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Implementing USB into Industrial Environments using FPGA technology

Interoperability, ubiquity, performance and ease-of-use are some of the features that have made USB 2.0 the hot swap connection of choice for PCs and a dazzling array of peripherals and gadgets. Boasting more than 2 billion ports worldwide, its widespread adoption in the PC and consumer electronics space is prompting many companies to engineer USB into their existing and roadmap embedded designs, furthering its reach and compatibility with other classes of device.

This development has given rise to the increased presence of USB in industrial markets and in this article we present how it is the coupling of the bus standard with FPGA technology that has turned dormant USB ports into live connections transporting real-time data between systems and their host.

The Industrial Context

The industrial control and measurement environment is an interdependent mesh of smart sensors, machine vision, relays, controllers, actuators, I/O connections, data acquisition (DAQ) subsystems, storage and human machine interface (HMI) terminals. The environment can be harsh and subject to extremes of temperature, humidity, vibration, impact and electrical noise. The industrial computer network itself, or fieldbus is a complex hierarchy of real-time distributed control systems. Within the network there is typically a management system or HMI that operates and monitors the system, connected to a middle layer of programmable controllers that are connected to the fieldbus measurement and control equipment (e.g. sensors and machine vision).

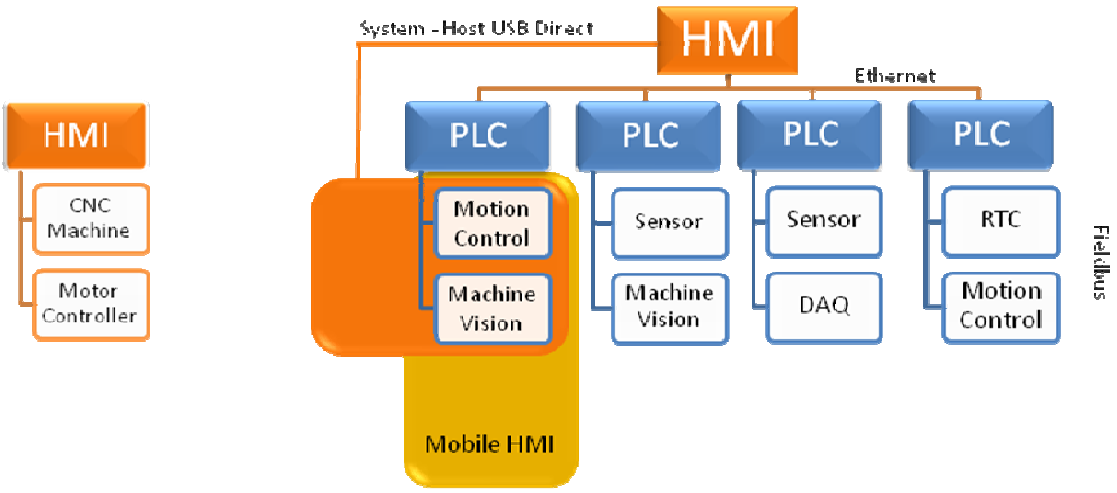
The FPGA + USB Proposition

With USB ports now widely available on operator-side PCs and HMIs the FPGA + USB proposition is to quickly, reliably and cost effectively connect these human machine interface terminals to industrial monitoring and control equipment, and enable quicker response times to trouble-shooting or unplanned field monitoring and diagnostics.

Figure 1 is a representation of how the Human Machine Interface (HMI) connects to the fieldbus measurement and control equipment via a PLC. By using an FPGA + USB solution a fast and direct

connection between the end-system and host can be enabled with the PLC functionality, DSP processing and control algorithms being implemented directly in the fabric of the FPGA.

Figure 1: representation of the Human Machine Interface connection to the fieldbus measurement and control equipment via a PLC or via USB direct



Point-to-point system host connectivity

HMI direct connect to the end-system and mobile monitoring via FPGA + USB

Remote diagnostics and dynamic monitoring are improved through the mobile operator being able to connect directly to the end-system using USB. The FPGA and PLC functionality is local to the system and USB is quick to set up and hot swappable

For point-to-point, low cost connectivity between a host and system, FPGA + USB removes the PLC from the control flow and is ideally suited to applications such as CNC pick 'n' place and an array of marketing system applications.

