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Full Diff Interface Circuit Realization with Self-Excitation Driving Mode of Vibration Micro-Machined Gyroscope

TAN Xiao-yun *, *LIU Xiao-wei*, *DING Xue-wei*, *Ma Yuan-fang*
(Harbin Institute of Technology MEMS Centre, Harbin 150001, *China)*

Abstract: Based on the object of Outside Drive Inside Sense frame vibration micro-machined gyroscope, given the circuits realization with CSMC 0.6 μm standard CMOS technology. The simulation result revealed that the self-excitation driving model can make drive AC voltage work at the resonance of sensor, have strongly restrain ability to temperature drift and time drift. The work mode of full difference can improve SNR dramatic evidently, and restrain the disturb of common mode noise, and have less sensitivity to carrier wave. At one atom environment, the sensor have responsibility 10 mV/deg, sensitivity 0.1 °/S · Hz^2.

Key words: micro-machined gyroscope; self-excitation driving; full diff interface circuit
EEACC: 2570D; 1205; 1250

自激驱动方式的振动式微机械陀螺全差动接口电路

谭晓昀 *, **刘晓为**, **丁学伟**, **马原芳**
(哈尔滨工业大学航天学院微电子科学与技术系, 哈尔滨 150001)

摘 要: 以外框驱动内框检测(ISOD)的框架式振动陀螺为对象, 采用 CSMC 0.6μm 标准 CMOS 工艺给出了驱动电路和检测电路的实现方式。仿真结果显示, 同外加驱动方式相比, 自激驱动方式能够让驱动电压工作于微机械陀螺的驱动谐振频率上, 对温漂和时漂有很强的抑制作用, 能够实现最大的检测分辨率, 微机械陀螺性能显著提高。采用全差动工作方式相对于单端工作方式, 可以有效的提高信噪比(SNR), 并可以抑制共模噪声的干扰, 并降低对高频载波的依赖度。在大气环境下, 微机械陀螺的响应度为 10 mV/deg, 灵敏度为 0.1 °/S · Hz^2。

关键词: 微机械陀螺; 自激驱动; 全差动接口电路
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Micro-machined gyroscope have got widely application in automatic drive turning detect and inertia navigation, etc. Because of its important value in the domain of army and civil, micro-machined gyroscope have got especially recognition in world[1-3]. The output of micro-machined gyroscope not only relation to the design of sensor structure, but also to the interface circuit which includes driving circuit and detect circuit. There are two driving mode, one is extra AC driving voltage, the other is self-excitation driving voltage. The former is easy to realize and it is low cost, but its frequency is difficult to be the same with the inherence frequency of the sensor's driving mode, and can not follow the change of drive mode's inherence frequency, which results in the reduce of sensitivity[4]. The latter uses the frequency-selected characteristic of sensor's drive mode and extra feedback circuit to realize self-excitation. Self-excitation drive mode works at the inherence frequency of driving mode and follows its changing. The work mode of full difference can improve SNR evidently, and restrain the disturbing of common mode noise, and have less sensitivity to carrier wave, restrain the miss match of sensor's difference capacitance in some way.

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1 Principle

Vibration micro-machined gyroscope uses Corilos domino effect to detect input angle rate. The principle of Corilos domino effect is: for a resonance object, when it has a steady resonance vibration in x-axis, if there is an angle rate input in z-axis, there will be an output which ratio to the angle rate. Figure 1 is the equivalent predigest picture of close loop driving micromachined gyroscope.

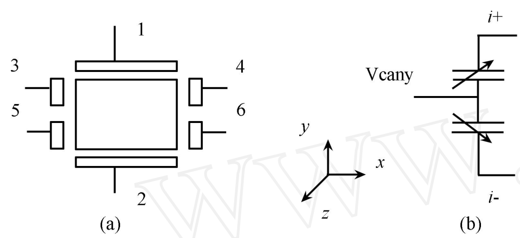

Fig. 1 the equivalent predigest picture of close loop driving micro-machined gyroscope and sense mode equivalent circuit

Figure 1(a) is equivalent predigest of sensor. Y-axis is detect direction. Node "1" "2" are detect electrode which detect the change of difference capacitance in sense mode. X-axis is drive direction. Node "3" "4" are detect electrode of drive mode, which detect the vibration of drive mode and send it to the extra feedback circuit. Node "5" "6" are drive electrode of drive mode, which accept the feedback voltage and bring it to sensor. By node "3 ~ 6" and extra feedback circuit, self-excitation driving (close loop drivie) has been realized. Figure 1(b) is detect model which is seen from detect circuit of detect mode. The detect model is realized by a difference capacitance, and the value of difference capacitance is alterable. "Vcarry" is a high frequency carrier wave. If there is a angle rate input, sense mode will has a vibration, then the value of difference capacitance of sense mode will change, node "1" "2" will have an change current, consequently sense the angle rate input.

