PnP MEMS IMU

An Enabling Technology for Small Satellites

SSC09-VI-2

Presented at:
Utah State Small Satellite Conference
August 11, 2009

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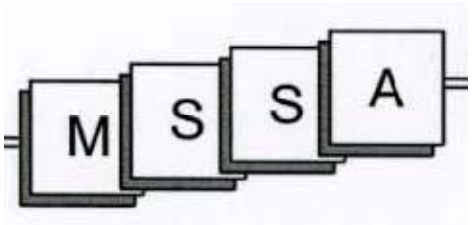

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Presentation Overview

- Why PnP MEMS IMU is an enabling device for small satellites
- MEMS IMU Overview
- Requirements for the MEMS IMU
- MEMS IMU Instrument Development
- Analog Drive / Read Electronics Development
- Digital Drive / Read Electronics Development
- Creating a Plug-and-Play (PnP) component
- Conclusions

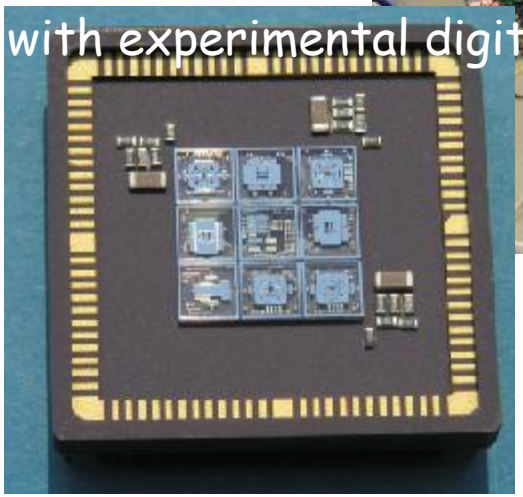
Small Satellite Enabling Devices

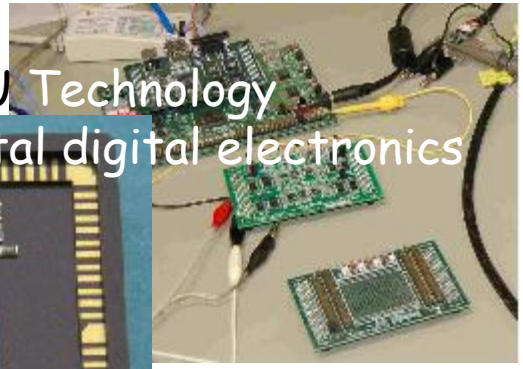
- Rapid Response Space
  - Change the paradigm of spacecraft development
  - No longer large, lengthy, and costly activities
  - Focus on quick turn-around, focused on near-term mission needs and 6-day spacecraft development
- Standardized PnP protocols and implementations
  - Allows for industry acceptance
  - A new way of doing business
- Micro-Electro-Mechanical System (MEMS) technologies
  - Developed and exploited by uninhabited aerial vehicles (UAVs)
  - Pushing into CubeSats and NanoSats
- The integration of the PnP capability with the MEMS technologies
  - Implementation at lower costs
  - Designed for use in the space environment
  - Move the spacecraft component industry toward supporting the next generation of small, highly capable satellites

MEMS IMU Overview

- Development program has had two aspects – near-term flight unit and high performance MEMS IMU for future use in space
- Overall focus on creating an integrated MEMS IMU
  - Using a MilliSensor Systems and Actuators, Inc. (MSSA) MEMS IMU on-a-chip, being developed under contract to the Air Force
  - Adding custom drive/read digital electronics
  - Add value added processing such as smoothing, filtering, and GPS aiding

New MEMs IMU Technology with experimental digital electronics





COTS MEMs IMU Technology packaged and augmented for space flight

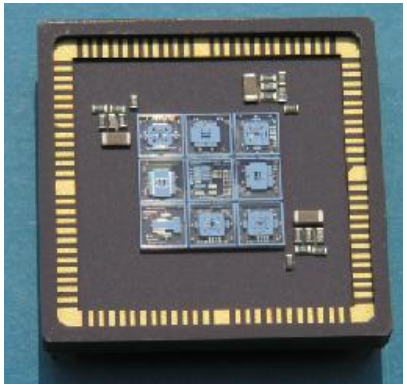
PnP MEMS IMU Requirements

- Performance
  - Angle Random Walk → 0.1 deg/sqrt(hr)
  - Bias Stability → 1-10 dph
  - Scale Factor → 8 mV/dps
- Environment
  - Launch vehicle constraints in terms of shock, vibration, and acoustics
  - Orbit constraints drive radiation, magnetic and electrostatic fields
  - Mission dictates out-gassing, contamination, and life-time issues

