Precise Positioning Enabled by ST IMU and GNSS Receiver

Stuart Ferguson
Automotive MEMS and Sensors
STMicroelectronics

Mike Horton
CTO
Aceinna

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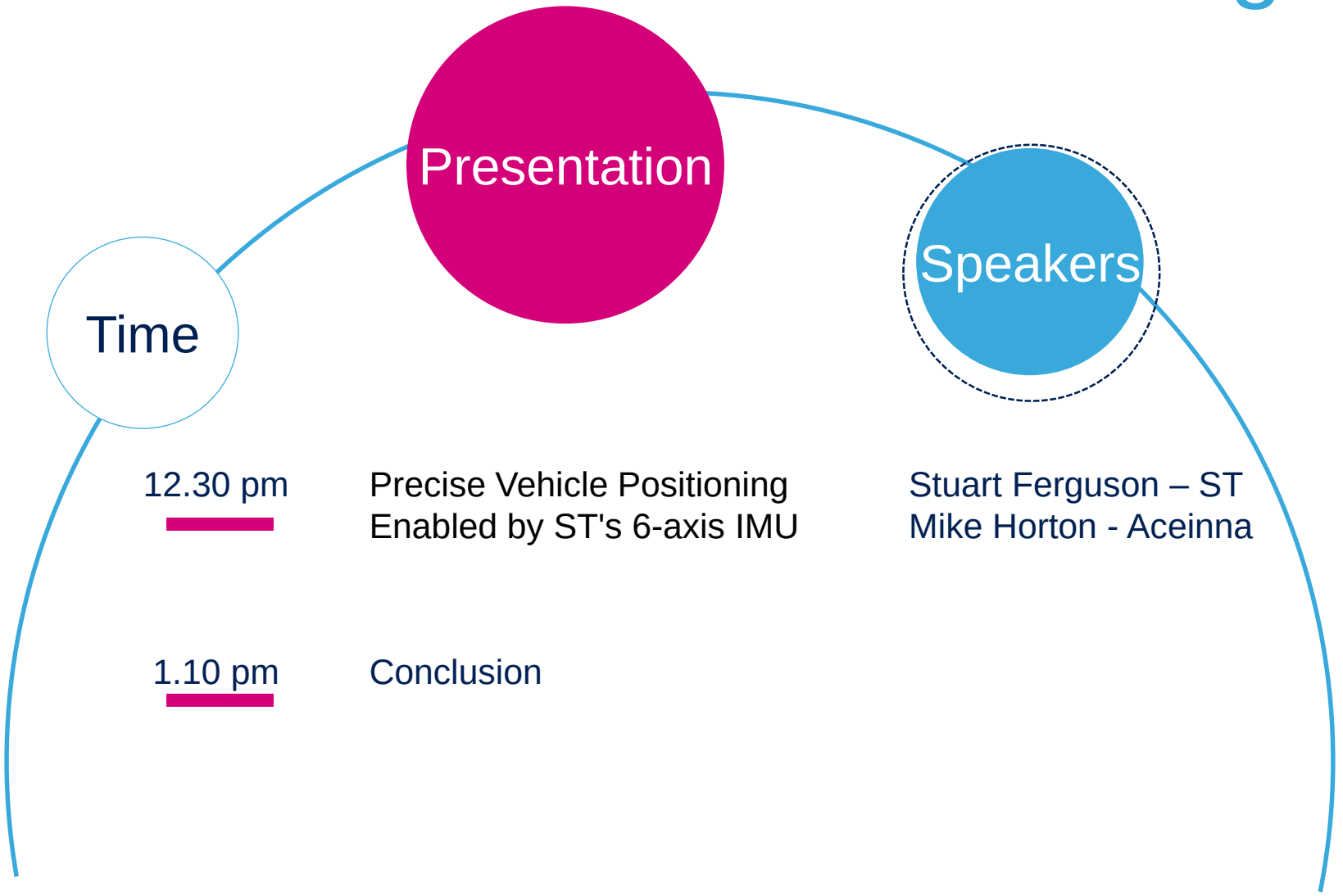
ST Developers Conference
September 12th, 2019
Santa Clara Convention Center - Mission City Ballroom
Santa Clara, CA

Agenda


Presentation
Time
Speakers
12.30 pm
Precise Vehicle Positioning
Enabled by ST's 6-axis IMU
Stuart Ferguson – ST
Mike Horton - Aceinna
1.10 pm
Conclusion

Topics

- STMicroelectronics (Stuart Ferguson)
  - MEMS and Sensors Portfolio
  - Introducing: New, High Accuracy IMU ASM330LHH
  - Teseo GNSS Evolution: ST Positioning Roadmap
- Aceinna (Mike Horton)
  - Intro to Aceinna
  - Building on the ASM330LHH to create High Performance Modules
  - OpenRTK330 INERTIAL NAVIGATION SYSTEM

20 Years of MEMS at ST

Accelerometer

Inertial module

Pressure sensor

Micro-mirror actuators

Piezo actuators

Water Proof Pressure sensor

Fluidic Micro-actuators

Gyroscope

Magnetometer

Microphone

Humidity sensor

GAS & VOC

2000 2005 2010 2015 2017 2018

Smart Things

Smart Home & City

Smart Industry

Smart Driving

ST Addresses Four End Markets

Automotive	Industrial	Personal Electronics	Communications Equipment, Computers & Peripherals

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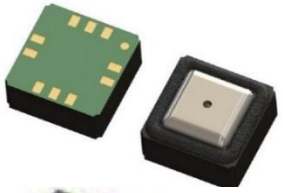
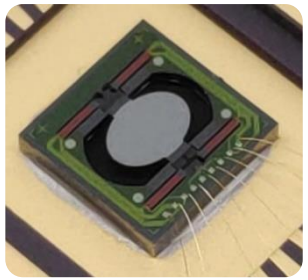
50% Market Share in Motion MEMS in Personal Electronics & Automotive Telematics

