Control Technology and the Impact of Smart Node Hardware

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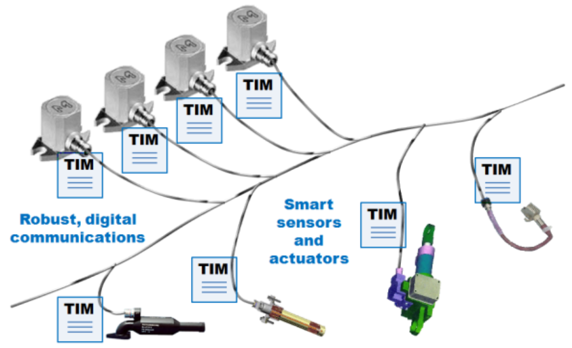
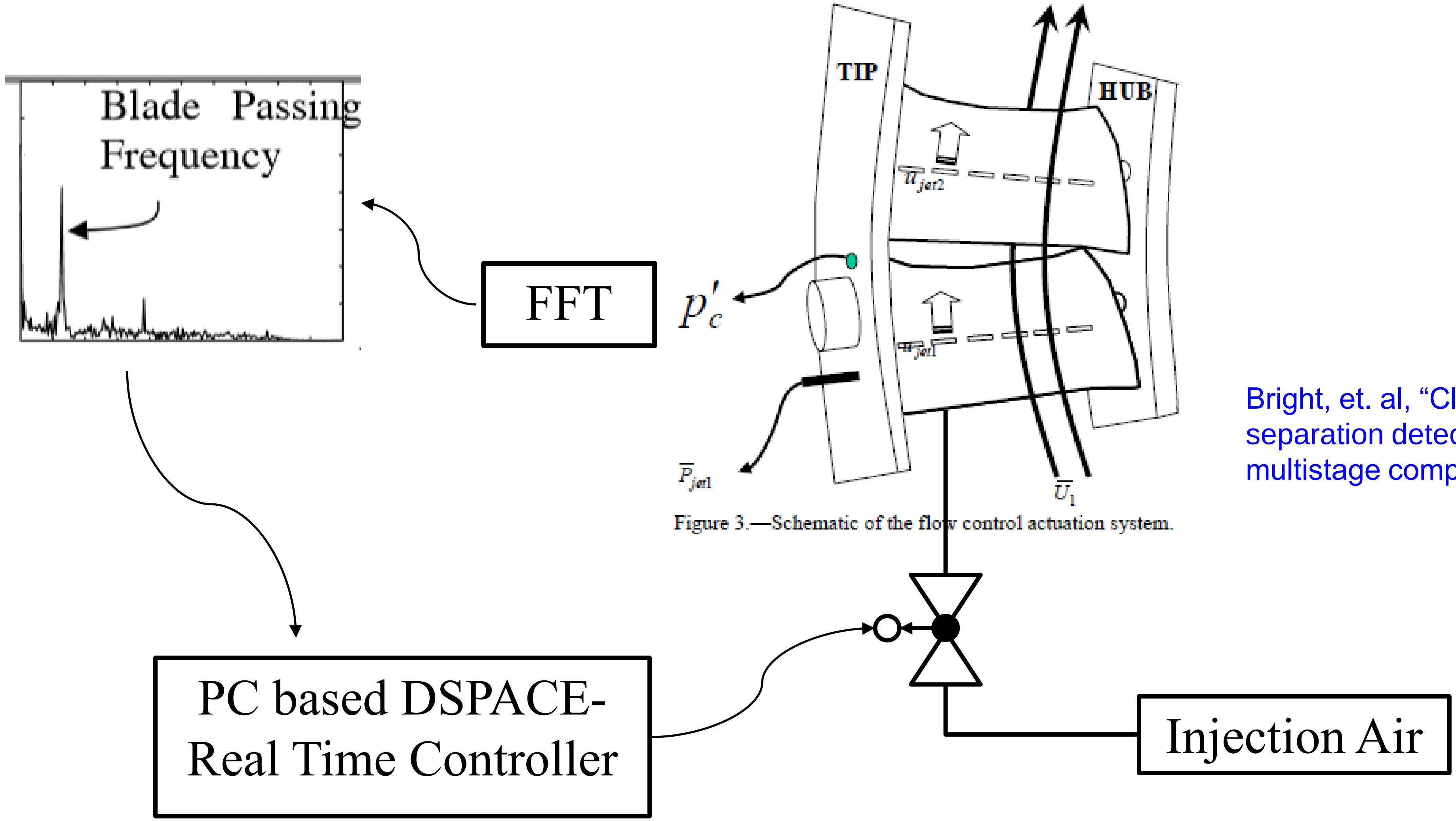
Why Distributed Engine Control?