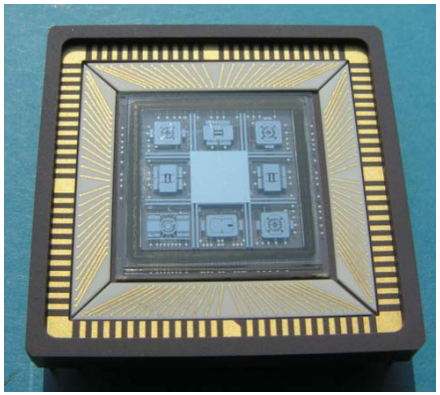
The combination of low cost, low mass, low power, and high performance expected from the PnP MEMS IMU is enabling technology for accurate pointing knowledge and control for the next generation of small satellites

MEMS IMU Instrument

- **IMU Chip** – the Chip contains all of the inertial instruments: 3 gyros and 6 accelerometers, providing 6 degrees of freedom on a planar form factor
- **Test Package** – the Test Package contains the Chip, mounted inside the vacuum-sealed package and 'wire bonded' to the output pins
- **Preamplifier Board** – the Test Package is attached via pins to the Preamplifier Board which are separate for the gyro and for the accelerometer

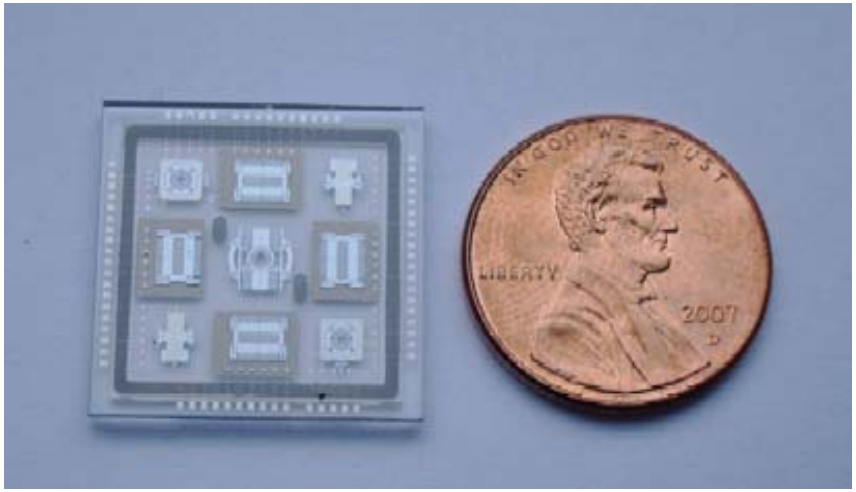


These are all being created by MSSA and provided to Microcosm for integration with electronics elements



