The Advantages of SoC-based Test Systems

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Introduction

Standalone test systems are historically the most heavily utilized type of equipment found in test labs. Test platforms such as oscilloscopes started in the analog domain by translating low-frequency electrical signals on a cathode-ray via vertical and horizontal amplifiers. However, with the advent of high-speed analog-to-digital converters (ADCs) and digital storage oscilloscopes (DSOs), this analog data could be sampled and converted into digital data for processing and display. Cutting-edge 64 gigasamples per second (GS/s) ADCs allow DSOs to reach sample rates up to 256 GS/s, with a real-time bandwidth of 110 GHz. Higher resolution 16-bit ADCs allow for even more fine-tuned viewing of differences in large amplitude signals by capturing 0.0015% amplitude signal distortion. Oscilloscopes have made major technological leaps in their front-end and data acquisition (DAQ) architectures, employment of state-of-the-art InP, SiGe, and basic CMOS processing technologies, and increasingly complex DSP techniques. The extremely high bandwidth real-time oscilloscope with advanced time interleaving techniques makes some standalone oscilloscopes run well into the million-dollar mark. Despite these advancements, low- to high-end standalone test equipment is still defined largely by their closed operating system (OS) and a user interface (UI) managed through buttons and dials. The nature of this architecture makes it optimized for a singular function. And, while add-ons and additional features are possible, they are costly and typically involve additional proprietary hardware and software.

SoC-based test systems include SoC hardware that often runs a native OS without the need for an external PC, providing a similar type of functionality and user configuration as standalone equipment. This diverges a bit from the familiar USB-based test equipment that is, more often than not, built on an FPGA and leverages the PC OS that supports and controls the customization of the equipment. This article uncovers the advantages of employing an SoC-based test system over the traditional standalone equipment while also diving deeper into how one engineering company is using these SoC-based systems as a viable test and measurement (T&M) solution.

A look at USB-based test systems

Most users are familiar with USB-based test systems as an alternative to standalone test equipment. The Digilent Analog Discovery 2 (AD2), for example, connects to a PC through a USB (***Figure 1***). The PC runs software that controls the AD2 for control and customization with test automation, data processing, graphics display, and external data communication. This supports more user configuration than traditional test equipment because it is FPGA-based. The FPGA processes all the data coming in from the ADCs and stores it in memory. This is a much more cost-effective solution than the custom DSP chipsets used in most standalone oscilloscopes that inherently restrain reconfigurability. A powerful enough FPGA could also leverage the basic hardware of the oscilloscope to provide the functionality of multiple instruments. The WaveForms™ virtual instrument suite uses the native PC OS (i.e., Windows, MAC OS X, Linux) to communicate and control the oscilloscope via USB to use a waveform generator, power supply, voltmeter, data logger, logic analyzer, static I/O, spectrum analyzer, network analyzer, and more.