- Distributing control from the FADEC to smart nodes enhances system
  - Augments total control system processing capability
  - Frees up FADEC processing to be used elsewhere
  - Distributes analog circuitry closer to sensors, on the smart nodes
- Advanced control technologies like Active Combustion Control or Active Stall Control will require Distributed Engine Control
  - Not practical to implement if loop closure is through the Engine controller
  - Smart node moves processing closer to sensor/actuator, allowing for higher bandwidth sensors
- But, distributing control functions to smart nodes requires new hardware based on high temperature electronics
  - *What kind of capability could we expect from that hardware???*

Public Release Photo Courtesy of Pratt & Whitney



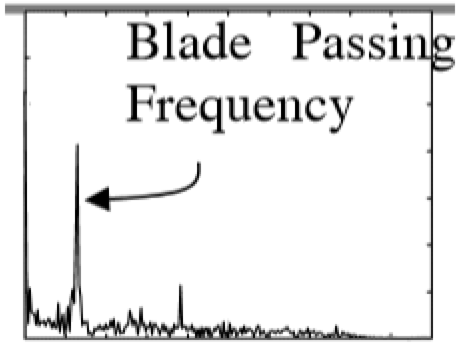
Active Stall Control Scenario



Bright, et. al, “Closed loop active flow separation detection and control in a multistage compressor,” AIAA2005-849

NASA Smart Node

- Demonstrate a smart node for a distributed control environment
- To demonstrate a smart P3 sensor, Develop a Smart Node design incorporating SiC and SOI components for sensing and processing of P3 pressure sensor signals
- Outcome: Reference design of room temperature smart node hardware for demonstration in the HIL simulator, which is representative of SiC and SOI components
  - Understand capabilities of hardware



- As part of active stall control, P3 smart node will:
  - condition and sample pressure signal for processing
  - Calculate Power in first harmonic of the blade passing frequency
  - Look at other algorithms to perform recognition of stall pressure signatures
  - Communicate with Hardware in the Loop controller

