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DEFINING THE FUTURE

Standard Tools for Hardware-in-the-Loop (HIL) Modeling and Simulation

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HIL Modeling and Simulation

Hardware-in-the-Loop (HIL) Simulations involve the integration of validated system simulations and prototype hardware.

Areas of Integration

- **Communication between Hardware and Computer models**
  - computer models simulate system dynamics and inputs into the hardware
  - Hardware outputs response signal back to the computer model
- **Simulation synchronization**
  - Real-Time Simulation

Hardware – SEL 300G Protection Relay

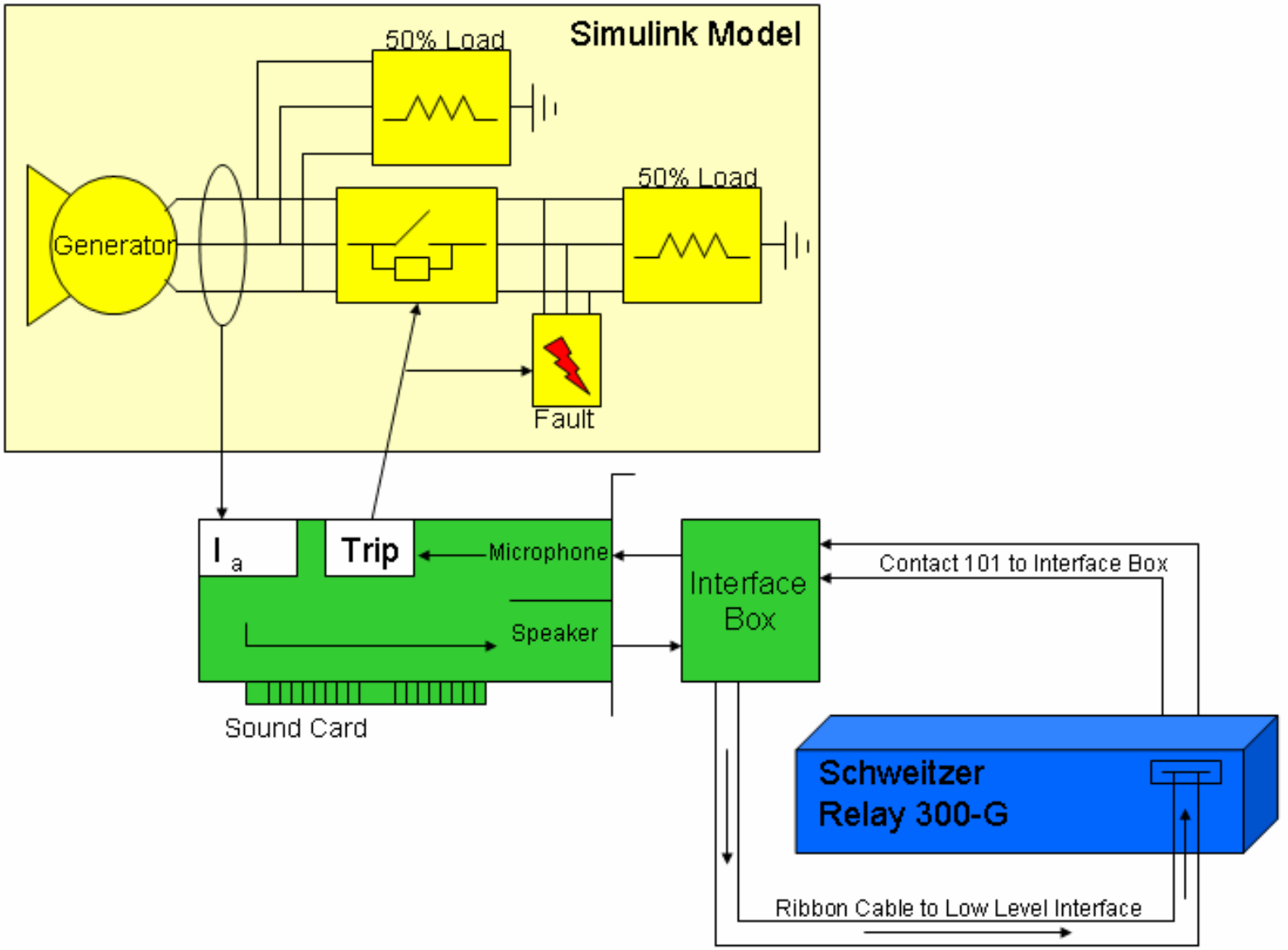
- **Hardware in the Loop:**
  - Schweitzer Engineering Laboratories (SEL) 300G Generator Protection Relay
    - Provides power protection
    - Detects 3- or 4- wire potentials, and 3 phase current
    - Voltage Input Range: ± 10V
  - The generator computer model was wired directly into the processing module via a low level interface.

