A Digital Demodulation Solution to Achieve Stable Driving for a Micro-machined Gyroscope with an AGC Mechanism

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Abstract

This paper presents a digital solution to restrain the impact from the unwanted low-frequency signal in the practical driving signal, i.e. carrier signal, in a MEMS gyroscope with automatic gain control (AGC) mechanism. For this purpose, an ASIC has been designed and fabricated. With digital signal processing(DSP) technique, the digital demodulated angular rate signal is adjusted by using a self-multiplied practical carrier signal after LPF in a digital divider. The simulation gives a SNR of better than 70dB, which indicates that good device performance can be possibly achieved with this principle even though the driving is not ideal.

KEYWORDS

Gyroscope, AGC, Digital Adjustment

INTRODUCTION

In vibratory gyroscopes, stable constant-amplitude drive is the first and fundamental requirement to achieve good sensitivity and resolution. This task may be accomplished in several ways, but automatic gain control (AGC) mechanism has already demonstrated its promise in experiments [1]. We have reported our bulk micro-machined electro-magnetically driven tuning fork gyroscope [2,3] as shown in Fig.1, which consists of bar structure proof masses and can works at atmospheric pressure. AGC is also applied to drive the device.

In an ideal AGC system, the frequency and amplitude of the carrier signal are fixed all the while, which is necessary for modulate-demodulate processing. However, the practical carrier signal is inevitably unstable, i.e., the practical carrier signal is regarded as a mixture of an ideal carrier signal and unwanted extra signals, which has negative impact on the accuracy demodulation. Fig.2 demonstrates unstable driving amplitude measured.

In this paper, we present a digital solution to significantly restrain the above mentioned impact from the extra carrier signal with special designed demodulation and adjustment mechanism.

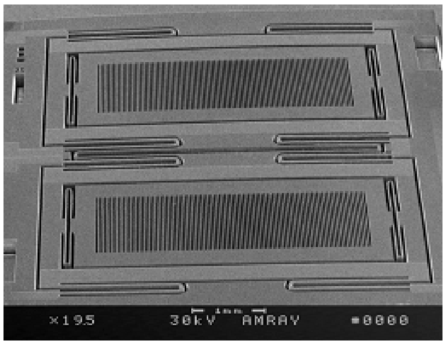


Fig.1 SEM photograph of micromachined gyroscope

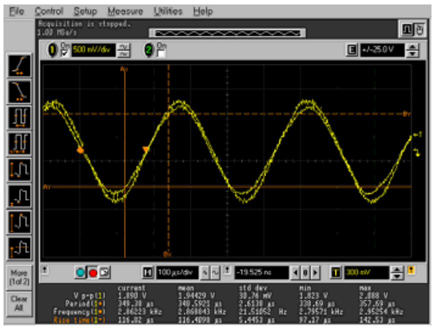


Fig.2 An example of unstable driving amplitude measured

ASIC DESIGN

Basically, the micromachined gyroscope can be divided into two parts, analog part and DSP part. The analog part consists of gyroscope itself, AGC loop, C-V converter and etc., while the DSP part will be discussed afterwards in detail.

The block diagram of the analog part is shown in Fig.3. The proof masses of the gyroscope are electromagnetically driven with AGC to maintain a stable vibration with a constant amplitude. The angular signal is first modulated with the driving signal, i.e. the carrier signal, and the C-V converted and amplified signal is then demodulated with the same carrier signal. The bandwidth and central driving frequency of the device are designed at around 50Hz and 3KHz, respectively. Both the modulated angular signal and the carrier signal output to DSP part.

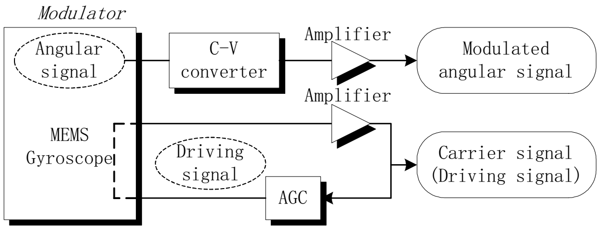


Fig.3 MEMS part Model

In practical, the carrier signal is ineluctably unstable, either its frequency or amplitude fluctuates slightly. In other words, the practical carrier signal can be regarded as a mixture of an ideal carrier signal and unwanted extra signals. The extra component is of low frequency and small fluctuation amplitude, the measured values in our device were 15Hz and less than 2% of carrier signal.

Though small, the extra component tends to increase the inaccuracy of modulation and demodulation, and thus it makes barrier for the improvement of the device performance.

In the next section about DSP part, we describe a digital solution to restrain the effect led by the extra component.

