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# Highly-reliable One-chip Signal Processor LSI for One Angular-rate and Two Acceleration Sensor Using Dual DSPs

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## 1. Introduction

The demand for inertial sensors [1][2] to detect the angular rate and acceleration has recently been increasing in automotive applications to control vehicle dynamics or in robotics applications to control motion. These applications require multiple axes detection of angular rate and acceleration, while it is necessary to reduce the total cost and keep the reliability of sensors.

We demonstrated a highly-reliable one-chip signal processor LSI for a one angular rate (the yaw rate) and two acceleration (XG, YG) sensor. This LSI has a novel architecture of dual highly-reliable digital signal processors (DSPs), and a fully synchronized DSP scheme to ensure both high degrees of reliability and accuracy in a low total cost.

## 2. Configuration of Signal Processor LSI

Fig. 1 has a block diagram of the signal processing LSI. The LSI is configured with an analog front-end that is connected to a sensor element [3], and DSPs that process the signals digitized at the analog front-end. The signal processing flows and functions of the LSI are described in the following. Small capacitance changes are input from the sensor element to the analog front-end, and they are then converted to a voltage, amplified, and finally converted to digital signals using delta-sigma converters (ΔΣADC) in the analog front-end. The analog front-end also has digital to analog converters (DAC) to feedback signals to the sensor element. On the other hand, the DSPs process multiple functions. The drive servo function maintains the yaw mass in the sensor element at stable resonation. The yaw servo function accurately detects the yaw-rate by using a zero method between the Coriolis effect and yaw feedback. These DSPs are also equipped with temperature-compensation, self-diagnosis, and SPI interface functions with cyclic redundancy check (CRC).

All signal processing and functions except for analog-signal processing are implemented using the DSPs to optimize the scale of the hardware of the LSI.

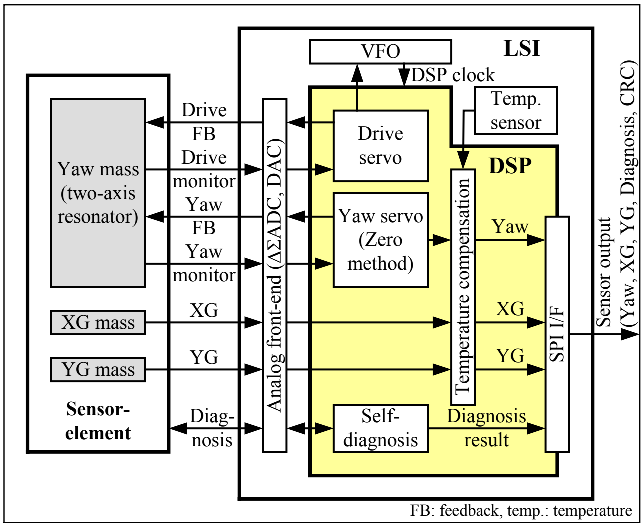


Fig. 1 Block diagram of signal processing LSI

## 3. Features of Proposed Dual DSP

A dual DSP architecture and a fully synchronized DSP scheme are proposed with this LSI. The dual DSP architecture offers excellent reliability, and the fully synchronized DSP scheme ensures extreme accuracy, which make this sensor well suited for automotive applications.

Fig. 2 outlines the dual DSP architecture. This LSI has two DSPs with different programs, and signal processing tasks are allocated to both DSPs according to their required execution cycles. DSP 1 operates in the same cycle as the vibration of the yaw element to achieve real-time processing of drive and yaw servo functions. DSP 2 operates in cycles that are four times longer than DSP 1, and carries out complicated tasks such as re-initialization of constants, temperature-compensation, and self-diagnosis.

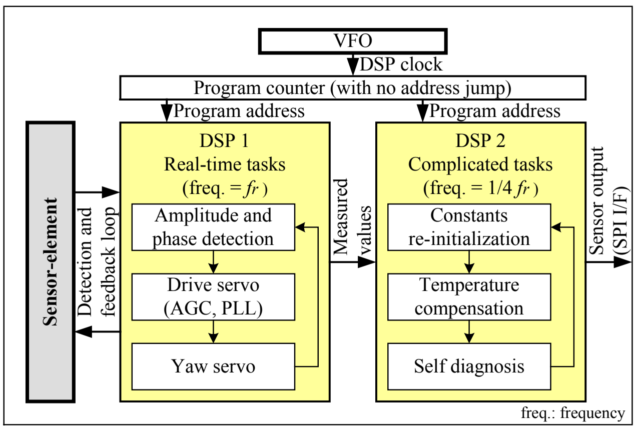


Fig. 2 Dual DSP architecture

The proposed architecture also achieves a non-runaway DSP [4] which enables to achieve high levels of reliability. The features of the non-runaway DSPs can be described as follows. These DSPs do not run with any program address jump to force them to always circulate all program addresses incrementally. As program address transitions have no branches in this operation, they inherently never go into an endless loop. Also, as every circulation of the program address includes a routine to re-initialize the constants, these DSPs do not need any reset signals, and they also quickly recover from soft error in the RAM/register without any redundant configurations. These two features ensure these DSPs are very reliable despite their simple configuration.