Data Acquisition – Sound Card

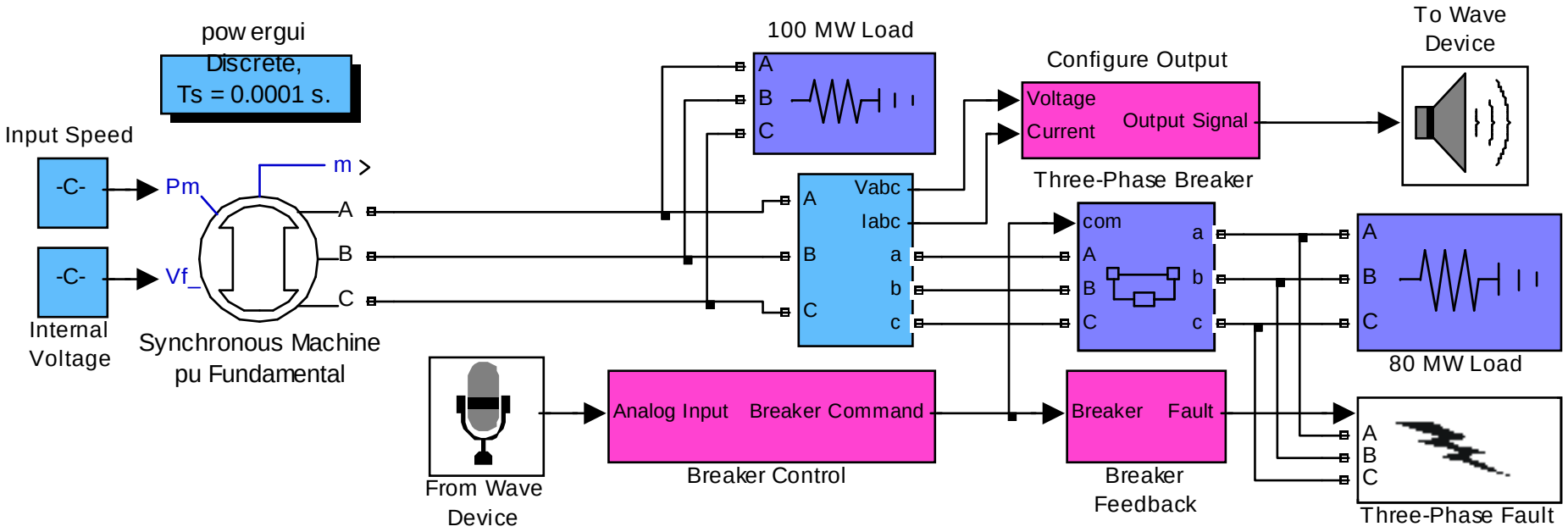
- **Integrated Sound Card – Analog I/O**
  - 2 Channels Input, 2 Channels Output (Stereo)
  - Sample Rate: 48 kS/s
  - Voltage Output Range: ± 2V
  - Frequency Range: 10 – 20000 Hz

- **PCI Sound Card – Analog I/O**
  - 2 Channels Input, 5 Channels Output (Stereo)
  - Sample Rate: 50 kS/s (approximately)
  - Voltage Output Range: ± 14V
  - Frequency Range: 10 – 50000 Hz

