Using PXI-based Fault Insertion & Sensor Simulation in Electronic Test

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Abstract

Electronic Control Units (ECUs) are present in many applications today, often used in mission- and safety-critical situations that demand not only high reliability but also high operational predictability. The correct operation of these ECUs is typically verified by using Hardware in the Loop Simulation (HILS), which replaces the sensors that monitor the ECU's real-world environment with electronic simulators. Fault insertion is also commonly used in HILS systems to ensure the ECU operates safely and reliably under all possible good and bad operating conditions, and with ever-increasing ECU complexity, it is essential to automate this fault testing to keep the validation process quick and repeatable. This article will discuss the benefits of using the industry-standard PXI platform for HILS automated fault insertion and sensor simulation.

Introduction

The job of an airplane test pilot used to be extremely dangerous. The only way a design could be thoroughly evaluated was when a working prototype was flown for the first time. Even when an aircraft was deemed flight-worthy and had entered production, the combination of many related or unrelated faults or circumstances could cause unpredictable aircraft behavior, resulting in planes crashing. In space, equipment failures are even more challenging to resolve.

As ECUs find their way more and more into cars and aerospace applications, the need for operational reliability and predictability is perhaps even more significant considering the number of vehicles there are running around our streets. With every vehicle added on the road, the chances of a billion-to-one set of circumstances coming together to create a fault situation increase. Such failures may create an environment for lawsuits, something every manufacturer is trying to avoid. These are the reasons why simulation – which can show how an ECU or other piece of equipment will behave under any number and combination of extreme circumstances - has become so necessary.

Hardware In the Loop Simulation

Hardware In the Loop Simulation (HILS) connects real signals from a controller to a test platform that simulates the final system's operation. Stimulus instrumentation simulates the ECU's sensor inputs, and measurement instrumentation is used to capture and verify the ECU control outputs. The goal is to make sure that the ECU operates correctly in a known good circumstance and to see if the ECU will do its best to ensure the safety of the vehicle and its passengers when something goes wrong. An example could be an anti-lock braking system; if the driver steps on the brake pedal and a wheel sensor has failed, the braking system still needs to stop the vehicle as quickly as possible.

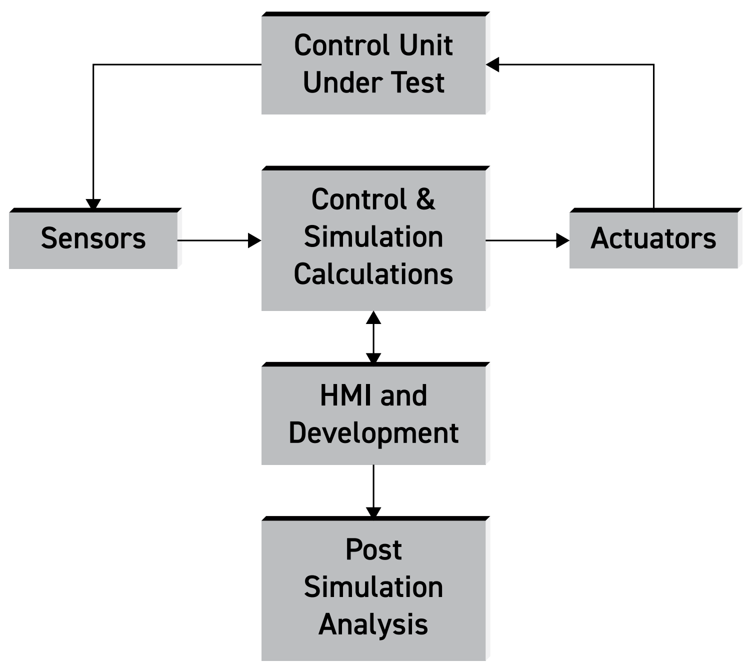


Figure 1. HILS Model Showing the Simulation of an Operating Environment

Design and verification iterations follow precisely as if the actual product were being implemented. All the possible scenarios that can be imagined involving countless combinations of different faults can be reproduced, enabling the ECU or controller to be comprehensively exercised without incurring the cost and time necessary to create the actual set of circumstances and perform the real physical tests.

