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RESULTS OF RESEARCH THE SOLID-STATE WAVE GYROSCOPE WITH METALLIC RESONATOR

Bondarenko T. G., Zeniv I.O., Nizhnyk R.S. Research results of solid-state wave gyroscope with metallic resonator.

In proposed article we present the results of an experimental research of solid-state wave gyroscope with a metal resonator. The developed block diagram of the equipment is described, which includes a low noise buffer amplifier of the capacitive sensor, a band-pass filters, a microcontroller for the formation of control signals of the equipment, a high-voltage drive pulse amplifier and a high-frequency pulse power supply. The oscillograms of the measured gyro sensor signals are shown during the rotation of the resonator and in its stationary state. The principle of formation of high-voltage excitation pulses resonator described. The phase and amplitude of signals carry information about the gyroscope angular rate and about the direction of rotation. The results prove the propriety of calculations to optimize the parameters of electronic circuits and that the proposed principle of signal processing can be used to build solid-state gyroscopes with metal resonators.

Keywords: solid state wave gyroscope, metallic resonator, rotation of resonator, oscillograms of the gyro sensor.

Бондаренко Т.Г., Зенів І.О. Ніжник Р.С. Результати дослідження твердотільного хвильового гіроскопу з металевим резонатором.

У статті, що пропонується, наведені результати експериментального дослідження твердотільного хвильового гіроскопа з металевим резонатором. Описано розроблену структурну схему устаткування, яка містить малошумливий буферний підсилювач ємнісного датчика, смугові фільтри, мікроконтроллер для формування керуючих сигналів апаратури, високовольтний підсилювач імпульсів розкачування, високочастотний імпульсний блок живлення. Описано принцип формування високовольтних сигналів розкачування резонатора. Наведені осцилограми сигналів датчика гіроскопа, що виміряні під час його обертання та у непорушному стані. Фаза та амплітуда сигналів несуть інформацію про кутову швидкість обертання гіроскопу та про напрям повороту. Отримані результати доводять вірність розрахунків з оптимізації параметрів електронної схеми та те, що запропонований принцип обробки сигналів може бути використаний для побудови твердотільних гіроскопів з металевим резонатором.

Ключові слова: твердотільний хвильовий гіроскоп, металевий резонатор, обертання гіроскопа, осцилограми сигналів датчика гіроскопа.

Бондаренко Т.Г., Зенив И.О. Ніжник Р.С. Результаты исследования твердотельного волнового гироскопа с металлическим резонатором.

В предлагаемой статье приводятся результаты экспериментального исследования твердотельного волнового гироскопа с металлическим резонатором. Описана разработанная структурная схема аппаратуры, включающая малошумящий буферный усилитель емкостного датчика, полосовые фильтры, микроконтроллер для формирования управляющих сигналов аппаратуры, высоковольтный усилитель импульсов раскачки и высокочастотный импульсный блок питания. Описан принцип формирования высоковольтных сигналов раскачки резонатора. Приведены осциллограммы измеренных сигналов датчика гироскопа во время вращения резонатора и в его неподвижном состоянии. Фаза и амплитуда сигналов несут информацию про угловую скорость вращения гироскопа и про направление поворота. Полученные результаты подтверждают правильность расчетов по оптимизации параметров электронной схемы и то, что предлагаемый принцип обработки сигналов может быть использован для построения твердотельных гироскопов с металлическим резонатором.

Ключевые слова: твердотельный волновой гироскоп, металлический резонатор, вращение гироскопа, осциллограммы сигналов датчика гироскопа.

Introduction

Many of the well-known works [1-4] describe the design and features of the operation of a solid-state wave gyroscope. However, gyroscopes with dielectric (quartz or sapphire) resonators were usually considered there. A theoretical calculation of the sensitivity of the circuit for measuring the quality factor of a solid-state wave gyroscope was carried out. The article presents the results of an investigation of a gyroscope with a metal resonator, which, as is well known, has a much lower Q-value.

The main material research

1. Overall block diagram

For the measurement of small mechanical vibration of resonator is proposed to use signal processing method with the capacitive sensor, as in the famous condenser microphone. The capacitor is charged through to high voltage. If you change the distance between the plates of the capacitor, it caused changes and the voltage across it. This voltage signal is to be amplified. Thus, the signal voltage will modulate the voltage on the capacitor.