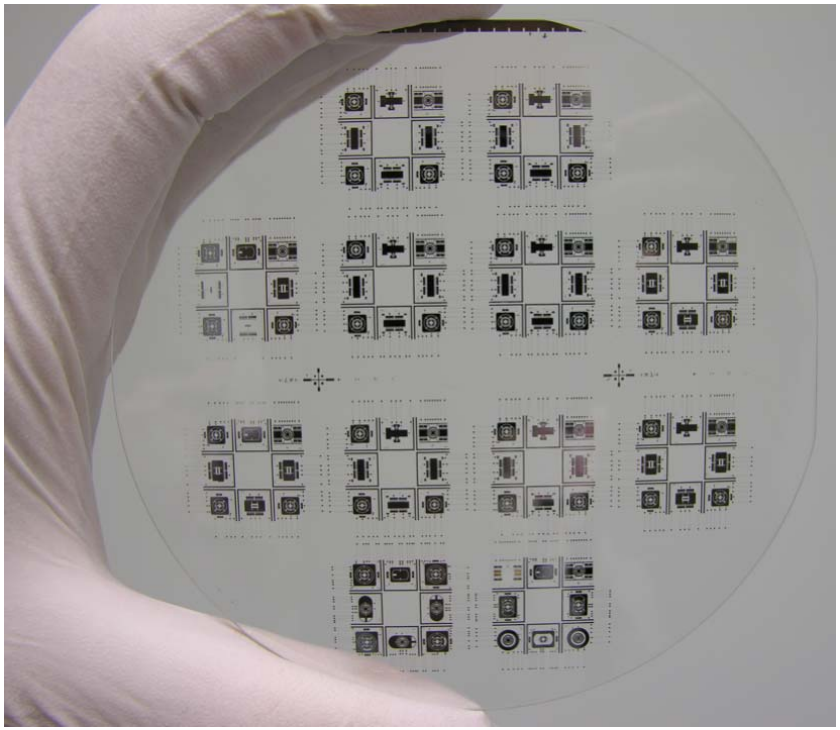
MEMS IMU Performance

- Each instrument measures a single degree of freedom
- Low cross-axis sensitivity of the gyros and accelerometers has been demonstrated
  - 100 deg/hr gyro bias stability
  - 0.5 mG accelerometer performance
  - Shock survival at the die level is 10Kg
- Added efficiency from single chip using common materials, with the same processes
  - Inherently common mechanical, thermal, and electrical characteristics
  - Instrument sensitivities are highly correlated



MSSA MEMS IMU Sensor chip with 6-degrees of freedom based on 3 gyros and 6 accelerometers in a small, planar form factor

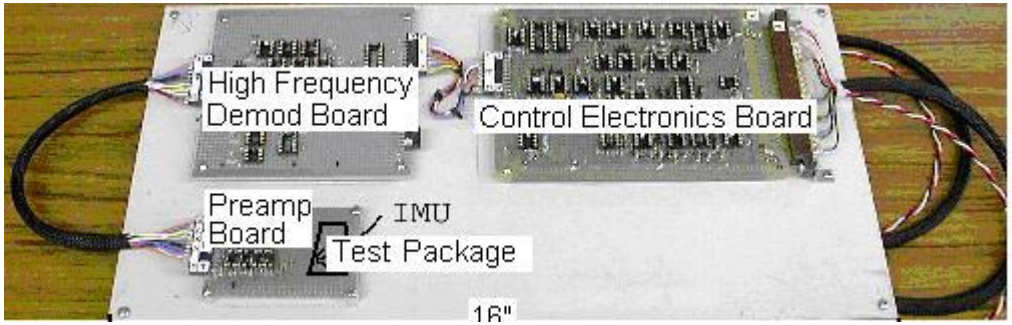
Instrument Fabricated Wafer



Enhanced instrument design increased yield while providing consistent, repeatable, quality

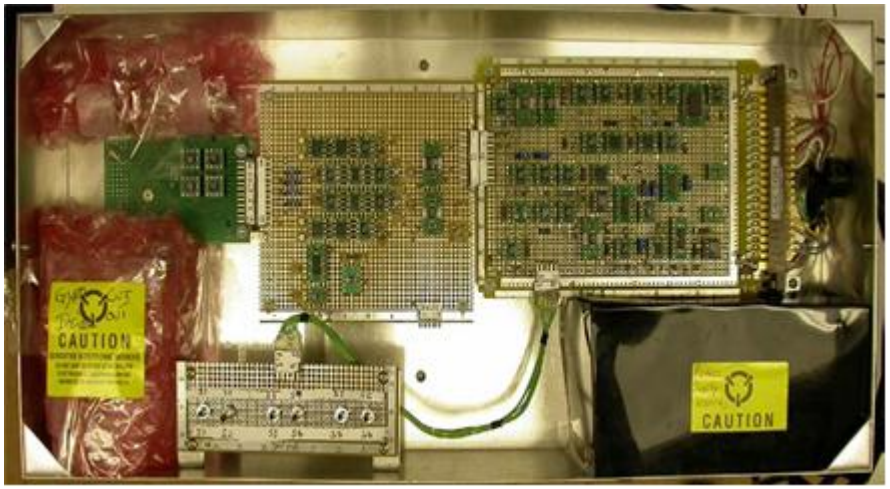
- Initial problems in yield resulted in a larger, thicker design
  - 3mm and 40 microns thickness
  - Consistent, repeatable quality
- At least 12 dies from each 4 inch square wafer providing sensing in 6-degress of freedom