By exploiting the flexible I/O and inherent reprogramability of FPGAs interfaces can be optimized for end-systems. The processing power of the FPGA can be harnessed for local processing of the DSP DAQ functions and the complex outbound control algorithms. Real-time functionality delivered by existing programmable controllers or PLCs can be implemented into the FPGA fabric enabling lower cost direction connections between system and host.

The dividend is an agile and more streamlined approach to faster, lower cost, reliable communications, allied to parallel processing that can be quickly implemented across an array of end-systems (Table 1).

Industrial Requirement	FPGA – USB Proposition	
	USB	**FPGA**
Cost Efficiency	• Standardisation • Proliferation • Commoditization • Low cost interface standard & cabling • Major OS support	• Spartan 3 offers the industry's lowest total cost FPGA • PLC functionality can be implemented inside the FPGA
Reliable Communications	• Transmission over twisted pair • Differential signalling to mitigate noise • Error checking built into the protocol	• Custom designed interface • Optimized for the end-system
Real-time monitoring & diagnosis	• Transfer rates up to 480 Mb/s. • Connectivity for up to 127 devices	• Flexible I/O • Parallel execution • Local processing of DSP function & control algorithms • Optimal buffering
Rapid response to localized troubleshooting and short-term diagnostics	• Hot swap, plug-and-play ease of use • Fast set up • No configuration	• 'Instant-on' • Reprogrammable • Low power for mobile operation • Powered from the USB port

Table 1: The FPGA + USB value proposition to industrial markets

Application

Representative applications for USB in the industrial segment include proportional–integral–derivative (PID) controllers, CNC pick 'n' place machines, data loggers for recording data from remote systems or to upload new data to remote terminals, short term industrial monitoring and troubleshooting, and to enable plug-and-play wireless for systems that need to connect over long distances. Moreover industrial applications are subject to measurement and diagnostic data from a large number of I/O channels and often at very high acquisition rates. The I/O bottleneck needs to be avoided and the I/O needs to offer the right mix for industrial applications.

To support this set of requirements and to make the implementation choice easier for the designer, Orange Tree selected the Xilinx Spartan-3 and Cypress EZ-USB FX2 USB to be at the heart of its ZestSC1 FPGA + USB platform (Figure 2). Expressly created as a high performance programmable system interconnect solution the ZestSC1 realizes the FPGA+USB proposition. In a small form factor it provides the designer with a configurable platform with less up front development cost, flexible I/O and sustained levels of performance.

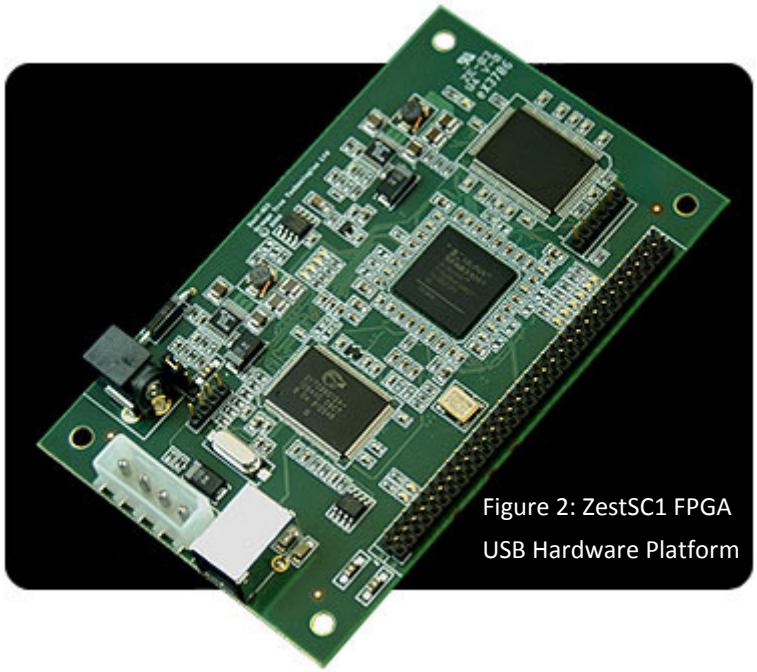


Figure 2: ZestSC1 FPGA USB Hardware Platform

There are three main devices attached to the FPGA on the ZestSC1:

