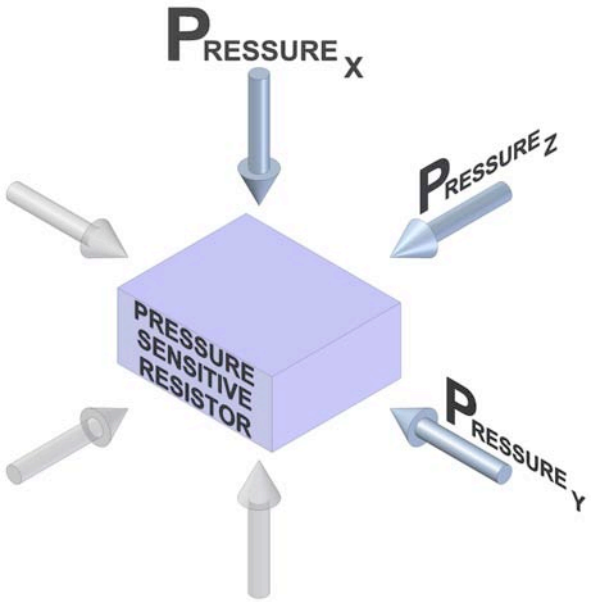
CTS Automotive Products

Automotive Pressure Sensors
based on
New Piezoresistive Sense Mechanism

AMAA Berlin
March, 2005



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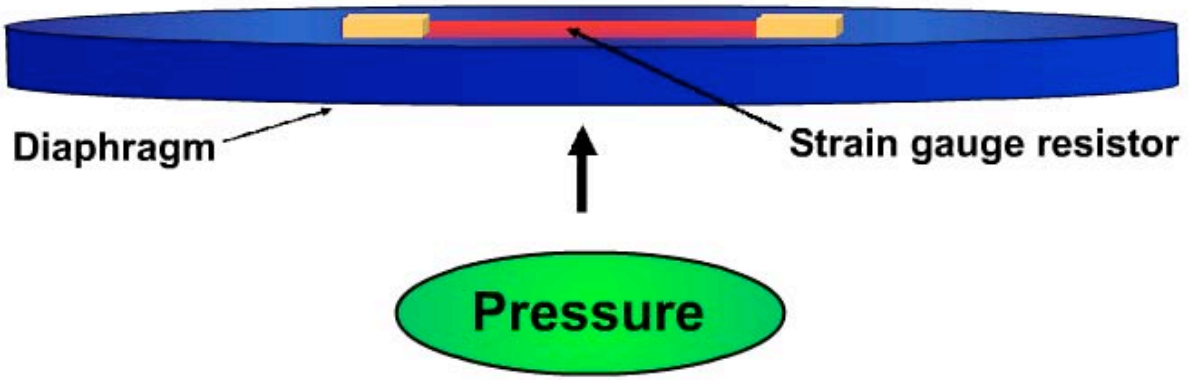
Current Pressure Sensor Technology

