Software now accounts for more than one-third of total automobile production costs... Driving the trend is embedded software's importance in vehicles to manage more electronics needed to meet new safety, fuel economy, and environmental protection requirements... Under-the-hood-and in-cab subsystems must increasingly communicate in real time with each other and the driver, calling for more complex and costly software in the electronic control units. Automotive OEMs continually seek to shorten design cycles and improve product quality/safety (by) developing and testing vehicles in a virtual prototyping environment. This relies on help from more modeling, simulation, and test automation tools.

Automotive embedded software development costs outpace other apps
Control Engineering, (January 15, 2004)
Simulation is widely recognized as an indispensable tool in the automotive product development process. Real-time hardware-in-the-loop (HIL) simulation takes simulation further into the development process by providing advanced capabilities as both a design and verification tool.

As automotive subsystems become increasingly complex and the costs associated with their development steadily increase, HIL simulation delivers assurance and efficiency for system design and verification.

Since its founding in 1957, Applied Dynamics International (ADI) has been in the business of designing, manufacturing, and marketing computer-based equipment for real-time HIL simulation of complex, dynamic systems. No other simulation solution provider has a longer history of supporting HIL simulation for new product development and testing applications than ADI.

ADI’s newest real-time HIL solution, the rtX Real-Time Expandable Simulation Computer, builds on the company’s SIMsystem product line, a complete set of hardware and software tools providing a full featured environment for interactive or automated Electronic Control Unit (ECU) test activities. The rtX extends the reach and usability of the SIMsystem product line by answering the automotive industry’s need for high-efficiency simulation and test automation tools that are modular, flexible, scalable, and price competitive.

For experienced simulation users as well as those who are just getting started, ADI’s rtX Real-Time Expandable Simulation Computer delivers flexible, high-quality HIL with microsecond determinism at an affordable price.

PRODUCT OVERVIEW

rtX Real-Time Expandable Simulation Computer

Extending the robust capabilities of the SIMsystem product line, the rtX provides an economical extension to the SIMsystem product line by delivering high-quality PC-based HIL, with microsecond determinism, at an affordable price.

Offering the same functionality as the SIMsystem, the rtX is a standards-based, open system that takes advantage to the greatest extent possible of today’s PC technology and commodity-priced products. At the same time, the rtX delivers the functionality needed for the future as the automotive industry strives to develop better products at lower cost and with shorter time to market.

The rtX takes advantage of the same graphical user interfaces and methods as the SIMsystem. The same "open systems" architecture applies as well, providing the capability to flexibly configure the system to suit your needs, and enabling the system to grow with your programs. This philosophy extends to coding environments, too, allowing users to run models written in various computer language types together.

Requirements imposed on the development of the rtX included modularity, scalability, flexibility in system configuration, ease of use, and compatibility with the powerful suite of SIMsystem software tools.

A choice of two available configurations, the Powertrain System and the Advanced Powertrain System configurations, provide tools at two different price points and levels of capability for automotive engine, transmission, and powertrain Electronic Control Unit testing. Each of these configurations can be expanded to meet the needs of particular applications.

rtX Software Tools

The rtX software tools provide a full-featured environment for interactive or automated Electronic Control Unit (ECU) test activities. These tools include co-simulation products and real-time, HIL simulators. The real-time tools allow the user to manipulate the simulation in a deterministic fashion. The non-real-time and real-time software tools have a consistent look and feel for easy assimilation into automotive engineering processes.
The ADvantage Toolset

The ADvantage toolset is common across the real-time platforms. Software compatibility will exist across the non-real-time PC simulation environment, RTS-based systems, and the rtX HIL simulator.

ADvantage Development Environment
ADvantage is an open tool that greatly simplifies integration of multiple models, interconnecting them, and connecting I/O points in the models to external hardware.

ADvantage provides a GUI that allows the user to specify the simulation project including model(s) to be executed, model connections, sensors/actuators or I/O devices to be connected, and the configuration of I/O devices.

All components of a system may be modeled in the same modeling tool or with multiple modeling tools. ADvantage allows the components developed in one or more modeling paradigms to be integrated and connected to each other automatically via model connections. The models may then be co-simulated in non-real-time on a PC or in real-time on an ADI real-time simulation system.

ADvantage allows for models to be developed using modeling languages such as: C, C++, Fortran, and Ada. Models may also be developed using model development packages such as Simulink, SystemBuild, Statemate, or in domain-specific high-level modeling packages such as CarSim.

