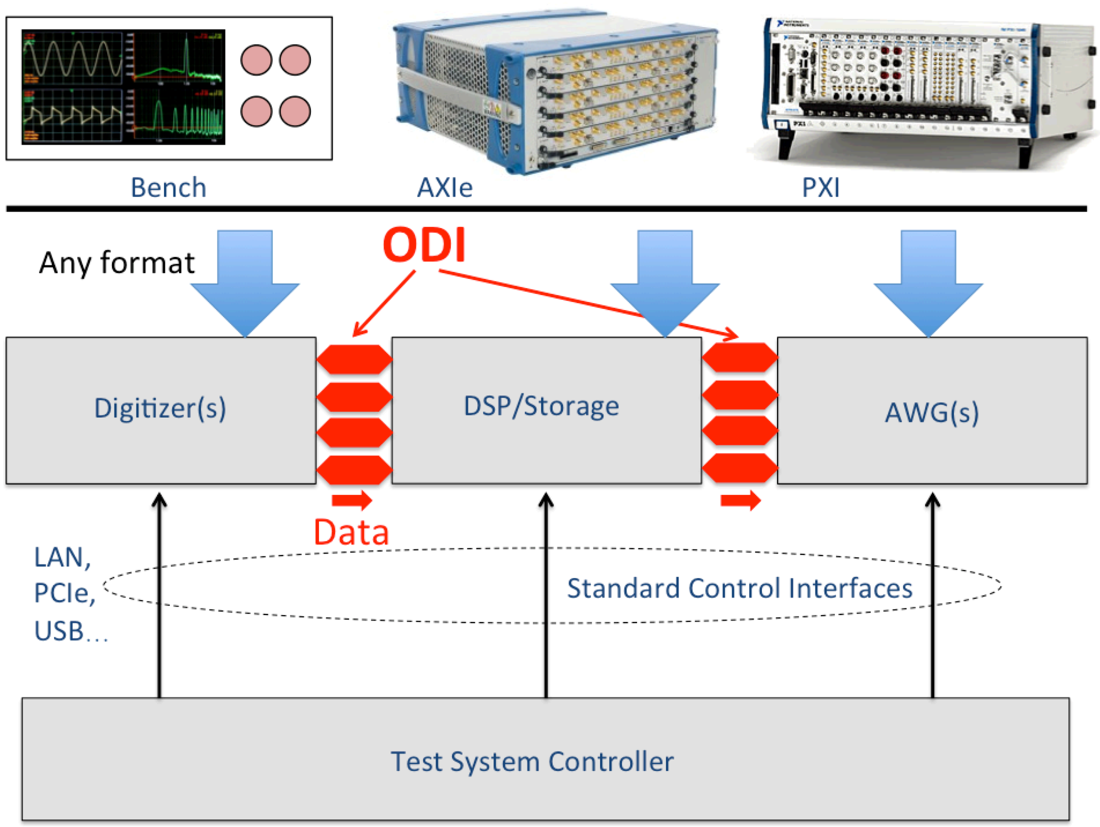

Figure 3 shows a system where four ODI ports are aggregated to increase total throuput, first from the digitizer to the storage system, then from the storage system to an arbitrary waveform generator. Four ports, each capable of 20 GBytes/s sum to a total bandwidth of 80 GBytes/s.

Point-to-Point vs. Bus

Most test and measurement buses are conceptually a bus structure. That is, a single controller connects to multiple instruments through a single interface, be that LAN, USB or PCI Express, as shown in Figure 4. ODI, on the other hand, is a dedicated point-to-point link. In many ways, ODI can be though of as a signal connection between two devices, with the signal being a digital representation of an analog signal.

