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Spartan-6 FPGA Based MEMS Accelerometer Processing Electronics for Navigation

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Abstract: Micro-Electro -Mechanical System (MEMS) technology holds great promise for navigation systems because of the reduced size and cost of MEMS inertial sensors relative to conventional devices In this project, Accelerometer sensors data has to be acquired from MEMS accelerometer board and processed in spartan-6 FPGA. The MEMS accelerometer board consists of one MEMS accelerometers and Instrumentation amplifier (IA) for the outputs of the accelerometer. The Instrumentation amplifier provides high CMRR for the accelerometer outputs. The output of IA is processed through Voltage-to-Frequency (VTF) in the processing electronic board. The processed output / pulses from VTF are given to the Spartan-6FPGA. These frequency pulses read through counters. The counter logics have to be implemented in the FPGA using VHDL coding. This VHDL code is interfaced to the Micro Blaze soft-core processor through AXI Bus. The Micro Blaze soft-core processor is to be embedded into FPGA using EDK tool. The temperature data of the accelerometer is converted to digital data using ADC. The ADC is interfaced to FPGA through parallel communication. The counters data and temperature data from the FPGA are transmitted to the Navigation Processor system at RS-422 level through UART.

Keywords: MEMS, UART, ADC, Voltage-to-Frequency(VTF), RS-422, VHDL, EDK.

I. INTRODUCTION

Navigation is a field of study that focuses on the process of monitoring and controlling the movement of a craft or vehicle from one place to another. The field of navigation includes four general categories: land navigation, marine navigation, aeronautic navigation, and space navigation. It is also the term of art used for the specialized knowledge used by navigators to perform navigation tasks. All navigational techniques involve locating the navigator's position compared to known locations or patterns.An Inertial Navigation System (INS) is a navigation aid that uses a computer, motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft. An inertial navigation system includes at least a computer and a platform or module containing accelerometers, gyroscopes, or other motion-sensing devices. The INS is initially provided with its position and velocity from another source (a human operator, a GPS satellite receiver, etc.), and thereafter computes its own updated position and velocity by integrating information received from the motion sensors. The advantage of an INS is that it requires no external references in order to determine its position, orientation, or velocity once it has been initialized. An INS can detect a change in its geographic position (a move east or north), a change in its velocity and a change in its orientation (rotation about an axis).

It does this by measuring the linear and angular accelerations applied to the system. Since it requires no external reference (after initialization), it is immune to jamming and deception. Inertial-navigation systems are used in many different moving objects such as aircraft, submarines, spacecraft and guided missiles. However, their cost and complexity place constraints on the environments in which they are practical for use. Gyroscopes measure the angular velocity of the system in the inertial reference frame. By using the original orientation of the system in the inertial reference frame as the initial condition and integrating the angular velocity, the system's current orientation is known at all times. This can be thought of as the ability of a blindfolded passenger in a car to feel the car turn left and right or tilt up and down as the car ascends or descends hills. Based on this information alone, the passenger knows what direction the car is facing but not how fast or slow it is moving, or whether it is sliding sideways. Accelerometers measure the linear acceleration of the system in the inertial reference frame, but in directions that can only be measured relative to the moving system (since the accelerometers are fixed to the system and rotate with the system, but are not aware of their own orientation). Based on this information alone, they know how the vehicle is accelerating relative to itself, that is, whether it is accelerating forward, backward, left, right, up (toward the car's ceiling), or down (toward the car's floor) measured relative to the car, but not the direction relative to the Earth, since they did not know what direction the car was facing relative to the Earth when they felt the accelerations.