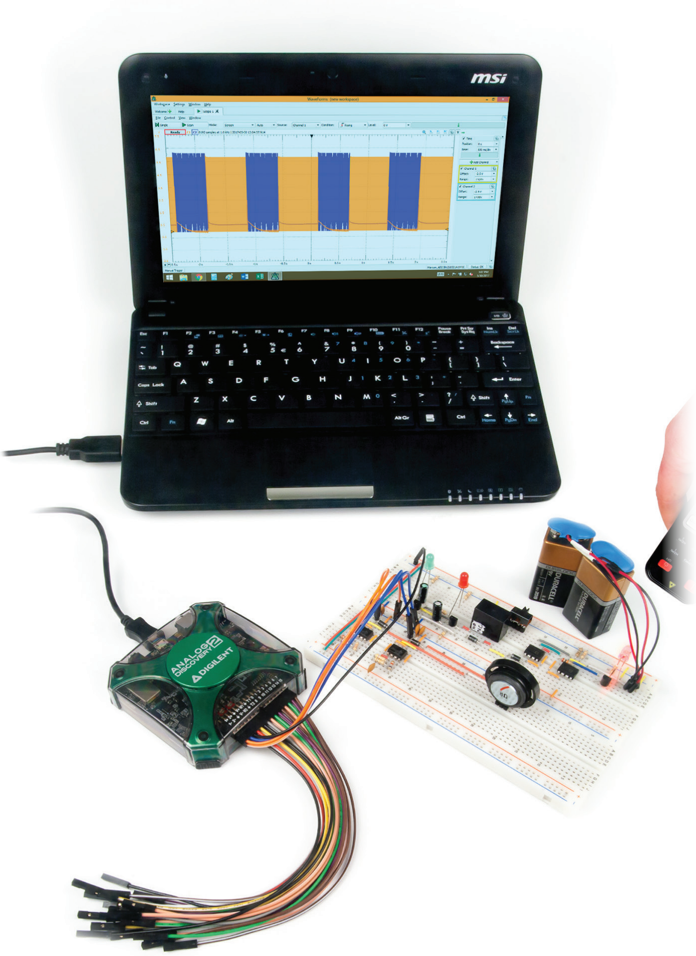


Figure 1*: The Analog Discovery 2 is a two-channel, 14-bit, 100 megasample per second USB oscilloscope that offers multiple instrument functions via the WaveForms SDK run from the laptop or PC OS.*

The Spectrum of Digilent SoC-based Test Systems

Newer, SoC-based systems are less familiar in the test and measurement space. These devices do not require a PC but differ from traditional standalone test equipment since they typically run an open OS with extensive support in software resources. Opening up the hardware and software in these types of systems has historically led to significant technological innovation. Open-source OS' offer platforms to navigate and customize testing routines, automation, data processing, response definitions, and remote access without the need for additional proprietary software. Digilent offers three SoC-based test systems of increasing complexity:

1. MCC DAQ HAT Series - mounts onto a Raspberry Pi SoC (Raspberry PI OS)
2. Analog Discovery Pro (ADP3450/ADP3250) (Linux OS)
3. Eclypse Z7 (Linux OS)

MCC DAQ HAT Series

The Measurement Computing Corporation (MCC) Data Acquisition (DAQ) Hardware Attached on Top (HAT) series is designed for a direct physical connection to a Raspberry Pi SoC board through the 40-pin GPIO header. The Raspberry Pi itself runs the Raspberry Pi OS. An open-source library of commands in C/C++ and Python allows users to develop applications on the Raspberry Pi. These HATs can be stacked on top of each other to provide the user with various DAQ capabilities, including:

- Voltage measurement
- Voltage output and digital I/O (DIO)
- Thermocouple measurement
- Integrated Electronics Piezo-Electric (IEPE) measurement

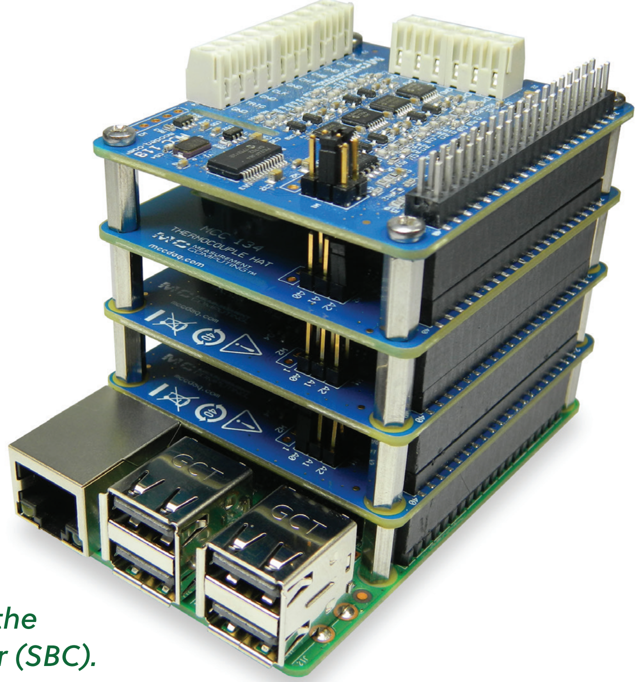


***Figure 2**: MCC HATs are stackable DAQ boards that connect to the 40-pin GPIO header on the Raspberry Pi single-board computer (SBC).*