ADvantage allows model I/O points to be easily connected to actuators/sensors or to other models or controlled through the user interface. ADvantage supports a unique and elegant concept of logical devices which allows hardware interfaces to be encapsulated as a sensor or actuator emulation. These logical devices have specifically named ports that are connected automatically in ADvantage to allow complex hardware to be driven easily by model variables or through the user interface.

ADvantageVI Test Environment
ADvantage Visual Interact is the point of entry for test project execution. Its rich Windows features allow users to get up and running quickly.

ADvantageVI's features include:

✦ Interactive execution control
✦ Data browser with visibility into models
✦ Tabular run-time data display
✦ Data logging system with multiple rates, multiple streams and powerful control features
✦ Debugging support
✦ SIM plotter package for high-speed signal plotting
✦ Altia panels for virtual instrumentation

Tests may be run in an interactive mode or alternatively, users may select from one of many automation modes. ADvantageVI provides three levels of automation:

✦ Real-time event scripting
✦ Command-line automation scripting
✦ Visual Basic application automation

The ability to interface ADvantageVI with other Windows applications such as Matlab, Excel, LabVIEW and Access provide extendibility to the test environment. Open interfaces are available to integrate test system-specific tools such as calibration tools, analyzer tools, databases, etc.
The Powertrain System and the Advanced Powertrain System are designed to offer the best value in terms of functionality and performance for testing powertrain, engine, and transmission ECUs for both spark ignition and diesel or compression ignition engines.

Because of the complexity of the tasks it has to perform and the interrelationships of the signals it has to deal with, the engine controller presents some interesting testing challenges. The engine's output is derived from its crankshaft, which in turn is driven by the engine's cylinders. Fuel injection, spark timing, intake and exhaust port valve operation, and camshaft position are all related to crankshaft position, as are the responses of some of the engine sensors such as the knock sensors and the lambda or oxygen sensors. Many I/O signals between the test system and engine ECU are interrelated. The I/O hardware has to accommodate these relationships.

The Powertrain and Advanced Powertrain Systems both provide tools appropriate for this type of ECU testing, and each can be expanded as needed to meet specific application requirements.

The Powertrain System handles engine configuration requirements between 2 and 8 cylinders and is readily expandable to handle larger or more complex engine configurations. It contains a variety of I/O and communications interfaces described in Table 1.

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC channels - 12-bit, multiplexed, ± 10 Volts</td>
<td>16</td>
</tr>
<tr>
<td>DAC channels - 12-bit, ± 10 Volts</td>
<td>2</td>
</tr>
<tr>
<td>TTL channels, bidirectional</td>
<td>32</td>
</tr>
<tr>
<td>Ratiometric Analog Output (DAC), Simultaneous Update, 16-bit, ±10V, Option ±20V</td>
<td>16</td>
</tr>
<tr>
<td>Thermistor Sensor Output - 16 bit</td>
<td>8</td>
</tr>
<tr>
<td>High-voltage discrete inputs, isolated, 0 to 50 Volts</td>
<td>16</td>
</tr>
<tr>
<td>Form C (SPDT) electromechanical relays, 0 to 50 VDC, 0 to 0.5 Amps</td>
<td>16</td>
</tr>
<tr>
<td>Fuel Injector Event Input</td>
<td>8</td>
</tr>
<tr>
<td>Spark Event Input</td>
<td>8</td>
</tr>
<tr>
<td>CAM (variable phasing)</td>
<td>4</td>
</tr>
<tr>
<td>PWM input signal measurement, 0 to 50 Volts</td>
<td>8</td>
</tr>
<tr>
<td>PWM output signal generation, 0 to 50 Volts</td>
<td>8</td>
</tr>
<tr>
<td>Crank Sensor-based edge monitoring</td>
<td>1</td>
</tr>
<tr>
<td>CAN Interface Controllers with a selection of 3 transceivers each</td>
<td>2</td>
</tr>
<tr>
<td>Stepper Motor input drive signals - quadrature decodes</td>
<td>2</td>
</tr>
<tr>
<td>Engine position (Crank/CAM)</td>
<td>8</td>
</tr>
<tr>
<td>Knock Sensor Interface</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1: I/O and Communications Interface Functionality for the Powertrain System

The boards included in the Powertrain System are listed in Table 2 below.
### Signal Type Board Quantity