The inertial navigation system is a system of aircraft navigation still used today in many large aircraft as the primary navigation system. Instead of using radio navigation aids or satellites, this system is entirely self-contained within the aircraft, computing the aircraft's position by sensing its acceleration and orientation. It, in essence, is a real accurate dead-reckoning computer. There are several names for it, some with slightly different uses:

- Inertial Navigation System (INS)
- Inertial Reference System (IRS)
- Inertial Navigation Unit (INU)
- Inertial Reference Unit (IRU)
- Inertial Measurement Unit (IMU)

II. EXISTING SYSTEM

An Inertial Measurement Unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. Recent developments allow for the production of IMU-enabled GPS devices. An IMU allows a GPS receiver to work when GPS-signals are unavailable, such as in tunnels, inside buildings, or when electronic interference is present. A wireless IMU is known as WIMU. The IMU is the main component of inertial navigation systems used in aircraft, spacecraft, watercraft, drones, UAV and guided missiles among others. In this capacity, data collected from the IMU's sensors allows a computer to track a craft's position, using a method known as dead reckoning. The existing configuration,

The MEMS based IMU having

1. Three Gyroscopes
2. Three Accelerometers
3. Inbuilt Electronics
4. Good Gyroscopes
5. But Poor Accelerometers

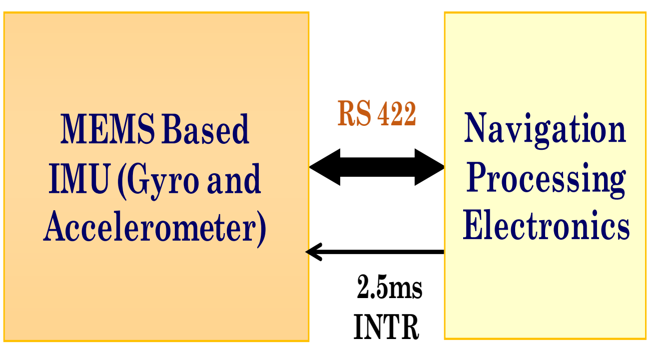

Fig 1. Existing configuration

III. PROPOSED SYSTEM

To improve accelerometer performance inbuilt temperature sensor in MEMS accelerometer itself for temperature compensation we are introducing in this project. MEMS accelerometer is a new extra small high end product dedicated to applications in the domains of inertial sensing. The robust and low power design combined with an excellent bias stability guarantee the superior reliability of the MEMS accelerometer.

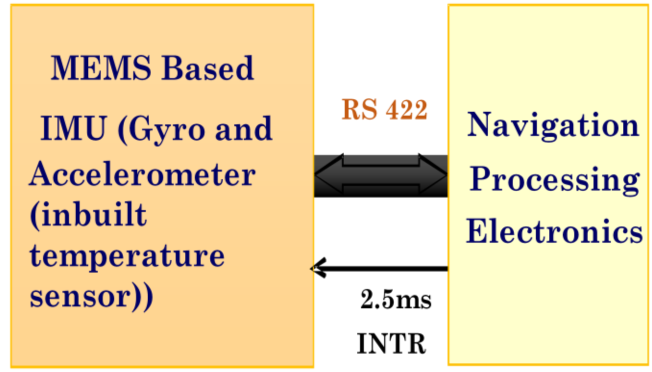

Fig 2. Proposed System.