The entire electronic circuit was assembled on four boards:

1) pre-amplifier with high input impedance and low noise, the board should be placed directly close to resonator,

2) main board, on which located: the amplifier - bandpass filter and amplifier of high-voltage excitation pulses,

3) power supply unit board,

4) microcontroller board.

Overall block diagram is shown in Figure 1.

Readout principle is the same: high DC voltage of +104V is applied to the common electrode of the gyroscope. Readout signals electrodes of two channels - main and quadrature, are charged to this high voltage. When vibrations resonator varies the distance between the common electrode and the partial electrodes of capacitors, then respectively, changes the voltage on the partial plates.

The preamplifier board receives the main and quadrature channels signals from resonator. Also to the preamplifier board come the signals: excitation impulses; ban impulse to key circuit performing disconnection of the amplifier inputs in moments of action the excitation pulse.

In main amplifier is performed frequency filtering and gain the main channel signal. The current objective of quadrature channel signal analysis is not put, so this channel is switched off. At the input of the main amplifier board also coming pulses generated by the microcontroller, from which the excitation pulses are generated in the high voltage amplifier.

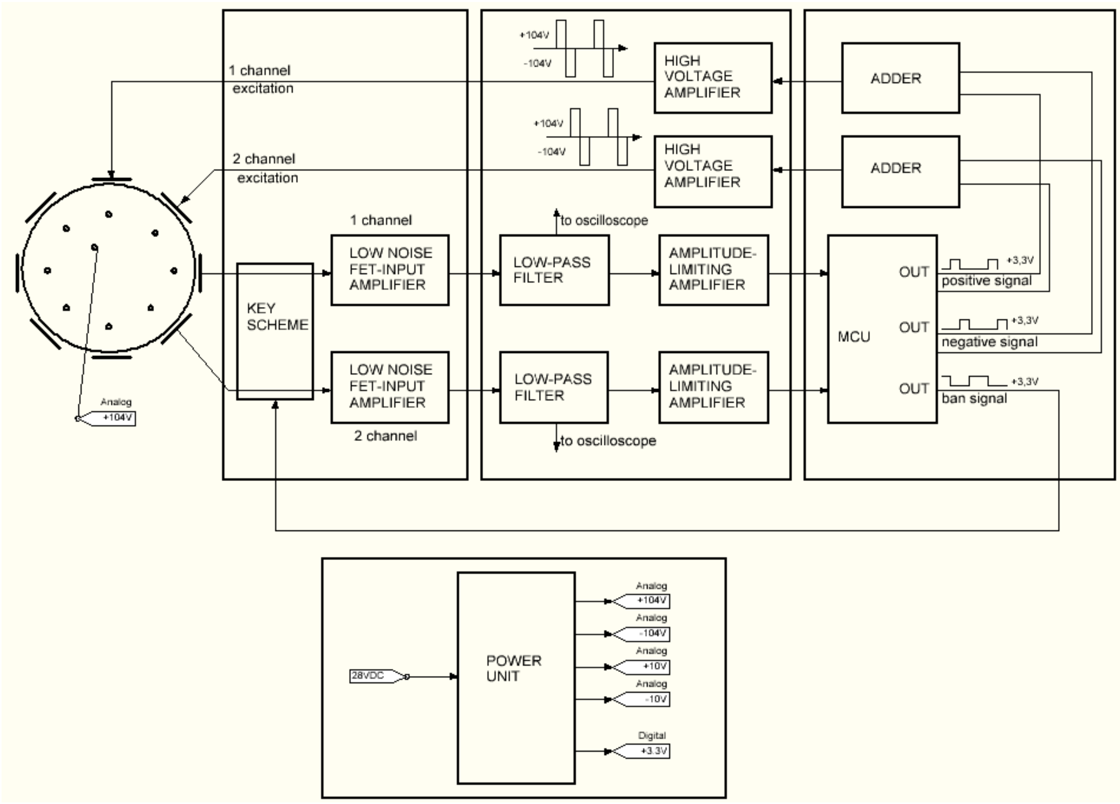


Fig. 1. Block diagram of the entire electronic circuit

Microcontroller card receives synchronization signal from an external master oscillator. In moments determined by the synchronization pulse, the microcontroller generates: pulses for creating the excitation pulses; pulse for suppression input voltage for the preamplifier.

The power unit produces stabilized voltage for all circuit boards.