MEMS Sensors & Actuators
Technology and Products





Next Generation ThELMA*

- Higher accuracy
- Ultra-low power
- Embedded Machine Learning Core

→ Motion sensors for Personal Electronics, Automotive & Industrial

Next Generation BASTILLE*

- Higher accuracy
- Size reduction
- Waterproofing

→ Environmental sensors for Personal Electronics & Industrial

Thin Film Piezoelectric PεTRA*

- Innovative piezoelectric materials
- Higher efficiency
- Lower cost

→ Microactuators for Ink Jet printing, Speakers & Infrared Scanners

*ST proprietary MEMS technologies

Source: IHS Markit

Ten Years Continuous Advances in Sensors

3x3x1mm LGA

+

4x4x1mm

	2009		2019
Current Consumption	6.1 mA	→	0.55 mA
			91% Power Reduction
Accel Noise	220 µg/√Hz	→	60 µg/√Hz
			73% Accel. Noise Reduction
Gyro Offset vs. temp	±0.03 dps/℃	→	±0.005 dps/℃
			83% Temp. Stab Improvement
Gyro Noise	30 mdps/√Hz	→	4 mdps/√Hz
			87% Gyro Noise Reduction
Size	25mm^2	→	7.5mm^2
			70% Size Reduction
Dynamic Full-scale	Up to ± 2000dps	→	Up to ± 4000dps
			100% Full-scale Range Incr.
Programmability	None	→	Pedo., FSM ,MLP
			Embedded FSM and ML Core
Cost		→	
			70% Cost Reduction

2.5x3x0.86mm

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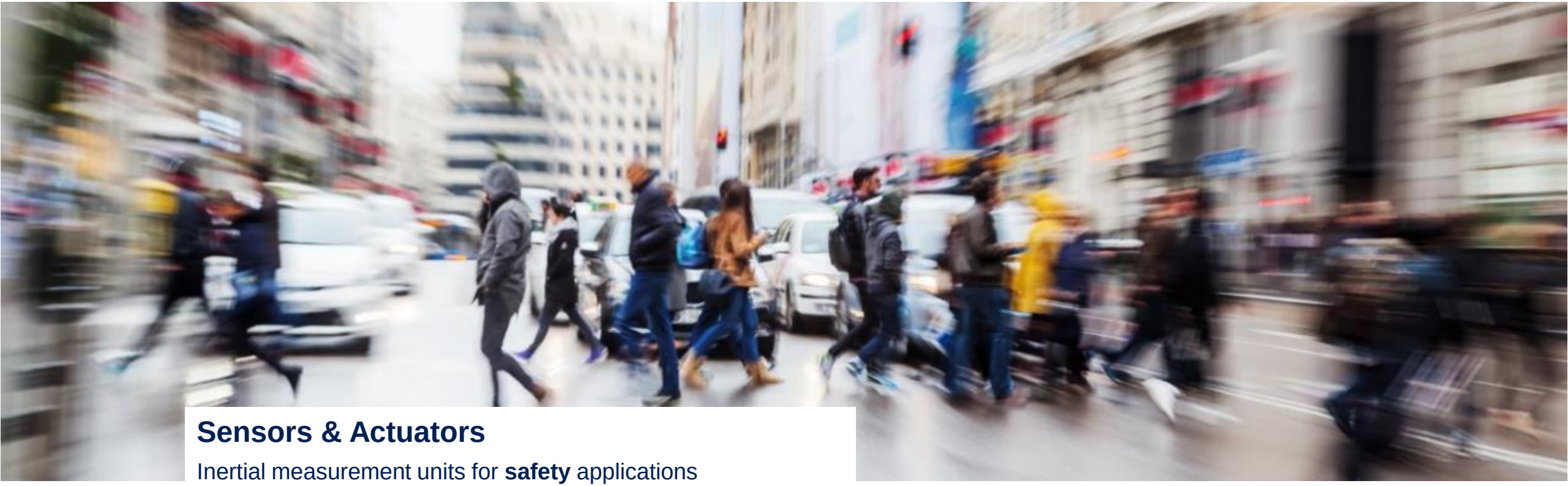
Smart Driving

Making driving safer, greener and more connected



Sensors & Actuators

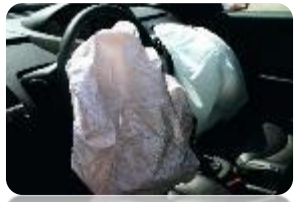
Inertial measurement units for **safety** applications

Microphones and accelerometers for **Active Noise Cancellation**

Motion MEMS for **dead reckoning**

Micro-mirrors projection for **LiDAR** and **adaptive headlights**

Sensors for Smart Driving

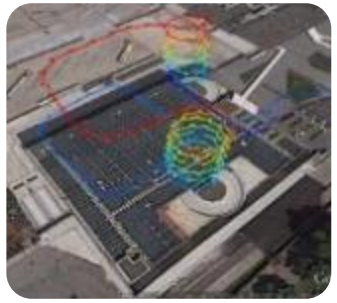
NON-SAFETY Applications	PASSIVE SAFETY Applications	ACTIVE SAFETY Applications	AUTONOMOUS DRIVING
• Navigational assistance • Anti-theft systems • Telematics (eCall, …) • Infotainment	• Airbag peripheral sensors • Airbag on-board sensors	• Vehicle dynamics • Electronic stability • Active suspensions • Hill-start assist • Roll stability control	• ADAS • Assisted / autonomous driving (bring the car to safety in case of emergency)
			
AIS328DQ accelerometer **A3G4250D gyroscope** **AIS3624DQ accelerometer**	**AIS1200PS accelerometer** **AIS1120SX accelerometer** **AIS2120SX accelerometer**	**Under Development (ASIL - ISO26262)**	**Under development (ASIL - ISO26262)**
ASM330LHH 6-axis combo **AIS2DW12 Ultra Low-Power accelerometer** New		**ST Combo family (from 3DOF to 5DOF* sensors)** New	**Highly Automated Driving* (HAD)**