- I/O – 49 I/O signals
- USB controller
- SRAM – 1Mb or 8Mb synchronous SRAM

The FPGA is connected to a host computer over High Speed USB (12 or 480Mbits/sec) for configuration and data communication. A synchronous SRAM of either 1 or 8 MBytes stores application data, and a pitch header can be used for I/O. The ZestSC1 block diagram is shown in Figure 3.

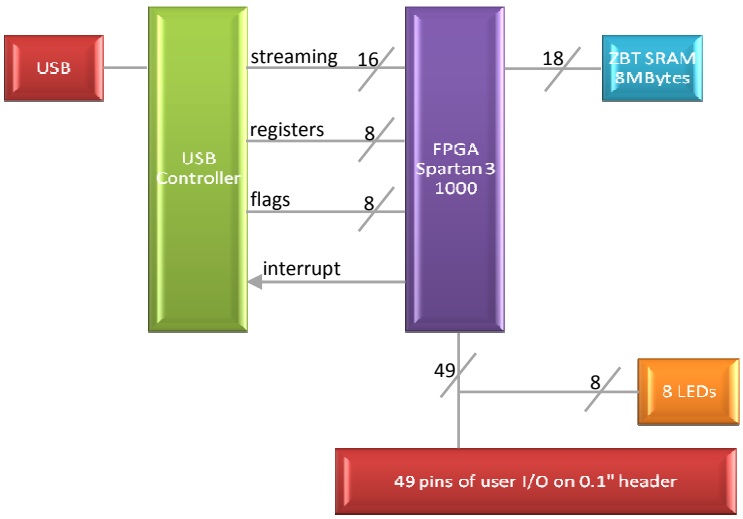


Figure 3: ZestSC1 FPGA-USB Block Diagram

The USB controller is the Cypress EZ-USB FX2 USB device that includes an 8051 microcontroller used for USB enumeration and board management firmware. The 8051 address and data buses are connected to the FPGA with the USB controller interface implemented entirely in the FPGA. The ZestSC1 comes fitted with an EEPROM containing firmware to communicate with the supplied host driver and the overall package is provided with additional software support.

Three interfaces between the FX2 device and FPGA are accessible using the supplied host library:

- Streaming – data streaming at the maximum USB bandwidth;
- Registers - control and status registers in the FPGA application; and,
- Signaling – single bit interrupt and flags.

Full software drivers and libraries for Windows are bundled with the ZestSC1, as are logic core libraries. The end result is a flexible, off-the-shelf package that can be quickly implemented to meet the demands of the industrial environment.

Conclusion

Following in the footsteps of Ethernet, USB penetration into the industrial space is growing. It has overcome concerns about its connector performance, communications reliability and throughput. It

is forecast to reach 4 billion ports by 2011 and whilst it is distance limited to 5m, hubs and extenders and can increase its range by 10X.

Closely coupling USB with FPGAs unlocks the latent potential of the bus interface in the industrial market. PLC functionality can be migrated to the FPGA, dynamic monitoring better supported and the end-benefit is more flexible and lower cost high throughput communications.

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About Orange Tree

Orange Tree Technologies is a board level embedded hardware and software company specializing in FPGA technology and system-host communications interconnect. Used by some of the world's leading technology companies our products and services help address the challenges of convergence in the defense, industrial, scientific and consumer electronics markets. For more information visit www.orangetreetech.com

Orange Tree Technologies has been providing FPGA based system interconnect solutions since 2001. Its product strategy concentrates on innovative deployments of high density FPGAs coupled with high performance bus technology and proprietary IP. OEM engagements are supported through customization via Orange Tree's dedicated design services function. Headquartered in Oxfordshire, UK, Orange Tree Technologies is a privately held company and operates internationally.