In carrying out the experimental measurements the very strong capacitive coupling between the electrodes of the resonator has been found, in the case of a metal resonator. Measurements showed that the parasitic capacitance connections between pairs of electrodes arranged perpendicularly was, on various occasions, from 23 to 32 pF. This is a large capacity, which leads to the emergence of a strong interference signal to the readout electrodes during the excitation pulses (Figure 2).

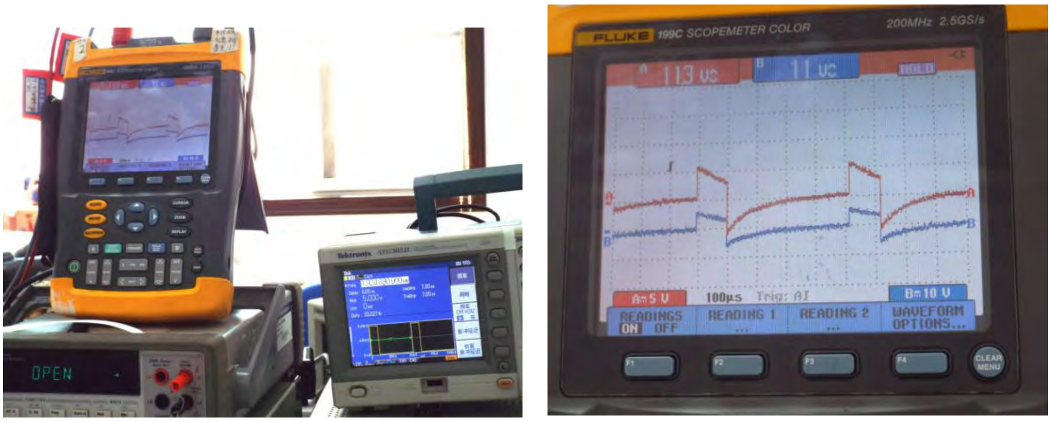


Fig. 2. Measured signals directly on the readout electrodes (without amplification and filtering)

On the screen red and blue color shows the signals taken from the electrodes of the main and quadrature channels (Left unit) at the time of the excitation pulse (right unit). As can be seen from the oscillograms, the interference pulse amplitude reaches 11V.

It is important to compare the displayed values of interference with useful signal value, which can be present on the electrodes of the reading [5,6] in the condenser sensor.

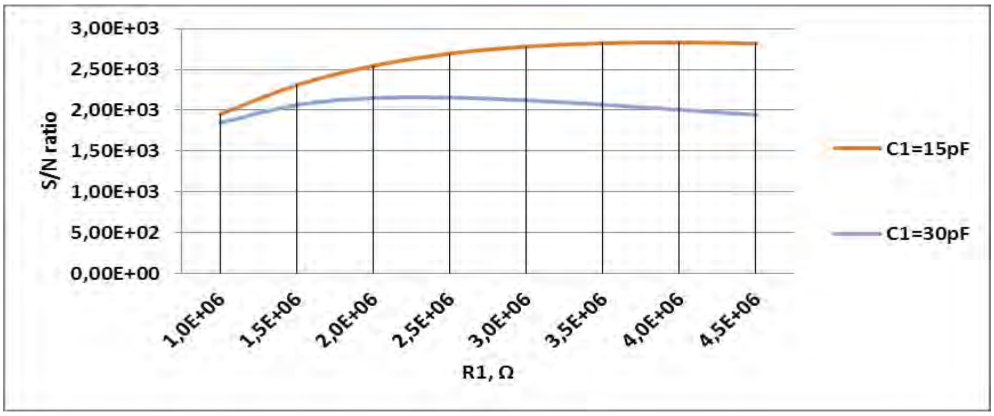


Fig. 3. S/N ratio depending from the value of resistor R1 in the input circuit (C1 - parasitic capacitance)

Calculations show that at the following initial data:

a) the frequency of resonator 1935 Hz;

b) the capacity of the two opposing readout electrodes 6 pF;

c) the modulation index m=0,001;

d) DC voltage bias U=100 V;

e) the bandwidth of filter 800 Hz (large enough);

f) the spectral density of the amplifier noise 14 nV/√Hz (not the best value);

g) value of resistor R1=3 MΩ in the input circuit,

so the useful signal amplitude on the readout electrode will be 17,4 mV while the parasitic capacitance C1=15 pF; and will be 13,3 mV with C1=30 pF.

We can see that these values are about 1000 times less than the amplitude of interfering signals which are observed. It is clear that without the use of a special method it will be difficult to select the desired signal on the background of such interference.