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Board</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADC Channels</td>
<td>PCI-MC6025 Board</td>
<td>1</td>
</tr>
<tr>
<td>DAC Channels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTL Channels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratiometric Analog Output (DAC)</td>
<td>PCI-DAC Board</td>
<td>2</td>
</tr>
<tr>
<td>Thermistor Sensor Output - 16 bit</td>
<td>PCI-Therm Board</td>
<td>1</td>
</tr>
<tr>
<td>High-voltage discrete inputs</td>
<td>PCI-AD7256</td>
<td>1</td>
</tr>
<tr>
<td>Form C (SPDT) electromechanical relays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Injector Event Input</td>
<td>PCI-565 Board</td>
<td>1</td>
</tr>
<tr>
<td>Spark Event Input</td>
<td>SCR-E565 Board</td>
<td>1</td>
</tr>
<tr>
<td>CAM (variable phasing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM input signal measurement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM output signal generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crank Sensor-based edge mon.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAN Interface Controllers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stepper Motor inputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Position (Crank/CAM)</td>
<td>IP-DigPat Board</td>
<td>1</td>
</tr>
<tr>
<td>Knock Sensor Interface</td>
<td>IP-Knock Board</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: I/O Subsystem Configuration for the Powertrain System

### Advanced Powertrain System

The Advanced Powertrain System handles up to 16 cylinder engines and contains the I/O and communications interface functionality described in Table 3.

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Voltage Input (ADC), Simultaneous Sampling, 16-bit, ±10V</td>
<td>32</td>
</tr>
<tr>
<td>Ratiometric Analog Output (DAC), Simultaneous Update, 16-bit, ±10V, Option ±20V</td>
<td>24</td>
</tr>
<tr>
<td>Thermistor Sensor Output - 16 bit</td>
<td>8</td>
</tr>
<tr>
<td>O2 Sensor Output</td>
<td>8</td>
</tr>
<tr>
<td>Variable Reluctance Sensor (VRS) Output</td>
<td>4</td>
</tr>
<tr>
<td>High-voltage Discrete Inputs</td>
<td>32</td>
</tr>
<tr>
<td>High-voltage Discrete Outputs</td>
<td>32</td>
</tr>
<tr>
<td>Fuel Injector Event Input</td>
<td>8</td>
</tr>
<tr>
<td>Spark Event Input</td>
<td>8</td>
</tr>
<tr>
<td>CAM (variable phasing)</td>
<td>4</td>
</tr>
<tr>
<td>PWM input signal measurement, 0 to 50 Volts</td>
<td>8</td>
</tr>
<tr>
<td>PWM output signal generation, 0 to 50 Volts</td>
<td>16</td>
</tr>
<tr>
<td>Crank Sensor-based edge monitoring</td>
<td>1</td>
</tr>
<tr>
<td>CAN Interface Controllers with a selection of 3 transceivers each</td>
<td>2</td>
</tr>
<tr>
<td>Stepper Motor input drive signals - quadrature decodes</td>
<td>2</td>
</tr>
<tr>
<td>Engine Position (Crank/CAM)</td>
<td>8</td>
</tr>
<tr>
<td>Knock Sensor Interface</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3: I/O and Communications Interface Functionality for the Advanced Powertrain System
The boards included in the Advanced Powertrain System are listed in Table 4 below.

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>Board</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Voltage Input (ADC)</td>
<td>PCI-PAS202N Board</td>
<td>1</td>
</tr>
<tr>
<td>Ratiometric Analog Output (DAC)</td>
<td>PCI-DAC Board</td>
<td>2</td>
</tr>
<tr>
<td>Thermistor Sensor Output</td>
<td>PCI-Therm Board</td>
<td>1</td>
</tr>
<tr>
<td>O2 Sensor Output</td>
<td>PCI-LVDAC Board</td>
<td>1</td>
</tr>
<tr>
<td>VRS Output</td>
<td>PCI-VRS Board</td>
<td>1</td>
</tr>
<tr>
<td>High-voltage Discrete Inputs</td>
<td>PCI-DI Board</td>
<td>1</td>
</tr>
<tr>
<td>High-voltage Discrete Outputs</td>
<td>PCI-DO Board</td>
<td>1</td>
</tr>
<tr>
<td>Fuel Injector Event Input</td>
<td>PCI-565 Board</td>
<td>1</td>
</tr>
<tr>
<td>Spark Event Input</td>
<td>SCR-E565 Board</td>
<td>1</td>
</tr>
<tr>
<td>CAM (variable phasing)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM input signal meas.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM output signal generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crank Sensor-based edge mon.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAN Interface Controllers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stepper Motor inputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine Position (Crank/CAM)</td>
<td>IP-DigPat Board</td>
<td>1</td>
</tr>
<tr>
<td>Knock Sensor Interface</td>
<td>IP-Knock Board</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: I/O Subsystem Configuration for the Advanced Powertrain System

**I/O and Signal Conditioning Boards**

The following boards are used in one or both of the above listed systems.