Analog Electronics Components

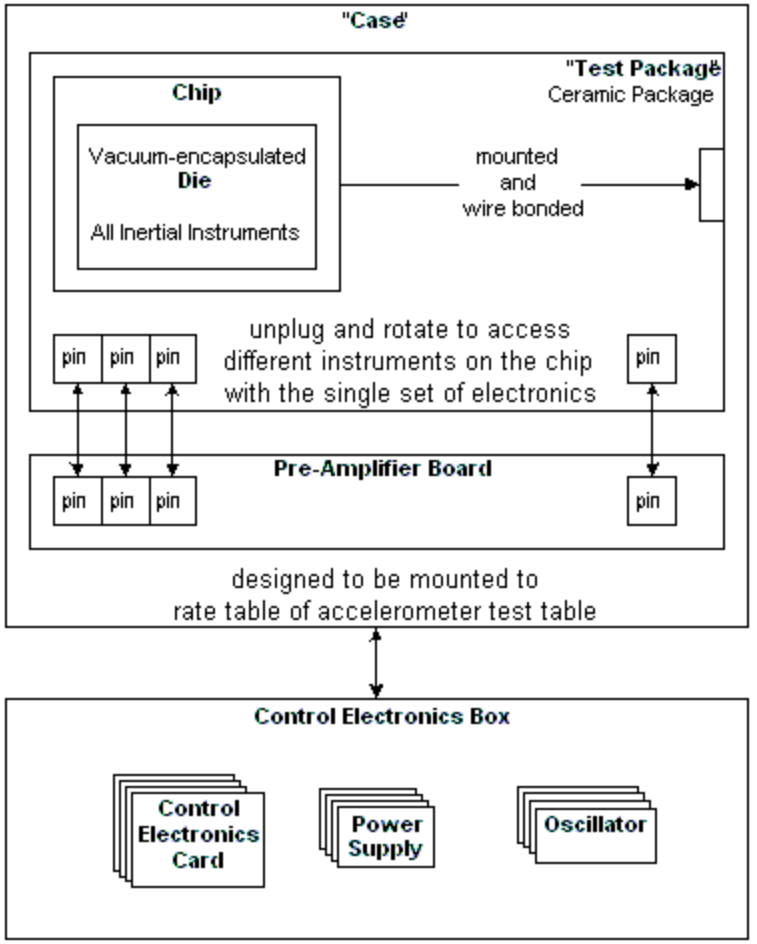


Prototype Board for Gyro Analog Electronics

16” long and 8” wide



IMU Package Block Diagram



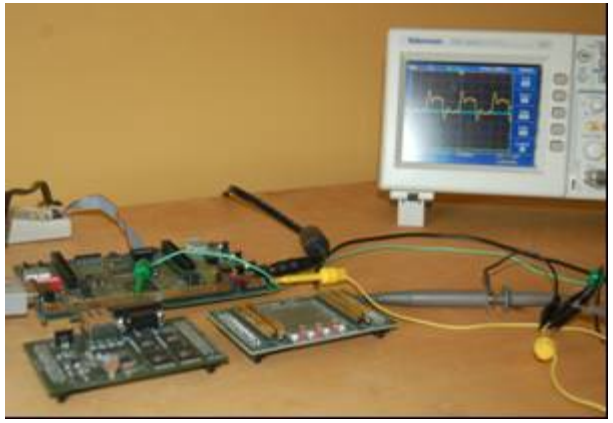
Digital Electronics Risk Reduction

- Incremental replacement of key functional elements within analog electronics based on vendor development kits and tools
  - Optimize the prototyping process
  - Tune and tailor parts for specific IMU implementation
  - Path-finding for new, innovative concepts such as sigma/delta modulation
- Quantifying improvement in instrument attributable to noise reduction from lower frequency excitation
- Identifying COTS IP for use in digital implementation
  - Will replace over 80% of current analog functions, outside the pre-amplifier
  - COTS IP is available for nearly 60% and others are being custom developed