Fault Insertion

Safety-critical ECUs will usually go through a certification process where a series of faults are introduced. The ECU response is checked to see that it operates in a safe and predictable manner. A manual patch panel is often employed to inject the faults. Cables are used to connect the ECU's I/O lines to stimulus and measurement instrumentation. The I/O lines may be disconnected to simulate open-circuits or tied together to simulate short-circuits to ground, voltage sources, or other I/O lines. An engineer moves the patch cables to simulate the desired fault and then measures the results. However, this arrangement has many inherent disadvantages.

One obvious issue is size, as patch panels tend to be large. The operation is also slow and prone to error, leading to a lack of repeatability. Maintenance and labor costs are high, and operation requires the accumulation and documentation of a skilled knowledge base. A traditional fault insertion system still in use is shown in Figure 2.

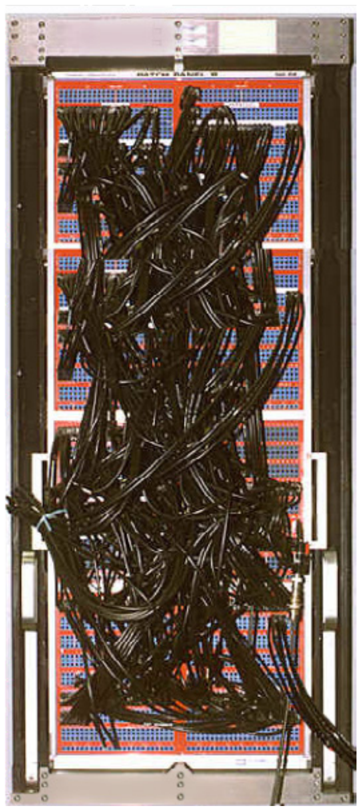


Figure 2. Traditional Fault Insertion System Using a Patch Panel to Inject Faults Manually

Quickly and precisely reproducing a failed test condition is a major advantage. Automating this type of test secures the best way of producing a traceable report, free from human error.

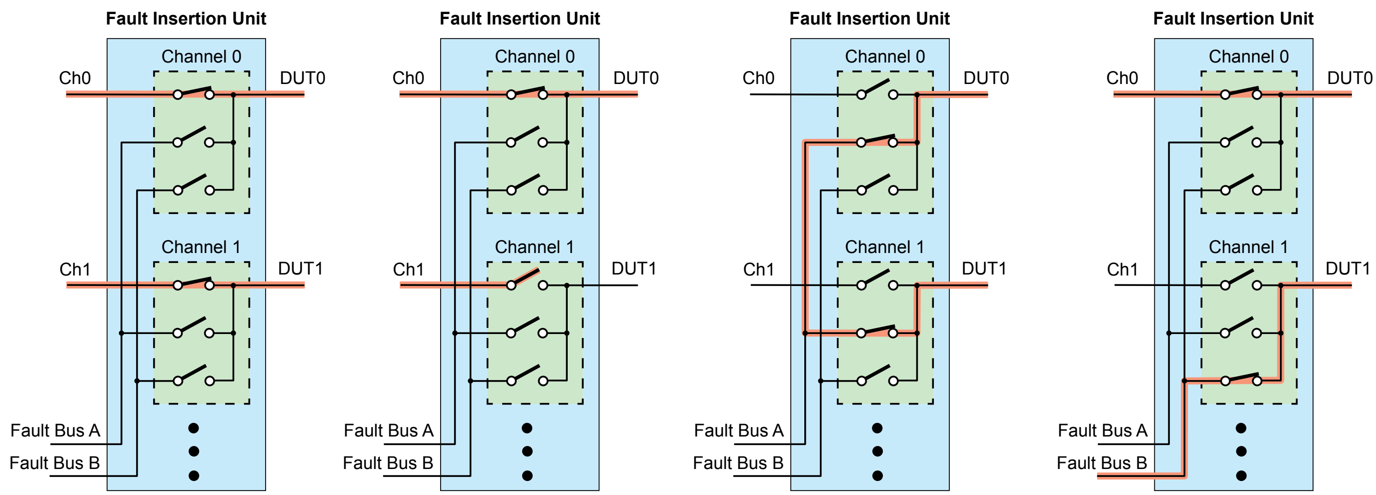
Automation

The ability to gain software control of both instrument routing and the insertion of real-time electrical faults greatly enhances the testing process. Fault insertion switching automates the fault insertion process. The principle is simple: switching modules sit between the simulator (test system) and the DUT (ECU/controller) and either pass the signals through unchanged or add a range of fault conditions.