In this connection it has been tasked to select the useful signal from the high-power interference and realize resonator's electrostatic excitation to a level at which it will be possible observation of useful signal.

1.1. The preamplifier board

Considering the small amplitude of the signal and the extremely low value of capacitance of the partial capacitors for signal amplification is necessary to use amplifiers with high input impedance and low input capacitance. During action the excitation signal the input of the amplifier is connected to the "ground" with the help of a key scheme. The principle of operation is shown in Figure 4.

In operating mode, the resistance between the chip's pins S1 and D1 is large, leakage current not exceeding 0,01 nA, and input capacitance is 4 pF.

When the ban signal arrived to input IN1, the resistance between the S1 and D1 becomes small, about 40Ω.

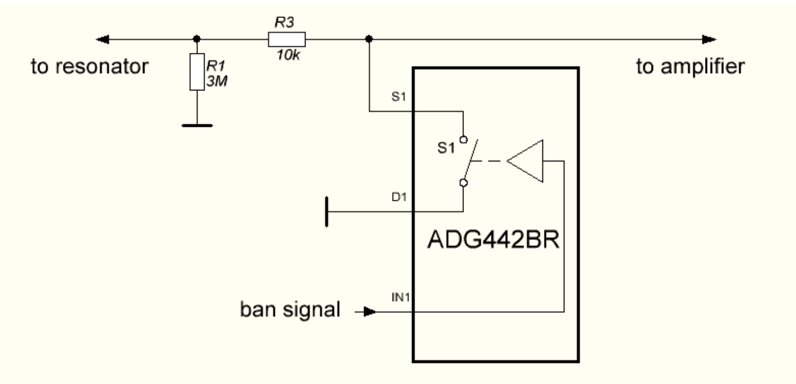


Fig. 4. The principle of the ban of the input signal

The board of the input amplifier also has circuit elements for supply DC +104V to the common electrode resonator (capacitors and inductance of the low pass filter). They are used to filter the DC voltage in order to reduce interference on the common electrode.

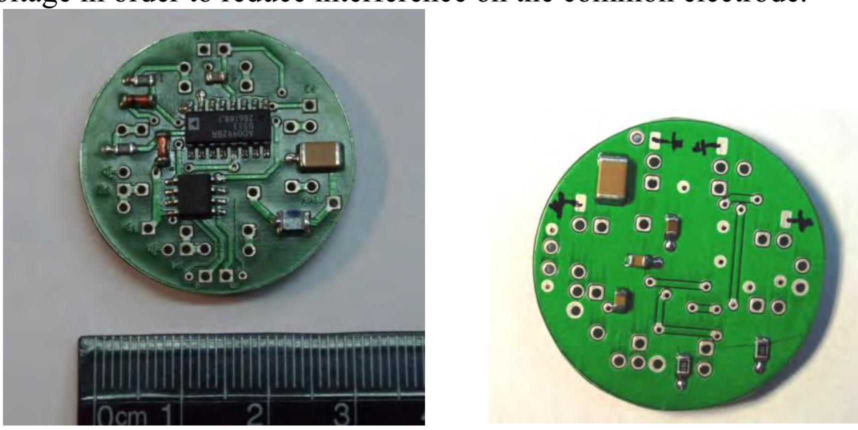


Fig. 5. Photo of preamplifier board

1.2. The main circuit board

Since this board is supposed to be used together with other resonators having a different frequency, the two-stage low-pass filter with cutoff frequency 3500 Hz is applied (Figure 6,7).

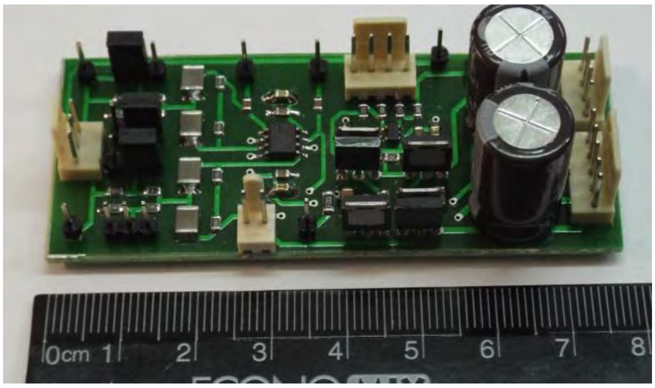


Fig. 6. Photo of main board

The schematic diagram of a high-voltage amplifier of drive pulses can be of interest (Figure 8).