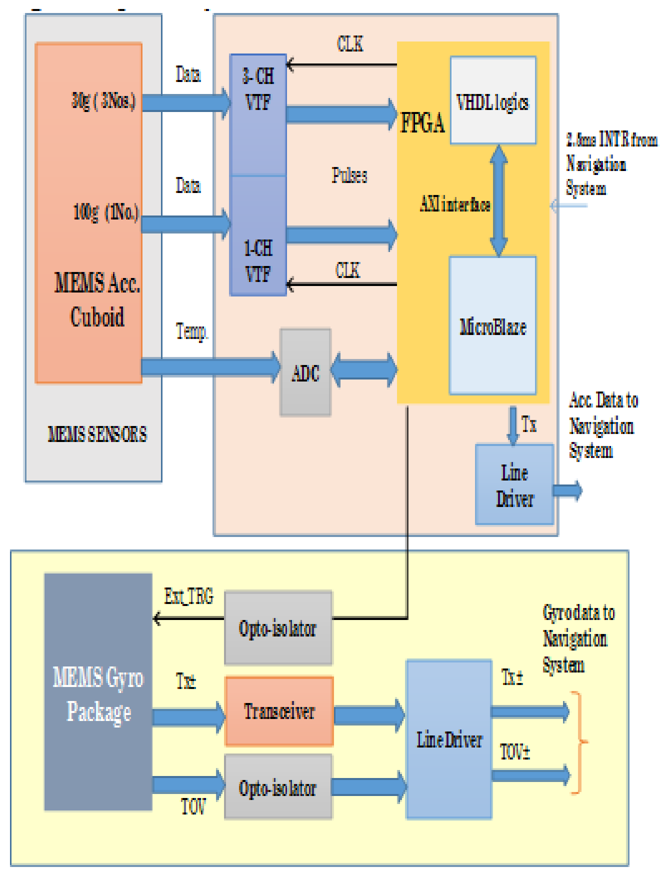

Fig 3. Block Diagram of the Proposed System.

The MEMS accelerometer is a MEMS capacitive sensor, based upon a bulk micro-machined silicon element, a low power ASIC for signal conditioning, a micro-controller for storage of compensation values and a temperature sensor. The product is low power, calibrated, robust and stable and the electronic configuration provides a solid power on reset and ensures a full protection against brown-out. Long-term stability of bias and scale factors are expected to be less than 0.1% of full-scale range. For the future ±2g version, typical bias temperature coefficient will be smaller than 100 µg/°C and scale factor temperature coefficients smaller than 100 ppm/°C.

IV. WORKING PRINCIPLE OF ACCELEROMETER

One of the most common inertial sensors is the accelerometer, a dynamic sensor capable of a vast range of sensing. Accelerometers are available that can measure acceleration in one, two or three orthogonal axes. They are typically used in one of three modes:

- As an inertial measurement of velocity and position.
- As a sensor of inclination, tilt or orientation in 2 or 3 dimensions as referenced from the acceleration of gravity ($1g=9.8m/s^2$).

As a vibration or impact (shock) sensor

A. Block diagram & electrical connections of Accelerometer

It is necessary to use decoupling capacitors [C] of 1µF each between VDD and VAGND and between VAGND and VSS, placed as close as possible from the accelerometer. *COG* or *X7R*

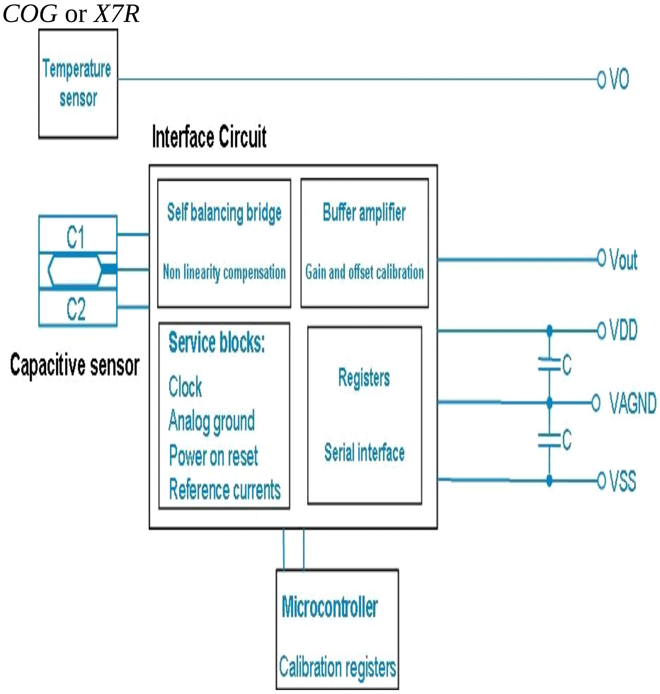

Fig4.Block diagram & electricalconnections of Accelerometer.