– Sense Resistors are arranged as part of a Wheatstone Bridge formation

  – Bridge voltage is proportional to applied pressure



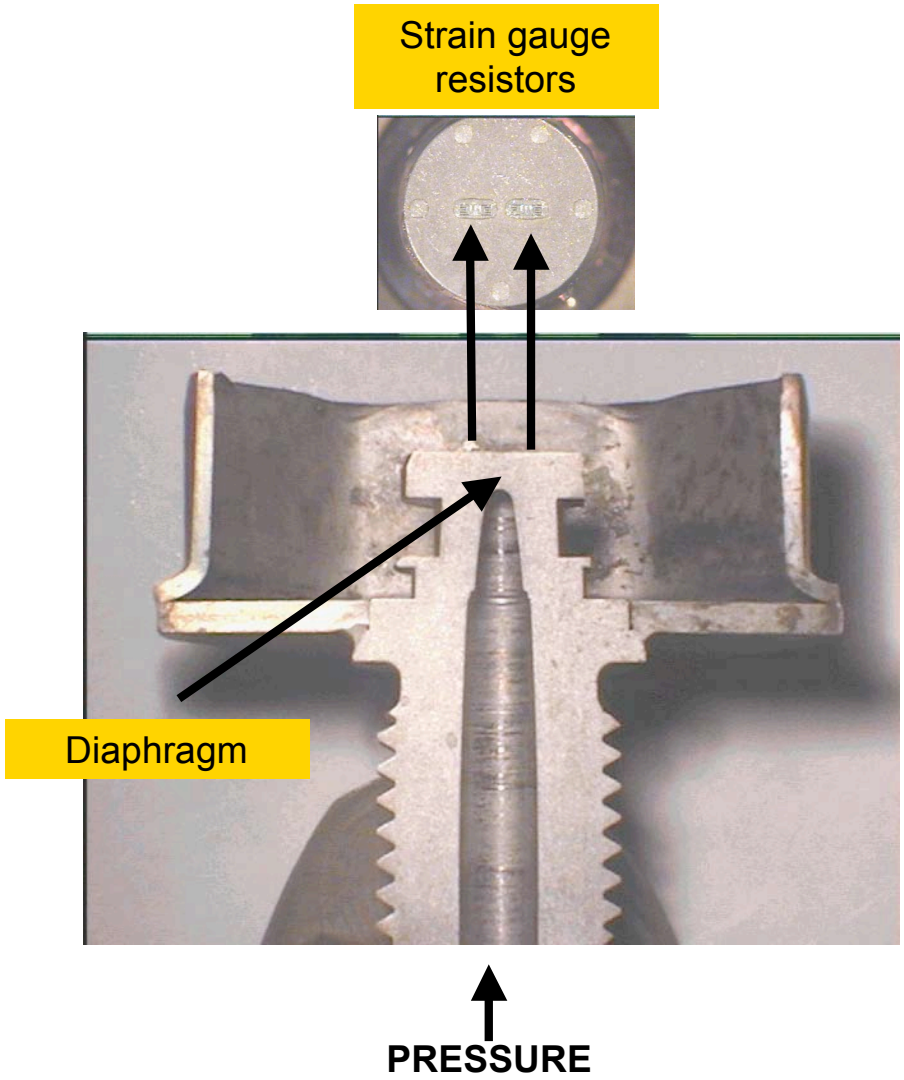
Piezoresistive Sense Elements

- Diffused silicon resistors
- Metal foil or thin film resistors
- Cermet thick film resistors

Diaphragm

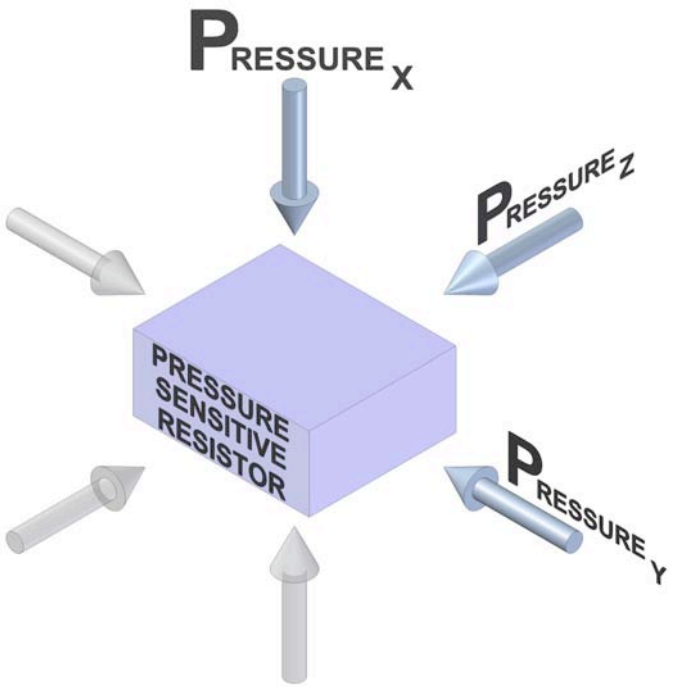
- Steel (most common for high pressure)
- Ceramic
- Silicon

Technical Issues with Diaphragm Sensors



- Diaphragm Thickness
  - Thick enough for highest pressure, thin enough for useable output
- Diaphragm Fatigue and Yield Stress
  - Causes hyteresis in measured outputs from strain gauges
- Accuracy is a function of sensor geometry
  - Repeatability of placement of bridge resistors
- Silicon strain gauge
  - Large and non-linear temperature coefficients
    - » Span
    - » Offset
  - Difficult calibration raises cost

