

TECHNICAL NOTE

Tilt / Inclination sensing

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The MS9001.D is the latest tilt sensor from Colibrys

Introduction

Low g Colibrys accelerometers are ideal products to measure tilt angle, using the earth's ground plate as reference. Tilt or inclination measurement is required in a wide variety of markets such as Energy, Mil/Aerospace, and Industrial & Instrumentation. Typical examples of applications are:

- Indication of pitch and roll of vehicles, sailing boat or aircraft
- Monitoring of boom angle
- Distance or height measurement
- Measuring drilling angle in well-logging
- Platform or antenna stabilization
- Compass correction
- High speed tilting train control
- Weapon security system

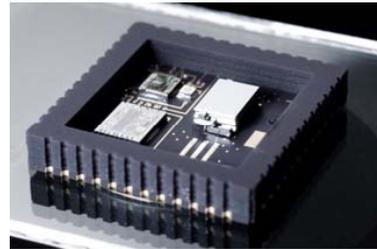


Fig 1: Open view of a MS8000 product

Colibrys MEMS accelerometers

The Colibrys products dedicated to tilt and inclination are MEMS capacitive accelerometer based on a bulk micro-machined silicon element, a low power ASIC for signal conditioning, a micro-controller for storage of compensation values and a temperature sensor.

Tilt measurements are quasi static measurement requiring typically $\pm 1g$ or $\pm 2g$ accelerometers with a low bandwidth. The MS9001 and MS9002 products are certainly the best tilt sensor from the complete family of Colibrys products. They operate from a single power supply voltage (between 2.5V and 5.5V) with a low current consumption ($< 0.5mA$ at 5V). The output is a ratiometric analog voltage that varies between 0.5V and 4.5V for the full-scale acceleration range at a voltage supply of 5V.

The sensors are fully self-contained and packaged either in a 48-pin LCC ceramic housing (MS8000.D) or in a 20-pin LCC ceramic housing (MS9000.D), thus insuring a full hermeticity. They operates over a temperature range of $-55^{\circ}C$ to $125^{\circ}C$ and can withstand shocks up to 6000g without performance degradation.

The Colibrys tilt sensing accelerometer products from Colibrys are:

- MS8002.D Traditional tilt sensing product
- MS9001.D Latest product designed for tilt applications
- MS9002.D Small 8.9mm x 8.9mm packaging size

Principle of operation

The accelerometer is using the effect of terrestrial gravity (1g) on the seismic mass as input acceleration to determine the inclination (Fig. 2). The inertial mass is the center wafer, supporting the proof mass through the spring. The accelerometer output signal "Vout" is a ratiometric analog voltage following the next equation:

$$V_{out} = Bias + (Scale\ factor \times Acceleration)$$

where:

- The Bias [V] is the output voltage at 0g acceleration
- The Scale factor [V/g] is the sensor sensitivity
- The Acceleration [g] is the earth acceleration (1g) applied through the sensitive axis



Fig 2: Principle of measure

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The angle ϕ is calculated using the following equation:

$$\text{Angle } \phi = \arcsin ((V_{out} - \text{Bias}) / (1g \times \text{Scale_factor}))$$

where ϕ is in degrees.

Variable capacitance accelerometer used as tilt sensor

The accelerometer rotated through the gravity acceleration produces a sinusoidal output signal. The figure 3 shows a schematic example of the accelerometer MS9002.D under various earth acceleration.

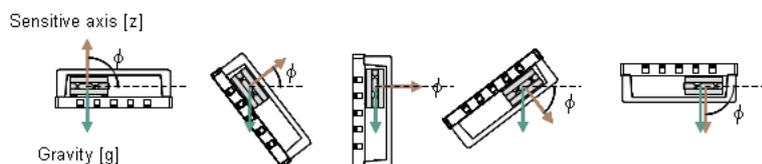
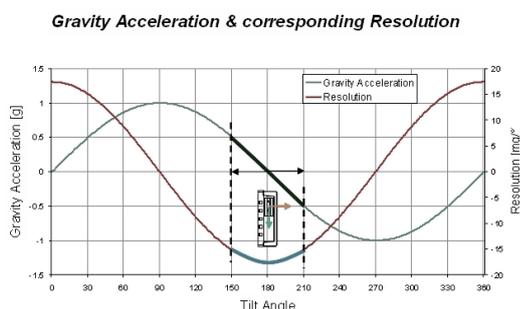


Fig 3: MS9002.D accelerometer at various angles

Example of tilt measurements using a MS9002.D

In this example, the accelerometer is rotated 360° around the X or Y axis. The corresponding angle [°], the acceleration through the sensitive axis [g], the output signal [V] and the resolution [mg/°] are presented in the Table 1. When representing the resolution vs. the angle, we can clearly see that even if the accelerometer will provide signal over 360°, the best working domain is a linear and symmetric zone of ±30° around 0° and 180°.



Tilt angle [°]	Sensitive axis acc. [g]	Vout [V]	Resolution [mg/°]
0	0	2.5	17.452
30	0.5	3	15.038
60	0.866	3.366	8.594
90	1	3.5	-0.152
120	0.866	3.366	-8.858
150	0.5	3	-15.190
180	0	2.5	-17.452
210	-0.5	2	-15.038
240	-0.866	1.634	-8.594
270	-1	1.5	0.152
300	-0.866	1.634	8.858
330	-0.5	2	15.190
360	0	2.5	17.452

Selection of a tilt sensor

Various specifications have to be considered to select the best accelerometer for a tilt sensing application. Short term and long term stability, hysteresis, repeatability and low noise output are the key parameters to consider for the best accuracy of a tilt measurement. Colibrys MS8002 and MS9002 accelerometers are among the best products in term of short term and long term stability (1) with less than 2mg for a ±2g full scale range. This represents stability better than 0.1° over one year. Excellent bias temperature coefficient without compensation (typically 100µg/°C or 0.007°/°C within ±30°), low hysteresis and high repeatability are also provided by these products. Finally, the combination of noise and bandwidth determine the resolution or smallest measurable angle of the tilt sensor. Colibrys products present a low noise level (typ. 20 µg/√Hz for a ±2g sensor) and therefore enable to measure angles with a typical resolution of 0.001° (RMS noise for 1Hz bandwidth).

(1) One year stability defined according to IEEE 528-2001: turn on / turn on, storage at -55°C and 85°C, -40°C to 125°C T cycling, -55°C to 85°C unpowered harass, vibration and shock

Conclusion

Colibrys accelerometers are qualified and integrated successfully since several years as tilt sensors in various applications such as compass correction, platform stabilization, transport and drilling instrumentation. The success of these integrations confirm Colibrys as a leader in the market for high-resolution tilt and inclination sensing

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