System Configuration w/ Sound Card



Computer Model w/ Sound Card



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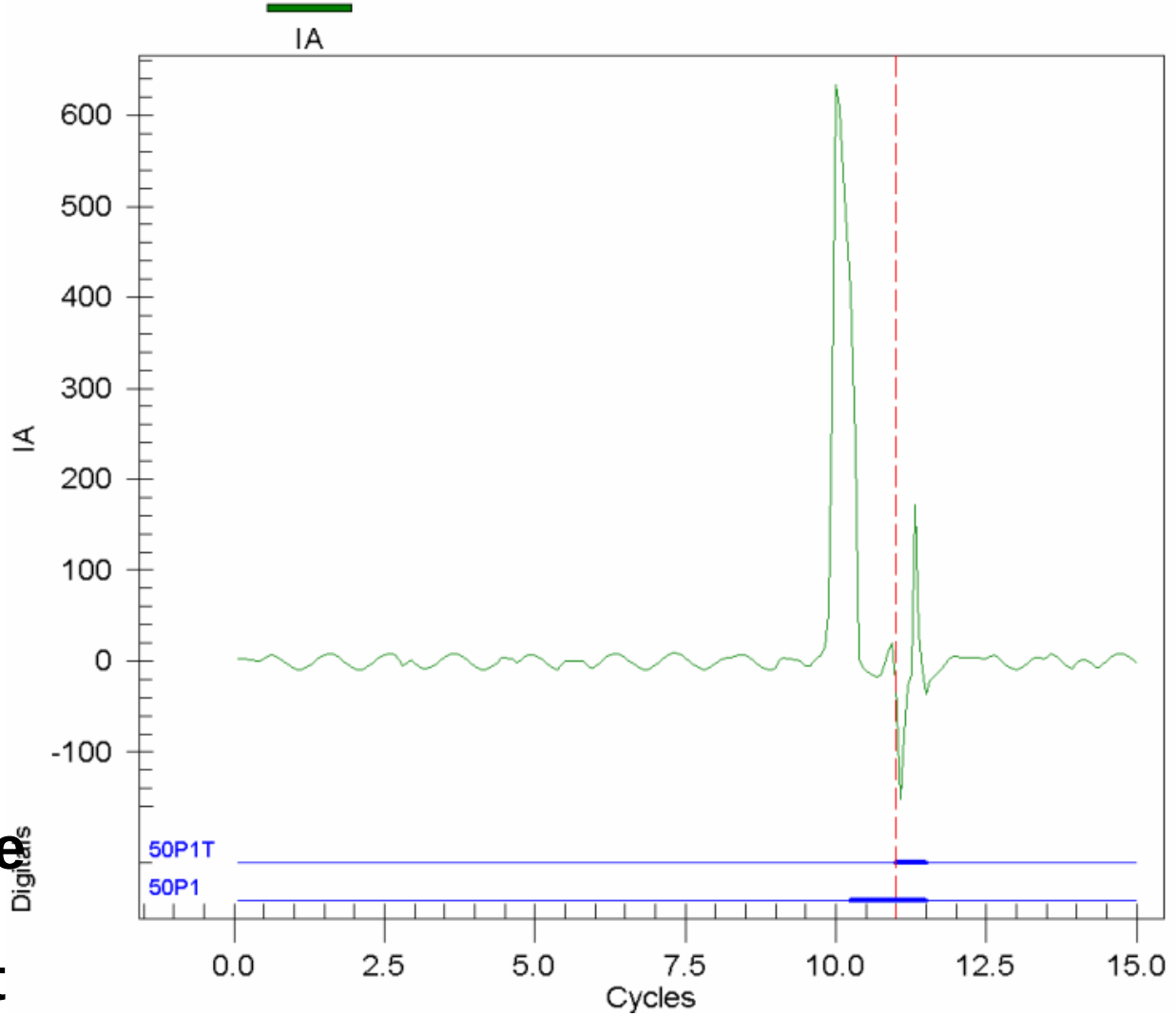
Relay Data w/ Sound Card

- Simulation Time Step: 1ms
- Bolted Fault @ 0.25s ~ 10 cycles
- Clears fault in 25ms
- Inconsistent reaction time
- Relay needs three phases or very large overcurrent (100 pu)