*Under development

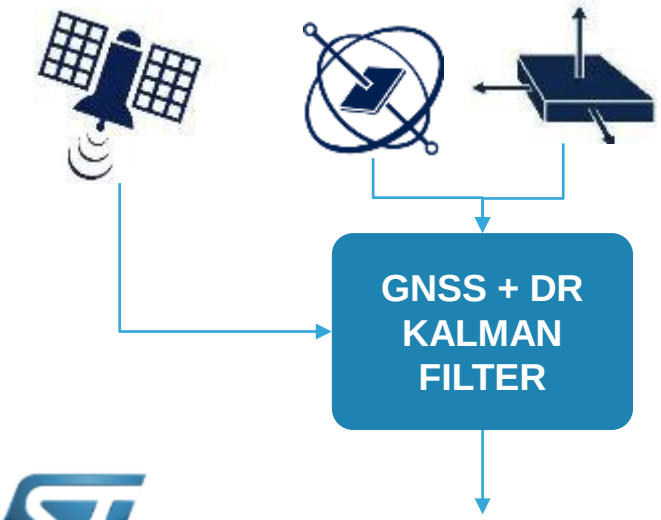
Smart Driving

Focus Applications

Navigation



6DOF IMU: GNSS assistant for Inertial Navigation System



Precise Positioning

TBOX

On Board Diagnostic

Driving Style

Insurance Boxes

Shock detection

Anti-theft

Inclination

eCall

Voice

PKE

Low power Accelerometer for Passive Key entry

Accelerometer

User Interaction
Detect walking type

Battery saving
Detect no move

SECURITY
Detect no move

ASM330LHH High Accuracy IMU

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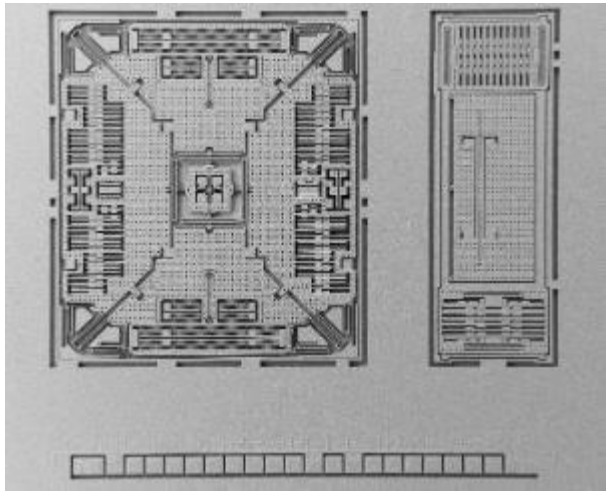
Motion Sensors

Fully Vertically Integrated

Motion MEMS - Three key elements

Micron-sized **Transducer** using specific Micro-Machining process



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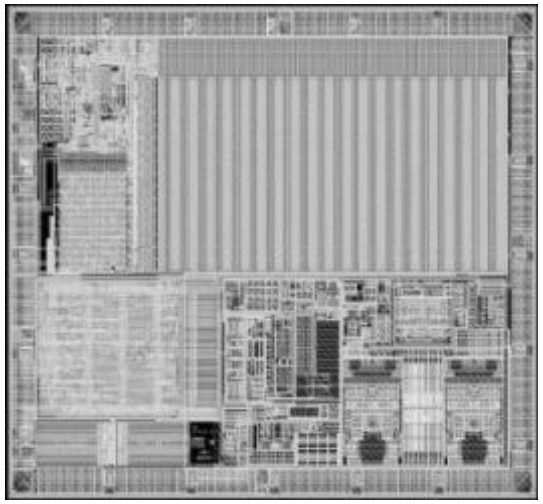
Dedicated **ASIC** with embedded smart functionality



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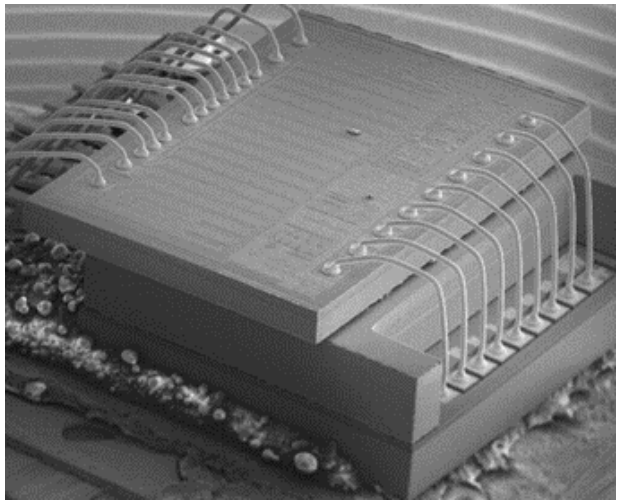
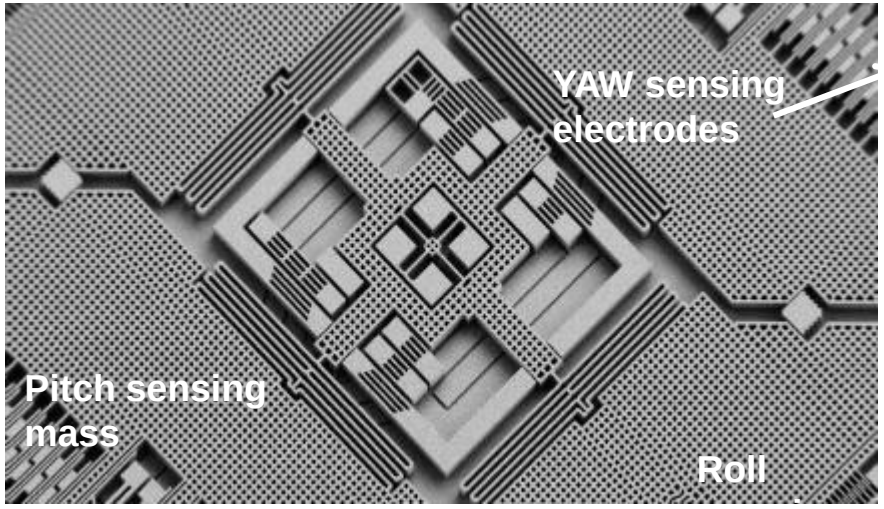
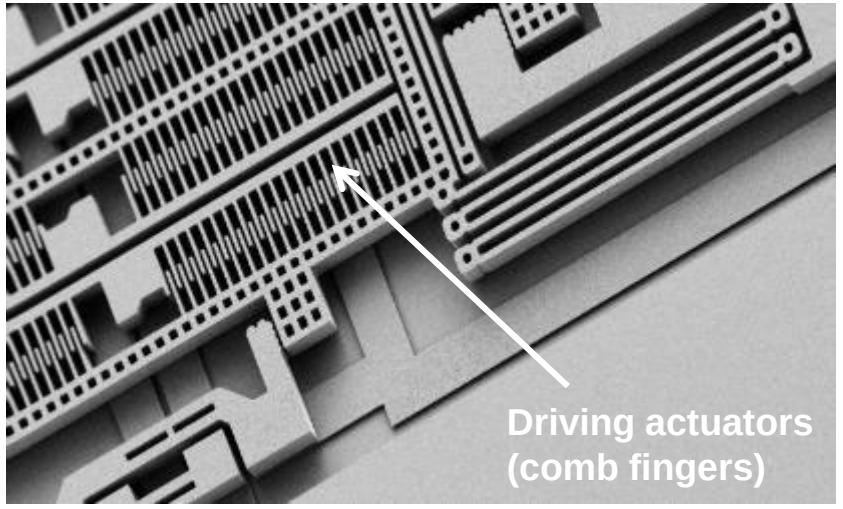
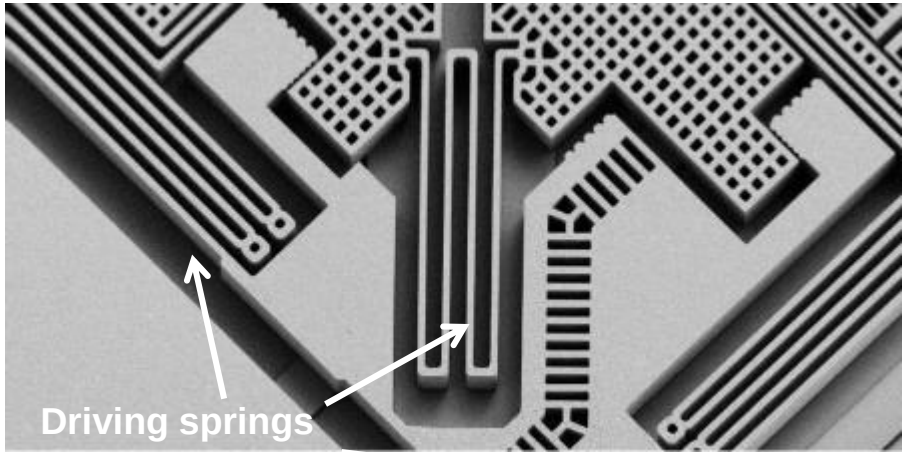
Dedicated **Package** and **Calibration** features