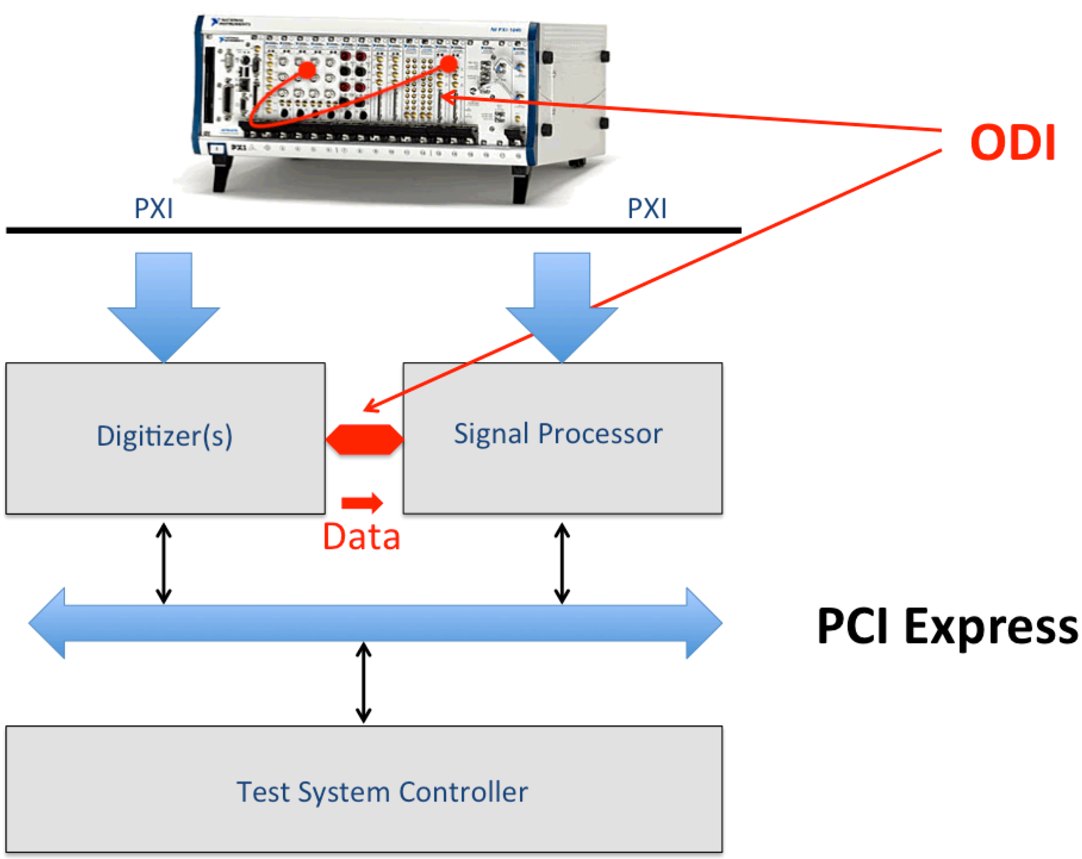

Figure 4 contrasts the topology differences between ODI and standard test and measurement buses, like PCI Express found within PXI and AXIe. The example shows a PXI system with an embedded controller, a multi-channel digitizer, and a signal processor. All are linked togther through the PCI Express fabric, where the control occurs. An ODI point-to-point link is connected from the PXI digitizer module to the PXI signal processor module on the faceplates, to create a user-customized signal analyzer.

Standardized Data Formats

From the above examples we can see many differences between ODI and standard test and measurement buses- speed, distance, control, and topology. ODI adds something else that standard buses don't – standardized data packets and formats. 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.