**Basic Engine Signals**

A two-board set is used to generate/measure basic engine signals. These boards are the PCI-565 Board and the Signal Conditioning and Routing (SCR) Board for the Engine or SCR-E565.

**The PCI-565 Board**

The PCI-565 Board forms the heart of both the Powertrain and Advanced Powertrain Systems. Two or more PCI-565 Boards can be incorporated, and synchronized, as needed for particular applications.

The PCI-565 Board contains a Motorola MPC 565 microprocessor and slots for three Industry Pack (IP) boards. The MPC565 contains a 48 MHz, 32-bit PowerPC processor core with floating point arithmetic capability and three Timer Processor Units (TPUs) as well as other I/O capabilities.

The IPs that mount on the PCI-565 Board are:

- An IP-DigPat (Digital Pattern Generator) for a digital crank sensor output and/or an IP-ARB for an analog crank sensor output
- An IP-Knock Board containing two independent channels for knock signal generation.

(Note: The IP locations on the PCI-565 Board are not available for general purpose IP use. The I/O wiring for these IP sites is restricted to the types of IPs specified above.)
The real-time compute engine performs the model calculations during each numerical integration frame and outputs the angular velocity of the crankshaft to the MPC 565 processor. This processor in turn adjusts the frequency input to the IP-DigPat or the IP-ARB, which generates the crank signal output that is fed to the engine controller under test. This output signal from the IP-DigPat or the IP-ARB must also be sampled and fed back to the real-time compute engine as part of a control loop to ensure that the hardware crank position signal accurately tracks the model's crank position variable. This is handled by the MPC565. Minimizing the model frame time and latency in this feedback loop are very important, particularly at high engine speeds, to ensure accuracy in the crank position signal generation.

The IP-DigPat outputs a set of digital patterns that are completely synchronized with the crank output signal. These digital patterns are available for triggering activities that have to be crank-synchronous. The IP-DigPat is used to simulate a digital crank sensor. The IP-ARB is used to simulate an analog crank sensor. In addition to the arbitrary function output, the IP-ARB also has four digital output patterns that are synchronized to the analog output. NOTE: For unusual situations, both the IP-DigPat and the IP-ARB can be used together where one is slaved to the other for synchronization purposes.

Note: The IP-DigPat, the IP-ARB, and the IP-Knock Boards are ADI products.

The TPUs contained in the MPC565 are used as follows:

- TPU 1 is used for accurately measuring time and crank angle position information for the rising and falling edges of up to eight fuel injector signals from the engine controller.
- TPU 2 is used for accurately measuring time and crank angle position information for the rising and falling edges of up to eight spark signals from the engine controller.
- TPU 3 is used for generating two-knock sensor gating signals and up to four dynamically phased camshaft position signals.

Camshaft position sensor output signals can be generated by using digital patterns from the IP-DigPat or analog waveforms from additional IP-ARBs if the camshafts are operated with a fixed angular relationship to the crankshaft. Some automotive engine control schemes employ dynamic phasing of the camshafts relative to the crankshaft and to each other. For this type of operation, TPU 3 is used for generating the output position sensor signal for each cam relative to the crankshaft position based on input from the engine model, which in turn is based on commands from the engine controller.

In addition to the TPUs, the MPC565 provides:

- 8 channels of PWM generation
- 8 channels of PWM measurement
- 1 channel of crank-based edge monitoring
- 1 J1850 channel
- 2 CAN interface controllers.

The SCR-E565 Board

The SCR-E565 (Engine Signal Conditioning and Routing) Board is used in conjunction with the PCI-565 Board to provide several important functions in both the Powertrain and Advanced Powertrain configurations:

- Standard (i.e., non-encoded) and encoded input signal handling for TTL and VBATT-level logic inputs where the encoded signals are quadrature encoded signals from the controller under test for operating stepper motors
- Output drivers configurable via jumpers to meet either high-side or low-side output drive requirements
- Three jumper-selectable transceivers for each of the two CAN interface controllers.

All discrete input signals to the simulator are limited to TTL levels through the use of resistor-diode clamping circuits. Stepper motor drive signals are decoded before being passed to the MPC565. Non-encoded input signals are passed to the MPC565 without being changed.
The output drivers are configurable for either high-side or low-side drive via removable jumpers. Drivers are arranged in groups of four with a common high-rail and low-rail line per group. The high-rail for each group will be user-specified. The low-rail line for each group is tied to system ground. Each driver is capable of sourcing or sinking 100 mA as appropriate for the driver configuration.