V. INSTRUMENTATION AMPLIFIER (AD8221)

The AD8221 is a gain programmable, high performance instrumentation amplifier that delivers the industry's highest CMRR over frequency in its class. The CMRR of instrumentation amplifiers on the market today falls off at 200 Hz. In contrast, the AD8221 maintains a minimum CMRR of 80 dB to 10 kHz for all grades at G = 1. High CMRR over frequency allows the AD8221 to reject wideband interference and line harmonics, greatly simplifying filter requirements. Possible applications include precision data acquisition, biomedical analysis, and aerospace instrumentation. Low voltage offset, low offset drift, low gain drift, high gain accuracy, and high CMRR make this part an excellent choice in applications that demand the best dc performance possible, such as bridge signal conditioning. Programmable gain affords the user design flexibility. A single resistor sets the gain from 1 to 1000. The AD8221 operates on both single and dual supplies and is well suited for applications where ±10 V input voltages are encountered. The AD8221 is available in a low cost 8-lead SOIC and 8-lead MSOP, both of which offer the industry's best performance. The MSOP requires half the board space of the SOIC, making it ideal for multichannel or space-constrained applications. Performance is specified over the entire industrial temperature range of −40°C to +85°C for all grades. Furthermore, the AD8221 is operational from −40°C to +125°C1.

A. Pin Diagram of Instrumentation Amplifier (AD8221).

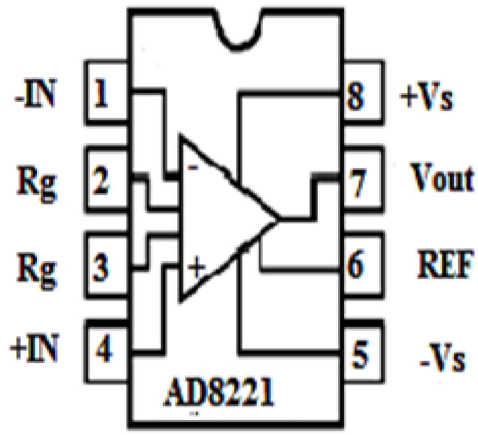

Fig 5. Pin Configuration And Function Description.

B. Interfacing ADC with FPGA

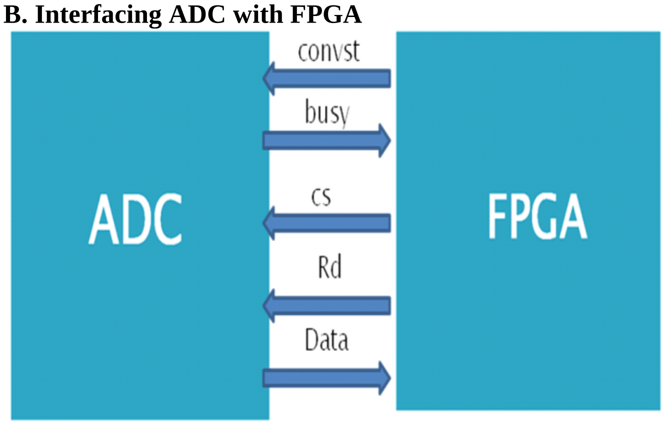

Fig 6. Interfacing ADC with FPGA.

C. Pin Configuration And Function Descriptions:

Pin 1 (-in): Negative Input Terminal.

Pin 2 (RG): Gain Setting Terminal. Place resistor across the RG pins to set the gain.

$$G = 1 + (49.4\ k\Omega/RG).$$

Pin 3 (RG): Gain Setting Terminal. Place resistor across the RG pins to set the gain.

$G = 1 + (49.4\ k\Omega/RG)$.

Pin 4 (+in): Positive Input Terminal.

Pin 5 (-Vs): Negative Power Supply Terminal.

Pin 6 (REF): Reference Voltage Terminal. Drive this terminal with low impedance

voltage source to level-shift the output.

Pin 7 (Vout): Output Terminal.

Pin 8 (+Vs): Positive Power Supply Terminal.