CTS Approach – Direct Measurement



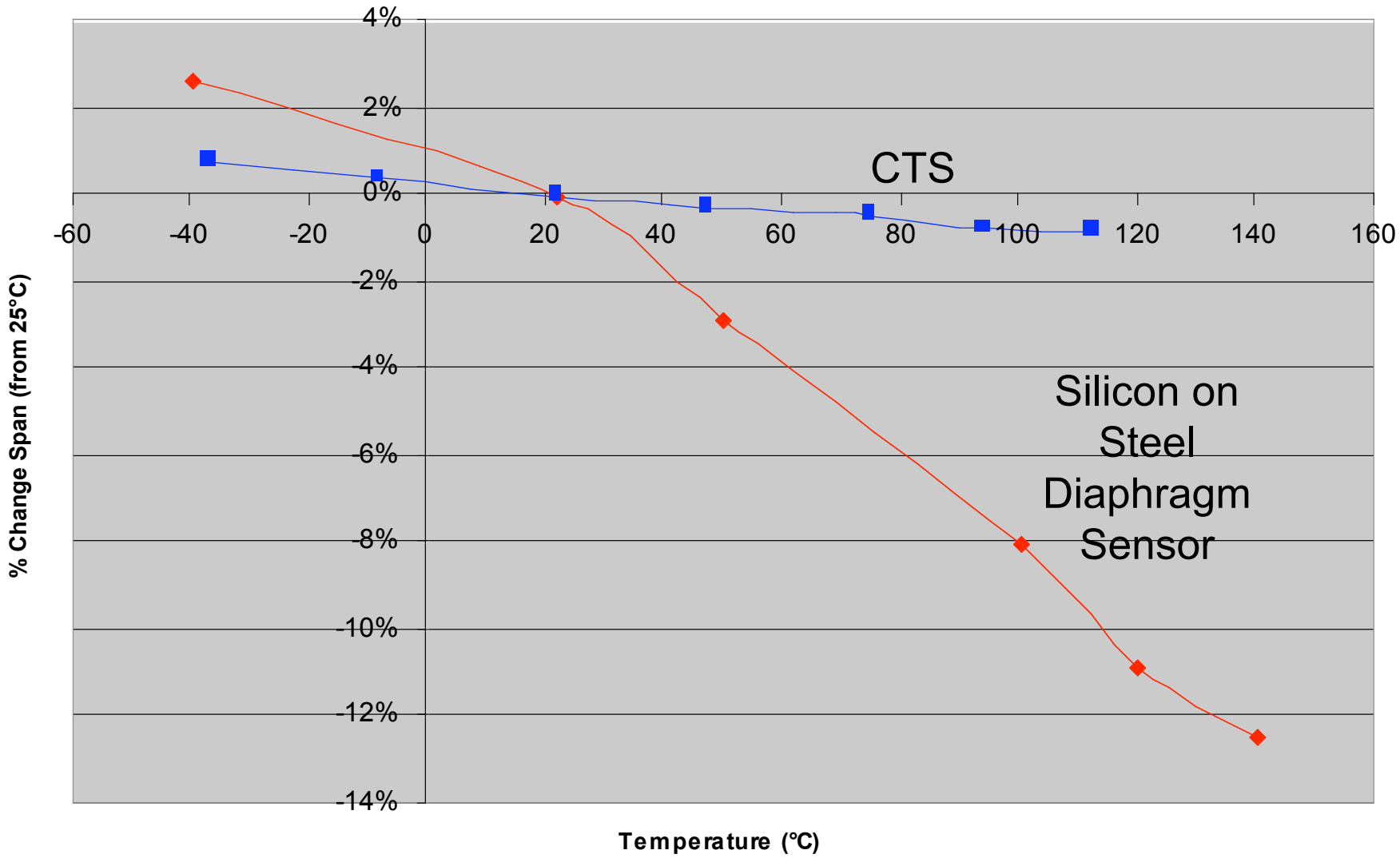
Hydrostatic pressure

sensitivity of CTS thick film resistors

- Technique
  - CTS proprietary thick film resistors on ceramic substrates
  - Direct exposure to medium
- Applications
  - Fluid pressure 250 to 3500 Bar
  - Where high accuracy is required
- Advantages
  - Eliminates diaphragm failure
  - No identified proof pressure limit
  - Accuracy is independent of geometry
  - Smaller and more linear temperature coefficients
  - Less difficult calibration → more cost effective

New Sense Mechanism Ideally Suited to Common Rail Pressure Sensors

TC Span (% full-scale): Diaphragm vs CTS



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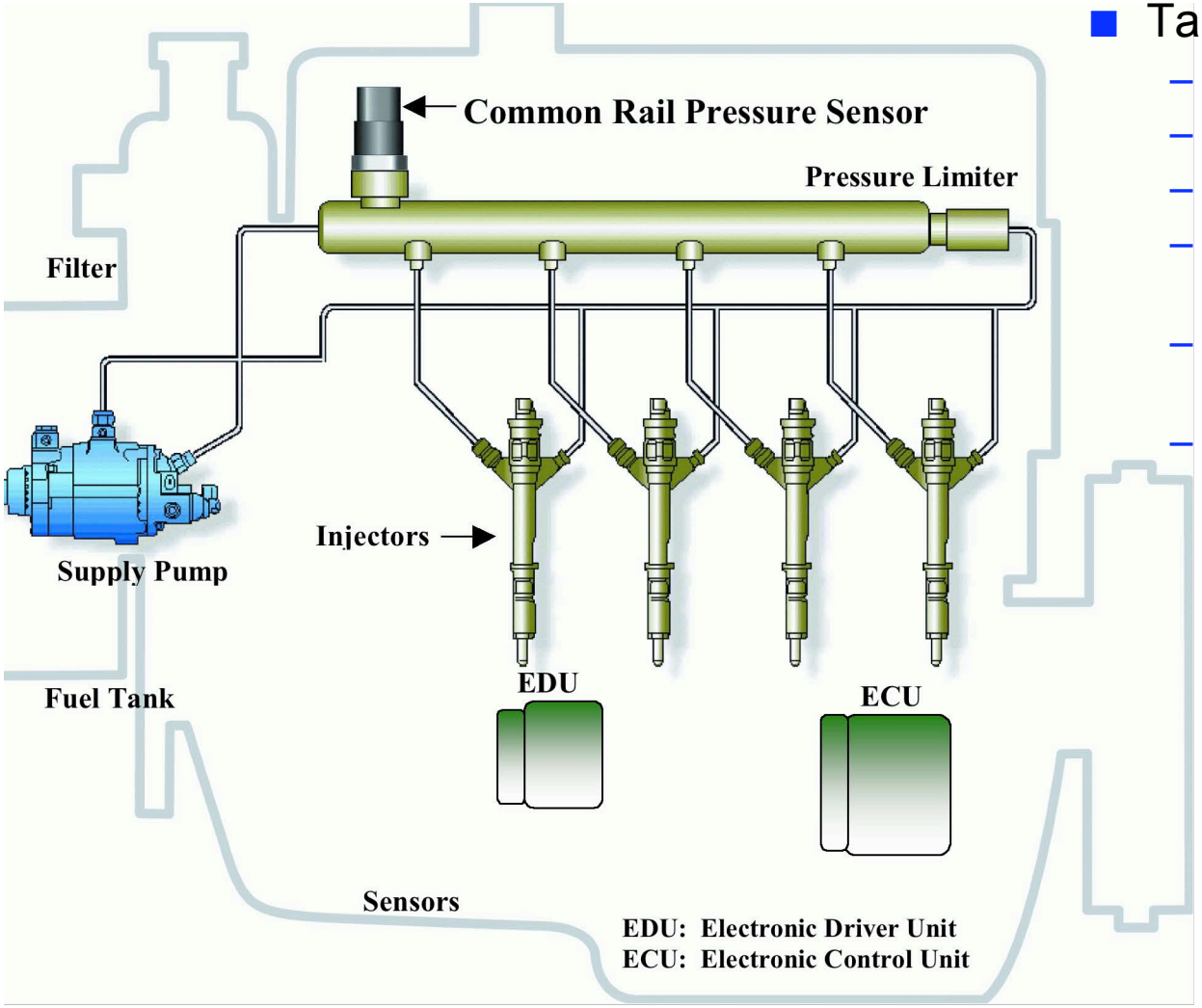
Figures of Merit Summary

