Design, Fabrication and Testing of Flight Worthy Fiber Optic Gyro based Sensor Package unit for Control Application

Hari Shanker Singh*, Murali Prakash**, Ramesh Babu**, Azimuddin**, Pradeep Kumar*, Unni Krishnan*, Jagannath Nayak*.
*Inertial System Group, RCI, Hyderabad.
**Electro Optical Instruments Research Academy, Hyderabad.

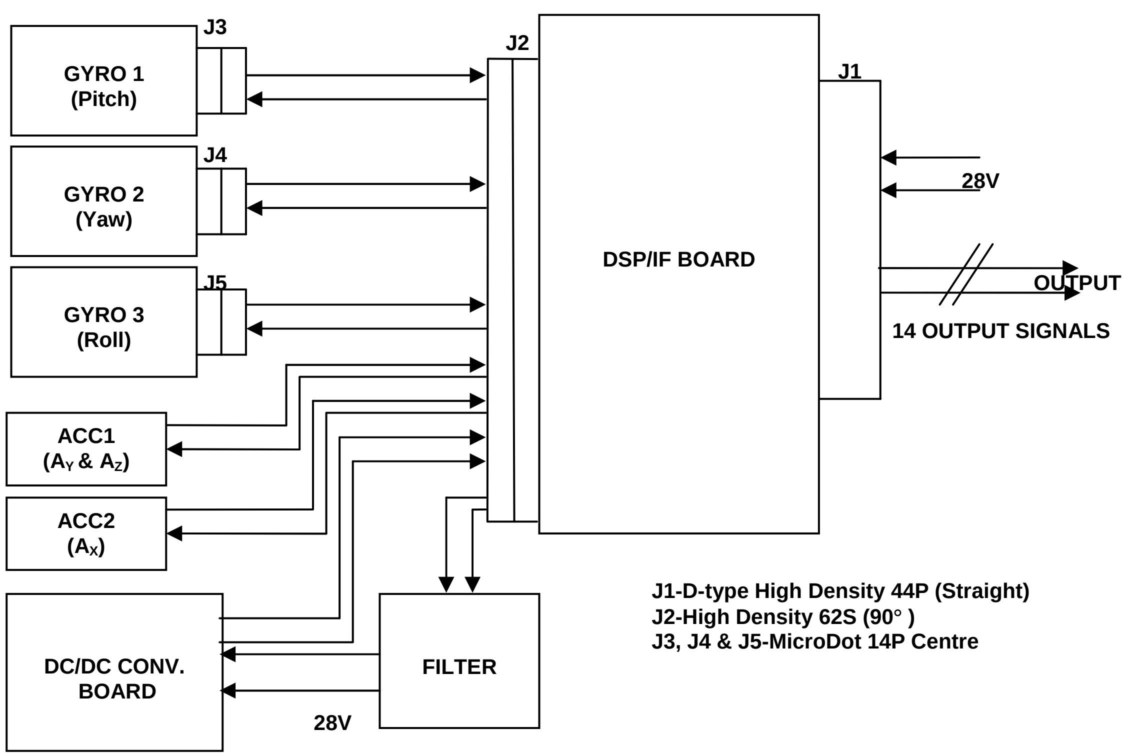
ABSTRACT

Control System of missiles and aerospace vehicle require body rate and acceleration information for guidance and stabilization. A Sensor package unit consists of three fiber optics gyroscopes, two dual axis micro-electro-mechanical (MEM) accelerometers and sensor interface card is developed and tested. Fiber optic gyros are indigenously developed and sensor compensation method is developed for all accelerometers. These units meet requirement for flight testing specifications. The test results meeting the environmental conditions such as temperature, damp heat, random vibration, EMI/EMC are presented.