The transceiver selection available for each CAN interface controller consists of:

✚ A high-speed transceiver compliant with ISO 11898-2/J1939/J2284
✚ A fault-tolerant transceiver compliant with ISO 11519-2 and/or ISO 11898-3
✚ A single-wire transceiver compliant with J2411.

The SCR-E565 Board:

✚ Does not have a PCI Bus connection-it only obtains power from the PCI Bus connector
✚ Is connected to the PCI-565 Board via internal cables
✚ Has a 100-pin, high-density, output connector.

**Discrete Input and Output Signals**

In automotive applications there is a need for discrete (or digital) signals that range between \( V_{\text{BAT}} \) on the high side and ground on the low side. In anticipation of the 42-volt automotive electrical architecture, the I/O subsystem circuitry for the rtX is designed to operate at supply voltages up to 50 volts where appropriate. The high rail for all discrete switches, PWM signals, etc., must be capable of being connected to supply voltages up to +50 volts DC.

**PCI-AD7256 (DI/DO) Board**

The PCI-AD7256 High Voltage Discrete Input/Discrete Output (DI/DO) Board is a product of ADLINK Technology, Inc. The ADLINK model number for this product is PCI-7256. This board contains 16 optically isolated discrete inputs and 16 Form C (SPDT), latching, electromechanical relays. The inputs are rated at 0 to 50 VDC, and the contacts for each relay are rated at 0 to 50 VDC and 0 to 0.5 Ampere.

The PCI-AD7256 Board is included in the standard Powertrain System configuration, but is not included in the Advanced Powertrain System configuration. This board does not require the use of an SCR board.

**The PCI-DI Board**

ADI's PCI-DI Board contains 32 isolated, discrete input sensing circuits where each sensing circuit features:

✚ An independently adjustable threshold for determining the On/Off state of the input signal
✚ Microsecond-level dynamic performance.

Each of these circuits is protected against faults to any voltage in the 0 to +50 Volt range.

The PCI-DI Board is used in the Advanced Powertrain System. This board does not require a separate SCR board.

**The PCI-DO Board**

ADI's PCI-DO Board contains 16 isolated, discrete output drive circuits. This board features output drivers that can be individually configured by the user to be either high-side or low-side switches. The switching times for these drivers are:

- High-side switch: \( \leq 140 \) microseconds for turn-on or turn-off
- Low-side switch: \( \leq 20 \) microseconds for turn-on or turn-off

Each high-side driver will operate with a high-rail voltage in the range of 8 to 50 Volts; each low-side driver will operate between ground and a high-rail voltage in the range of 0 to 50 Volts. Each driver is capable of sourcing or sinking 100 mA as appropriate for the driver configuration.

Internal current limiting and thermal overload protection circuitry protect both high-side and low side drivers.
A PCI-DO Board is included in the Advanced Powertrain System configuration. This board does not require a separate SCR board.

**Analog Inputs and Outputs**

There is often a need for some general-purpose analog inputs in HIL simulation testing for data acquisition purposes. Various third-party PCI boards are available to meet these needs. ADI has selected two boards for use in the rtX to meet this need.

**The PCI-MC6025 (Multifunction) Board**

The PCI-MC6025 Board is a product of Measurement Computing Corp. that contains:

+ 16 multiplexed ADC channels (12-bits)
+ 2 DAC channels (12-bit)
+ 32 bi-directional TTL channels.

The PCI-MC6025 Board is included in the standard Powertrain System configuration, but is not included in the standard Advanced Powertrain System configuration.

**PCI-PAS202N Analog Input Board**

Precision Analog Systems Co. model PAS 202N/AI is a standard PCI card containing 32 channels of 16-bit simultaneous sampling, parallel ADCs. Each channel contains a high-resolution, 250K samples per second Analog to Digital Converter. There are five programmable input ranges for the board, namely, ±10V, ±5V, ±2.5V, 0 to +5V, and 0 to +10V. The number of channels to be scanned can be selected from 1 to 32 in six binary-weighted programmable steps. A RAM buffer with one word of storage per ADC channel is provided for intermediate data storage.

The board contains a 32-bit RISC processor that performs auto-calibration calculations on all ranges. Both block mode and demand mode data transfers are supported over the PCI Bus. This board does not require the use of a separate signal conditioning/routing board.

A PCI-PAS202N Board is used in the Advanced Powertrain System.

**PCI-PAS2015 Analog Output Board**

Precision Analog Systems Co. model PAS 2015/AO is a standard PCI card containing 32 channels of 14-bit Digital to Analog Converters (DACs). Each DAC has double-buffered input registers allowing all channels on the board to be updated simultaneously or each channel to be updated individually. Software selectable voltage output ranges for the board consist of: ±10V, ±5V, ±2.5V, 0 to 10V, 0 to 5V, and 0 to 2.5V. Each DAC output amplifier is capable of supplying ±5mA current. All DAC outputs can be simultaneously isolated from the field wiring through low impedance FET switches.