DSP BLOCK MODEL

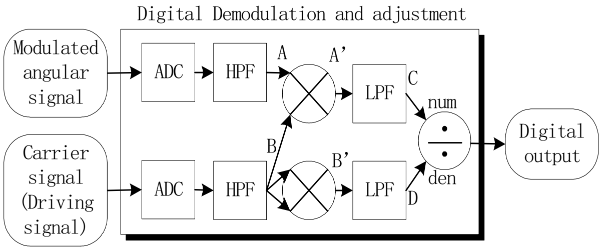


Fig.4 The digital demodulation and adjustment arithmetic of DSP part

The block diagram of DSP part is shown in Fig.4. There are two channels, 1 and 2, for modulated angular signal and carrier signal input from the analog part, respectively. In channel 1 and 2, the signals are digitized with Sigma-Delta ADCs and filtered with high-pass filters, and reach node A and B. Then the signal at node A in channel 1 is multiplied with the signal from node B in channel 2, followed with a LPF step, and the digital demodulation step completed at node C. Meanwhile, the signal at node B in channel 2 is self-multiplied, followed with a LPF step, and reaches at node D. In the divider, the demodulated angular signal is then adjusted with the output signal at node D. Thus, the digital demodulation and digital adjustment complete. In this DSP part, the Sigma-Delta ADC, HPF, multiplication and LPF modules for two channels use the same arithmetic.

High Pass Filter

All the components in analog part, such as MEMS gyroscope, C-V converter， power amplifier and etc, always introduce 1/f noise, even though low-noise components are selected. As an example, the measured noise spectrum for the angular signal after C-V converter is shown in Fig.5, where significant 1/f noise exists at low frequency. In driving loop, similar 1/f noise behavior was also observed.

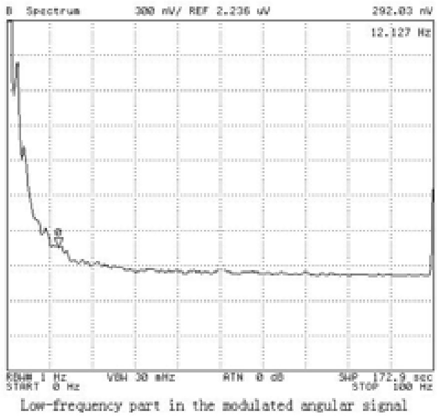


Fig.5 Measured noise spectrum of the modulated angular signal at low-frequency, which indicates 1/f noise

In our DSP part, the high pass filter plays an important role in improving 1/f noise behavior. After Sigma-Delta ADC, the modulated angular signal and the carrier signal are filtered by HPFs. The stop frequency of the HPF is designed as 1KHz, while the carrier signal frequency is about 3KHz.

Digital Demodulation

The modulated angular signal is first digitized and then digital demodulated with a multiplier and a LPF combination by using the carrier signal, as described in previous section until node C in channel 1.

In the case of ideal carrier signal, we can obtain the perfect demodulated angular signal easily at node C. Fig.6 exhibits the frequency spectra for modulation and demodulation steps as the carrier signal is ideal.

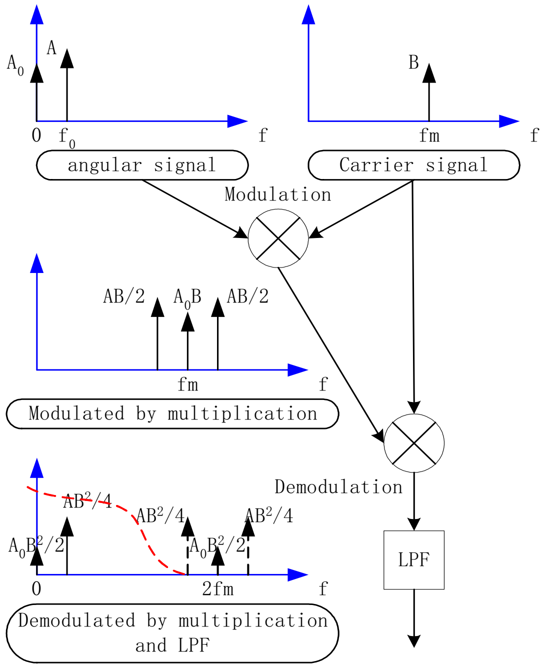
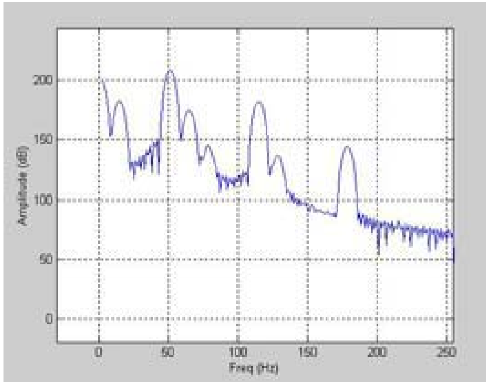


Fig.6 Spectrum anlysis of ideal modulation and demodulation

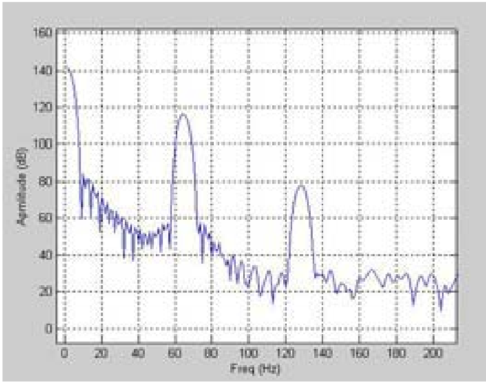
However, in practical, the angular signal can not be accurately extracted with above mentioned modulation and demodulation steps, due to the existence of low frequency extra carrier signal. As shown in Fig.7(a), the low-frequency spectrum at node A’ represents an inaccurate demodulated angular signal. While in Fig.7(b), the low-frequency spectrum at node B’ represents the self-multiplied carrier signal, containing extra unstable signal, whose function will be described as an important module in the additional digital adjustment solution proposed in the next section.