1.0 INTRODUCTION

Missile control system require three rate gyros and three accelerometers outputs along Roll, Pitch and Yaw directions for auto-pilot control. An indigenously developed control sensor package based on fiber optic gyros and MEMS accelerometers, which is meeting all the requirement of flight conditions. It consists of indigenously developed three miniaturized FOGs based on all-fiber approach at RCI, Analog Devices accelerometers (ADXL-278) are used where analog compensation technique is developed to meet the entire temperature range requirements.

The paper presents the target specifications, design, packaging and testing of a flight worthy FOG based Sensor Package Unit (FSPU).



2.0 DESIGN

2.1 Fiber Optic Gyro (FOG)

Fiber Optic Gyro (FOG) contains two modules:

i) Optical Module

This module comprises Super Luminescent Diode (SLD) source, polarizer, isolator, two fused fiber optic couplers, PZT based optical phase modulator and photo detector.

ii) Electronics Module

This module contains the temperature and power controller circuit for SLD, photo detector front end amplifier circuit and signal processing circuit.

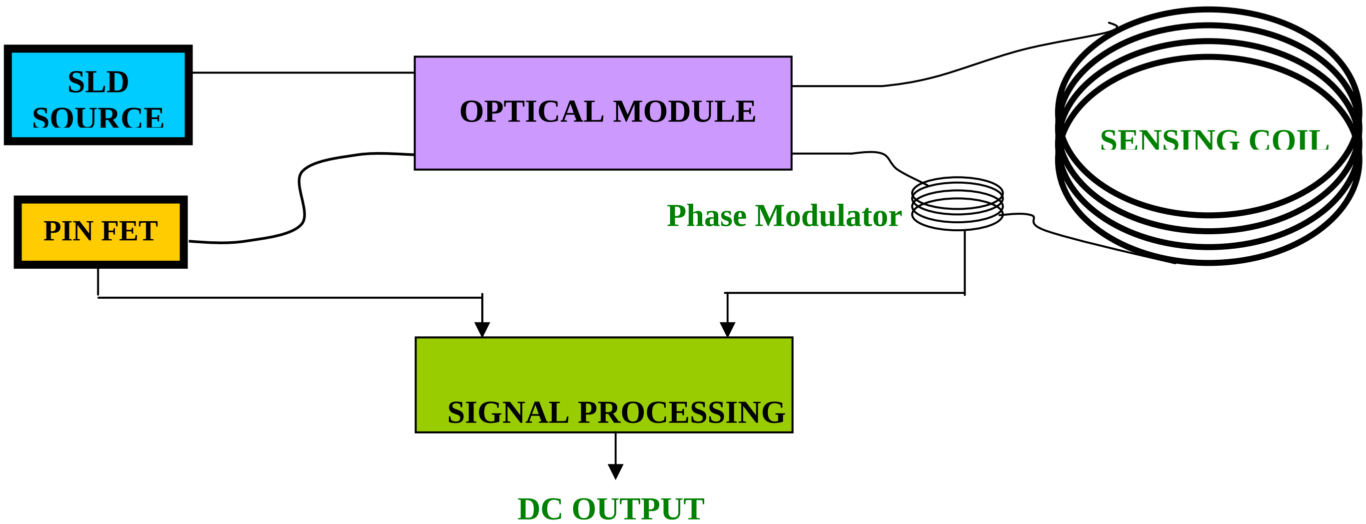


Figure 1: Basic Configuration of FOG

When system is at rest the light propagating in clockwise (CW) and counter clockwise (CCW) directions traverse identical paths and so there is no phase difference between them. When the system rotates at an angular velocity Ω, then CW path will be longer by (LR/ C)Ω and CCW path will be shorter by (LR/ C)Ω i.e.

$$L_{ccw} = 2\pi R - R\,\Omega t_{CCW}$$

and

$$L_{cw} = 2\pi R + R\,\Omega t_{CW}$$

This yield

$$\Delta L = c(t_{CW} - t_{CCW}) = 4A\Omega/c$$

Thus the phase difference produced between CW and CCW wave is obtained from above expression as

$$\Delta\phi_R = \frac{8\pi NA}{\lambda c}\Omega \qquad (2.1)$$

Where $\Delta\Phi_R$ is the Phase shift due to rotation rate, $A = \pi R^2$, the area enclosed by the path of radius R, L is length of the coil $L = 2\pi RN$, N being the number of turns of fiber loop and c is the speed of light, λ is source wavelength.