For example, the voltage measurement DAQ HATs have an analog input of 8 single-ended or 4 differential channels. Each device has a maximum sample rate of 100 kilo-samples per second for taking single point or waveform voltage measurements. With the ability to stack up to eight MCC HATs onto a singular Raspberry Pi, up to 64 channels of data can be measured with a maximum throughput of 320 kilo-samples per second. The measurements can be taken from the screw terminals mounted on the board, where the analog data is conditioned to provide the best resolution and converted via the on-board 16-bit ADC (***Figure 3***). The voltage output and DIO HAT offers two analog outputs from an internal dual, 12-bit DAC with 8 bi-directional digital bits. The analog outputs and DIO can be configured and updated simultaneously with software. These HATs take signal analog and digital signal inputs and offer the user the basic ability to read, store, display, and interpret these signals. The IEPE measurement HAT can also take sound and vibration measurements from IEPE sensors such as accelerometers and microphones, while the thermocouple HATs can accurately measure temperature. Since most mechanical faults in rotating machines lead to a detectable increase in vibration levels, the IEPE HAT, for instance, could measure and interpret vibrational data from motor-driven systems (CNC machines, conveyor belts, etc.) to discern slight deviations from nominal behavior and failure events. The major benefit of leveraging these HATs comes from the open-source examples in common programming languages (C/C++ and Python) as well as the comprehensive API and hardware documentation. This way, users new to data acquisition have a shortened learning curve with access to literature for everything from choosing the right software environment and libraries to facilitate development, to troubleshooting, firmware updates, and to specific application examples that help streamline a user's project.