Most applications require the following faults to be modeled as a minimum:

- Open Circuit Connections to DUT
- Short Circuits between DUT pins
- Short Circuits to Ground or Power
- Resistive Faults

Figure 3 shows a fault insertion switch unit (FIU) with two I/O channels. In Figure 3 (i), the FIU is in the default mode of operation, where all signals are passed through. In Figure 3 (ii), an open-circuit is being simulated on Channel 1; in figure 3 (iii), there is a pin-to-pin short between Channels 0 and 1; and in Figure 3(iv), a short-to-power fault simulation is produced on Channel 1.



i. Normal Mode *ii. Open Circuit* *iii. Pin-to-pin Short* *iv. Short to Power*

Figure 3. Open & Short Fault Simulation

Resistive faults – can also be simulated by inserting external resistance via fault buses (Figure 4).

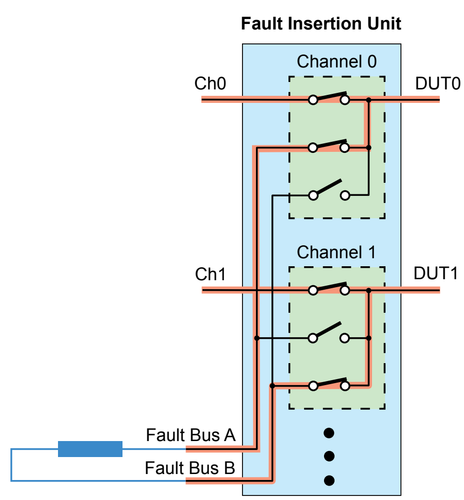


Figure 4. Insertion of Resistive Faults

Modular Systems Using PXI

Several vendors produce dedicated, proprietary, software-intensive HILS systems that include hardware fault insertion functionality. These can be highly accurate, but they are also costly, tend to be very large, and customers can find themselves locked to one supplier. Also, the system will be very dedicated to one application, so possibly relatively inflexible.

Another approach is to use a standard modular platform – such as PXI – to create a real-time simulation system using best-in-class Fault Insertion units (FIU) for each function that are available from several PXISA members.

PXI Fault Insertion Solutions

FIU modules use similar hardware to regular switch modules – Reed Relays, EMRs, and Solid-State devices. This means that the same parameters and questions you use to select regular switching modules apply to FIU selection. Once you have decided on relay types for voltage and current, the key parameters required to select the right FIU modules are as follows:

- How many channels? Of all the I/O connections on the DUT, how many will have to be tested using Fault Injection?
- Pin Shorting – Will it only be necessary to short adjacent pins together or do you need to simulate a cable short which could be any pin to any pin?
- Number of Simultaneous Relay Closures – We have worked with customers who needed all but one connection on the DUT to be connected to all other pins on the UUT. This can be an issue with some FIU designs as they have a limited number of simultaneous closures. This specification should be stated in the module's datasheet. If not, ask your vendor of choice for the information.
- How many external faults will be required? If the program requires external injection of faults, the number of fault buses is important. Typically, an FIU module will have anywhere from two to eight fault buses.

There are two different styles of FIU modules. There may be variations within these styles, but they generally do the same thing. The main differences have to do with the number of channels, number of fault buses, and complexity of the switching portion.

Straight-Through Fault Insertion Modules

This is the most popular type of Fault Insertion module. The "Straight-through" reference explains that the module is designed to go in series with the DUT connections and the ATE instruments, power supplies, switching, etc.