Where sense resistors are arranged as part of a Wheatstone Bridge

Figure of Merit	*Pressure Sensor Type*		
	Silicon (Diaphragm)	***Thin Film (Diaphragm)***	***CTS Thick Film (Direct Sensing)***
Span uV/Bar	88.9	27.8	55-110, depending on substrate choice
Span Temperature Dependence (ppm/C)	1078, non-linear	125, linear	120, linear
Element TCR (ppm)	3740, non-linear	~425, non-linear	~65, linear

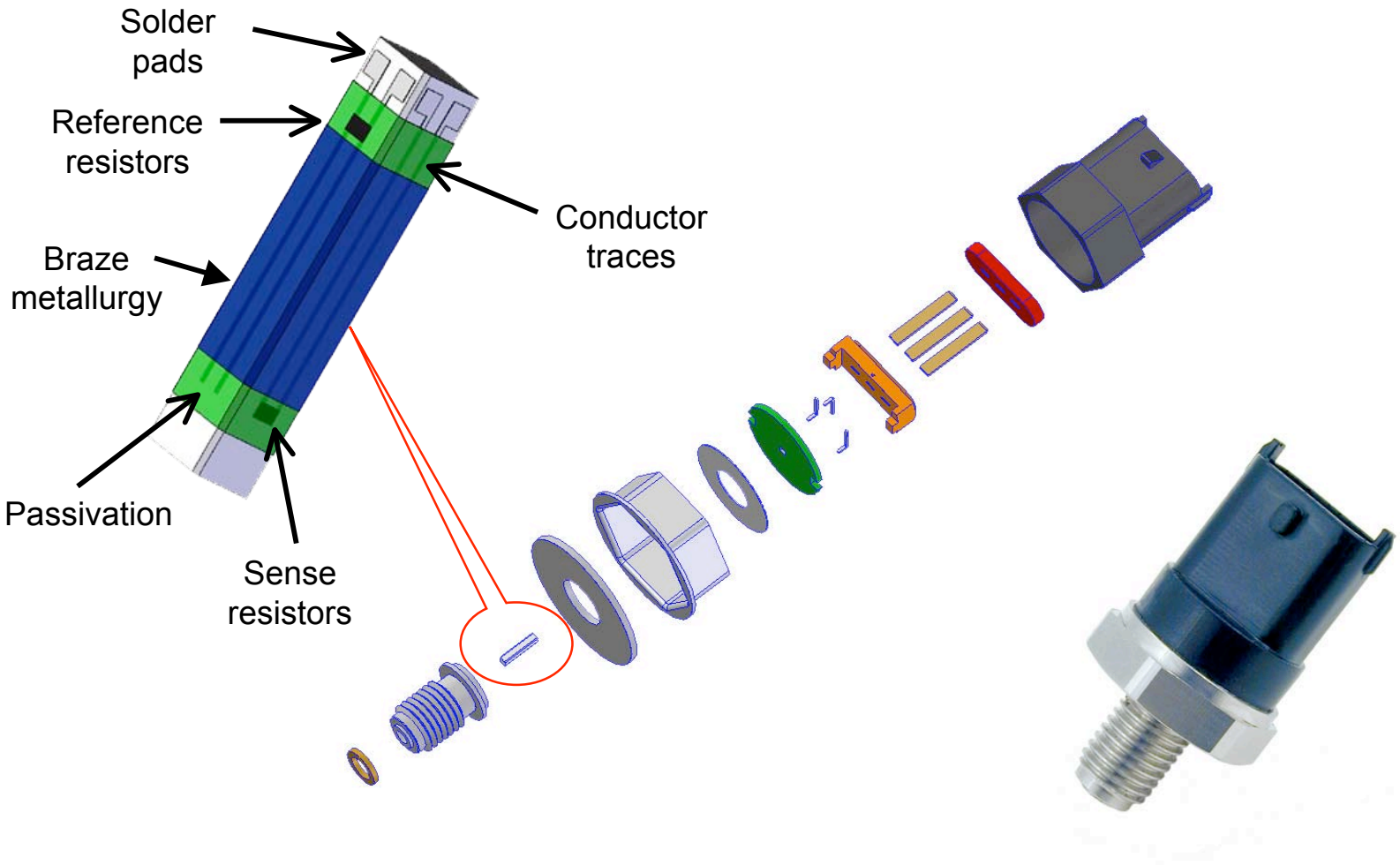
Above figures based on unamplified and uncompensated bridge outputs