D. Counter Logic Implementation Flow Chart

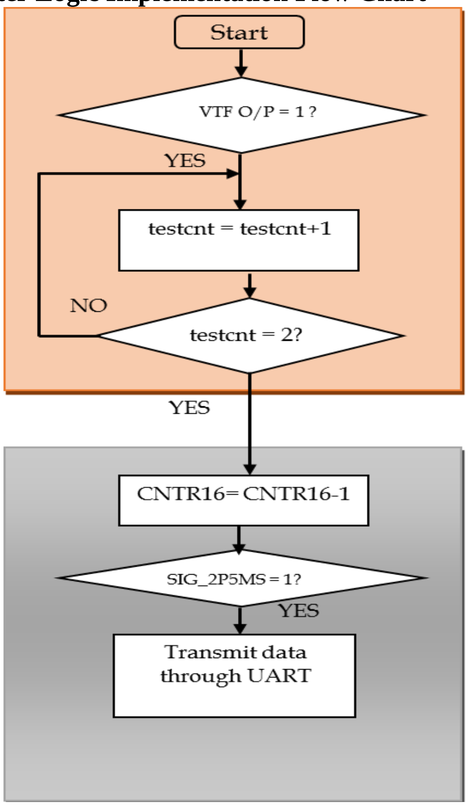

Fig 7. Flow Chart For counter logic.

E. Flowchart for ADC Parallel Data

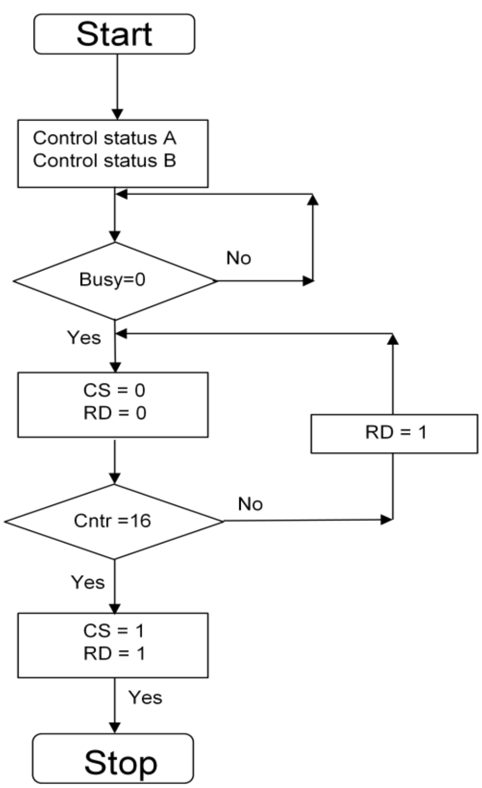

Fig 8. Flowchart for ADC Parallel Data.

VI. RESULT

XILINX ISE 14.2: Xilinx ISE (Integrated Synthesis Environment) is a software tool produced by Xilinx for synthesis and analysis of HDL designs, enabling the developer to synthesize ("compile") their designs, perform timing analysis, examine RTL diagrams, simulate a designs reaction to different stimuli and configure the target device with the programmer.

Spartan-6 Product Advantage: Spartan®-6 devices are the most cost-optimized FPGAs, offering industry leading connectivity features such as high logic-to-pin ratios, small form-factor packaging, and a diverse number of supported I/O protocols. Built on 45nm technology, the devices are ideally suited for a range of advanced bridging applications found in automotive infotainment, consumer, and industrial automation

Applications:

- Full-HD Intelligent Digital Signage
- Industrial Networks
- Vehicle Networking and Connectivity

COUNTER LOGIC SIMULATION RESULTS:

The MEMS accelerometer output is an analog form and this output is connected to VTF for digitization. The VTF output is PWM format and these PWM signals are sampled at 491.52 KHz to avoid spurious signals. The generation 491.52 KHz sampling frequency using shift down counters from 14.7456MHz clock as shown in the figure.

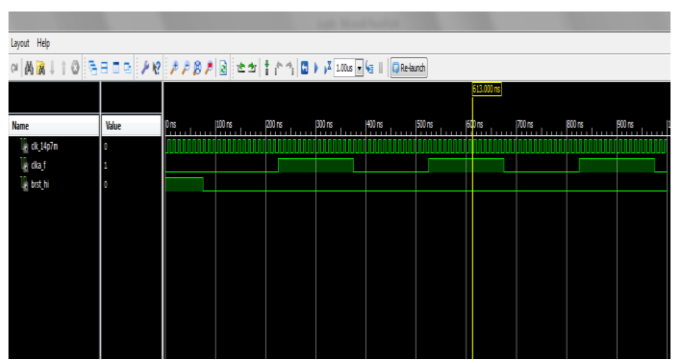

Fig 9. Sampling clock generation.