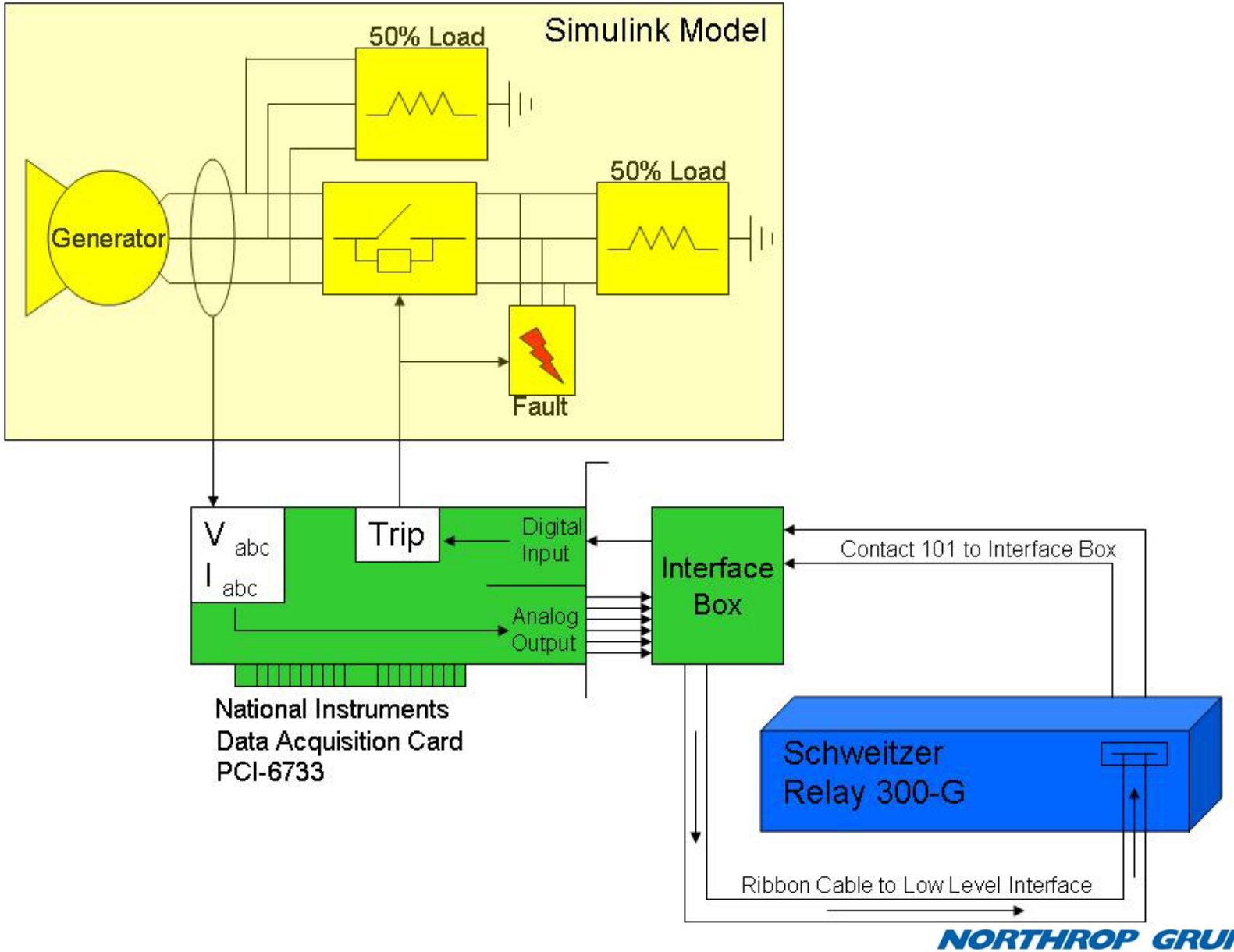
Sound Card Interface

- **Pro**
  - Availability – Standard in Computers
  - Inexpensive
- **Con**
  - Limited I/O ports – Two Channels (Stereo)
  - Limited Data Type – Analog only
  - Limited fidelity – 16 bit data
- **Simple Standardized Tool for I/O interface**

Data Acquisition – Dedicated I/O Card

- **National Instruments Data Acquisition (NIDAQ) Card**
  - NI PCI-6733
  - Analog Output (No Input)
    - 8 Channels
    - Voltage Range: ± 10V
    - Update Rate: 1MS/s
  - Digital I/O
    - 8 Channels, TTL Logic
    - Voltage Range: ± 5V