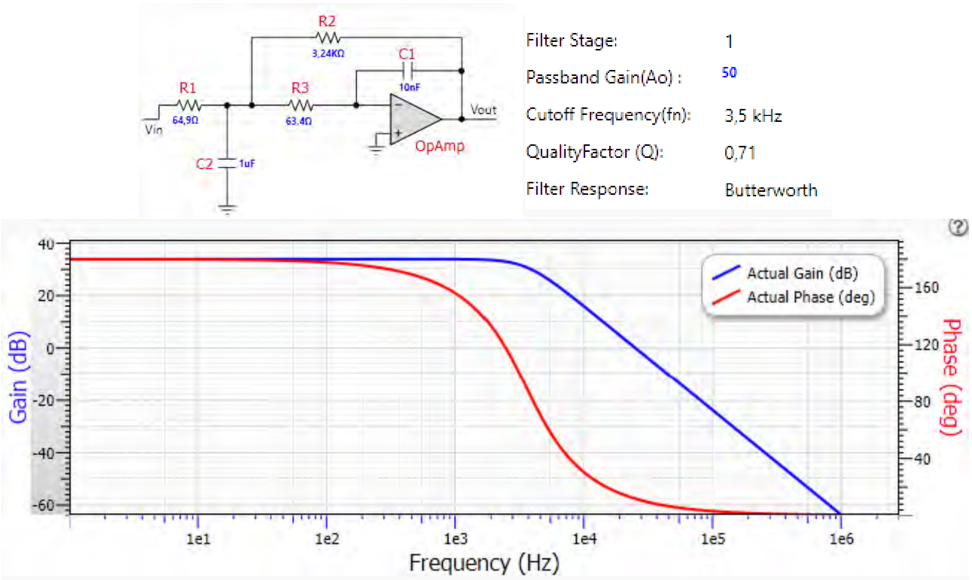


Fig. 7. The results of calculation of the low-pass filter

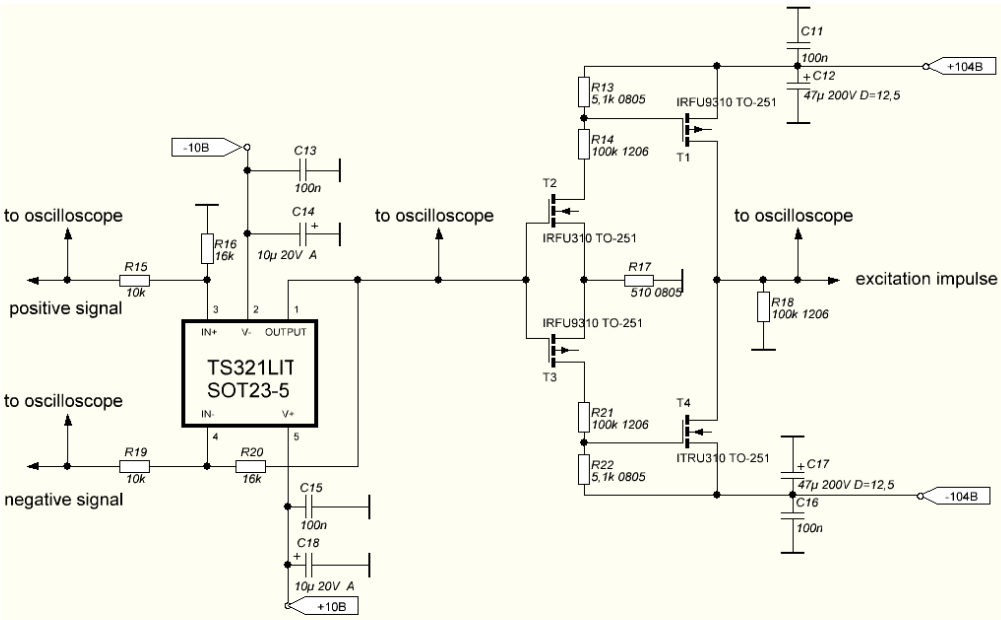


Fig. 8. Circuit diagram of a high-voltage drive pulse amplifier

1.3. The power supply board

Constant voltage + 28V is supplied to the input of the power supply unit (Figure 8). This unit generates the following constant stabilized voltage:

a) constant voltage +104V for the high voltage amplifier of excitation pulse, and for supplying the bias voltage to the common electrode of the resonator,

b) constant voltage -104V for the high voltage amplifier of excitation pulse,

c) constant voltages ± 10V for chips.

