Intelligent Digital 3-Axis IMU for Automotive and Robotic Applications

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ABSTRACT

The intelligent digital 3-axis IMU system integrated with the MEMS sensing cores, the signal processing electronics, and the network interface is presented. The MEMS sensing cores are fabricated by using the SBM (Sacrificial Bulk Micromachining) process. The fabricated sensing core accomplishes the high performance, high yield and high reliability by the inherent high-aspect-ratio, footing-free advantages of the SBM process. The accelerometer channel of the system has the resolution of 50 μg, input range of over ±10 g, nonlinearity of 0.37 %FSO, and 4-hr bias stability of 1.1 mg. The gyroscope channel of the system has the resolution of 0.027 deg/s, input range of over ±70 deg/s, nonlinearity of 0.1 %FSO, and 1-hr bias stability of 2.6 deg/min. The system provides the digital output compatible with serial interface, thus the system can achieve reduced setup cost, reduced signal conditioning efforts, improved system reliability, improved network connectivity, and advanced functionalities.

Keywords: sacrificial bulk micromachining, inertial measurement unit, accelerometer, gyroscope, intelligent sensor

1 INTRODUCTION

Rapid developments in sensor technologies including micro-electro-mechanical system (MEMS), semiconductor electronics, and information technologies are enabling the intelligent sensor systems. In the intelligent sensor systems, the sensing element, analog/digital mixed-signal processing circuits, and network interface are integrated allowing versatile network-ready configurations. The intelligent sensor system can achieve reduced setup cost, reduced signal conditioning efforts, improved system reliability, improved network connectivity, and advanced functionalities.

This paper presents the intelligent digital 3-axis IMU (inertial measurement unit) system that can measure the x/y-axis acceleration and z-axis angular velocity integrated with the MEMS sensing cores, the signal processing electronics, and network interface .

2 FABRICATION OF MEMS SENSING CORES

The MEMS sensing cores are fabricated by using the SBM process [1-3]. The fabricated sensing core accomplishes the high performance, high yield and high reliability by the inherent high-aspect-ratio, footing-free advantages of the SBM process [4]. The notchless flat bottom surface fabricated by the SBM process gives near perfect device symmetry, and thus the off-axis error is minimized, which in turn, gives extremely low bias stability levels. The large sacrificial gap between structure and substrate fabricated by the SBM process also allows the high shock immunity and reduces the air damping.

To protect the sensing core from environmental attacks such as temperature variations, dust, and humidity, the wafer-level hermetic packaging is performed by using glass-silicon anodic bonding [5]. The glass "cap" wafer with via hole interconnection and protection cavity is anodically bonded to the silicon wafer. Next metal interconnection layer is deposited and patterned for wire bonding. The hermeticity of the sensing core is verified by dipping the bonded wafer in isopropyl alcohol (IPA) for two days. Figure 1 and Figure 2 shows the fabricated silicon structure of sensing core and cross-sectional view of the wafer-level hermetic packaged sensing core.

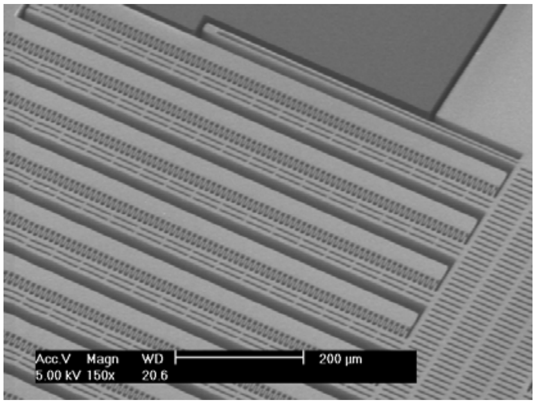
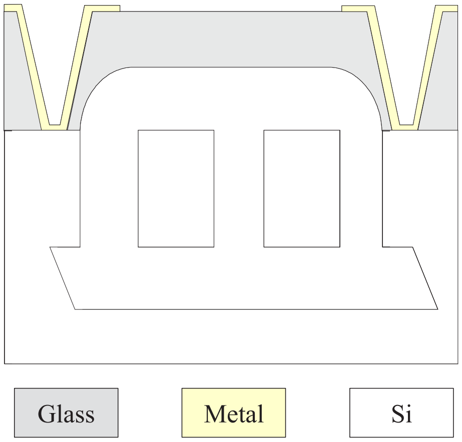
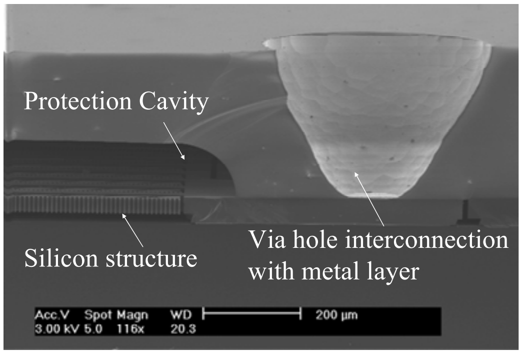


Figure 1: Fabricated silicon structure of sensing core



(a) Schematic diagram of cross-section



(b) SEM photograph of cross-section

Figure 2: Cross-sectional view of the wafer-level hermetic packaged sensing core.