Fig. 3 outlines the fully synchronized DSP scheme. These DSPs operate with a clock input from a built-in variable frequency oscillator (VFO). Further, the output frequency of this VFO is controlled by a phase locked loop (PLL) function in the drive servo function to make the vibration frequency of the yaw element match its own resonation frequency, by adjusting the drive clock frequency (divided from VFO output). Consequently, both the cycle for the vibration of the yaw element and the processing cycle for servo functions at DSP 1 are synchronized to the resonance frequency of the yaw element. This relationship ensures a high degree of accuracy for the following reasons. First, the resonation of the yaw element yields large vibration amplitude at the same driving voltage, which derives a large and accurate change in capacitance input to the LSI. Second, the phases of the detect and feedback timing in servo functions are inherently fixed to the vibration of the yaw element. Since the precision of the phase in feedback timing is the key factor in accurately detecting the yaw rate in gyros have resonant vibration, this configuration is extremely accurate.

## 4. Evaluation Results

An Actual LSI was fabricated, and its yaw-rate and acceleration-detection characteristics were evaluated. Fig. 4 has the microphotograph of the LSI, and Fig. 5,6 shows the static characteristics for yaw rate and acceleration detection. As a result, extremely high accuracies with a yaw-rate non-linearity of 0.1 [%FS], and an acceleration non-linearity of 0.2, 0.4 [%FS] for each XG, YG axes were confirmed for this LSI.

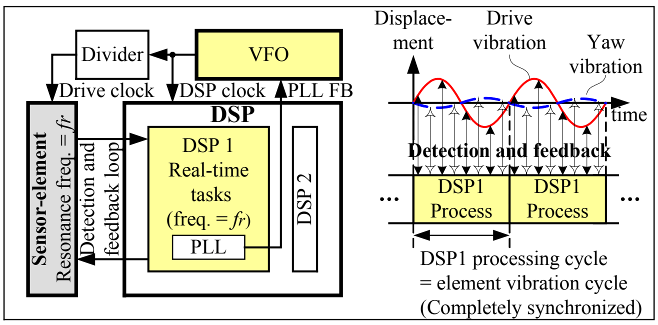


Fig. 3 Fully synchronized DSP scheme

## 5. Conclusion

In this paper, we proposed two concepts for a multi-axis inertial sensor. The dual DSP architecture with non-runaway DSP ensured high levels of reliability. The fully synchronized DSP scheme enables high degree of accuracy. We fabricated a one-chip LSI with these architectures for a combined one angular-rate and two acceleration sensor, and confirmed the high accuracy for this LSI.


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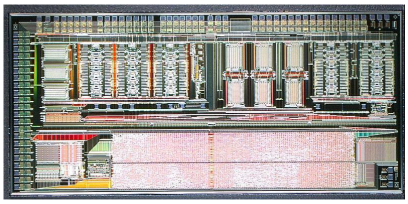

Fig. 4 Chip microphotograph of the LSI

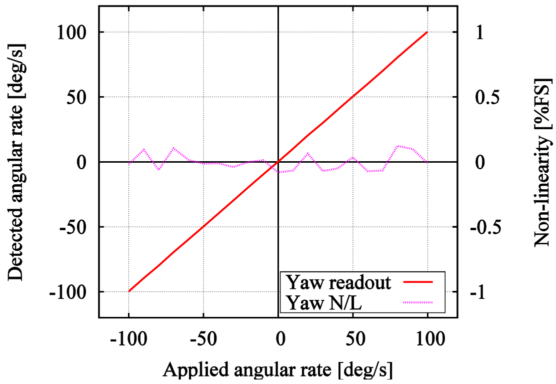


Fig. 5 Static characteristics of yaw rate detection

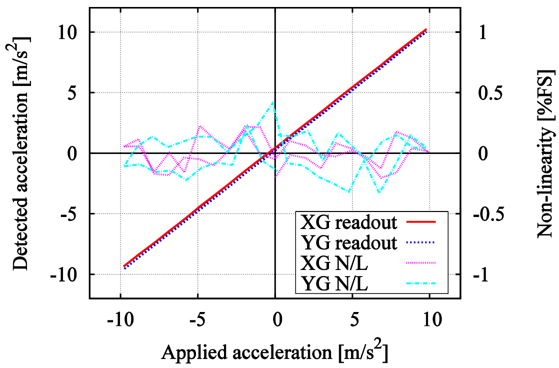


Fig. 6 Static characteristics of acceleration detection