Smart Node Architecture

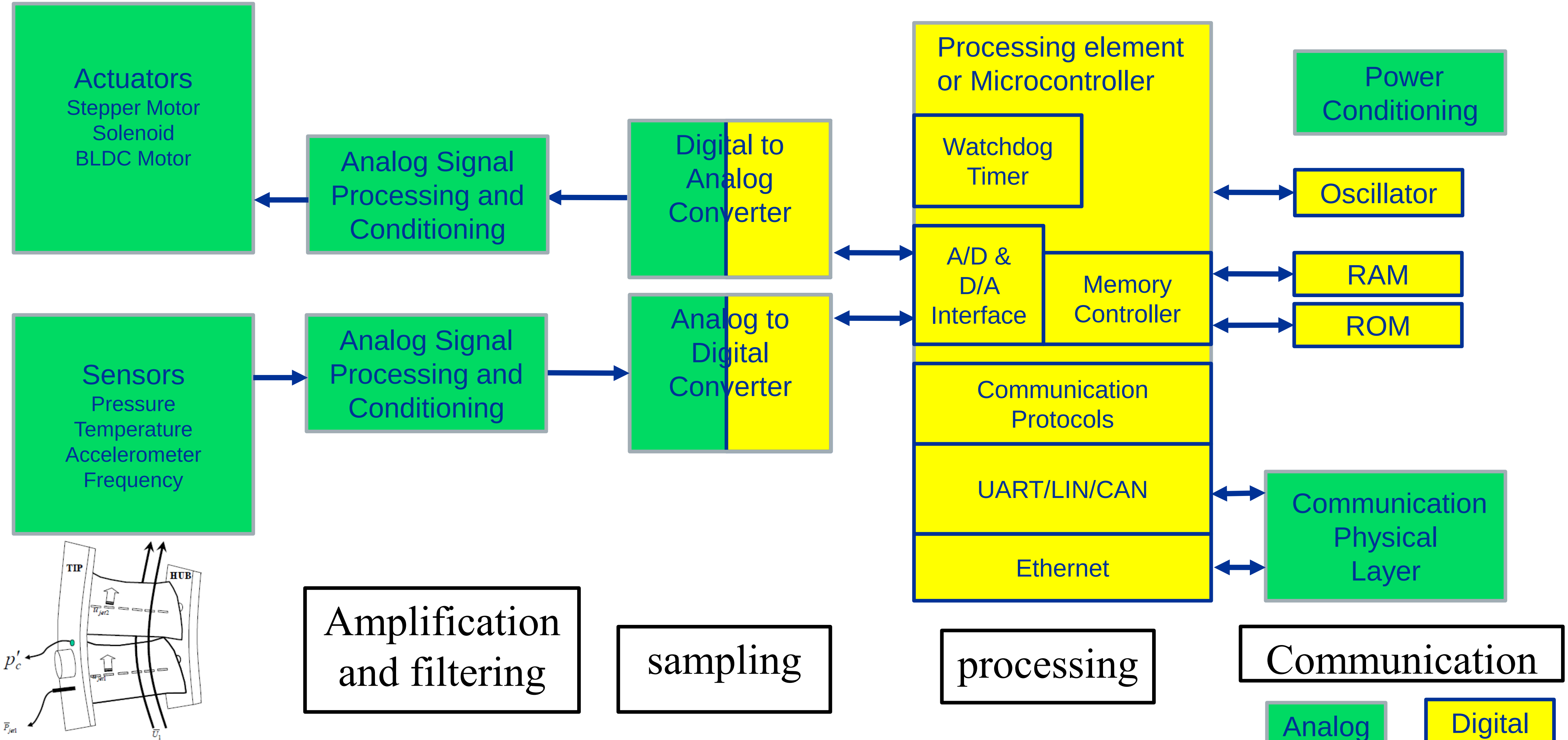


Figure 3.—Schematic of the flow control actuation system.

NASA Smart Node Functions as functions of temperature

SiC hardware capabilities are improving:
Flip flops, logic gates, D/As, A/Ds, op amps?

- High Bandwidth Pressure Sensor
- Signal Conditioning
- Signal Processing
- Signal Digital Conversion
- Signal Processing (FFT)
- Algorithms
- Control loop?
- Communication (Network Protocols)

SiC (500°C)

SiC/SOI (>225°C)

SOI (>225°C)

Embedded electronics will need to accommodate as high a temperature as possible to move closer to the sensors

Many SOI Integrated Circuit functions are available commercially

500°C → 225°C

Arm Cortex-M Processors

- 32 bit processors
- M4 designed for DSP
- M0+ minimal, but instructions can run on the M4

Functions	M0	M0+	M3	M4
	M3 - Features	M3 - Features		M3+Features
Memory protection unit	No	Yes	Yes	Yes
Thumb-2 instruction set	56 instruction subset	56 instruction subset, but adds Conditional pipeline, two stage for greater throughput	74	137+(32 F.P) DSP (Hardware MAC), Single Instruction multiple data, floating point instructions
Debug support		More Debug support	More Debug Support	More Debug Support
DMIPS/MHz	0.87	0.95	1.25	1.25 w/o FPU 1.27 w/ FPU

Microcontroller

8051 (+225˚C)

Honeywell HT83C51

Tekmos TK80H51

- 8 bit
- 16 MHz
- Performance relies on peripherals
- << 1 DMIPS

Relchip RC10001 (+300˚C)

- Cortex-M0
- 4K RAM
- UART and LIN 2.0
- Two 16-bit timers with PWM
- Two 32-bit timers with PWM
- 32bit hardware multiplier
- 5MHz-8MHz operation
- 5V supply

SiLabs EFM32ZG222 (+85°C)

- Cortex-M0+
- 4K RAM
- UART, no LIN or CAN
- Two 16-bit timers with PWM
- 32bit hardware multiplier
- 1-28MHz RC Oscillator, or 1-32MHz Crystal Oscillator
- 12 bit – 1MS ADC (SAR) w/ mux
- 2V to 3.8V supply

SiLabs EFM32WG232 (+85°C)