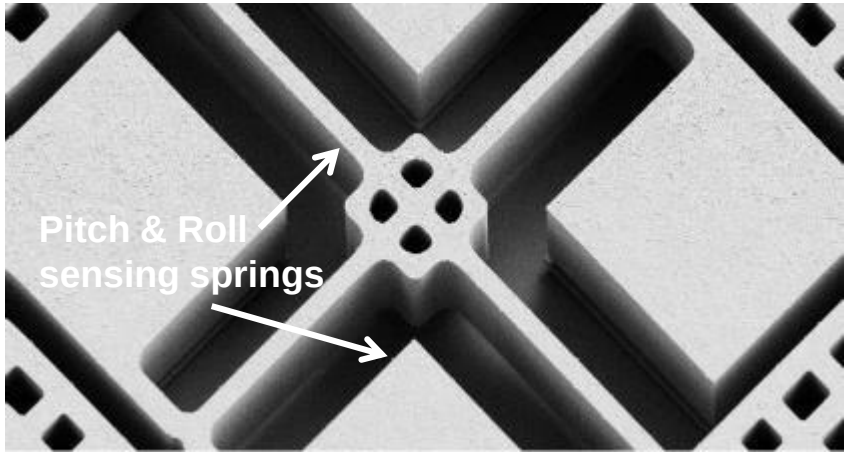


Gyroscope
Reference Images









ASM330LHH for Accurate Navigation

Temperature Features

Extended Temp. Range: up to **+105°C**

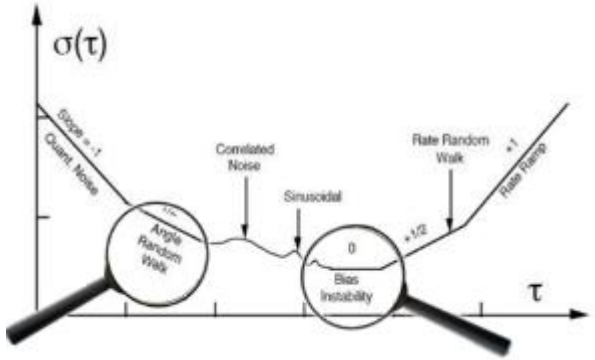
High Resolution: **256 LSB/°C**

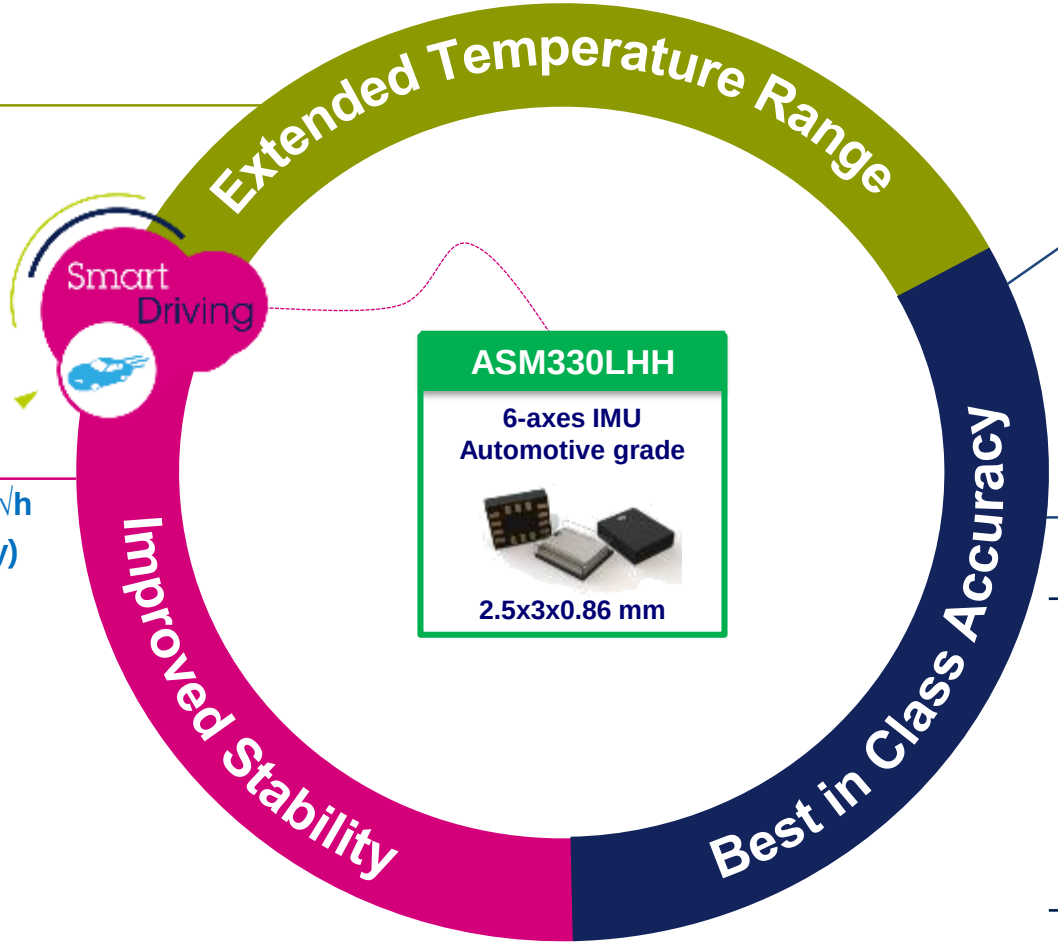
Stability Features

Typ. Angular Random Walk (ARW): **0.21 deg/√h**

Typ. Bias Instability (BI): **3°/hr (High accuracy)**

Stability: **Over time & Temperature**





Accurate Navigation

Accuracy 1st

#axes	6 (3 XL + 3 GYR)
Accelerometer range	2/4/8/16 g
Gyroscope range	125 dps to 4000 dps
Accelerometer noise density	60 ug/√Hz
Gyroscope noise density	5 mdps/√Hz

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New: Advantages of ASM330LHH

- **Qualification:**
  - AEC-Q100 Grade 2
    - Operation from -40ºC to +105ºC

- **FE Golden Flow:**
  - Dedicated defectiveness control plan & specific parametric test associated to reliability performance
  - EWS Test based on Automotive standards including temp test
  - Final Test to guarantee automotive DPPM level:
    - Temperature verification **at extremes of operation**
    - Extended Quality Control
    - Reliability monitoring on assembly lot basis

- **Continuity and stability of supply**

AEC - Q100 - REV-H
September 11, 2014

Automotive Electronics Council
Component Technical Committee