Digital Adjustment

Now the signal at node C is divided by that at node D shown in Fig.4. This critical step is applied to adjust the demodulation in the condition of unstable driving. Fig.8 displays the frequency spectrum of the output signal in DSP part. In this system, the ratio of the extracted angular signal to the extra signal is better than 70dB as simulated with MATLAB. This digital demodulation and adjustment solution demonstrates the possibility of removing the impact led by the extra low-frequency part of carrier signal. Finally, the unwanted extra carrier signal is restrained significantly and the wanted angular signal can be extracted accurately.



(a)



(b)

Fig.7 Low-frequency spectra at (a) node A’ and (b) B’

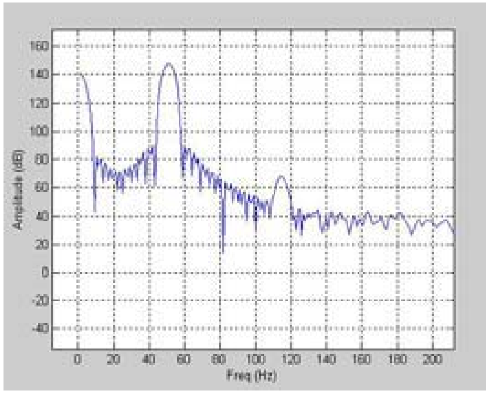


Fig.8 Frequency spectrum of output signal

The above arithmetic provides a solution to restrain the impact from the unwanted signal led by the disturbed driving amplitude, which improves the stability of the driving amplitude and frequency and a better resolution of the device can be achieved as well.

ASIC LAYOUT

Based on the above described principle[4], we completed the design of an ASIC in Shanghai Belling Co., Ltd. for our MEMS-DSP system, which integrates the analog C-V converter and DSP part. Fig.9 gives the snapshot of the ASIC layout. The ASIC has been fabricated in Shanghai Huahong NEC Electronics Co., Ltd.

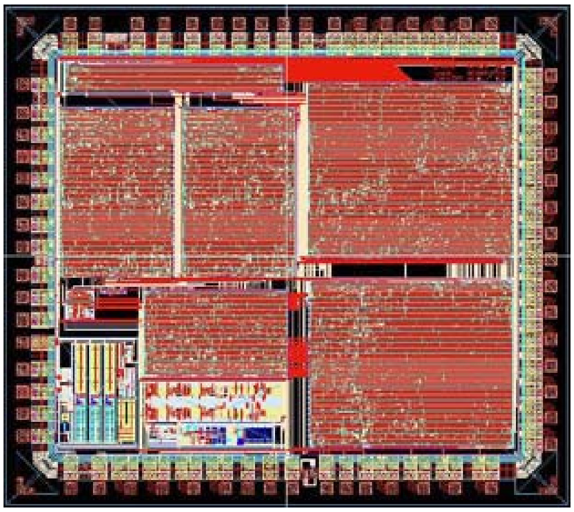


Fig.9 The layout of ASIC

CONCLUSIONS

In order to restrain the impact from the unwanted low-frequency signal in the practical driving signal, i.e. carrier signal, in a micro gyroscope with AGC, digital signal processing(DSP) technique is applied. The digital demodulated angular rate signal is adjusted by using a self-multiplied practical carrier signal after LPF in a digital divider. The simulation gives a SNR of better than 70dB, which indicates this principle is effective to attain a good device performance even though the ideal driving is difficult to be available.

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ACKNOWLEDGEMENT

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REFERENCES

[1] M'Closkey, R.T., and et al., "Analysis of a Microsensor Automatic Gain Control Loop", Proc. 1999 American Control conference, pp.3307-3311, June 1999

[2]Yong Chen, Jiwei Jiao, and et al., "Micromachined Bar-structure Gyroscope with High Q-factors for Both Driving and Sensing Mode at Atmospheric Pressure", Abstract Book for IEEE Sensors 2003，Toronto, Canada (2003) 245

[3]Yong Chen, Jiwei Jiao, and et al., "A novel Tuning Fork Gyroscope with High Q-factors Working at Atmospheric Pressure", J. Microsystem Technology, in press

[4]Wang Xiangli, and et al., "A method of demodulation and adjustment for unstable carrier signal and the same", Chinese patent in pending