3 SIGNAL PROCESSING ELECTRONICS

The schematic diagram of the signal processing electronics is shown in Figure 3. The analog front-end circuit adopts the chopper stabilization method for the capacitive sensing. A couple of square-wave carriers with amplitude of VDD/2 and phase difference of 180 degree are applied to the each sensing core. When external motion is applied, the capacitance changes from sensing cores are converted to the voltage signals modulated with the carrier. Then, the modulated voltage signals are demodulated by the synchronous demodulator and low-pass filtered. The EEPROM gain and offset trimming circuitry is adopted to reduce the die-to-die variations.

The digital signal processing circuit includes the 24-bit delta-sigma A/D converter, the digital filtering circuit, and the network interface. The output signals from analog front-end circuit are converted into the digital signals using 24 bit delta-sigma A/D converter, then the digital filtering is performed to reduce the noise and drift. The network connection to the host platform is established using the serial interface. Figure 4 shows the implemented 3-axis IMU system.

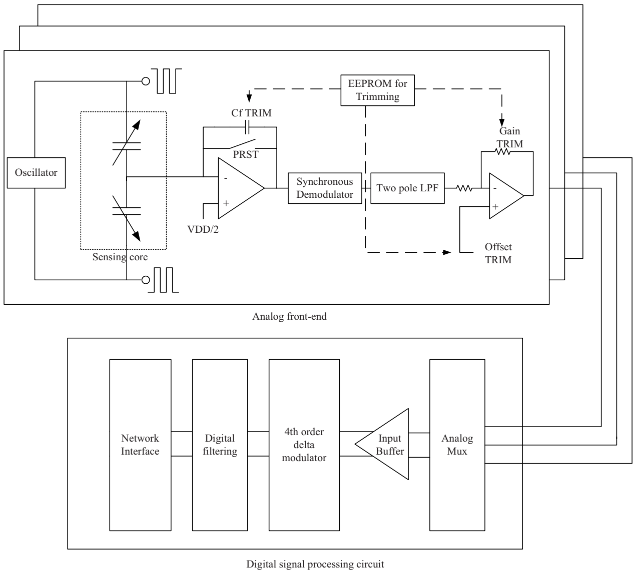
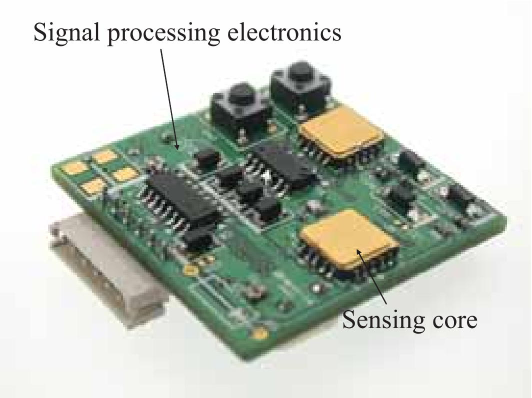