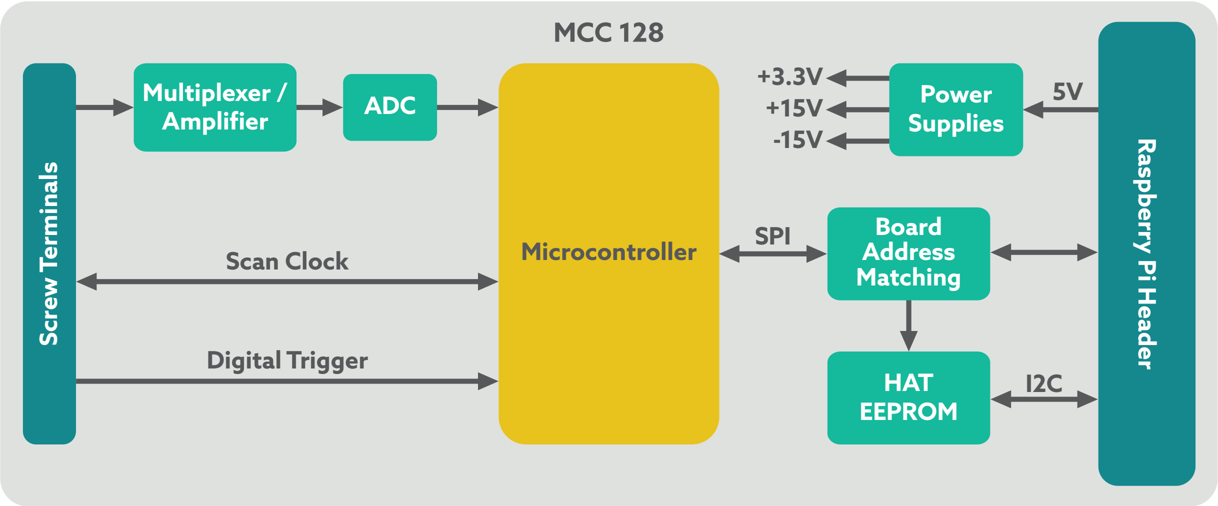


Figure 3*: Voltage Measurement HAT (MCC 128) block diagram.*

Analog Discovery Pro

While necessary, data acquisition (DAQ) is just one aspect of test and measurement. More complex systems and functions are necessary to better analyze modern high-speed signals straight off the board. The Analog Discovery Pro (ADP) modules offer USB-driven and standalone functionality to suit lab and portable test and measurement use cases. The higher-end ADP3450 has up to four analog channels and 16 dedicated digital channels for a true mixed-signal oscilloscope and offers a 14-bit resolution and up to a 500 MS/s sample rate. With the Zynq-7000 ARM/FPGA SoC, the ADP3450 can function as a solid mid-range oscilloscope and thirteen different instruments.

The standalone Linux Mode provides an on-device, terminal-based OS that allows for the customization of entire test routines without PC intervention. First, the ADP module must be connected to the host computer via USB to activate Linux Mode in the WaveForm SDK. A user can program any test sequence or further the ADP3450's capabilities with additional peripherals through the Linux root filesystem. The Ethernet interface can be enabled in standard boot mode via WaveForms for customization over an internet connection. This very same concept can be applied with remote access to the ADP3450 using a USB Wi-Fi dongle in Linux boot mode to, for example, send data to a cloud-based platform (e.g., ThingSpeak) for further analysis (***Figure 4***). These customized test programs can be embedded on the device to stream data via ethernet, Wi-Fi, or on-device storage to capture buffers of millions of samples.

Figure 4*: A USB Wi-Fi dongle connected in the back of the ADP3450 for remote testing and control.*

Eclypse Z7

The Eclypse Z7 leverages the Xilinx Zynq®-7000 SoC and a software API that allows the FPGA host board to interact with Digilent's Zmod™ family of peripheral modules. The Zynq-7000 SoC leverages a hybrid architecture to combine the software programmability of an ARM®-based processor with the hardware programmability of an FPGA, opening up opportunities for hardware acceleration over a singular platform. The Eclypse Z7 interface board offers modular high-speed I/O capabilities and conforms to Opal Kelly's open SYZYGY specification for high-performance peripheral connectivity. Ultimately, the Zmod peripheral modules connect with these SYZYGY interfaces. Soft IP-cores specific to each Zmod initialize and facilitate communication with the modules, and the Zmod library, a C++ software library designed to control these systems of soft IP, runs in the Zynq Processing System. (***Figure 5***). With a software architecture containing pre-built Linux images with a high-level API, developers do not have to directly interface with the hardware and perform hardware acceleration much more rapidly. This way, engineers can focus on rapidly developing and testing a functional prototype initially and easily generate hardware optimizations later on in the development cycle. The Zmods themselves come with a dual-channel, 14-bit, 100 MS/s ADC or DAC. The combination of the powerful FPGA with 13,300 programmable logic slices and innovative software to function alongside high-speed Zmods can produce high-speed instrumentation, software-defined radio (SDR), ultrasound, medical devices, and more.

