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A 3-axis 12 bit CAN-compatible MEMS inertial sensor cluster for Vehicle Dynamics Control

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Abstract: A 3-axis 12-bit CAN-compatible MEMS inertial sensor cluster for vehicle dynamics control is presented. The sensor cluster can measure the x/y-axis accelerations and z-axis rotation. The MEMS sensing elements are fabricated using the sacrificial bulk micromachining (SBM) process. The sensor interface circuit is fabricated using a standard 0.18-μm CMOS process. The input capacitive amplifier adopts a fully-differential, chopper-stabilized switched capacitor (SC) architecture to obtain low noise characteristics. The output of input amplifier, modulated with the chopping frequency, is converted to a digital signal by 12-bit algorithmic analog-to-digital converter (ADC), to achieve a high resolution while maintaining a low power. The digital signal is demodulated in a digital demodulator, which removes non-ideal behaviors of a multiplier. The white-noise level of the demodulated signal is effectively reduced by a subsequent decimation filter, and then 16-bit acceleration and rotation signals are obtained. And then through the MCU which integrated on PCB, the sensor cluster can interface with 12-bit CAN network to enhance the user-connectivity. The fabricated system is applicable for automotive systems, such as vehicle dynamic control (VDC).

1. INTRODUCTION

With the continuously maturing Micro-electromechanical Systems (MEMS) technologies, inertial measurement unit (IMU) has been successfully commercialized in various application areas, including electronic stability program (ESP), continuous damping control (CDC), and roll-over detection. Especially the capacitive type IMUs are used in automotive application, because the capacitive sensors are known to have several advantages when compared to the piezoresistive or piezoelectric micro-accelerometers with their good DC response, low noise performance, low drift and low temperature sensitivity.

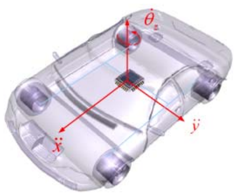

Fig. 1 diagram of inertial sensor for VDC

A high performance IMU system with fully differential, 16-bit over-sampled capacitive readout circuit is presented. The x/y axis accelerometers, the z axis gyroscope, and the readout ASIC are integrated in this system. The MEMS sensing elements are fabricated using the wafer level hermetic packaged (WLHP) sacrificial bulk micromachining (SBM) process. The capacitive readout circuit is fabricated using a standard 0.18-μm CMOS process. The system integration of WLHP SBM devices and low noise capacitive readout circuit enhance the reliability and performance while maintaining low noise, wide dynamic range and small form-factor. Figure 1 is a diagram of the sensor cluster integrated on vehicle.

2. MEMS BASED SENSING ELEMENT

2.1 Accelerometer Sensing Element

The fabrication results are shown in the left of figure 2. To protect the silicon structure of the MEMS sensing element, a wafer-level hermetic packaging process is performed. We reported sub-mg bias stability of this device [H. Ko, et al. (2007)].

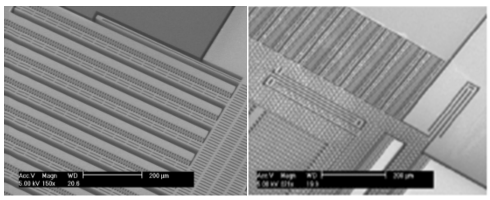

Fig. 2 SEM of fabricated MEMS Accelerometer & Gyroscope Sensing Element

2.2 Gyroscope Sensing Element

The right of figure 2 shows the SEM of fabricated MEMS Gyroscope sensing element, respectively. The z-axis gyroscope is fabricated using the wafer level vacuum packaged (WLVP) SBM process. The decoupled vibratory structure is adopted to reduce the quadrature error and to obtain low bias stability. The sub-degree per hour bias stability was reported using this structure.