The board contains a precision reference voltage source that drives the analog input of each DAC and a 32-bit RISC processor that performs auto-calibration calculations for each DAC channel.

This board does not require the use of a separate signal conditioning/routing board.

A PCI-PAS2015 Board is used in the Advanced Powertrain System.

**Thermistor Signals**

**The PCI-Therm Board**

ADI’s PCI-Therm Board is an intelligent I/O board developed by ADI that provides eight independent thermistor simulators. Each thermistor simulator is designed for use in the type of circuit shown in Figure 1. The output of the thermistor simulator is a voltage set by a 16-bit DAC. Each thermistor simulator:

+ Can cover the range of 200 KOhms to 0 Ohms
+ Is protected against a short to any voltage in the range ±50 Volts
+ Can determine the value of Vref and Rscale in the Engine Controller to compensate automatically for any scaling change in the Controller’s sensing circuit.
The PCI-Therm Board contains a Motorola MPC565 processor operating at 48 MHz to control the multiplexed, 16-bit ADC and eight 16-bit DACs on this board. This processor performs all necessary calculations, including calibration calculations, to determine the appropriate output voltage for each thermistor simulator given the temperature for that thermistor provided by the engine model.

The Thermistor Board is used in both the Powertrain and the Advanced Powertrain System configurations.

Figure 1: Thermistor Simulator Operation

**Ratiometric Sensors**

There are two methods available for generating ratiometric signals in the rtX. One method uses an IP having three multiplying DACs. The other method is an intelligent I/O board that contains eight ratiometric simulator circuits. Only the Intelligent Ratiometric Board is used in the Powertrain and Advanced Powertrain Systems.

**PCI-DAC Board**

ADI’s PCI-DAC Board contains a Motorola MPC565 processor operating at 48 MHz to control a multiplexed, 16-bit ADC and eight 16-bit DACs on this board. This processor performs all necessary calculations, including calibration calculations, to determine the appropriate output voltage for each DAC.

The setting for each DAC can be either ratiometric or non-ratiometric depending on the software that controls the board. For ratiometric DAC operation, the multiplexed ADC on the board is used to read the reference voltages generated in the ECU under test to drive ratiometric sensors. (A ratiometric sensor is a sensor whose output voltage is proportional to the reference voltage driving the sensor.)

The standard version of this board has ±10 Volt outputs. A ±20 Volt version of this board is available as an option. Each channel is protected against a short to any voltage in the range of ±50 Volts. Each output has over-current protection for currents outside the range of ±20 mA.

The DAC outputs can be updated individually or can be grouped together for simultaneous update of a group. Furthermore, the DACs on multiple boards can be simultaneously updated if the boards are interconnected in a master/slave arrangement for this purpose.

The PCI-DAC Board is used in both the Powertrain and Advanced Powertrain Systems. A separate Signal Conditioning and Routing Board are not required for use with this ratiometric board.
**O2 Sensors**

The PCI-LVDAC Board

ADI's PCI-LVDAC Board contains a Motorola MPC565 processor operating at 48 MHz to control a multiplexed, 16-bit ADC and eight 16-bit DACs on this board. This processor performs all necessary calculations, including calibration calculations, to determine the appropriate output voltage for each DAC.

The setting for each DAC can be either ratiometric or non-ratiometric depending on the software that controls the board. For ratiometric DAC operation, the multiplexed ADC on the board is used to read the reference voltages generated in the ECU under test to drive ratiometric sensors. (A ratiometric sensor is a sensor whose output voltage is proportional to the reference voltage driving the sensor.)

This board has ± 1 Volt outputs. These DACs can be used for any sensors, including O2 or lambda sensors and thermocouples that have low output voltages.

Each channel is protected against a short to any voltage in the range of ± 50 Volts. Each output has over-current protection for currents outside the range of ± 20 mA.

An important feature of this board is that each channel can be independently synchronized to the crank angle signal. This is handled via software in the on-board MPC565 processor.

**Variable Reluctance Sensor Simulators**

The PCI-VRS Board

When sensing a sharp edge on a tone wheel, a Variable Reluctance Sensor (VRS) produces a doublet type output signal whose amplitude increases with frequency. At higher frequencies, the VRS output signal may have amplitude in the ±100 Volt range or more. In general, the information of particular interest in Controller testing is the zero-crossing point of the VRS waveform and, perhaps, the slope of the VRS waveform as it goes through zero. Producing a simulated VRS output signal that goes beyond ±10 Volts is expensive and does not provide additional benefit in most applications. ADI has built systems with high voltage VRS outputs, but has found that most users do not want this added expense.