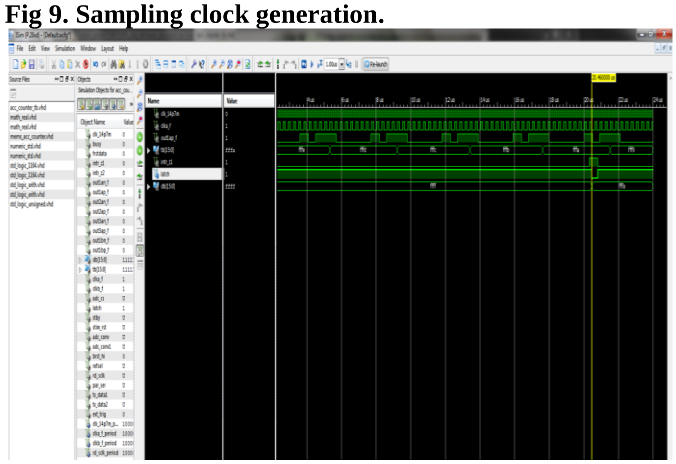

Fig 10. Latch signal generation and data Latching.

MEMS ADC Simulation Results

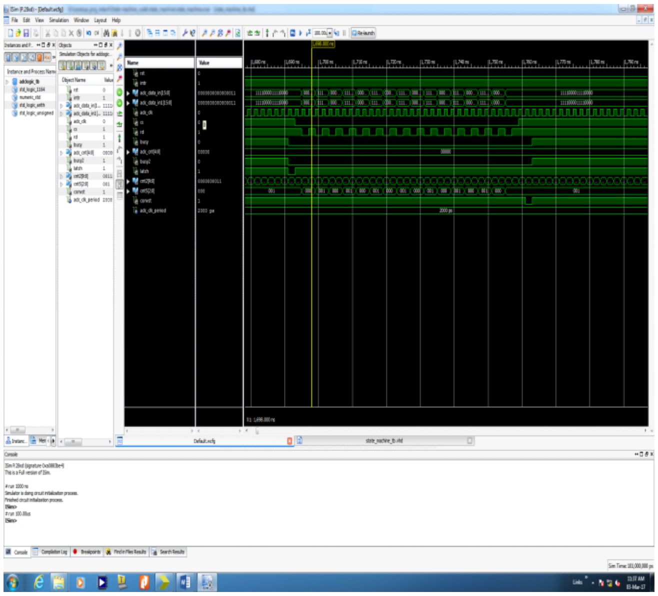

Fig 11. Generated ADC Data Count Pulses

VII. CONCLUSION

The Integrated INS and OBC Package is designed for good accelerometer performance with MEMS sensor including temperature sensor. 3-channel VTF and 8-channel ADC chips are incorporated for MEMS sensor data. The counter logics developed using VHDL for MEMS sensors data acquisition in FPGA, these logics are simulated and tested. The MicroBlaze soft-core processor is embedded into FPGA using EDK tool. This processor read the data from FPGA through AXI interface. The ADC code is developed using VHDL for MEMS temperature data acquisition in FPGA, these logics are simulated and tested. The counters data and temperature data from the FPGA are transmitted to the Navigation Processor system at RS-422 level through UART.

VIII. REFERENCES

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N. Lavanya received her Bachelor's degree in 2010 in Electronics and Communication Engineering from Swami Ramananda Tirtha Institute of Science And Technology, India which is affiliated with Jawaharlal Nehru Technological University, Hyderabad, India. Her areas of interest include VLSI Systems, Embedded Systems. Currently, she is pursuing her M.Tech in VLSI SYSTEM DESIGN from Teegala Krishna Reddy Engineering College.

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