Common Rail Pressure Sensor Application



- Target Product Spec
  - 2200 bar full scale pressure
  - 3000 bar burst pressure
  - ± 0.8% total error
  - -40°C to +140°C temperature range
  - Drop-in replacement for existing sensors
  - Option to integrate temperature sensor

CTS Design – Exploded View



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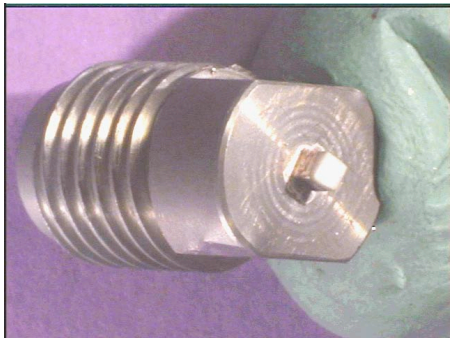
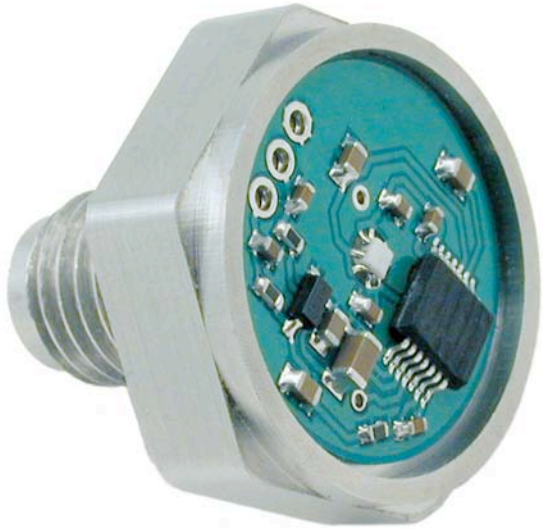
CTS Design – Key Features