System Configuration w/ NI DAQ Card



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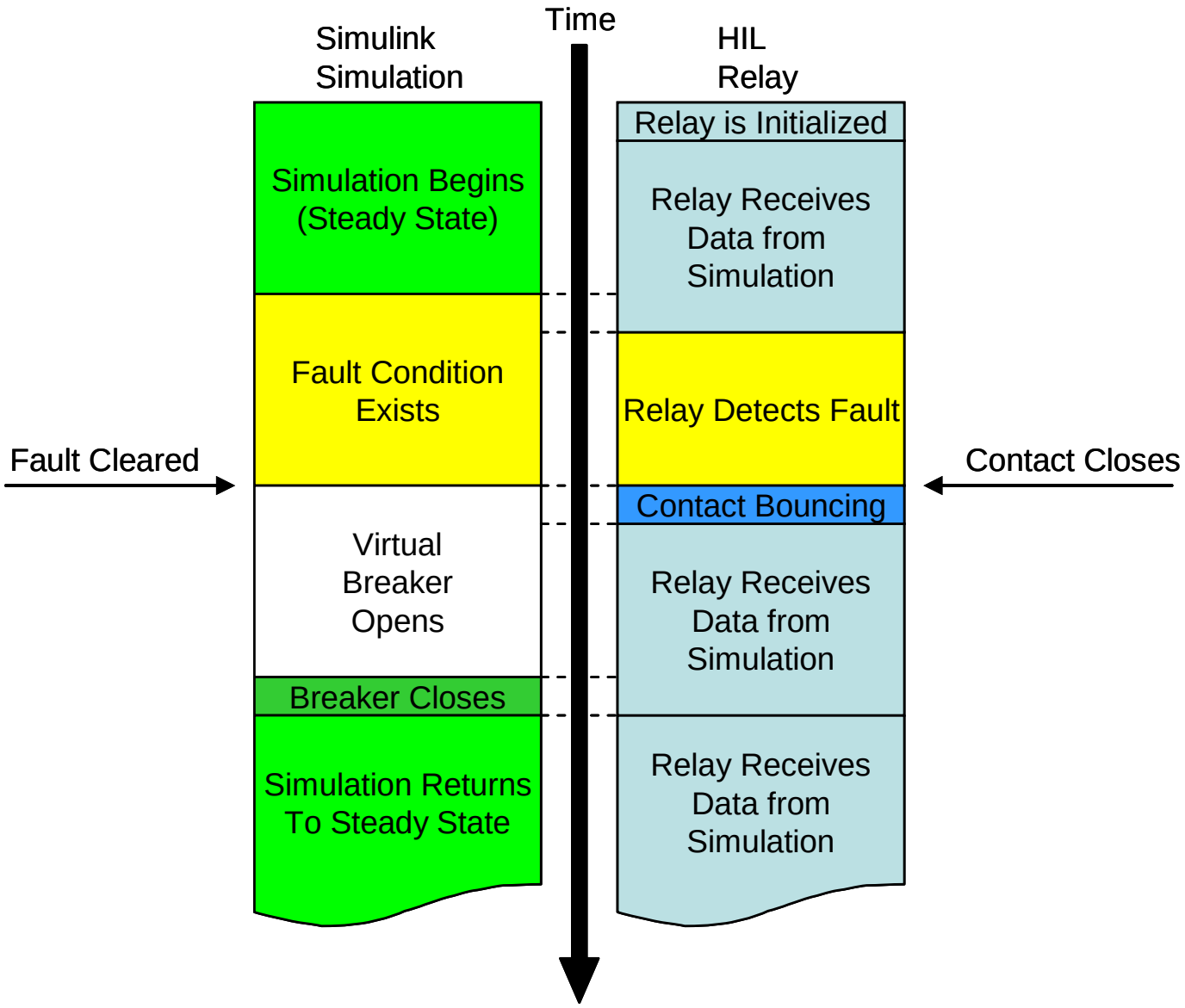
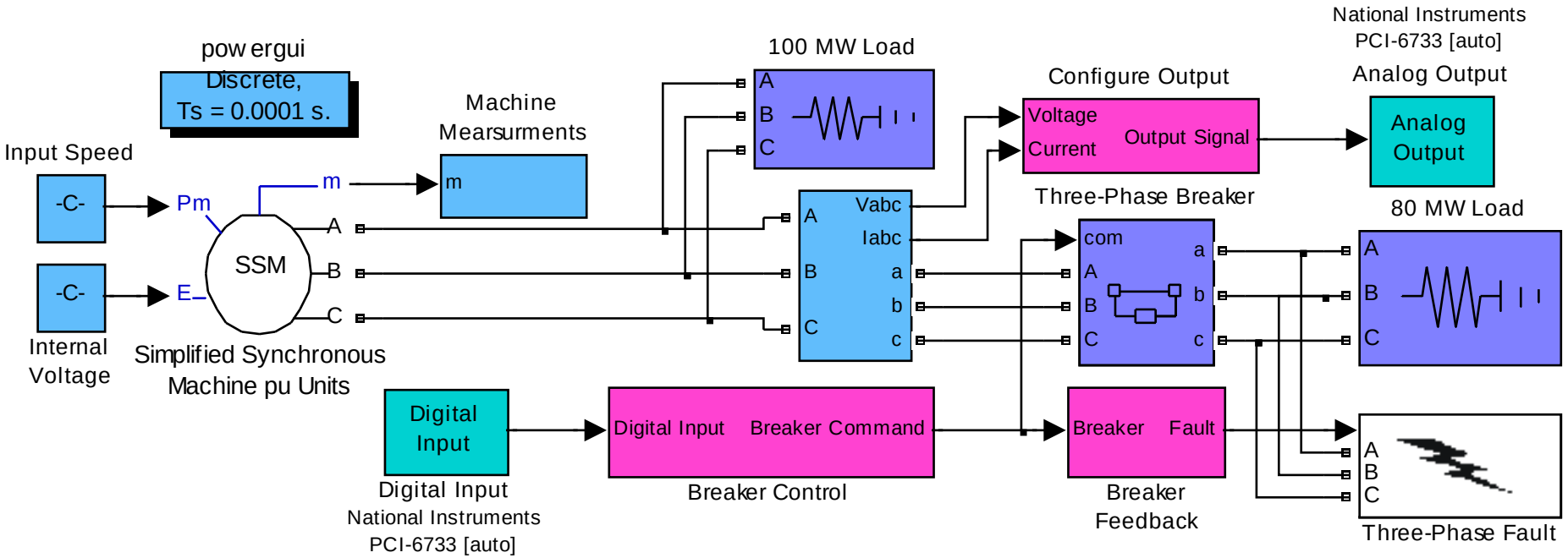
HIL Timing Diagram



