User-configurable FPGA modules boost PXI-system versatility

Richard Quinnell - June 10, 2010

The advent of PXIe (Peripheral Component Interconnect Express) created new opportunities for PXI systems to handle more data faster. Module developers turned to FPGAs (field-programmable gate arrays) as hardware-configurable alternatives to high-speed or multicore CPUs for handling this data. Now, such FPGA performance and configurability are becoming available to system developers and end users, adding a new range of design possibilities for PXI systems.

PXI-module developers began using FPGAs in their high-performance designs nearly a decade ago to handle ever-increasing data rates and to reduce latency. The configurable hardware offered significant performance advantages over software-based designs. Sebastien Maury, Sundance Multiprocessor Technology’s regional director for the Americas, estimates that an FPGA can provide 20 to 30 times more digital-processing performance than a PXI host controller.

According to Ryan Verret, FPGA-for-test product manager at National Instruments, the performance boost can be as much as several orders of magnitude. "It's really staggering what computation you can do on an FPGA," he says. "Some devices have more than 500 DSP blocks on them, allowing you to do lots of FFTs [fast Fourier transforms] in real time."

Flexibility is another reason for incorporating FPGAs into module designs. David Manor, vice president of hardware engineering at Geotest-Marvin Test Systems, points out several advantages that stem from field configurability. "Using FPGAs allows us to get products that relate to new standards out early, even before the standards are fully defined," he says. "We have to make some assumptions, so we may not get everything exactly right at first, but [we] can release updates and bug fixes for users to download without the need to return their boards to us."

The use of FPGAs also simplifies the creation of unique functions for customers. "The customer simply installs new firmware to gain new features," Manor says. He adds that the ability to upgrade and modify module functions in the field helps keep Geotest’s products viable longer in a given
Configurable FPGAs

Until recently, however, the FPGAs in PXI modules have been nearly inaccessible to end users. Upgrades and enhancements came from module vendors, and users could not readily implement their own design ideas. That situation changed in the last year with the introduction of user-configurable FPGA modules for PXI from at least four manufacturers: Geotest, NI, OpenATE, and Sundance.

The Geotest GX3500 PXI module connects 160 digital I/O channels to an Altera Cyclone III FPGA with 55,000 logic elements, four PLLs (phase-locked loops), and 2.34 Mbits of memory. The FPGA has access to all PXI-bus resources, including clocks and triggering. The module also supports an internal expansion-card assembly that customers can use to customize the front-panel I/O connections (Figure 1).

NI offers the FlexRIO family of FPGA modules, which uses Xilinx (www.xilinx.com) Virtex-5 FPGAs of varying capacities. The NI PXI-795x series comprises conventional PXI modules, whereas the PXIe-796x-series instruments are PXIe modules. FlexRIO modules offer 132 I/O lines and accept front-panel-mounted adapters that customize the I/O interface for connection to analog, Ethernet, IEEE 1394 (FireWire), Camera Link, and other specialized interfaces (Figure 2). Adapter modules are available from NI as well as from third-party partners, such as Adsys Controls, Averna, NexFrontier Solutions, and Prevas.

OpenATE also uses a Xilinx Virtex-5 FPGA on its FPGA carrier card. The OpenATE card offers a more basic design than those from Geotest and NI, however, with the FPGA handling the PXI-bus interface. The company does provide PXI-interface IP (intellectual property), as well as IP for a DIMM (dual-inline-memory-module) interface. The FPGA carrier supports a user-defined daughtercard that handles 156 I/O lines but provides no built-in front-panel connections. Users must customize the front panel along with the daughtercard.

The Sundance SMT-700 FPGA card offers a PXIe interface, a variety of front-panel serial interfaces, and internal digital-I/O headers along with a choice of several Xilinx Virtex-5 devices. Front-panel serial interfaces include 10/100/1000 GbE (gigabit Ethernet), fiber optic, and USB (Universal Serial Bus). Dual internal mezzanine connections allow developers to attach Sundance analog modules or additional digital I/O to the FPGA card. The connections reside on both sides of the board, causing the FPGA card to occupy two PXI slots when populated.

Customize I/O

Although these FPGA modules have significant differences, they do share some attributes. For example, you can convert each of them from a simple data-processing card into a fully defined instrument with the addition of customization circuitry, through either a mezzanine or an extension card. FPGA-module vendors offer both predefined cards and open specifications from which users can develop their own cards. This ability to define the module's I/O-signal conditioning and formatting combines with the FPGA's configurability to give users an unprecedented opportunity for creating innovative PXI-module functions from off-the-shelf building blocks.