ADI's PCI-VRS Board contains four speed sensor simulator circuits. Each speed sensor simulator circuit has a variable frequency, variable output amplitude, arbitrary function generator followed by a gain of ten, operational amplifier with output hard limiting at ±10 Volts. This type of speed sensor simulator allows the user to define the waveform to be used. This waveform can simulate either a VRS or a Hall Effect sensor, for example. The user can control the amplitude of the output signal, at least at low frequencies.

The gain of ten output amplifier provides the proper slope of the speed sensor output signal at its zero crossing that an unlimited speed sensor signal would have at higher frequencies. The hard output limiting characteristic of the output amplifier essentially “clips” the simulated speed sensor signal at the limit points without adversely affecting the dynamics of the signal inside the limit range.

**rtX Architecture**

The rtX employs a host-target architecture.

Like its VM E-based precursor, the SIM system’s RTS hardware, the rtX employs a host-target architecture consisting of:

- The host computer which serves as the Human/Machine Interface to the simulator
- The target computer or real-time computing engine in the rtX
- The Input/Output processing subsystem that provides the interfaces between the real-time computing engine and the external hardware including the device(s) under test.
Figure 2 shows the basic architecture of the rtX.

The host computer is a standard PC running the Microsoft Windows 2000 Operating System. The minimum requirements for the host computer can be met by almost any present-day PC system configuration. The host computer for an rtX system can be upgraded without having any effect on the real-time compute engine or the I/O subsystem.

![Figure 2: rtX Real-Time System Architecture](image)

The rtX Basic system contains the real-time compute engine(s) consisting of one or more Intel (Pentium 4 or Xeon) or AMD (Opteron) processors mounted on a standard PC motherboard with PCI Bus on the PC motherboard. This PCI Bus connects the I/O subsystem to the real-time compute engine(s) in the rtX.

The rtX runs the POSIX-compliant, QNX Real-Time Operating System (RTOS). QNX provides a multitasking, multithreading environment to optimize the run-time usage of rtX CPU resources. The run-time software architecture is structured to ensure models run in “hard” real-time while accommodating data capture and parameter modifications. Each model runs as a separate multithreaded process that can be targeted on a single-processor or multi-processor rtX without modifying the simulation architecture. A GNU C++/C compiler is provided with the QNX RTOS.

**Ethernet Communications**

Ethernet is used to connect the host computer to the user's LAN. Ethernet is also used to connect the host computer to the rtX. In order to isolate the basic rtX system from the user's LAN, the host computer needs to be equipped with two separate, independent Ethernet ports as shown in Figure 1.

Port #1 is connected to the user's LAN only; Port #2 is used for intra-simulator communications only. These connections are via 10/100 Base T Ethernet.

The host Ethernet interface to the user's LAN (Port #1 in Figure 1) is used for:

- Moving models, test scripts, etc., to the simulator from a server or other devices on the user LAN
- Moving test data from the simulator to a server or other devices on the user LAN.

Once test information has been loaded into the simulator's host computer, test execution on the simulator is controlled completely from the host computer via the simulator network that connects to Host Ethernet Port #2 (see Figure 1). Test execution is completely independent of the user's LAN environment. This means that the simulator can operate normally even if the LAN is unavailable. Because the simulator has its own internal network that is used for all testing activities, the connection of the simulator to the user's LAN does not affect its operational performance.
In addition to these uses of Ethernet, the rtX can be equipped with one or more independent Ethernet ports for communication with other simulator systems or external hardware devices on a point-to-point or small network basis. The rtX supports 1 Gigabit Ethernet for such uses.

### rtX Electronic Controller Test System Architecture

Figure 2 illustrates how the rtX fits into the architecture of a real-time, HIL Electronic Controller Unit (ECU) test system. Some parts of this architecture are required; others are optional. The blocks labeled “rtX Real-time Compute Engine(s)” and “rtX I/O and Communication Interfaces” denote functional entities rather than packaging configurations. As noted in the discussion of Figure 1, the rtX Basic system contains a PC motherboard having one or more PC processors that provide the real-time computing capability and a PCI Bus with a small number of PCI slots—usually 5 or 6. In a small rtX system, the I/O and communication interface devices may be contained completely within the rtX Basic system.