The power supply unit is high frequency switching, running at 43 kHz, uses a chip SELF-OSCILLATING HALF-BRIDGE DRIVER IC IRS21531D, has no singularities.

Converter from +10V voltage to +3.3V for the microcontroller placed on the microcontroller board.

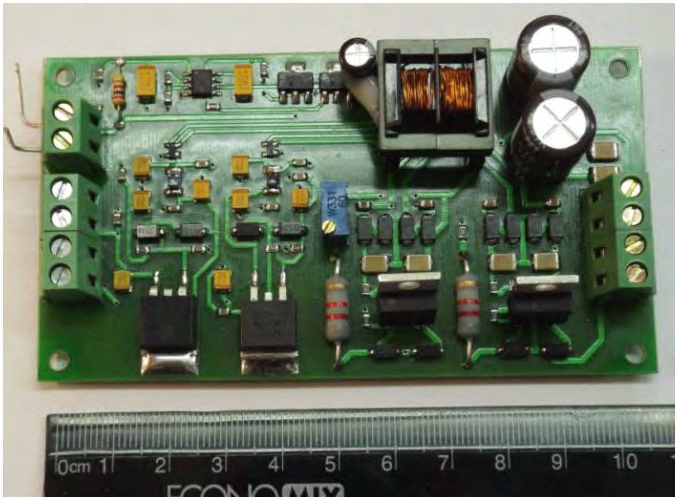


Fig. 8. Photo of power supply board

1.4. Features of microcontroller

In this scheme, the microcontroller (Figure 9) is designed to generate pulses that control the operation of the buffer and the high-voltage amplifiers.

Therefore pulses from the external master clock are used with a repetition rate from 1935 Hz to 2751 Hz, which are applied to the microcontroller input for synchronization of all circuit elements.

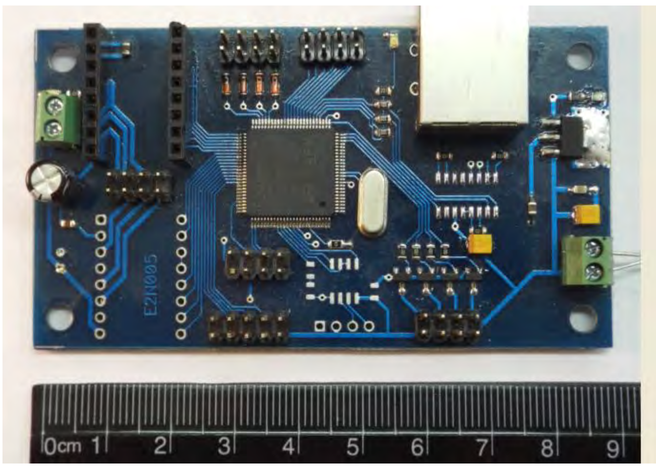


Fig. 9. Photo of microcontroller PCB

Diagram of signals that generates the microcontroller is shown in Figure 10.