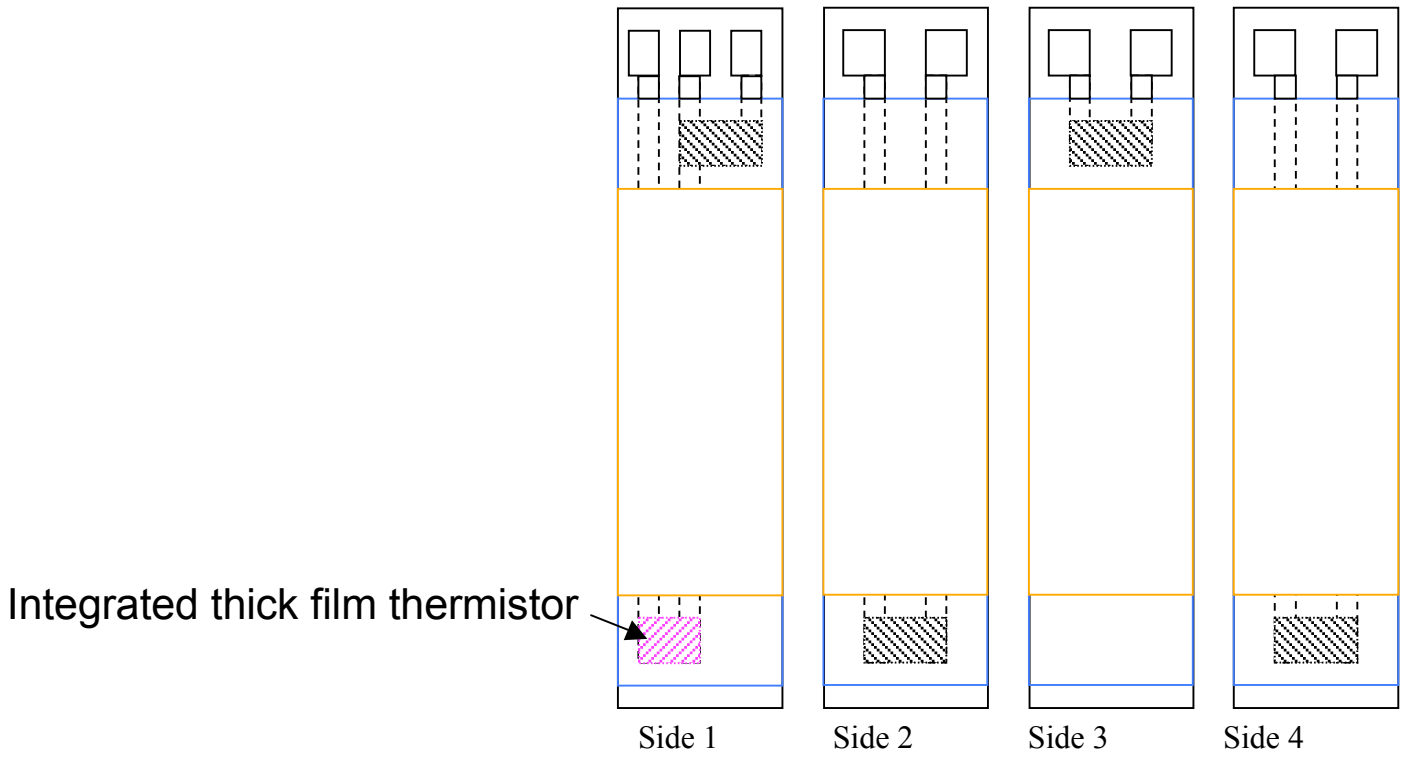
Ceramic Pin in Stainless Steel Header

- Brazed pin seals the assembly, carries sense and reference resistors
- Brazing temperature below thick film firing temperature
- Header is then heat treated
- Welded onto hex body

Hex Body with PCB

- Printed Circuit Board (PCB) with sensor electronics soldered to pin
- Electrical output programmable with ASIC
- Plastic connector housing connects to PCB

Integrated Temperature Sensor Option



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CTS TEST RESULTS

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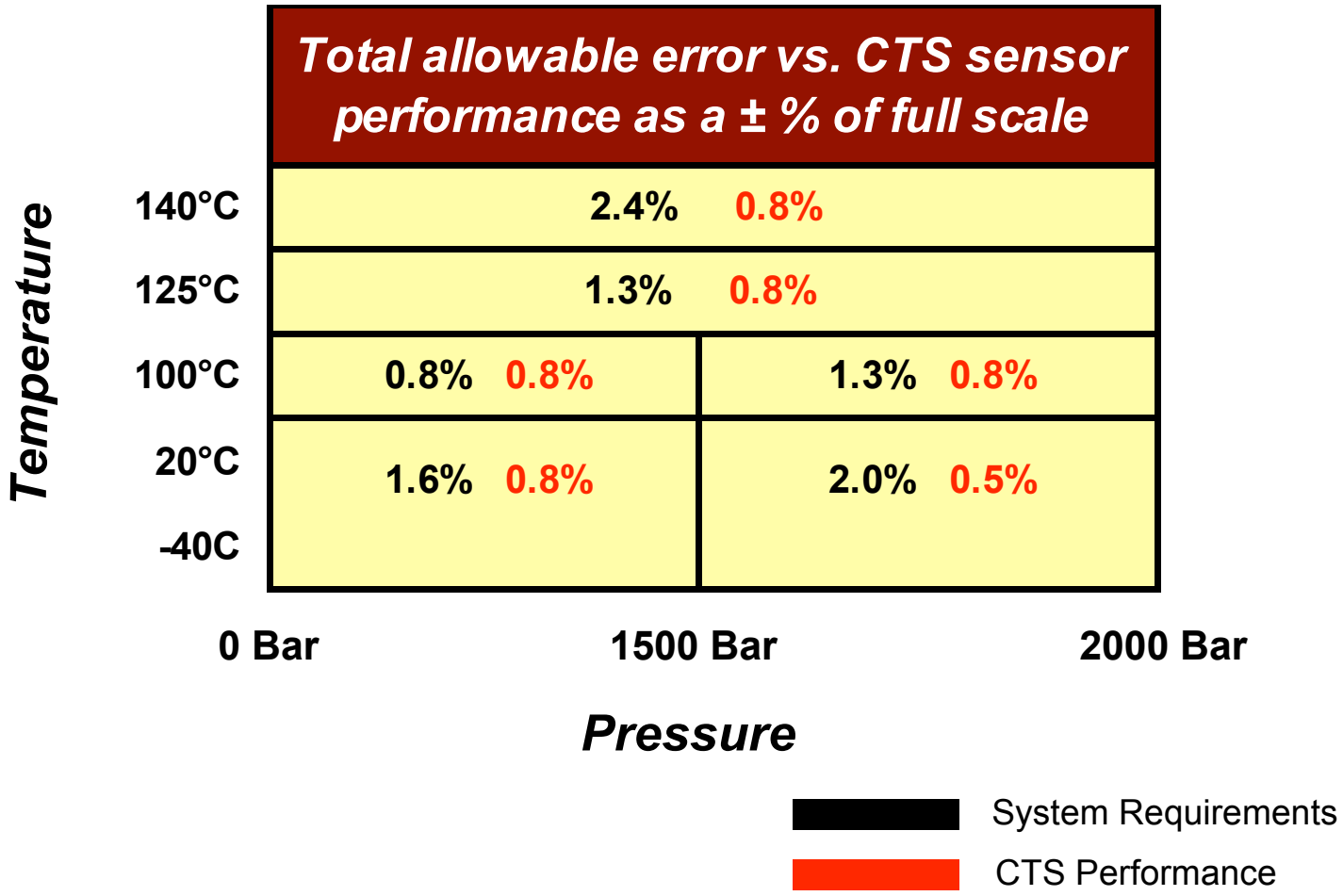
Performance Over Temperature and Pressure