2 Design of the Interface Circuit

2.1 Model Founded of Self-Excitation Driving

Figure 2 is a frame chart of self-excitation driving, which includes predigest picture and equivalent picture of driving mode and extra feedback circuit. "drive +" "drive -" are drive AC voltage, "i^{+}_{sense}" "i^{-}_{sense}" are current detect from sense comb of drive mode. The two current flow into extra feedback circuit. They are changed to be voltage and amplitude, feed back to drive electrode of drive mode at last. Thereby a close loop has been realized. We can take the drive part of micro-machined gyroscope as a two ports network, the input of two ports network is voltage and output is current. Then we can see a impedance R_x from input to output.

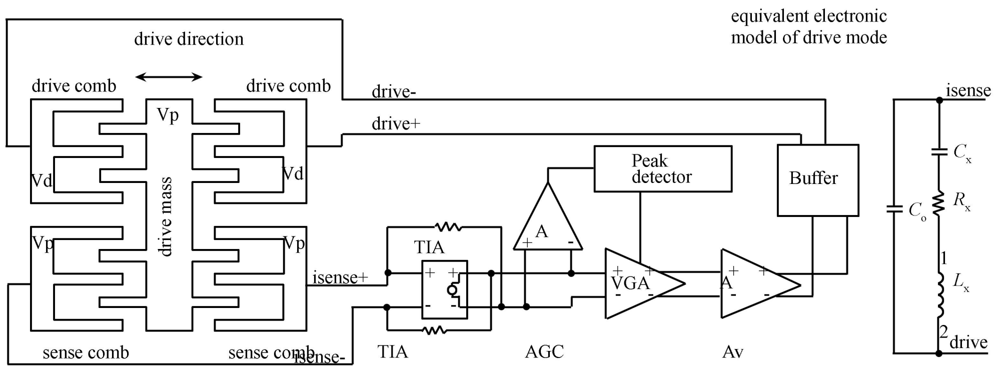

Fig. 2 realization of self-excitation driving

$R_x = \frac{u_x}{i_{sense}}$, u_x is AC drive voltage at drive electrode of drive mode, is current detected by sense electrode of drive mode. When resonance, R_x will change to be:

$$R_x = \frac{m_d \omega_x}{2NMQ_d(\varepsilon_0 z_0/y_0)^2(V_p - V_D)(V_p - V_S)}$$

m_d, drive mass, Q_d: drive mode quality facter; ω_x, drive mode resonance frequency; y_0, space between comb; z_0, width between comb; M, number of drive comb; N, number of sense comb; V_P, DC voltage at drive mass; V_D, DC voltage at drive electrode of drive mode; V_S, DC voltage at sense electrode of drive mode. For a bunch connect R, L, C loop which can seen at the right side of figure 2, it will be only a resistance characteristic while if resonates. We can use this loop to simulate the characteristic of sensor's drive mode. We define

$$C_x = \frac{\eta^2}{k_d}, L_x = \frac{m_d}{\eta^2}, R_x = \frac{b_d}{\eta^2},$$

$$\eta = \sqrt{2NM(\varepsilon_0 z_0 / y_0)^2 (V_p - V_D)(V_p - V_S)},$$

$$\omega_x = \frac{1}{\sqrt{L_x C_x}}$$

C_o is coupling capacitance between drive comb and sense comb. Total amplify times $A_v = R \cdot A_{v1} \cdot A_{v2}$, R is the resistance of TIA, Av_1 is amplify times of AGC, the value of Av_1 will change with the change of amplitude of drive AC voltage, Av_2 is amplify times of output stage.

While $A_v > R_x$, the circuit will get up to oscillate. $A_v = R_x$, the circuit will realize constant amplitude oscillate.

By the parameter of sensor, we enactment $C_x = 4$ fF, $L_x = 730000$ H, $R_x = 80$ MΩ, $C_o = 100$ aF. Figure 3 is the simulation result by Hspice. V(e) is drive voltage, v(ttt) is peak detect voltage. We can see that while the peak detect voltage comes to constant, the amplitude of drive voltage also comes to constant.