In addition, not shown in the flow charts, the expected end of life failure rate may be an important
criterion. Regarding failure rates, the following points should be considered:
 No fails in 231 devices (77 devices from 3 lots) are applied as pass criteria for the major
environmental stress tests. This represents an LTPD (Lot Tolerance Percent Defective) = 1, meaning a maximum of 1% failures at 90% confidence level.
 This sample size is sufficient to identify intrinsic design, construction, and/or material
issues affecting performance.
 This sample size is NOT sufficient or intended for process control or PPM evaluation.
Manufacturing variation failures (low ppm issues) are achieved through proper process
controls and/or screens such as described in AEC-Q001 and AEC-Q002.
 Three lots are used as a minimal assurance of some process variation between lots. A monitoring process has to be installed to keep process variations under control.
 Sample sizes are limited by part and test facility costs, qualification test duration and limitations in batch size per test.

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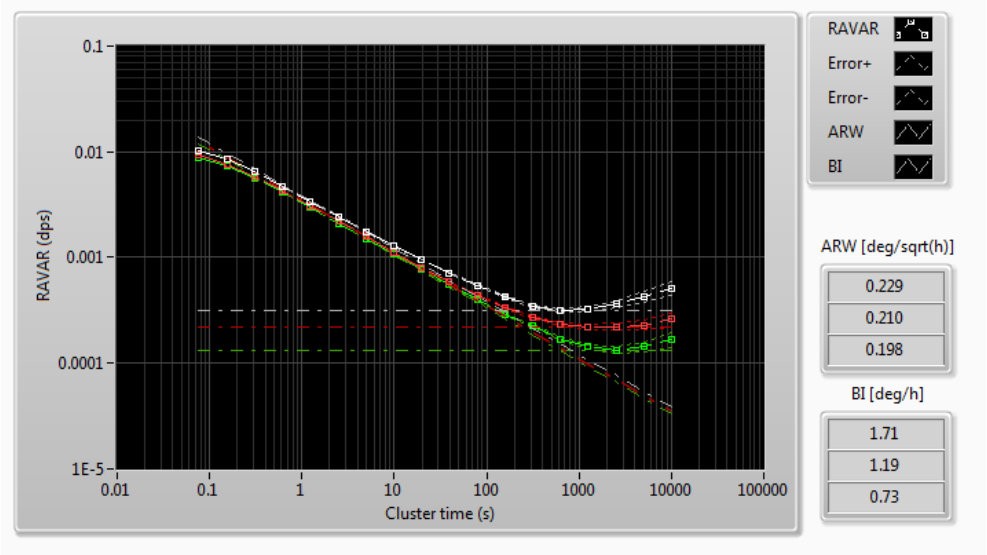
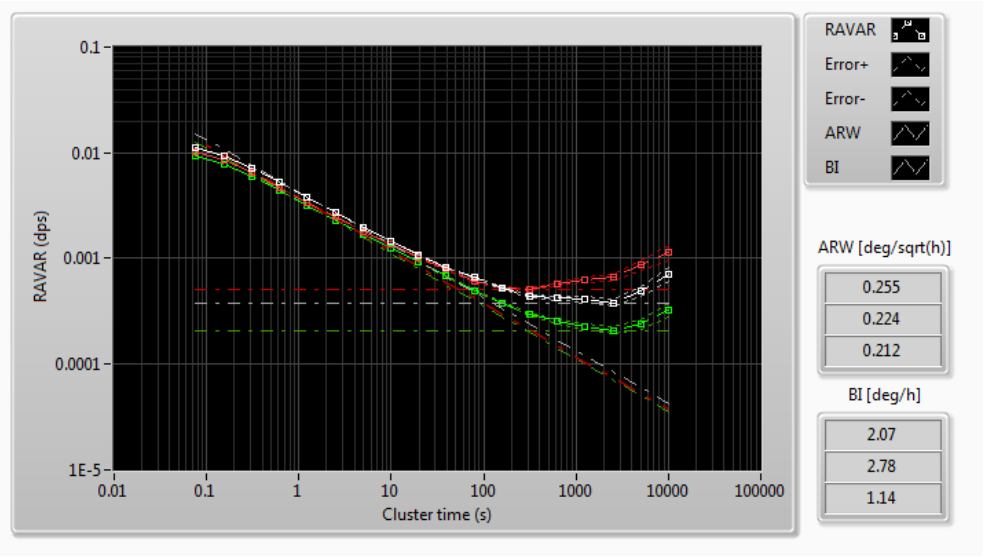
ASM330LHH AVAR

Key Parameters for Navigation



Addressing the most demanding applications



ARW	Angular random walk	T = 25 °C		0.21		deg/√h
BI	Bias instability(7)	T = 25 °C		3		deg/h