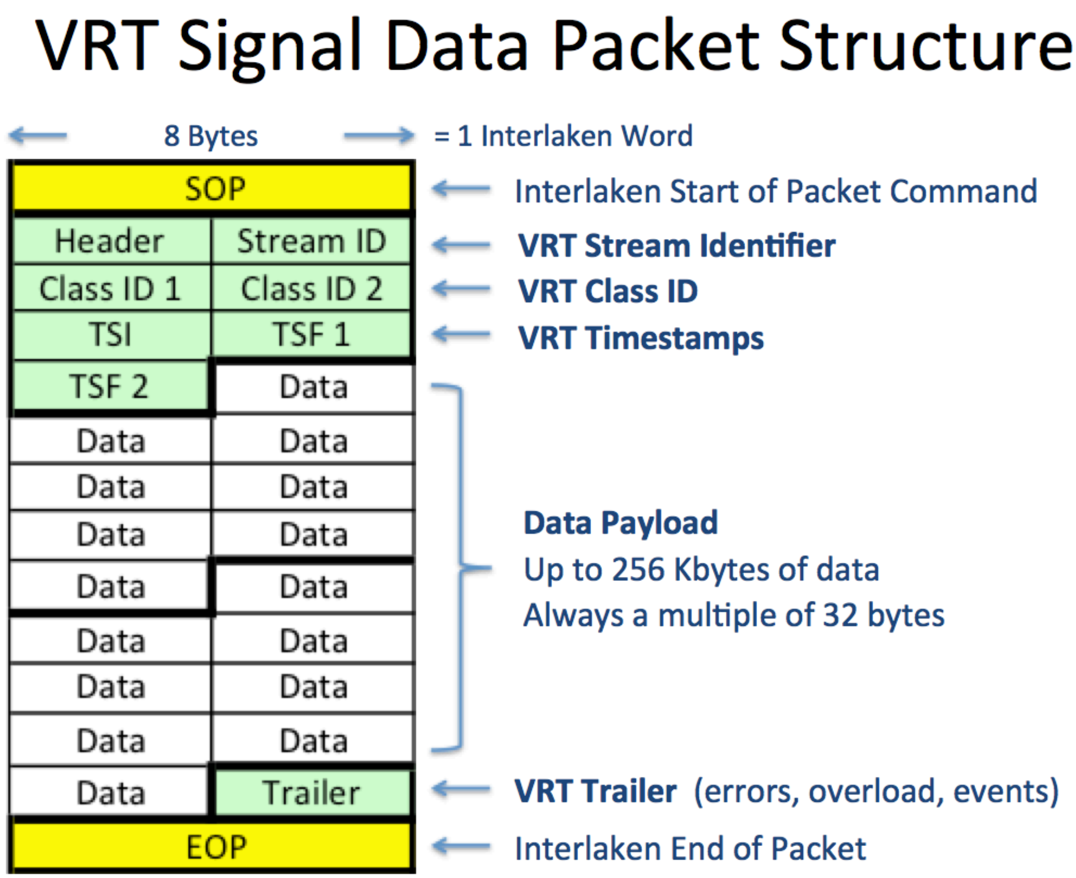

Figure 5 shows the structure of a VRT (VITA Radio Transport) Signal Data Packet. The yellow shows the Start of Packet and End of Packet commands from the Interlaken protocol, part of the ODI physical layer. Green cells denote the Prologue and Trailer of the VRT packet, which carry metadata about the 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.

Figure 5 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.

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 examaning 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 Command Packets. Context packets can occasionally send meta-data about the signal, such as its RF and IF frequencies, bandwidth, and amplitude. ODI-2.1 incorporates a standard Context Packet for measurement applications. Command Packets allow one device to send control information to another, and future revisions of ODI will incorporate Command Packets as well.

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 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 togther 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 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 determines the number of signal channels, complex or real numbers, binary or floating point, the length (number of bits) 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 detectors. Everything is included in the Class ID fields to completely determine the meaning of the data payload.

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. If timestamps are used, ODI mandates the use of GPS timestamps.

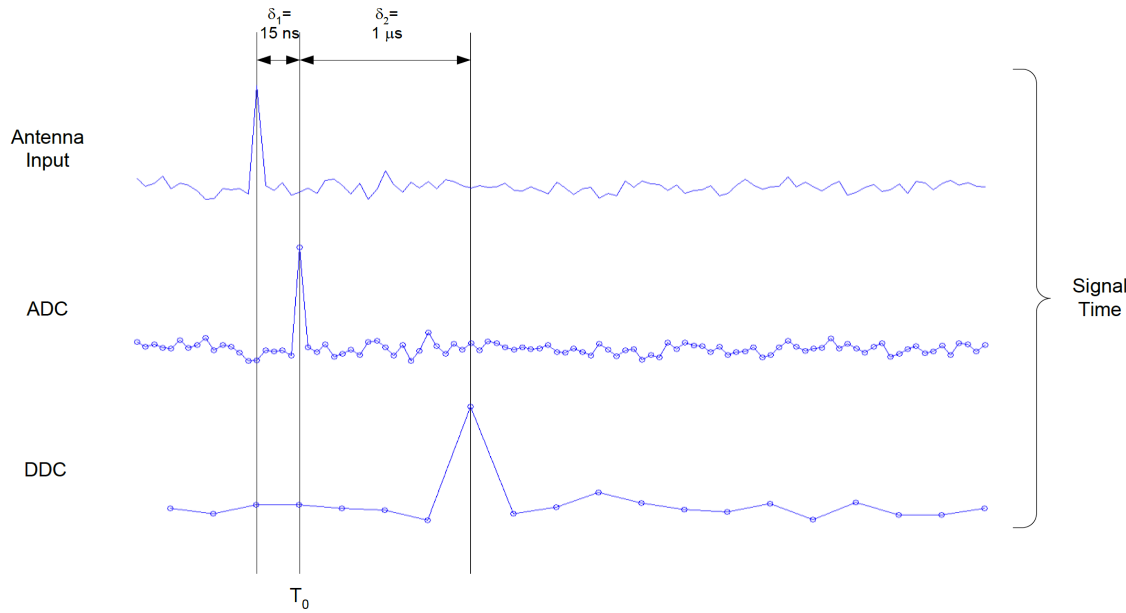

Figure 6 shows how signals may occur at different points of the measurement system. Timestamps allow the alignment of signal data, even when it comes from different devices. Applications such as beamforming require precise time matching of data, which can be achieved through the VRT timestamps. Image courtesy of VITA 49.2.

Trailer. All ODI 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, which allows the handling of any resolution in-between. These resolutions match well with the speeds delivered by ODI. Longer data sample lengths and floating point representations are also allowed.

Embedded. The VRT packet structure and protocol was initially invented for embedded applications, such as that found in 5G systems or mil/aero avionics. It is not specific to embedded applications, and works over any communication medium. 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 to be 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.

For more detailed information about the ODI specification, please go to the ODI specification web page here.