3. CAPACITIVE SENSING SoC

The input capacitive amplifier adopts a fully-differential, chopper-stabilized switched capacitor (SC) architecture to obtain low noise characteristics. The output of input amplifier, modulated with the chopping frequency, is converted to a digital signal by over-sampled 12-bit algorithmic ADC, to achieve a high resolution while maintaining a low power. The digital signal is demodulated in a digital demodulator, which removes non-ideal behaviours of a multiplier. The white-noise level of the demodulated signal is effectively reduced by a subsequent decimation filter, and then 16-bit acceleration and rotation signals are obtained. The SPI and I2C interface are integrated to enhance the user-connectivity.

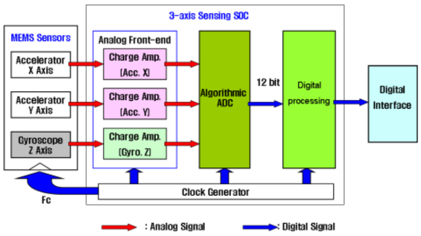

Fig. 3 System Block diagram of sensor cluster

4. SENSOR CLUSTER for VDC

The sensor cluster consists of x/y axis accelerometer, z-axis gyroscope, capacitive-readout sensing SoC, and micro-control-unit that can be used in automobiles. The module can measure 2-axis acceleration and 1 axis gyration. Moreover, the MCU integrated on module can interface with CAN network which used the vehicle network. The module is supplied 5V single power. The output data rate is 100 Hz. Figure 4 shows that image of Chip on Board (CoB) packaged MEMS inertial sensing element. By using CoB, the module is developed without LCC package. Because of this, we can reduce the developing cost.

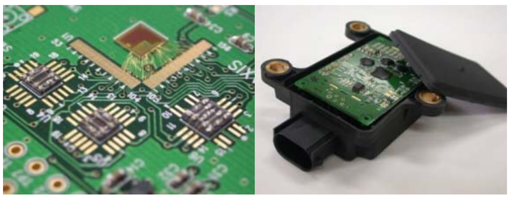

Fig. 4 Image of CoB sensing element and assembled cluster for vehicle dynamics control

5. EVALUATION RESULT

Figure 5 shows the linearity and the sinusoidal output of developed x/y axis accelerometer. The input range of accelerometer sensor is ± 2 g, the resolution is 0.98 mg/bit, and the non-linearity is 0.6% FSO, and bias instability is 1.15 mg.

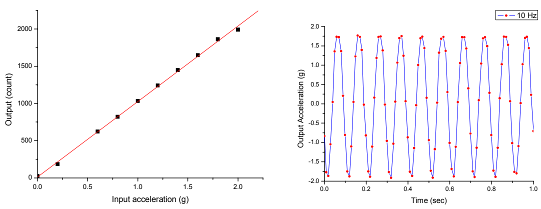

Fig. 5 Performance of developed MEMS accelerometer

Figure 6 shows the linearity and the sinusoidal output of developed z-axis gyroscope. The input range of gyroscope sensor is ± 100 deg/sec, the resolution is 0.056 deg/sec/bit, and the non-linearity is 0.49 %FSO, and bias instability is 0.008 deg/sec.

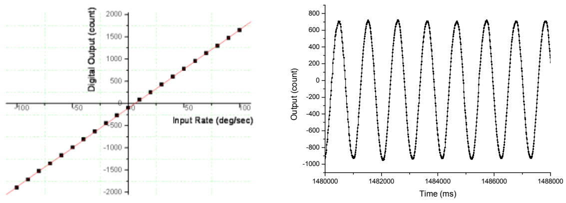

Fig. 6 Performance of developed MEMS gyroscope

6. CONCLUSIONS

A high performance 3-axis IMU system is presented. The IMU system can measure the x/y-axis accelerations and z-axis rotation. The system integration of WLHP SBM devices and low noise capacitive readout circuit enhance the reliability and performance while maintaining low noise, wide dynamic range. The fabricated system is applicable for automotive systems, such as VDC.

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