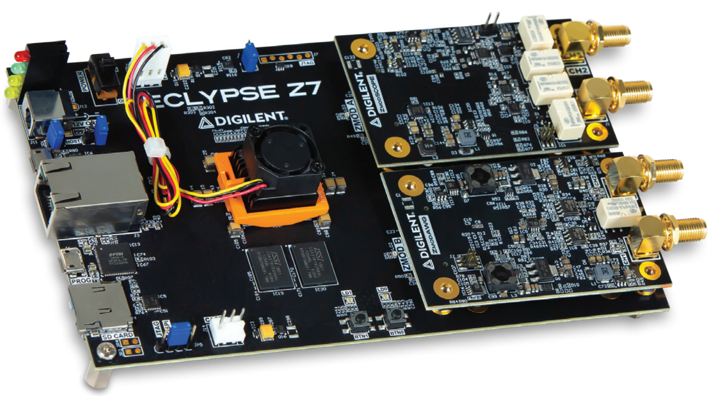
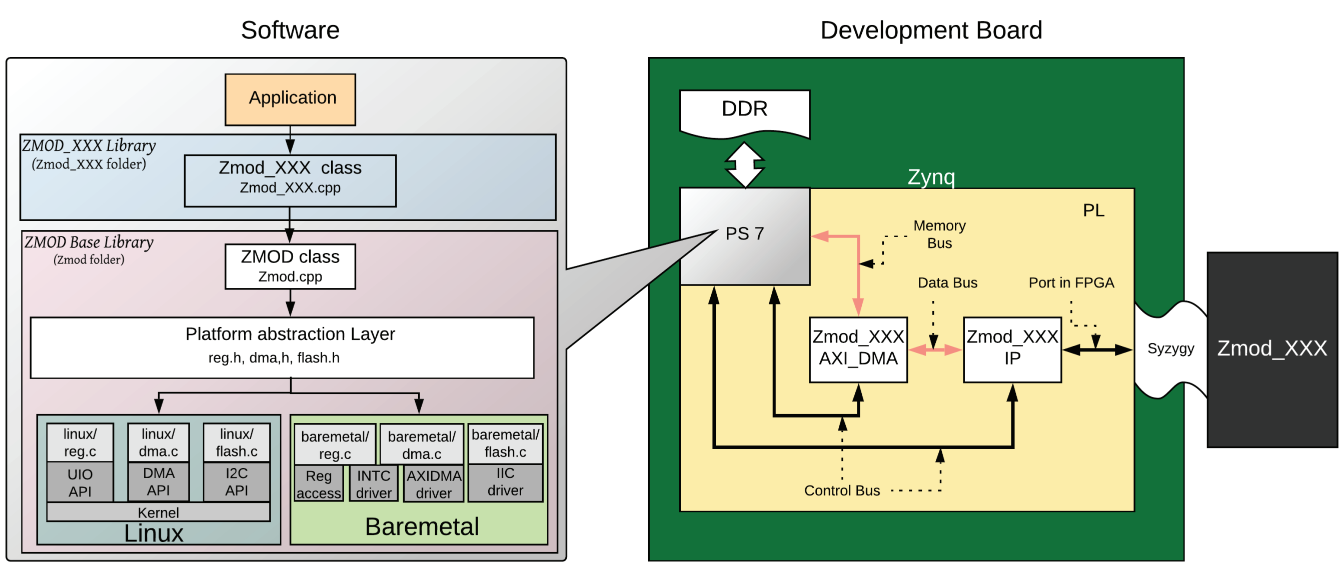


***Figure 5**: The Eclypse Z7 enables the rapid development of embedded measurement systems by leveraging the powerful Zynq-7000 SoC as well as high-speed SYZYGY standard interfaces for plugging in Digilent's expansion boards. This enables users to quickly develop embedded testing solutions with Zmods that can be readily configured as a 2-channel 14-bit Arbitrary Waveform Generator (AWG) or a 2-channel 14-bit Oscilloscope.*



Conclusion

The modern test and measurement ecosystem has dramatically improved front-end architectures, compute-performance, and processing techniques. One major trend is the move towards USB-based test systems for higher-end applications. This is due to the improvements in these instrument's capabilities that match, if not extend, those of many standalone oscilloscope options. However, many applications that could use USB-based instruments face the bottleneck of throughput with the USB interface and the limitations of requiring an external PC to interface with the equipment. This is sidestepped with the SoC-based test systems. These systems can utilize powerful compute-intensive platforms to enable device customizability with automated testing, remote access, and the addition of peripherals based upon the user's needs. This empowers the testing facility and engineers to leverage internal expertise to generate a highly specific test or an automated test setup without relying heavily on an external test and measurement vendor's proprietary software and hardware. The implications of this technology cannot be understated. It is more straightforward to find talent to create custom test schedules in C/C++ or Python with an open OS than to outsource that knowledge entirely or take on the non-recurring engineering (NRE) costs to produce equipment internally. Now, with SoC-systems, traditional USB-driven test equipment can operate in a standalone fashion while also benefiting from cost-effectiveness and open-source support.

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