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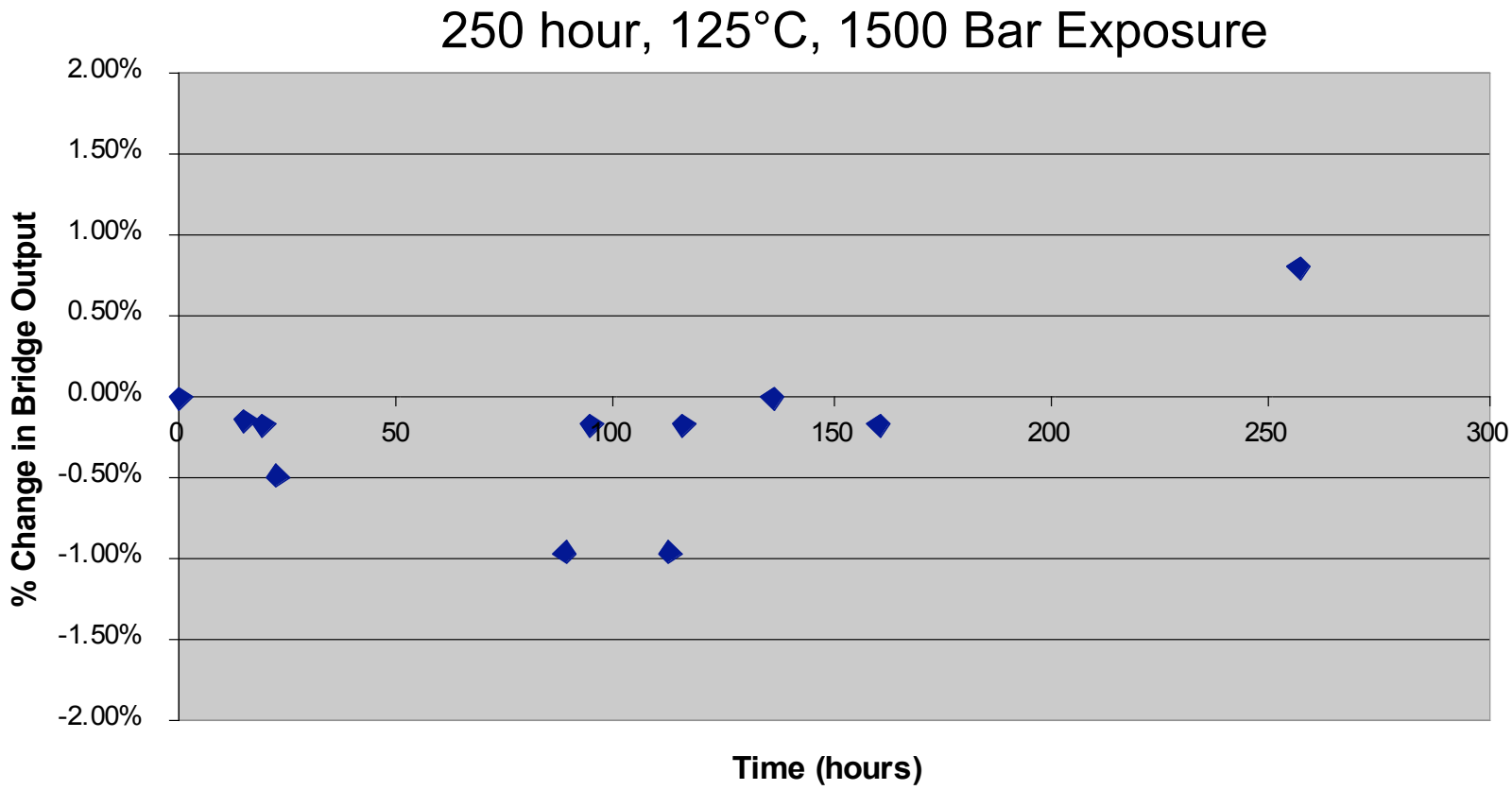
CTS Environmental Test Results

- Burst Pressure: 3400 Bar (49,000 psi)
  - Passed with no issues.
- Diesel / 5% Salt Water Corrosion: 500 hours, 100°C
  - Chose the most aggressive test criteria.
  - Passed. No change in bridge output; met burst pressure.
- Thermal Shock: 500 thermal shocks –40 °C to + 125 °C
  - Passed >2000 Thermal shock cycles -55°C to +125°C with 3400 bar burst pressure test every 100 cycles. No leaks or resistance changes.
- Pressure Cycling: 10 million cycles, 200 – 2200 Bar (32,000 psi)
  - Tests run at 10Hz up to 3 Million cycles on DOE parts.
  - Larger sample size to be built and qualified.