Digital Electronics Components

- **Outer Member (OM) Signal Generator (OMSG)** – the OM is excited and maintained using a high frequency Phase Lock Loop (PLL)
  - Gyro drive member is excited at 1mHz while the read function executes at 0.5 MHz
  - Accelerometer excitation frequency is lower (100kHz) and sigma/delta modulation techniques are being evaluated to reduce complexity
- **Inner Member (IM) Signal Generator (IMSG) –** the IM contains the actual measurement devices that are excited at known frequencies, then sampled and filtered to ascertain motion about the specific axis represented by the specific IM
- **High Frequency Demodulation Board and Control Electronics Board** – separate boards are used for each function with separate boards for the gyro and for the accelerometer functions
- **Xilinx VRTX 2/4 Board --** integrates signal processing, demodulation, sampling and filtering, control electronics and value added implementation that creates quaternions from orthogonal axes rate measurements

Digital Electronics created by HRP Systems for integration with MSSA MEMS IMU Instrument and Pre-Amplifier

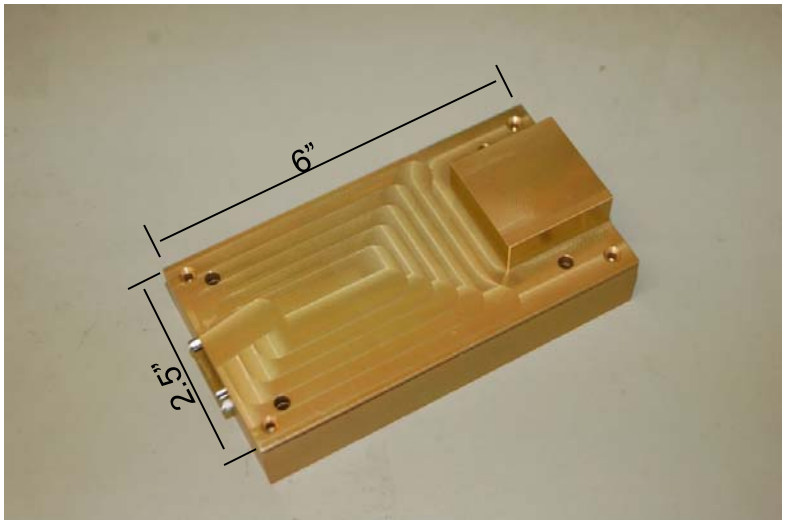


Digital Electronics Board

- Based on prototyping and path-finding effort, an 8 layer digital electronics board has been designed
  - I/O pins for 3 gyro devices
  - I/O pins for 3 accelerometer devices
  - I/O pins for sigma/delta modulation that will be integrated with the 3 "redundant" accelerometer devices
- Integrates FX12 OEM board as "daughter" board to provide the VRTX4 functional element
  - Provides mechanism for rapid prototyping
  - Create quiet board with limited complexity
  - Evaluate quantity and type of value added software to be accommodated

Creating a PnP IRU

- Based on Analog Devices ADIS-16355 with provides 3- axis gyro and 3-axis accelerometer information
- Value added software includes smoothing filter and reduction of 100Hz data to 10 Hz output
- Added gen1 ASIM (Data General) for interface with SPA-S (spacewire) on PnPSat and packaging (SpaceWorks)
- Installed and tested on PnPSat-1 demonstrating PnP concepts
- 80% of this effort is directly applicable to PnP MEMS IMU



Conclusions

- This R&D effort has demonstrated key risk reduction elements
  - High yield, quality IMU instrument dies have been created
  - An first revision digital electronics board has been designed and fabricated
  - Integration and test of electronics with IMU instrument requires additional funding
- Desk–top demonstration unit is in work
  - Demonstrate to potential customers unique characteristics of the MSSA IMU chip
  - Highlight flexibility of programmable digital electronics
- Protoflight PnP MEMS IMU can be achieved in near term with adequate funding and potential flight opportunity

This PnP MEMS IMU represents a new generation of spacecraft components that is designed from the outset with small, rapid response spacecraft as the target market