As you can see in the diagram here, the relays between the "M" connections and the "U" connections are normally closed – opening these relays simulates an open connection. Other relays connected to these channels are used to short other pins together or insert bad signals via the fault buses. The example here has 74 channels. Depending on the voltage and current in the test, this channel count will vary depending on the size of the relays and available FIU real estate.

As you can see in figure 5, there are eight fault buses available to the test programmer. An optional "Monitor" connection is used to connect instrumentation to the fault buses to see how the signal is being presented to the DUT.

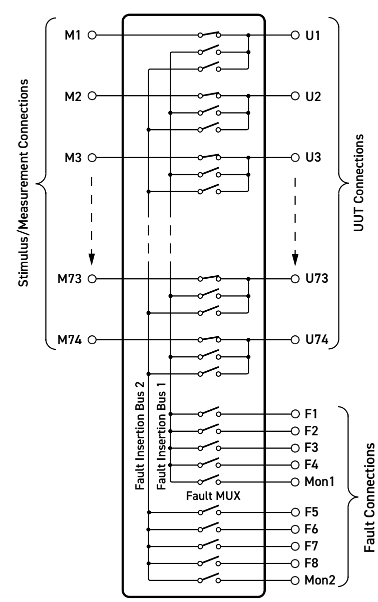


Figure 5. Straight-through FIU

FIBO (Fault Insertion Break Out) Matrices

Cross-point matrices are the most flexible switching system you can implement. With the right configuration, you can route virtually any test resource to any test point on the DUT. Also, because of its flexibility, it is easy to reconfigure new DUTs with minimal wiring changes.

In Fault Insertion testing, a matrix can easily create shorts between two or more test points as well as open the connection. To further improve the matrices' fault injection capability, a few extra relays are all that are needed.

In figure 6, you see how a FIBO Matrix is created. Across the X-Axis, a fault bus is added. For example, X1 has three added relays – X1.1, X1.2, and X1.3 – all three of these relays can be used to inject a resistive load, faulty serial buses, and a number of other faults. In this particular design, you can see an additional relay between X1.1 and half of the X1 bus. Using these relays, it is possible to split the matrix into two matrices for even greater flexibility.