Extended Time at Pressure and Temperature

- Un-amplified bridge (63 mV @ 1500 bar)
- Less than 0.5 mV change



Results – No Measurable Change

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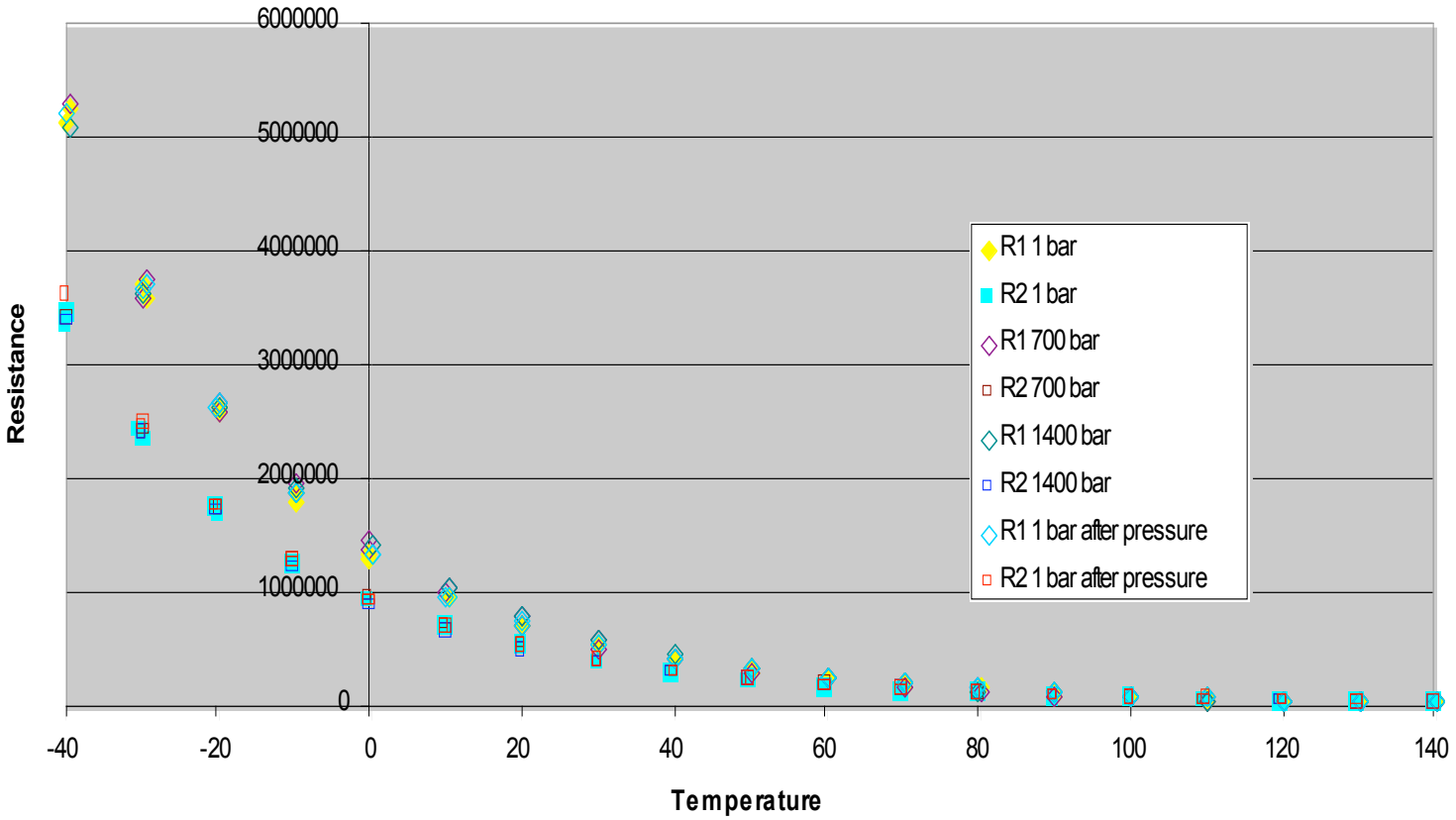
CTS Integrated Temperature Sensor Option



Thermistor resistance does not vary with pressure

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Summary and Conclusions

- CTS has developed a novel sensing approach using direct exposure of thick film piezoresistive materials.
- This approach is applicable for sensing pressures above 250 bar.
- Eliminates issues relating to conventional diaphragms.
  - Proof pressure
  - Fatigue failure of the diaphragm
  - Linearity and hysteresis errors due to geometric variations
- Low and linear variation of offset and span with temperature.
  - Highly accurate
  - Cost effective calibration and temperature compensation
- Stable to aggressive media exposure.