2.2 MEMS Accelerometers

Dual-axis high-g accelerometer is of low power with signal conditioned voltage outputs. It is temperature stable and accurate over the temperature range, with a self-test feature that fully exercises all the mechanical and electrical elements of the sensor with a digital signal applied to a single pin.

It provides fully differential sensor structure and circuit path, resulting in high resistance to EMI/RFI effects. It uses electrical feedback with zero-force feedback for improved accuracy and stability. The sensor resonant frequency is significantly higher than the signal bandwidth set by the on-chip filter, avoiding the signal analysis problems caused by resonant peaks near the signal.

Each sensor includes several differential capacitor unit cells. Each cell is composed of fixed plates attached to the substrate and movable plates attached to the frame. Displacement of the frame changes the differential capacitance, which is measured by the on-chip circuitry.

Complementary 200 kHz square waves drive the fixed plates. Electrical feedback adjusts the amplitudes of the square waves such that the ac signal on the moving plates is zero. The feedback signal is directly proportional to the applied acceleration. This feedback technique ensures that there is no net electrostatic force applied to the sensor. The differential feedback control signal is also applied to the input of the filter, where it is filtered and converted to a single-ended signal.

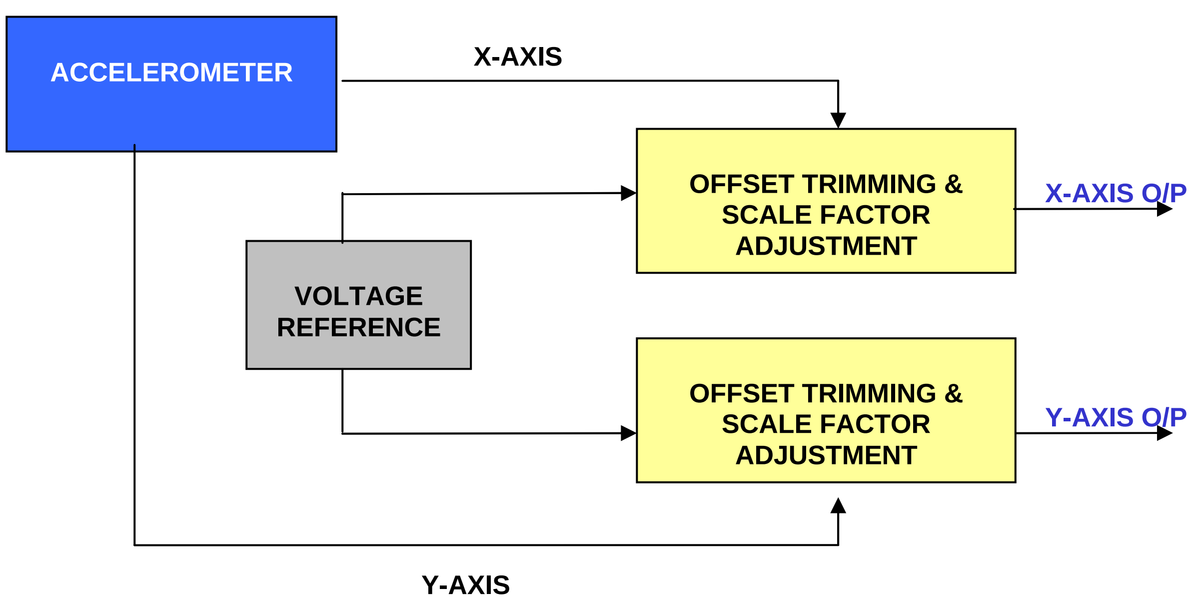


Figure 2: Block Diagram of Accelerometer

3.0 PACKAGING

FOG based on Sensor Package Unit has been fabricated based on the recommendations as per the structural analysis results. Dimensions of the package are very critical for mounting in the missile, height of the package is 89 mm, overall diameter is 240mm and mounting portion radius is 166 mm.