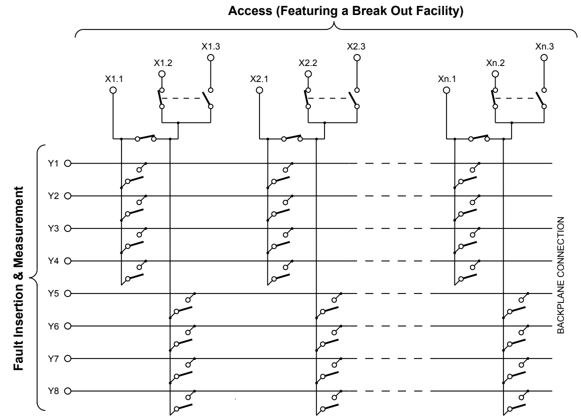
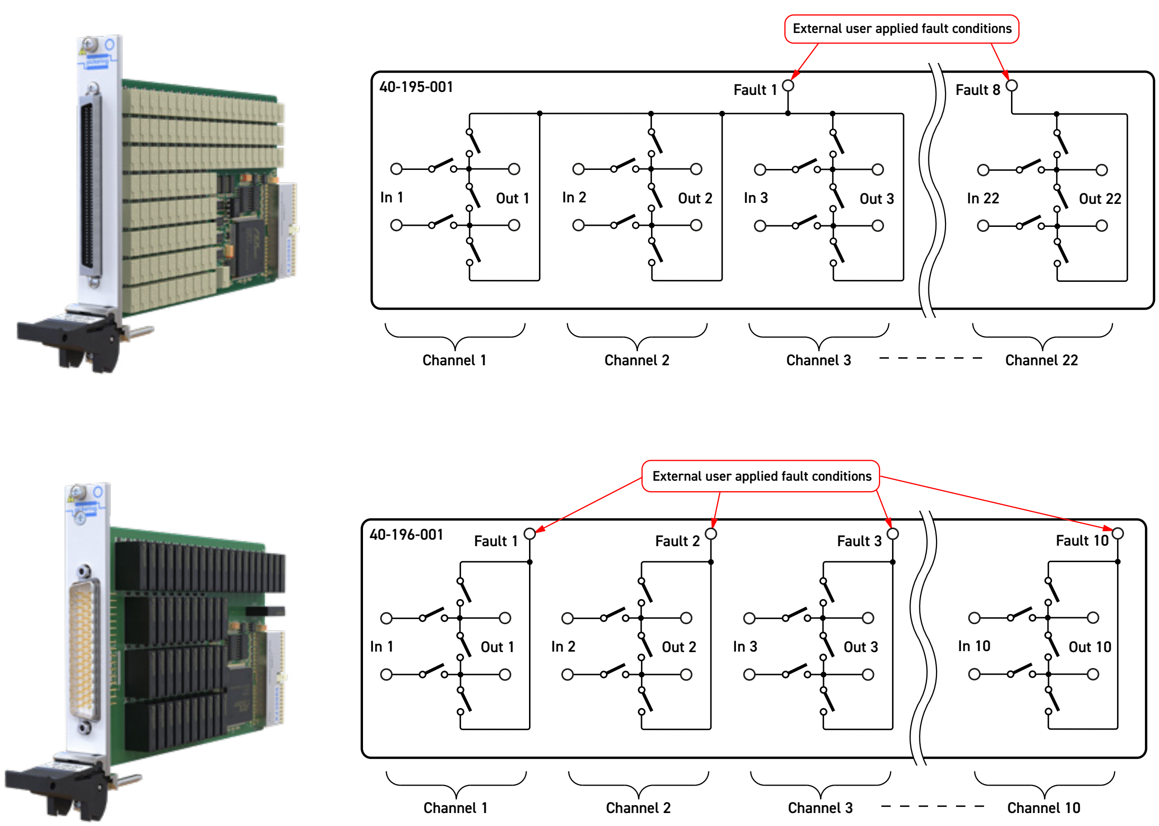


Figure 6. FIBO Matrix

Differential Signals

There are several other variations that the industry has requested. Working closely with a leading French aerospace integrator, a PXISA Member developed two signal pair solutions, as shown in Figure 7.



(5 Amp Switching)

Figure 7. Signal Pair FIU products

Break Out Box

It may become necessary to make manual measurements and introduce faults manually before writing test code. The majority of the Breakout Boxes (BoBs) used today are not modular and are fixed in configuration, creating test solutions limited in scope. In addition, they have cable configurations that are cumbersome and, in many cases, expensive.

One PXI member's low-cost Modular Breakout System combines a BoB feature set with the added flexibility of an FIU. By mating the PXI chassis directly to the BoB, cabling is minimized, creating a more compact, reliable design and improving signal integrity. Also, all cables to the simulation system and the UUT are located behind the front panel of the BoB, creating a simpler front panel that is less prone to damage.

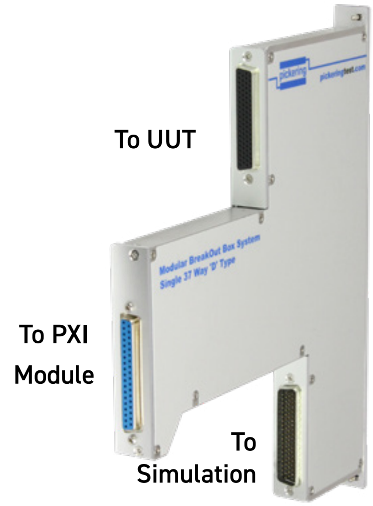


Figure 8. Ease of connection to Breakout System and FIU

PXI & PXIe Simulation Solutions

Programmable Resistors

While many sensors are used in everything from automotive to satellites, it is not practical to incorporate the actual sensors into a HILS system. Several PXISA members manufacture programmable resistor modules that can substitute these sensors, thus speeding up a HILS test and improving accuracy and repeatability. Models are available as simple resistor ladder networks, high precision models, as well as simulators for RTDs.