Figure 3: Schematic diagram of the signal processing electronics



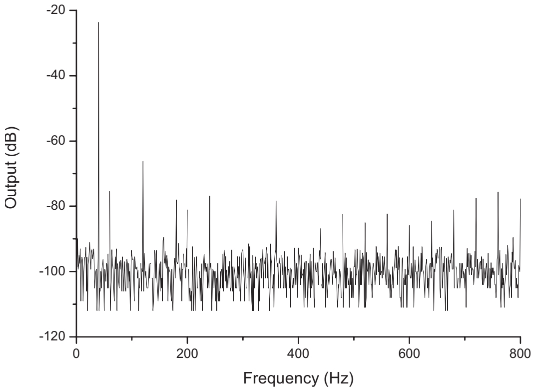
(a) PCB implementation of 3-axis IMU

(b) 3-axis IMU with shock-resistive housing

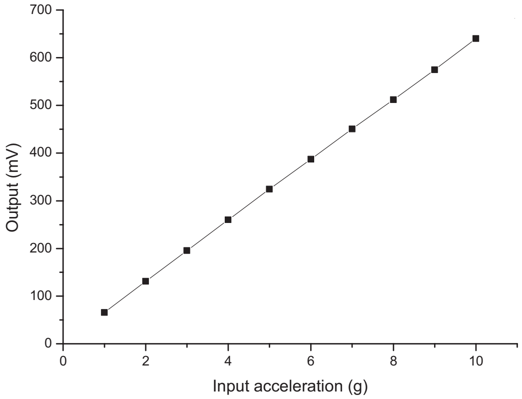
Figure 4: Implemented 3-axis IMU

4 PERFORMANCE CHARACTERISTICS

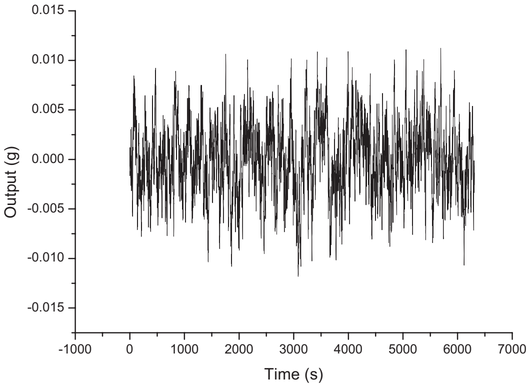
Figure 5 shows the performance characteristics of the accelerometer channel of the system. The accelerometer channel has the resolution of 50 μg, input range of over ±10 g, nonlinearity of 0.37 %FSO, and 4-hr bias stability of 1.1 mg. Figure 6 shows the performance characteristics of the gyroscope channel of the system. The gyroscope channel has the resolution of 0.027 deg/s, input range of over ±70 deg/s, nonlinearity of 0.1 %FSO, and 1-hr bias stability of 2.6 deg/min.



(a) Output spectrum with 40 Hz, 0.5 g input acceleration

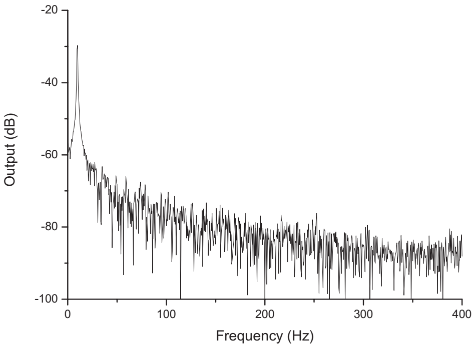


(c) Input-output characteristics

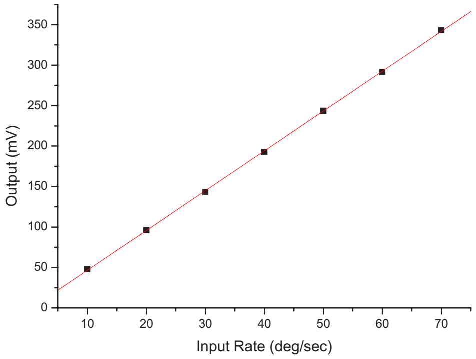


(c) Output with zero input acceleration

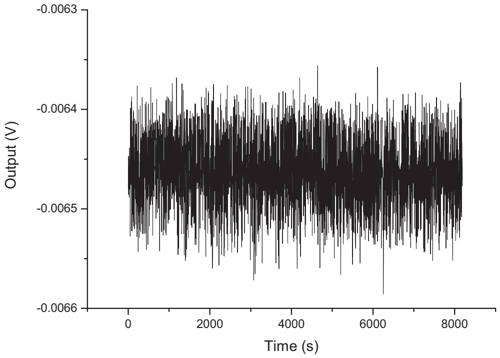
Figure 5: Performance characteristics of the accelerometer channel



(a) Output spectrum with 10 Hz, 10 deg/sec input rate



(b) Input-output characteristics



(c) Output with zero input rate

Figure 6: Performance characteristics of the accelerometer channel

5 CONCLUSIONS

The intelligent digital 3-axis IMU system integrated with the MEMS sensing cores, the signal processing electronics, and network interface is presented. The system provides the digital output compatible with serial interface, thus the system can achieve reduced setup cost, reduced signal conditioning efforts, improved system reliability, improved network connectivity, and advanced functionalities. The accelerometer channel of the system has the resolution of 50 μg, input range of over ±10 g, nonlinearity of 0.37 %FSO, and 4-hr bias stability of 1.1 mg. The gyroscope channel of the system has the resolution of 0.027 deg/s, input range of over ±70 deg/s, nonlinearity of 0.1 %FSO, and 1-hr bias stability of 2.6 deg/min.

The presented IMU system is readily applicable in many consumer applications, including automotive, navigation, and robotics. Our next generation sensing cores will allow application to smart munitions and other military applications.

ACKNOWLEDGEMENT

This research, under the contract project code A1100-0400-0058, has been supported by the Intelligent Robot Sensor Project sponsored by Ministry of Information and Communication

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