Accelerometer boards are mounted on the two sides of solid block in such way that all three axis acceleration outputs can be read. Separate slots are provided for internal wiring.

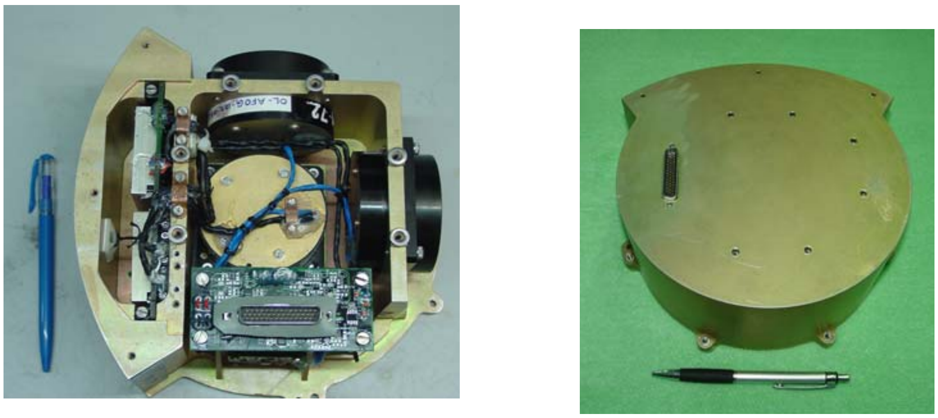


Figure 3 : FSPU package diagram

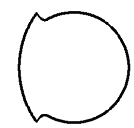
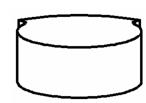
4.0 TESTING AND ANALYSIS

Functional tests and Environmental tests are carried out and sectional vibration has been carried out by mounting the unit in the missile section. All the tests i.e., Functional tests include rate gyro checks, accelerometer checks and zero offset checks and Environmental tests include temperature tests, humidity test, vibration and bump have been successfully carried out.

4.1 Functional Test results

4.1.1 Rate Gyros checks

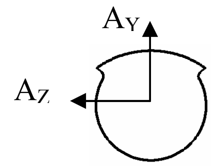
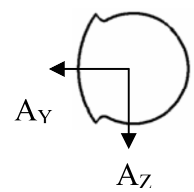
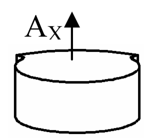
Sign Check

Nomen-clature	Rotation (°/sec)	Output		Position
		Target Specification	Measured	
G1 (Pitch)	Clockwise: 50	– 5 ± 0.25V	-5.1761V	
	Clockwise: 100	– 10 ± 0.5V	-10.4463V	
	Counter Clockwise: 50	+ 5 V± 0.25V	5.1743V	
	Counter Clockwise: 100	+ 10V ± 0.5V	10.439V	
G2 (Yaw)	Clockwise: 50	+ 5V ± 0.25V	5.014V	
	Clockwise: 100	+ 10V ± 0.5V	9.9741V	
	Counter Clockwise: 50	– 5V ± 0.25V	-5.008V	
	Counter Clockwise: 100	– 10V ± 0.5V	-9.9739V	
G3 (Roll)	Clockwise: 50	+ 5V ± 0.25V	5.1496V	
	Clockwise: 100	+ 10V ± 0.5V	10.3258V	
	Counter Clockwise: 50	– 5V ± 0.25V	-5.146V	
	Counter Clockwise: 100	– 10V ± 0.5V	-10.3203V	