The traditional BoB designs discussed earlier feature a manual potentiometer for creating resistive faults. A test engineer can automate this process using one programmable resistance module. The module can be controlled manually through a soft front panel as well as programmatically – speeding up a test process and ensuring repeatability. .

Figure 9. PXI Programmable Resistors

Thermocouple Simulation

As thermocouples are not resistive in nature, you cannot use resistor modules to simulate these devices. There are PXI-based millivolt thermocouple simulator modules that provide multiple channels of accurate low voltage sources. The channels can cover most thermocouple types. Additional relays in each channel allow the module to simulate an open connection to each thermocouple.

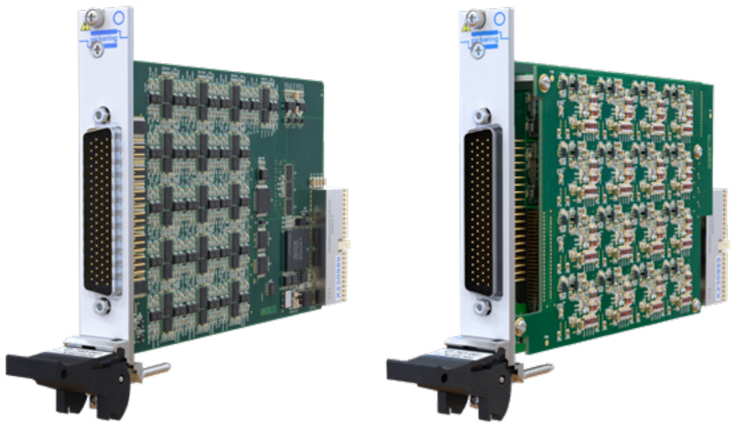


Figure 10. PXI Thermocouple Simulators

Battery Stack Simulation

Battery simulator modules are available in PXI and PXIe formats. They are ideal for Electric Vehicle (EV) battery stack emulation in Battery Management Systems (BMS) test applications. These simulators must exhibit high isolation voltage as channels will be connected serially, adding up to hundreds of volts, to simulate a complete battery stack. The simulator can sink or source current just as a battery would, plus have a fast response to changing loads.

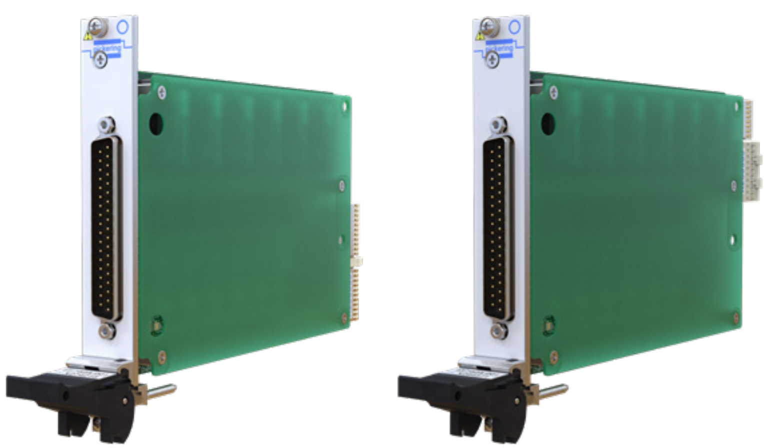


Figure 11. PXI & PXIe Battery Simulators

Conclusion

Simulation and fault insertion are essential in mission-critical, must-not-fail applications typically found in the aerospace and automotive sectors. Many companies in these fields turn to modular PXI-based systems for cost, size, repeatability, versatility and ease of use. Also, they are increasingly using HILS systems on the manufacturing floor as well as in product development. In the production environment, the benefits of modular systems mentioned above are even more apparent.

The emergence of these relatively low-cost, low barrier-to-entry systems also means that other industries can benefit from simulation. Industrial automation is an obvious area that could also benefit. In the future, it is possible to see that, for legal reasons, complex home or office automation systems might also be required to undergo the kind of exhaustive simulation that is currently mainly the preserve of hi-rel systems. Learn more at **pickeringtest.com**