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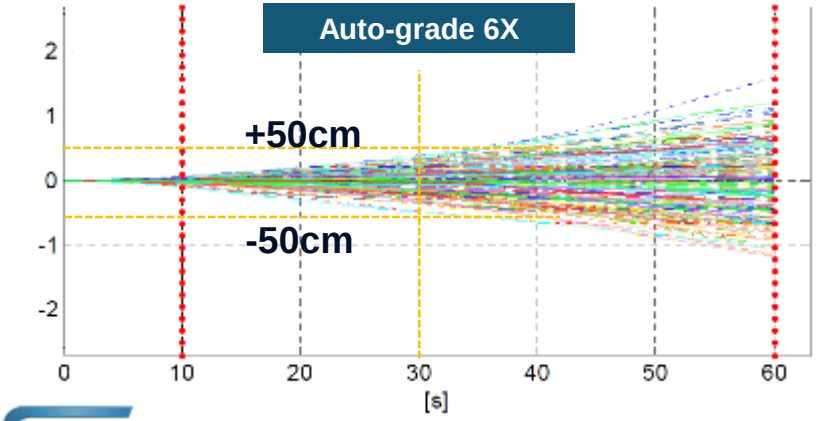
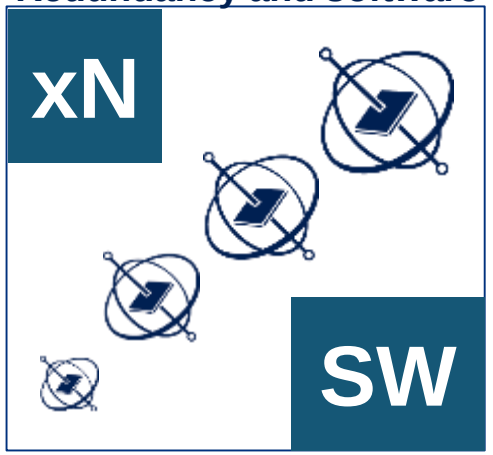
Vehicle Positioning Accuracy



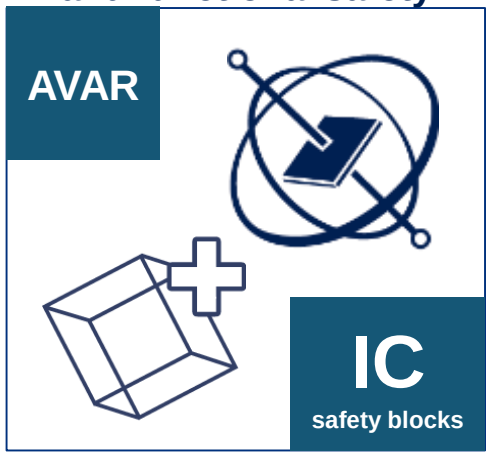
Paths

L0→L3

IMU modules
Redundancy and software



Advanced specification and functional safety



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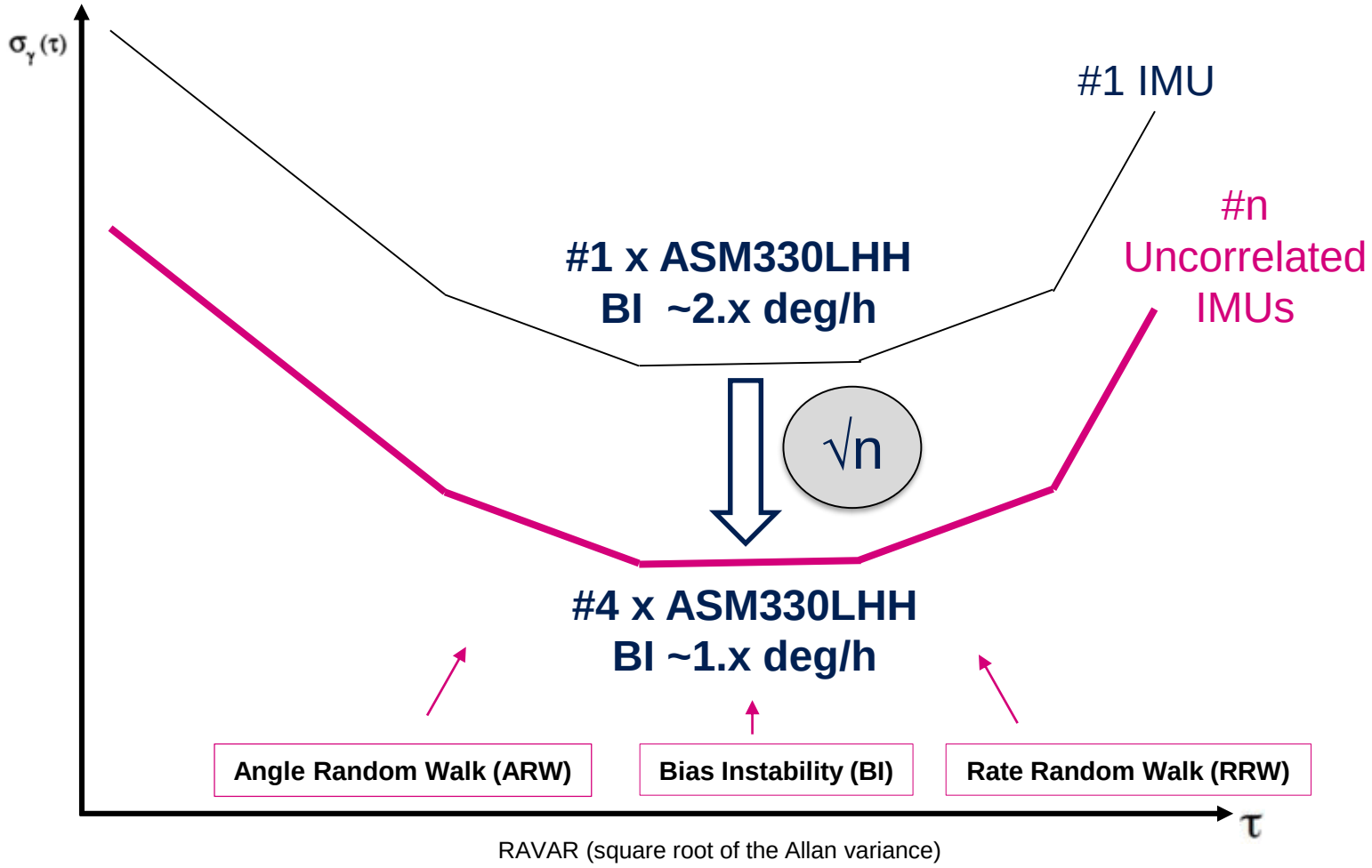
ADAS: Advanced Driver Assistance System
ASIL: Automotive Safety Integrity Level