Scale Factor

Nomenclature	Output	
	Target Specification (mV/°/sec)	Measured (mV/°/sec)
G1(Pitch)	100 ± 5	103.50
G2(Yaw)	100 ± 5	100.20
G3(Roll)	100 ± 5	102.95

4.1.2 Accelerometers checks

Nomenclature	Target Specification (mV)	Measured Output (mV)	Position
Y Axis(A1) Accelerometer for 1g	– 400 ± 20 ± offset	– 409.6	
Z Axis Accelerometer(A2)	< ±120	– 3.4	
Longitudinal Accelerometer (A3)	< ±120	2.9	
Y Axis Accelerometer(A1)	< ±120	8.0	
Z Axis Accelerometer for 1g (A2)	– 400 ± 20 ± offset	– 406.4	
X Axis Accelerometer (A3)	< ±120	– 4.1	
Y Axis Accelerometer(A1)	< ±120	15.8	
Z Axis Accelerometer(A2)	< ±120	– 2.0	
X Axis Accelerometer(A3) for 1g	– 400 ± 20 ± offset	– 400	

4.2 Sectional Vibration

Sectional vibration has been done to analyse the performance of the unit. FSPU was mounted in the missile section along with all other units and the output was monitored through OBP as well as recorder directly.

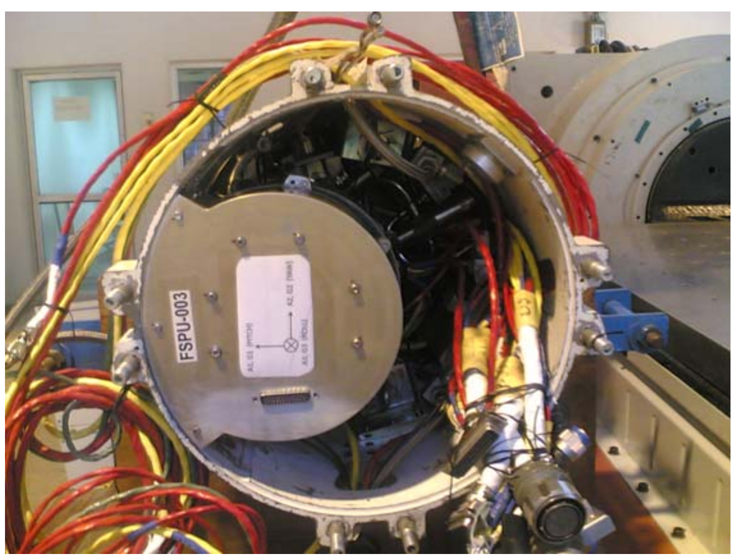


Figure 4: Sectional Vibration set-up

4.2.1 Results

S. No.	PARAMETER	VIBRATION RESULTS					
		X-axis		Y-axis		Z-axis	
		RAW DATA (P-P in V)	OBP DATA (P-P in V)	RAW DATA (P-P in V)	OBP DATA (P-P in V)	RAW DATA (P-P in V)	OBP DATA (P-P in V)
1.	Pitch Gyro	± 0.65	± 0.035	± 0.9	± 0.05	± 0.9	± 0.05
2.	Yaw Gyro	± 0.04	± 0.01	± 0.18	± 0.01	± 0.045	± 0.025
3.	Roll Gyro	± 0.6	± 0.25	± 3.0	± 1.3	± 1.0	± 0.45
4.	Acceleration (A_Y)	± 1.2	± 0.06	± 2.2	± 0.105	± 2.2	± 0.015
5.	Acceleration (A_Z)	± 0.4	± 0.02	± 3.2	± 0.2	± 0.6	± 0.03
6.	Acceleration (A_X)	± 1.8	± 0.8	± 0.4	± 0.2	± 0.4	± 0.15

5.0 CONCLUSION

FOG based Sensor Package Unit (FSPU) based on FOG and MEMS accelerometers is successfully which is meeting all the requirements of missile control applications. The units are ready for flight testing. Further design work is under progress to minimize the package size as well as weight.

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