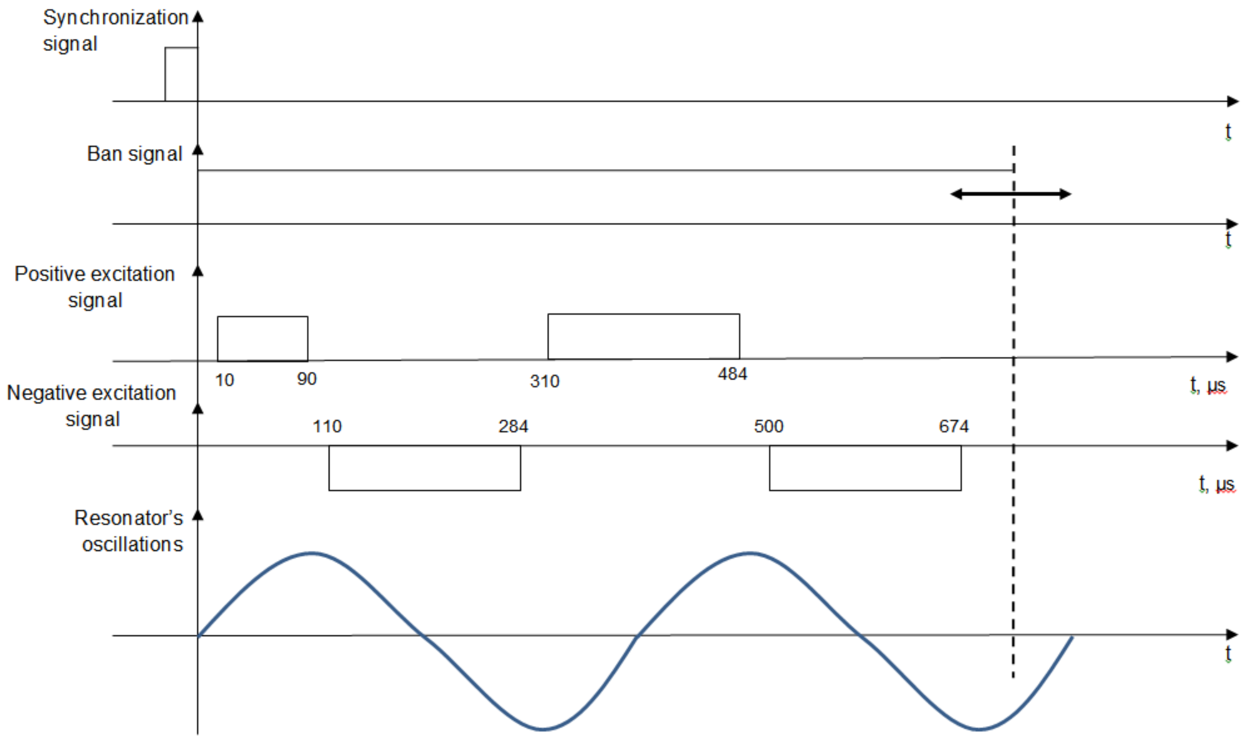


Fig. 10. The signals at the input and output of the microcontroller

In the first quarter of resonator oscillation, when the distance between the plates of the main channel reading capacitor (read-out) decreases, to the orthogonally positioned swinging electrode must be fed a high potential «Excitation signal N4» from high-voltage amplifier.

This will lead to the absence of attraction between the excitation electrode and the resonator, whose potential is large. Voltage on all other electrodes (including on the read-out signal pickoff electrodes) will be zero, and they will be attracted by resonator. Therefore, the resonator will move away from the excitation electrode and approach to read-out electrode.

In the second quarter of resonator oscillation, when the distance near the read-out electrode begins to increase, the output voltage «Excitation signal N5» of the high-voltage amplifier will be negative, so the resonator will be acts force of attraction. Consequently, the resonator will be attracted to excitation electrode and keep away from the read-out electrode.

Excitation pulses are not generated during the signal read-out.

2. Results of measurements and oscillograms

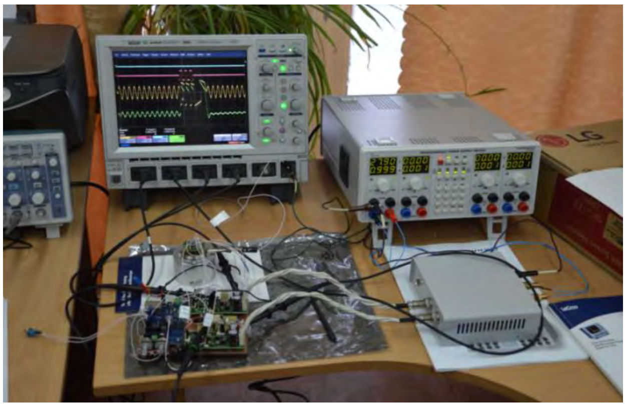


Fig.11. Hardware in experiment

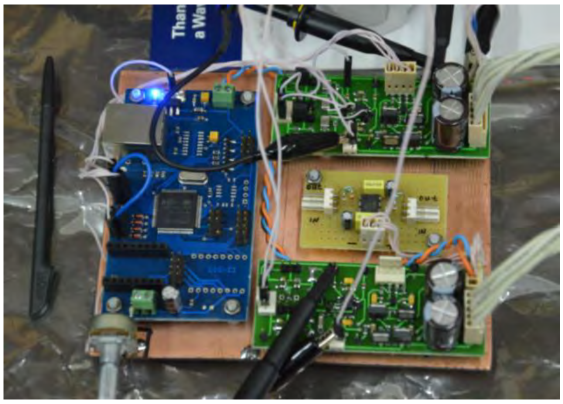
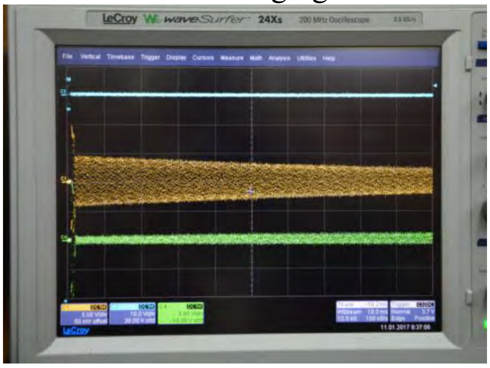