An FPGA module with high-speed ADCs on the customization card, for instance, has all the necessary hardware to serve as a digital spectrum analyzer. Because of the tremendous parallelism available in the FPGA, the analyzer can provide continuous monitoring across a wide frequency band...
in place of the usual swept-spectrum analysis. As NI’s Verret points out, this feature allows the FPGA-based instrument to analyze time-multiplexed communications protocols, such as RFID (radio-frequency identification), that use short energy bursts. Swept-spectrum instruments can easily miss these bursts. Verret also notes that the continuous monitoring allows an FPGA-based instrument to generate triggering signals based on complex power-frequency spectrum masks. This feature can be helpful in reducing the capture-depth requirements of downstream data-acquisition systems.

Developers can also configure an FPGA module to dynamically generate test signals, reducing the number of test vectors necessary in an ATE (automated-test-equipment) system. For example, when a conventional ATE system needs to send data to a communications port on an IC under test, the system must use a long series of test vectors to drive arbitrary-waveform generators that produce the signals driving the port. These vectors must describe the signal values at every time step throughout the data transfer and can be long. By using an FPGA, developers can create a state machine that can control the signal timing so that the test vectors describe only those data values that will be transferred and not the signal's entire time history.

Dynamic signal generation also allows an FPGA-based instrument to handle situations that are difficult or impossible to handle with static vectors. Testing of RFID devices, for instance, is difficult with static vectors because they involve multiple stimulus-response interactions, which may have variable timing. Similarly, the testing of an engine-control module requires that the tester emulate how the engine and drive shaft will behave in response to the control signals. Such responses are virtually impossible to emulate with vectors, and host-controller-based emulation is often too slow or has too much latency. An FPGA-based emulator can resolve all these issues.

FPGA modules can even adapt their functions on the fly. According to Sundance’s Maury, systems can partially reconfigure an FPGA while the module is running to change its behavior in response to incoming signals. Such dynamic changes might include altering test vectors to more extensively test functions that appear marginal or automatically revising signal-processing-algorithm parameters to tune them for the current test conditions.

**Development support**

The extreme flexibility that user-configurable FPGA modules provide PXI developers does come at a price. NI’s Verret, for instance, points out that designing the logic of an FPGA may not be within the abilities of many test engineers because of the need to work with an HDL (hardware-description language) to define their designs. "Even if they have the skills," says Verret, "[configuring an FPGA] is harder to do than writing processor code." To minimize the FPGA-configuration effort, most module vendors offer development support. NI, for instance, has created an FPGA-module extension for its LabView development tool. This extension allows developers to describe their entire test-system design and data-processing algorithms in LabView and have the tool automatically prepare the FPGA-programming code. The company is also providing a library of IP for more complex, application-specific functions. NI's third-party partners offer additional IP as well as full turnkey solutions.

Geotest has made its FPGA module fully compatible with standard Altera object files, meaning that developers can use the free Quartus II Web Edition development tools that Altera provides in support of its FPGAs rather than needing proprietary tool sets. Geotest also provides drivers and a virtual panel for interactive design, debugging, and deployment of the FPGA configuration. Interface files for this tool support programming tools and languages, such as ATEasy, C/C++, Visual Basic, and LabView. The company offers an online tutorial to help developers get started.
Sundance, which caters to more experienced hardware-design customers, provides only some basic software to developers. For full development support, the company works in partnership with software company 3L. The 3L Diamond tool set allows developers to create a task-based model of the FPGA's function, and it then automates the design's compilation to FPGA-programming vectors. It also supports the synchronization of multiple FPGAs for achieving extended performance through multiprocessing. Developers can also use a tool such as The MathWorks Matlab to capture their designs and convert the tool’s output to an HDL for compilation using Xilinx tools.

**Will an FPGA help?**

Although the level of programming involved in customizing a user-configurable FPGA module for their applications may be daunting to many PXI users, the results can be well worth the effort. The key is deciding whether the effort is necessary. NI's Verret recommends that users consider an FPGA module if they can benefit from custom triggering that will reduce the amount of data the host controller must process and when data-processing requirements demand the performance that an FPGA provides. Geotest's Manor says that the use of an FPGA card is justified when there is nothing available to support a special function that an application requires or when there is a need to change functions on the fly.

Ultimately, customer feedback will determine the long-term future of these user-configurable PXI modules. Vendors anticipate continuing to offer larger, faster FPGAs as they become available and will likely create additional daughtercards and IP based on the frequency of customer requests.

Even if the FPGA module remains only a specialty item, however, the future is secure for FPGAs in stock PXI-instrument modules. "We couldn't be where we are today in PXI without FPGAs," says Geotest's Manor. "They have been a key component in the success of PXI as a performance platform."

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