Computer Model w/ NI DAQ Card



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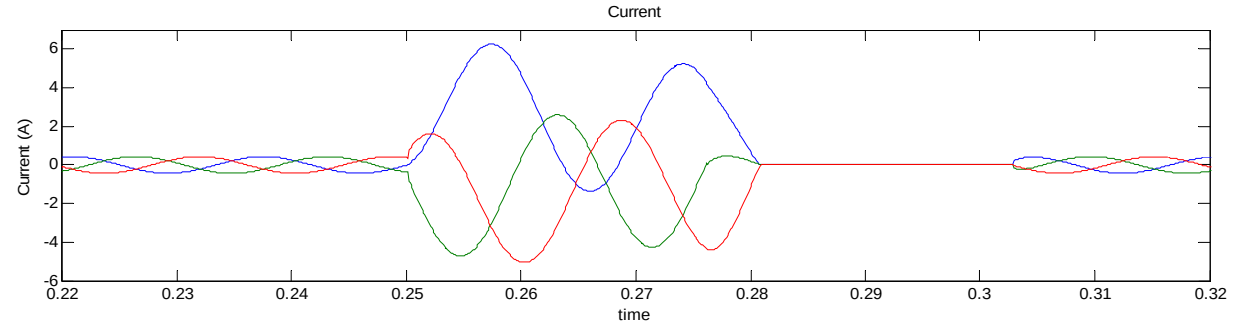
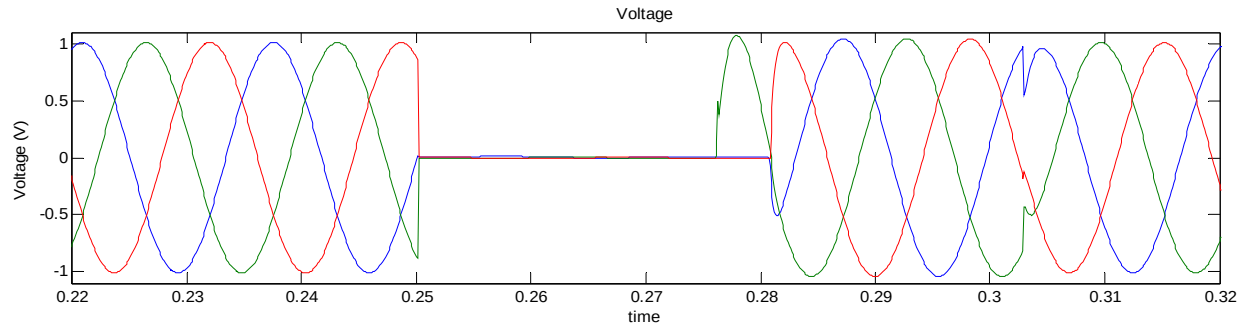
Computer Model Data w/ NI DAQ Card