Using Multiple IMUs to Increase Accuracy



RAVAR (square root of the Allan variance)

Variance

$$\mathrm{Var}(z) = E[z^2] = \sigma^2$$

Averaged Variance

$$\mathrm{Var}\left(\frac{1}{n}\sum_{i=1}^{n} z_i\right) = \frac{1}{n^2}\mathrm{Var}\left(\sum_{i=1}^{n} z_i\right) = \frac{1}{n^2}\sum_{i=1}^{n}\mathrm{Var}\,(z_i)$$

…since noise variance is constant

$$\mathrm{Var}(N_{\mathrm{avg}}) = \mathrm{Var}\left(\frac{1}{n}\sum_{i=1}^{n} z_i\right) = \frac{1}{n^2}n\sigma^2 = \frac{1}{n}\sigma^2$$

Stdev

$$\boldsymbol{Stdev(N_{avg}) = \frac{\sigma}{\sqrt{n}}}$$

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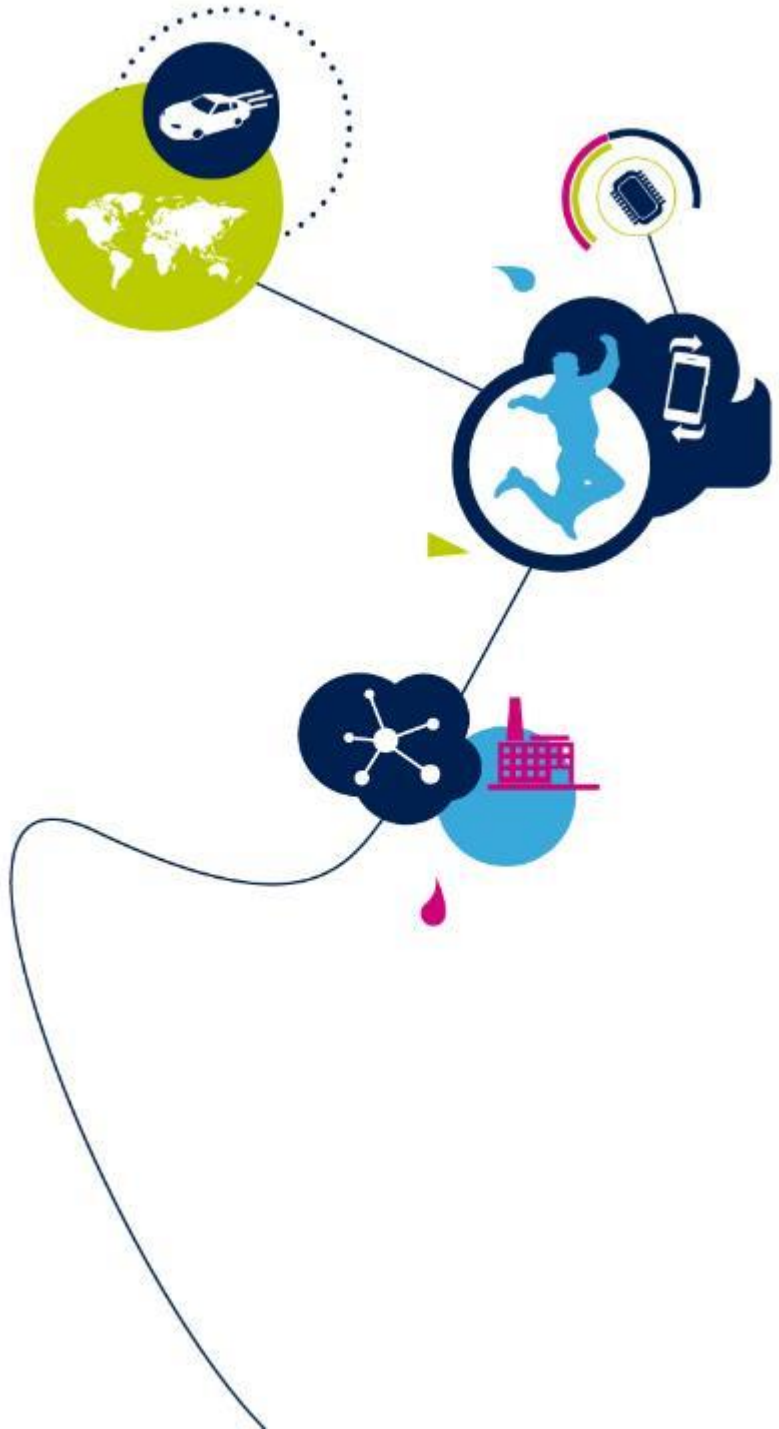
Teseo GNSS Solution & Roadmap



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ST Positioning Roadmap

Software					
TESEO GNSS	BeiDou		IRNSS	L2	L5
TESEO-DR	3D DRAW		2D Teseo UP		TC-IMU
TESEO-PPP	L1 Carrier Phase			RTK	RTPPP