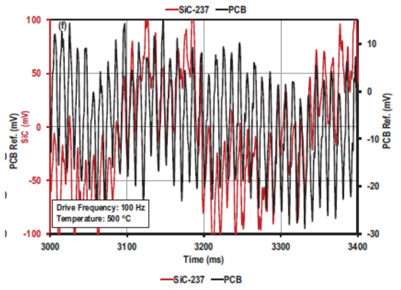
- Cortex-M4
- 32K RAM
- UART, no LIN or CAN
- Four 16-bit timers with PWM
- Floating Point Unit
- 1-28MHz RC Oscillator, or 1-32MHz Crystal Oscillator
- 12 bit – 1MS ADC (SAR) w/ mux
- 2V to 3.8V supply

Analog to Digital Converter

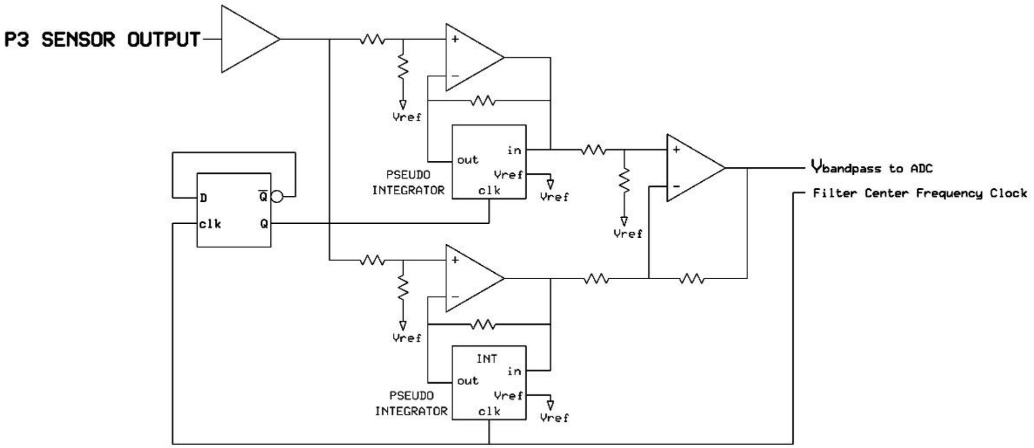
- HTADC12 (Honeywell)
  - 12bit, 100kSample
  - Parallel or SPI interface
  - Onboard SAR clk, 2.5V VREF

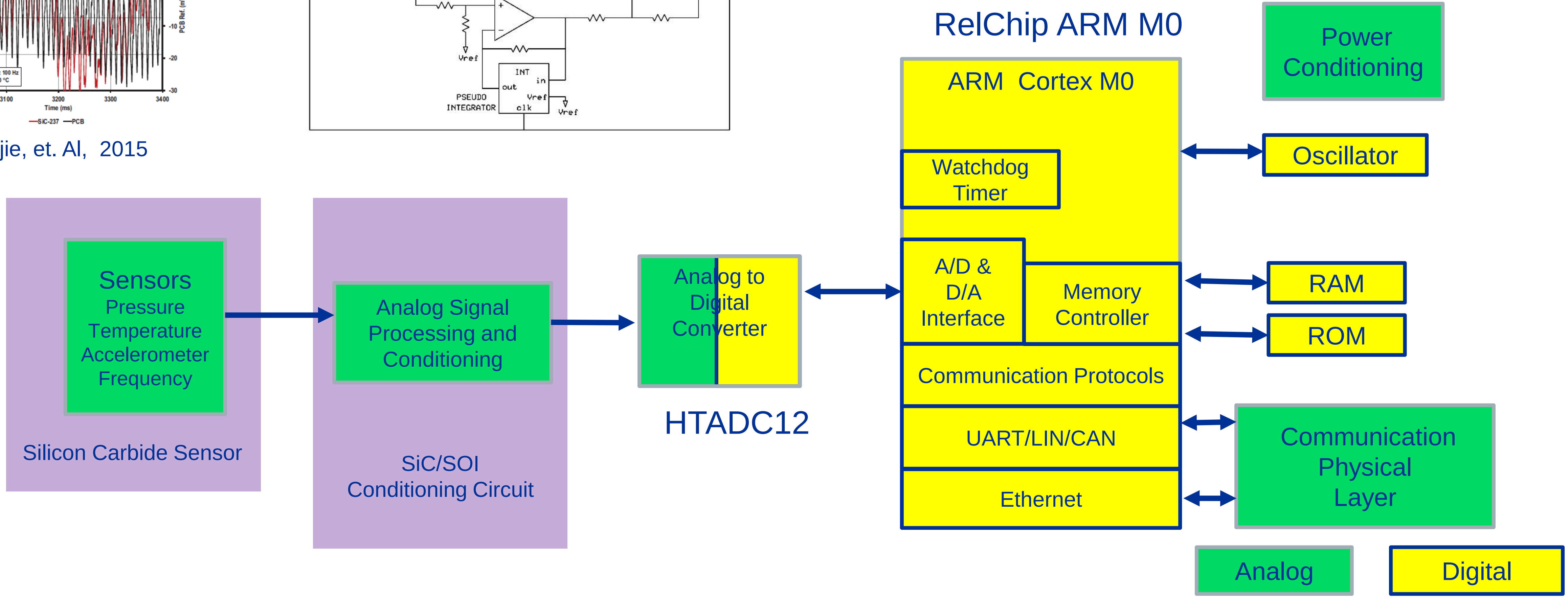
- Silabs on board ADC
  - 12 bit,
  - Parallel interface
  - Onboard SAR clk, 2.5V VREF
- SAR clk programmable to ~100kSample

