Temperature Compensating MEMS Accelerometers with Programmable Signal Conditioners

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• Introduction to MEMS accelerometers
• Thermal calibration – how does it work?
  • Conventional approach
  • Programmable signal conditioners
• Test results
• Additional considerations
• Summary
MEMS (Micro Electro-Mechanical Systems) accelerometers are typically fabricated from silicon wafers:

- Surface & bulk micro-machining
- Piezoresistive & capacitive designs
- Miniature sensing elements

- Capable of both static and dynamic measurements
Thermal Errors in MEMS Accelerometers

- Thermal non-linearity errors (offset and span) in MEMS accelerometers are attributed to many factors:
  - Strain sensitivity over temperature
  - Bridge resistance over temperature
  - Manufacturing tolerances
  - Bonding
- Non-linear thermal errors are very difficult to compensate using conventional methods.
Thermal Errors of MEMS Elements

Thermal Offset and Sensitivity of Uncompensated MEMS Element

-50 -40 -30 -20 -10 0 10 20 30 40 50

-60 -40 -20 0 20 40 60 80 100 120 140

Temperature (°C)

% Error

Sensitivity Error
Offset Error
Conventional Approach to Thermal Calibration

- Utilize a complex resistor network to reduce TC errors by balancing bridge over operating temperature range
- Utilize active thermistors in concert with a resistor network for more accurate correction
- Limited Results
  - Very labor intensive
  - Typical TC errors; ±.04%/°C
  - Temp range typically limited to -20°C to +80°C
Typical Schematic of Conventional Approach

- $R_{zb}$ – offset adjustment
- $R_{set}$ – span adjustment
- $R_{ztc}$ – TC offset adjustment
- $R_{stc}$ – TC span adjustment
The advent of programmable signal conditioners has enabled very accurate temperature correction over full operating temperature range.

- Each sensor output is characterized over the complete operating temperature range.
- Sensor corrections; Offset, SPAN and TC drifts.
- Programming of signal conditioner is done on complete assembly taking into account all errors including sensor & electronics.
Schematic of Accelerometer with Programmable Signal Conditioner

- Voltage Reg.
- PR Bridge
- ASIC
- Buffer/Filter

Inputs:
- Vexc (RD)
- Vo- (WHT)

Outputs:
- Vo+ (GRN)
- GND (BLK)
• Polynomial curve-fit generates a mathematical model of the accelerometer over temperature
• Mathematical model in stored in look-up table on the onboard EEPROM
• Internal temperature sensor is continuously monitored to correct the output
Compensating for Thermal Errors

- A typical polynomial curve-fit will enable non-linear corrections of thermal offset and span errors
- 5pt, 7pt, and 9pt temperature curve fit corrections

Theoretical Span of MEMS Sensor

Span Correction of Programmable Signal Conditioner
Thermal Offset Errors (ref to +25°C)
Model 4602-010 vs Standard VC Accelerometer

Offset Error (%FS) vs Temperature (°C)
Thermal Sensitivity Errors
10g FS Range Accelerometers

Thermal Sensitivity Errors (ref to +25°C)
Model 4602-010 vs Standard VC Accelerometer
Thermal Offset Errors (ref to +25°C)
Model 4602-030 vs Standard VC Accelerometer
Thermal Sensitivity Errors
30g FS Range Accelerometers

Thermal Sensitivity Errors (ref to +25°C)
Model 4602-030 vs Standard VC Accelerometer
Thermal Offset Errors
100g FS Range Accelerometers

Thermal Offset Errors (ref to +25°C)
Model 4602-100

Temperature (°C)

Offset Errors (%FS)

VC Accelerometer
Thermal Sensitivity Errors
100g FS Range Accelerometers

Thermal Sensitivity Errors (ref to +25°C)
Model 4602-100

Temperature (°C)

Sensitivity Error (%)
Additional Considerations

- Measurement bandwidth
  - DC-3000Hz depending upon characteristics of programmable signal conditioner
- Filtering of output signal
  - Optimum resolution
- Turn-on time
  - ASIC limits turn-on to ~100msec
  - Maximum slew rate; 7.5°C/msec (175°C span/24 msec)
  - Remote compensation module possible
- Packaging
  - Standard IC packages or utilize die components for miniaturization
• The use of programmable signal conditioners allows tremendous improvements in the thermal accuracies of MEMS accelerometers
  • Thermal Offset accuracies of ±.002%FS/°C achievable
  • Thermal Sensitivity accuracies of ±.003%/°C achievable
  • Compensated temperature range of -55°C to +125°C
• Very small unit-to-unit deviation in sensitivity due to programmable output
• Customization of output Offset, SPAN, and TC accuracy
Questions & Comments?