### Optional Equipment

#### eXpansion Boxes

In larger systems, one or more eXpansion Boxes are used to house the I/O and communication interface devices. There are two versions of the rtX eXpansion box. One is a PCI version. The other is a version without a standard backplane where the boards connect to the rtX via a high-speed serial link such as IEEE 1394.

The rtX Basic is connected to the PCI eXpansion Box through a PCI-to-PCI bridge. The PCI eXpansion Box contains a PCI backplane with either seven or thirteen PCI board slots. This eXpansion Box will hold standard PCI I/O boards.

Other types of expansion are also possible in an rtX system. For example, a Compact PCI chassis can be connected to the rtX Basic via a PCI-to-PCI bridge. A PXI chassis can be connected to the rtX Basic through the use of a PCI-to-PXI bridge containing a MXI-3 Control link.

#### conneXions Boxes

The conneXions Box is an optional interface unit that simplifies connection of simulator I/O lines to the Device Under Test (DUT) and/or other external hardware. Cables from the various I/O devices terminate on the rear of this unit. Cables to the DUT and other external hardware or instruments terminate on the front of the unit. A choice of DUT connector types is provided.

The conneXions Boxes have screw terminal units inside to simplify the internal wiring tasks and to facilitate wiring changes. There are two versions of the conneXions Box:

- The Low-power conneXions Box is used for low-power signals such as analog and TTL signals
- The High-Power conneXions Box is used for all other signals.

The High-Power conneXions Box has provision for mounting low-power loads. High heat-dissipation loads and other hardware devices will be located external to the High-power conneXions Box. A connector interface is provided for cabling to external loads and hardware.
Having these two types of connexions Boxes greatly aids in separating the signal types and shielding sensitive signals. This helps to minimize electrical noise issues in the test setup.

The connexions Box is is strongly recommended for all but the smallest rtX systems to simplify wiring issues between the rtX I/O and external hardware.

**Programmable Power Supply**

The programmable power supply is another optional item. ADI offers a 1200-Watt Kepco power supply unit (Kepco Model KLP 75-33-1200) as a standard product to meet Vbatt requirements. The maximum output voltage available from this supply is 75 Volts; the maximum current is 33 Amperes. (NOTE: ADI’s software driver for the Vbatt supply will limit the output voltage to 50 Volts maximum to protect the simulator I/O system.) The user can select either the output voltage or the output current and the supply will automatically set the maximum value for the other parameter. For example, at 50 Volts output voltage, the maximum current is 24 Amperes. For any output voltage in the range of 0 to 36 Volts, the maximum output current is 33 Amperes. If the user specifies a Vbatt requirement that cannot be met by this Kepco power supply, ADI will recommend an alternate solution.

**Programmable Vbatt Mode Switching**

For applications that require ignition-type switching of Vbatt power, ADI provides eight independently controlled FET switches for Vbatt power. These switches are mounted in a connexions Box. Each switch is capable of handling 20 Amperes of continuous current. For high-current applications, ADI provides a stand-alone mode-switching unit containing electromechanical relays, where each relay is capable of switching up to 300 Amperes. In either case, the switches are controlled from within the rtX system.

**Fault Insertion Unit**

Another product available as an option for use with the rtX system is a Fault Insertion Unit (FIU). The FIU handles faults consisting of open circuits, shorts to ground, shorts to an external voltage source (such as Vbatt), and shorts between I/O signals and is controllable either interactively via a user GUI or through commands from a test script.

**rtX Packaging Configurations**

The single-processor rtX Basic is available in either tabletop or rackmount packages. The ATX motherboard for the single-processor rtX Basic has 6 PCI slots and 1 non-PCI slot. The standard Powertrain configuration described in Table1 will fit the rtX Basic without the need for an eXpansion Box.

The two-processor version of the rtX Basic is also available in both tabletop and rackmount configurations. However, the ATX motherboard for the two-processor rtX Basic only has 5 PCI slots. If a standard Powertrain I/O configuration is used with a two-processor rtX Basic, an eXpansion Box is required.

The use of a connexions Box is optional, but highly recommended, for the Powertrain System configuration. The use of connexions Boxes is strongly advised with the Advanced Powertrain System.

**SUMMARY**

To stay at the forefront of product design, today’s engineers need the best tools.

For experienced simulation users as well as those who are just getting started, the rtX offers high-quality HIL with microsecond determinism at an affordable price.

A choice of two available configurations, the Powertrain System and the Advanced Powertrain System configurations, provide tools at two different price points and levels of capability for automotive engine, transmission, and powertrain Electronic Control Unit testing. Each of these configurations can be expanded to meet the needs of particular applications.
For more information about how the rtX can enhance and optimize your product verification and design process, please contact us at:

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