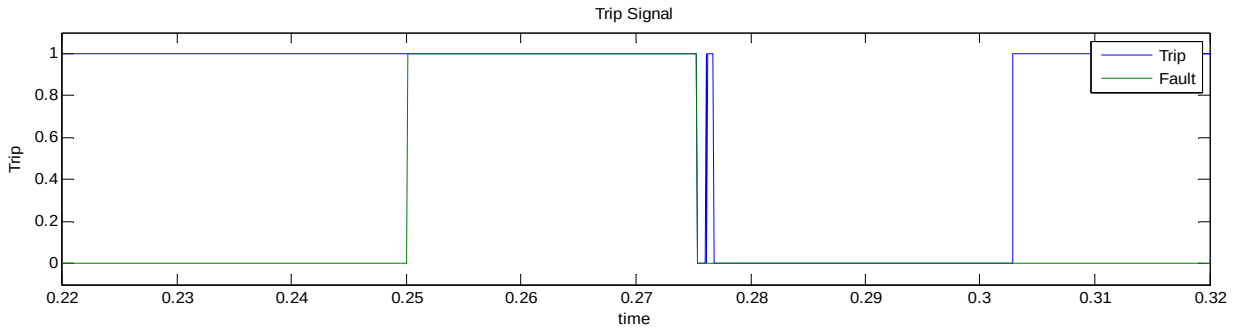
- Simulation Time Step: 10 μs
- Bolted Fault @ 0.25s ~ 10 cycles
- Clears fault immediately