Fig.12. Main board & MCU

2.1. Observation of swinging of the main channel



- Blue – excitation pulses
- Yellow – main channel output
- Green – quadrature channel output

Fig. 13. Observation of swinging of the main channel only. There are oscillations in the quadrature channel appear too. We observe the transfer of energy from the main channel to the quadrature channel

2.2. Observation of swinging of the main and quadrature channels

- Blue – excitation pulses in main channel
- Red - excitation pulses in quadrature channel
- Yellow – main channel output
- Green – quadrature channel output

Fig.15. The oscillations in the main channel are excited. The oscillations in the quadrature channel are suppressed by the suppression pulses (red)

- Blue – excitation pulses in main channel
- Red - excitation pulses in quadrature channel
- Yellow – main channel output
- Green – quadrature channel output

Fig. 16. Adjustment of the suppression in the quadrature channel by changing the duration and phase of the first suppression pulse

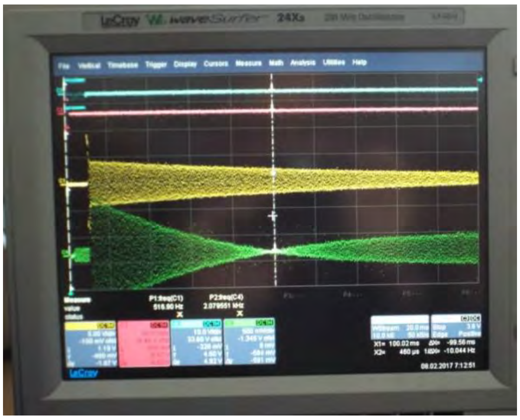


Fig. 17. The oscillogram after setting the suppression in the quadrature channel at time moment 0.1 seconds

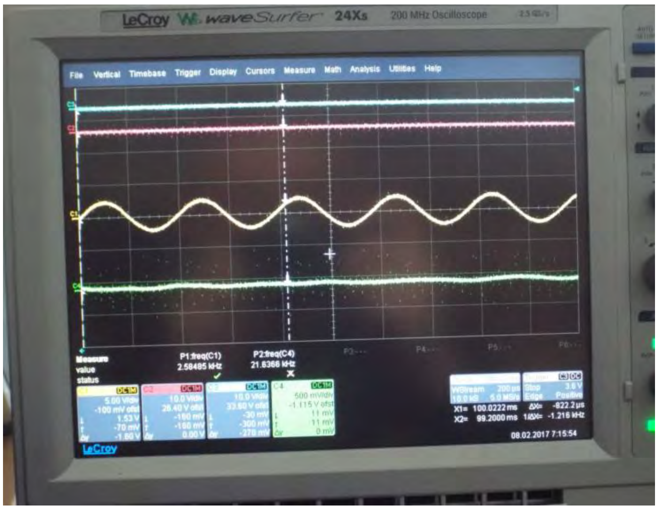


Fig. 18. The oscillogram after setting the suppression in the quadrature channel in the neighborhood of the time moment is 0.1 seconds. We observe almost complete suppression of the signal in the quadrature channel. The resonator is stationary

2.3. Observation of the gyroscope rotation

Fig. 19. Rotate the gyroscope clockwise. Rotation speed 10 degrees per second

Fig.20. Rotate the gyroscope counter clockwise. Rotation speed 10 degrees per second. The change in the phase of the oscillations in quadrature channel carries information about the direction of rotation

Conclusions

It has been experimentally verified that it is possible to observe and measure the signals in the quadrature channel when the solid-state gyroscope rotates. The amplitude and phase of the signal carries information about the angular velocity and direction of rotation.

Further research can be carried out in the direction of automatic calibration of the measuring system using a microcontroller. Calibration consists in compensation of oscillations in a quadrature channel at a certain time.

A program for automatic processing of measurement results should also be developed.

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