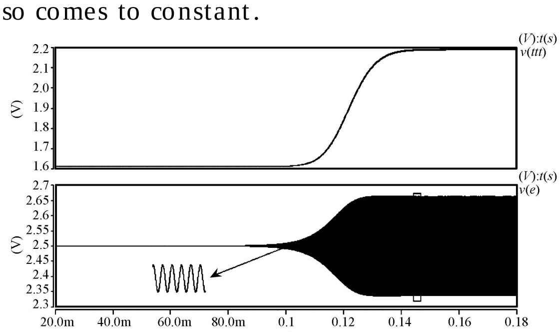

Fig. 3　Simulation result of self-excitation driving

2.2　Interface Circuit Realize

All of the interface circuit of micro-machined gyroscope work at full diff mode. TIA (trans impedance amplifier) was used I-V convert. The resistance used by TIA was made by MOS transistor working at liner region. VGA (variable gain amplifier) was used to amplify the signal from TIA, its gain range is 1～0.01. Peak detect circuit was realized by diode demodulation. Full diff amplifier was used to amplify signal from VGA, and improve drive ability. While constant oscillate, the amplitude of drive voltage is only decided by amplify times of peak detect circuit, and has none business to loop amplify times.

Detect circuit part includes full diff integrator, full diff amplifier, demodulation circuit, filter, high frequency carrier wave, etc. Full diff integrator is used to detect the current from the difference capacitance of micro-machined gyroscope's sense mode, and realize I-V convert. Full diff amplifier is used to amplify the signal from integrator. Diff to single circuit is used to convert the diff signals to single signal. The aim to choose this stage is to simply next stage such as demodulation circuit and filter circuit, and decrease cost. There are twice demodulation, the first is to demodulate the rate signal and from form high frequency carrier wave, the second is to demodulate the rate signal from AC drive voltage. LPF is used to filter the noise signal, which is higher than angle rate frequency. LPF is also used as a buffer for output.

Figure 5 is the simulation result of final output signal and input angle rate signal. V(w) is equivalent input angle signal, v(fout) is final output signal of the interface circuit. From the simulation result, we can see that the interface circuit can detect the input signal with low distortion. The responsibility of interface circuit is 10 mV/deg, sensitivity is 0.1 deg/S $\cdot$ Hz^{-2}.

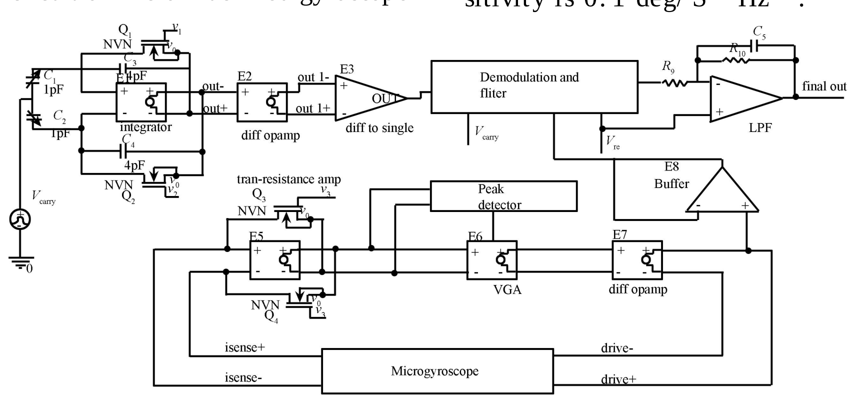

Fig. 4　interface circuit of micro-gyroscope

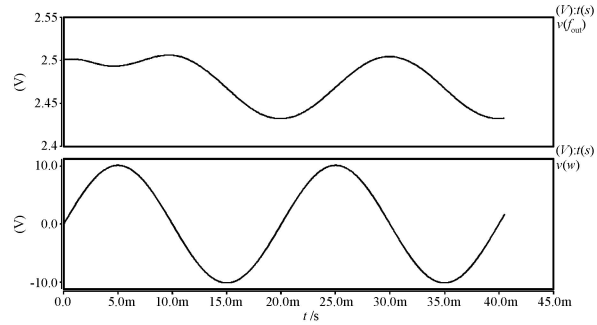

Fig. 5 final output and input angle velocity

3 Conclusion

We have analysed the principle of vibration micro-machined gyroscope with self-excitation driving mode. Founded the equivalent electronic model of the sensor 's driving mode. At last the full diff interface circuit of the vibration micro-machined gyroscope has been given. We can see from the simulation result that self-excitation driving can follow the change of inherence frequency of micro-machined gyroscope 's driving mode, and restrict temperature drift and time drift effectively. SNR have been improved at least two times than single interface circuit. The characteristic of gyroscope have been improved effectively with full diff interface circuit. The responsibility of the system is 10 mV/ deg, sensitivity is 0.1 °/S · Hz^{-2}.

谭晓昀(1960-),男,副教授,主要研究领域为 MEMS 系统,固态传感器等,txj @ hit. edu. cn.

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