Closes Breaker in 25ms later

- Switch bouncing can be seen
- Detects fault at 1.5pu overcurrent

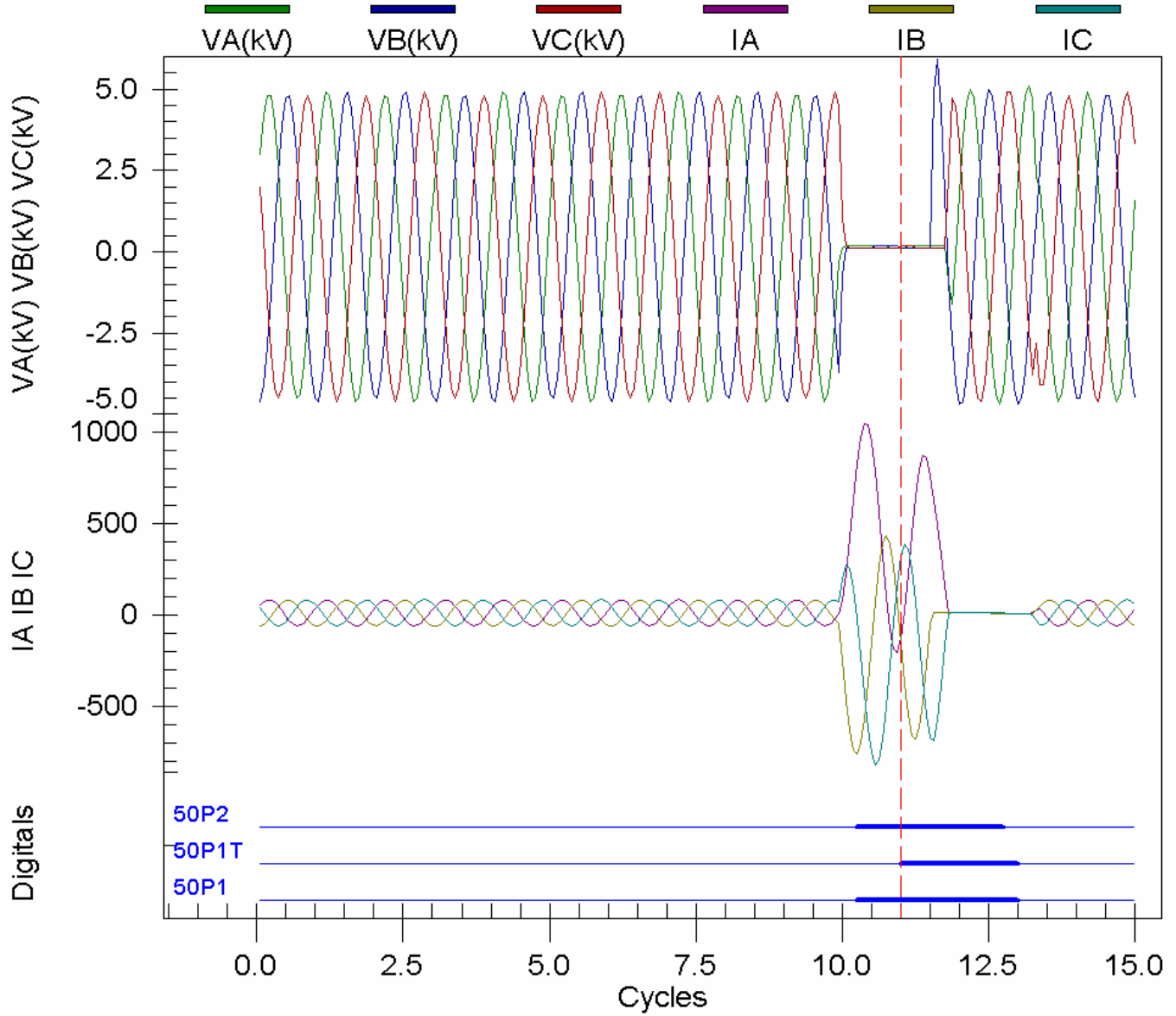






Relay Data w/ NI DAQ Card

- Three Phase Voltages
- Three Phase Currents
- Fault Detection Signals



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Interface – w/ NI DAQ Card

- **Pro**
  - Numerous I/O ports
  - Analog and Digital Data support
  - High Fidelity rate (1Mb/s or better)
  - Current controlled I/O ports available
- **Con**
  - Expensive
  - Not standard in Computers – Add-on PCI Card
- **Multi-port Interface for Control Simulation**

Conclusion

- **The relay in the HIL environment was able to receive Voltage and Current analog signals from the power system simulation running in a Simulink real-time environment.**
- **The relay acted on the signals as if the relay had been installed in an actual power system.**
- **The relay was able to communicate back to the Simulink simulation. (Closing the Loop)**
- **The simulation used the relay feedback information to control a virtual breaker and clear a fault.**

Conclusions, Cont.

- **For very simple HIL interface needs, a computer sound card can be used as a data acquisition tool.**
  - For multiple signals, multiple sound cards could be used.
- **For more complex HIL interface needs, a dedicated I/O card should be chosen.**
- **Windows Real-Time Target simulation environment is necessary for this HIL testing.**
- **Next stage is to use xPC target, as it is completely independent of windows.**
- **HIL provides a cost effective method of testing prototype hardware with standard tools.**
  - Simulink/MATLAB real-time environment
  - Desktop Computer/PC
  - Data Acquisition Card
    - Sound Card
    - Dedicated I/O Card – National Instruments DAQ

Questions