High Temperature Smart Node

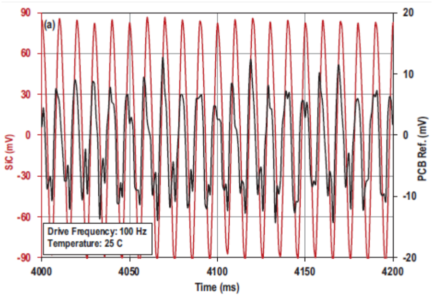


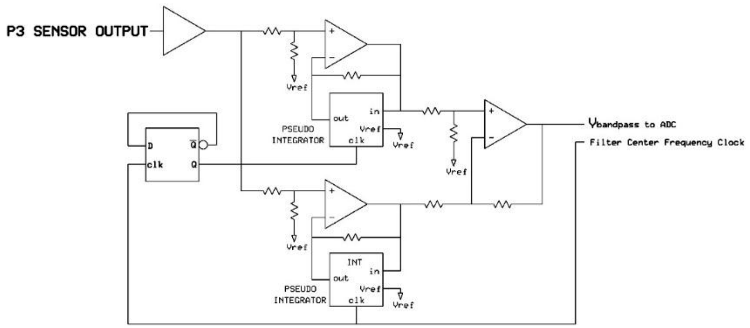
Okojie, et. Al, 2015





NASA Smart Node Demonstration





Test Fixture Data Set (from Pressure samples)

Silabs EFM32ZG222

Power Conditioning

ARM Cortex M0

Watchdog Timer

Oscillator

Sensors
Pressure
Temperature
Accelerometer
Frequency

Silicon Carbide Sensor

Analog Signal Processing and Conditioning

SiC Conditioning Circuit

Analog to Digital Converter

A/D & D/A Interface

Memory Controller

RAM

ROM

Communication Protocols

UART/LIN/CAN/EADIN

Ethernet

Communication Physical Layer

Analog

Digital

Conclusion

- Distributed Control smart nodes provide an opportunity to add new performance-enhancing technology to the engine system
  - They offload computational burden from the Engine Controller so its resources can be used elsewhere
  - They eliminate custom analog circuitry from the Engine Controller thus reducing its volume/complexity
  - They augment total processing capability available to the control system
- Wide bandwidth control technologies are not practical to implement if the loop closure is through the Engine Controller
- Smart nodes are based on common microcontroller technology but must be implemented in high temperature electronics for embedded applications on the engine.
- These considerations are discussed in an analysis of potential high temperature node hardware capabilities.

References

- Bright, M., Culley, D., Braunscheidel, E., and Welch, G., “Closed Loop Active Flow Separation Detection and Control in a Multistage Compressor,”, 43rd AIAA Aerospace Sciences Meeting and Exhibit, January, 2005.
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- Okojie, Robert S. Meredith, Roger D., Chang, Clarence T., Savrun, Ender, “High Temperature Dynamic Pressure Measurements Using Silicon Carbide Pressure Sensors,” International Conference on High Temperature Electronics (HiTEC 2014), Albuquerque, NM, May 13-15 2014.