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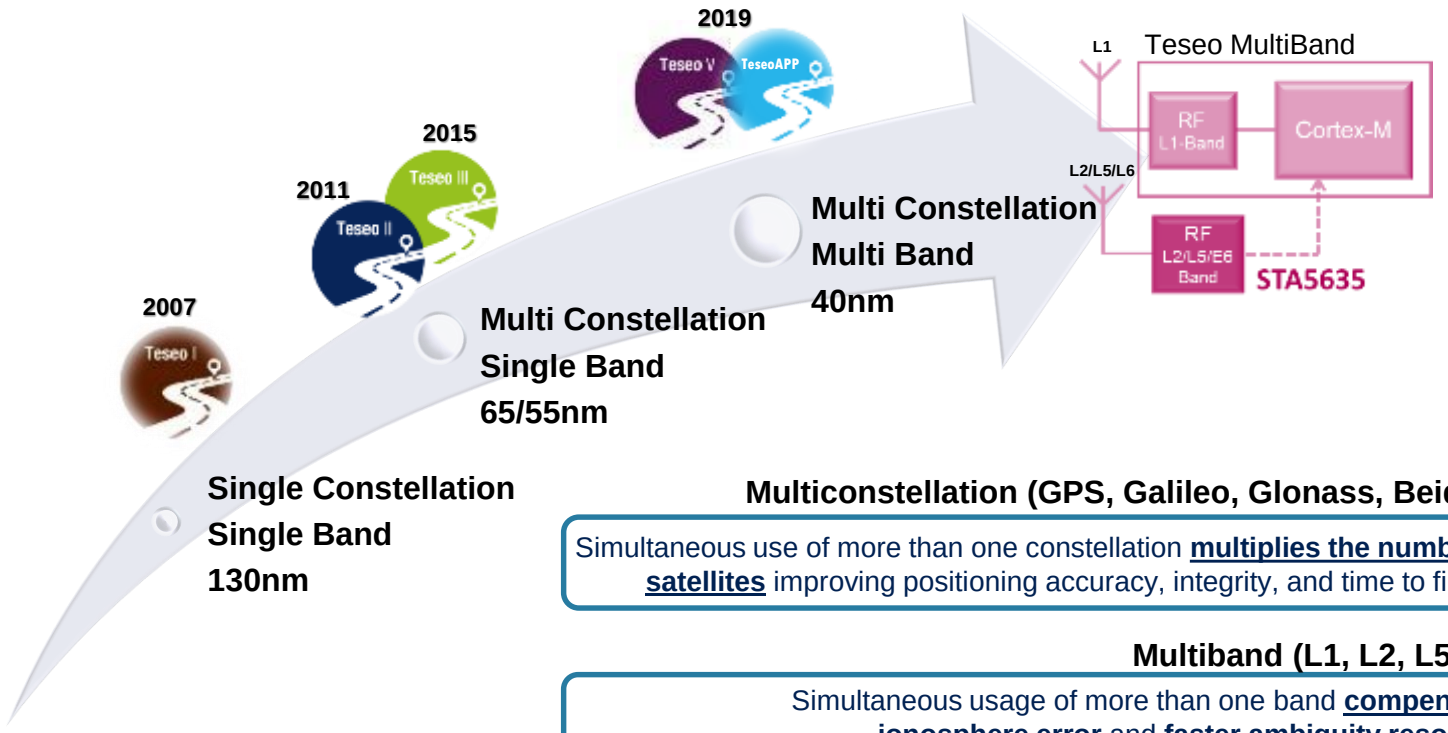
Teseo Evolution

Towards reliable precise positioning



Multiconstellation (GPS, Galileo, Glonass, Beidou,)

Simultaneous use of more than one constellation **multiplies the number of satellites** improving positioning accuracy, integrity, and time to first fix

Multiband (L1, L2, L5, E6)

Simultaneous usage of more than one band **compensates ionosphere error** and **faster ambiguity resolution**

- **Teseol II III Mass Production:**
  - **100% first cut functional silicon**
  - **TeseoV designed with same LPRFCMOS technology and libraries**

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ACEINNA
POWERFUL SENSING SOLUTIONS

Precise Navigation Made Easy

Simple, Safe, Reliable

Mike Horton, CTO

ACEINNA Corporate Overview

- Company Profile:
  - Founded 1999 (MEMSIC, Inc), HQ in Andover MA
  - First pure MEMS IPO (2007)
  - Formation of ACEINNA Inc (2017)
  - R&D Facilities in San Jose CA, Andover MA, and Chicago IL
  - Manufacturing facility in Wuxi, China

- Technology Leadership (Field Proven):
  - Invented and brought to market unique thermal MEMS accelerometers
    - > 30Mu shipped into Automotive ESC and Rollover Applications (Ford, GM, Land Rover, Volvo, Jaguar, Hyundai, Nissan, etc)
  - First to offer MEMS-based FAA-certified AHRS
    - Inertial modules qualified in > 600 different aircraft types
    - Leading Supplier of IMU's to Heavy Equipment Market
  - Shipped 1 billionth sensor in 2016

- Automotive and Inertial Expertise
  - Over 50 man-years of Inertial experience in Aeronautical and US defense industry
  - Over 10 years experience in automotive system development and manufacturing

Quick Summary

- ACEINNA is building out a complete portfolio of Precise Positioning Solutions for the automotive market
  - IMU's – High Precision, Redundancy, Cost Effective
  - RTK/INS– High Accuracy, High Redundancy
  - CloudRTK – Robust correction network

- ACEINNA offers an Innovative and Easy-to-Use Open Navigation Platform to reduce development time and complexity

- Developing for Automotive Market to meet Quality and Reliability requirements

ISO 26262
Road Vehicles - Fuctional Safety

Why Inertial Sensor Fusion?

CAMERA

DEPTH + AMBIGUITY

LIDAR

WEATHER GEOMETRY

RADAR

LOW RES + REFLECTIONS

GPS (RTK) Odometer

URBAN CANYON

HD Maps

OUT OF DATE

IMU Key Benefits:

- No External Dependence or Surface
- No Jamming, Weather Invariant
- Up a few minutes of Gap Coverage during GNSS outages
- **High-Performance & Inexpensive**

2019 Design News Golden Mousetrap Award Winner

ACEINNA's OpenIMU Development Platform is a 2019 Gold Winner for Automation & Motion Control!!

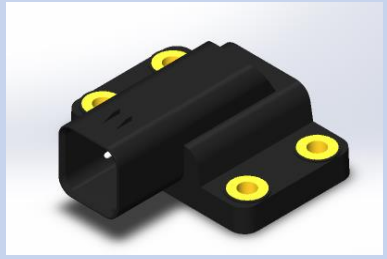
GOLDEN MOUSETRAP AWARDS 2019 GOLD WINNER

- ACEINNA OpenIMU Development Platform
  - OpenIMU enables advanced, easy-to-deploy localization and navigation algorithm solutions for a fraction of the time and cost of traditional methods. OpenIMU's combination of open-source software and low-cost hardware enables rapid development of advanced solutions for drones, robotics, and autonomous applications.
  - https://www.aceinna.com/openimu

ACEINNA POWERFUL SENSING SOLUTIONS

Open Navigation Platform: What is it?

OpenIMU™ Hardware



IMU Module

Embedded Software

+

ACEINNA Navigation Studio™

Simulation
Data Logging
Charting
Mapping
App Marketplace
Community

=

Open Navigation Platform

Major Benefits:

Cutting Edge HW & Algorithms

Minimize Time-to-Market

Reduce NRE and Development Costs

Learn, Grow & Follow a trusted partner

- OpenIMU: www.aceinna.com/openimu
- Navigation Studio: https://developers.aceinna.com

IMU Technology Roadmap

Gen 1
- Bias: 6°/hr (1σ), ARW: 0.3°/√h

Gen 2
- Bias: 2-5°/hr (1σ), ARW: 0.2°/√h
- Open IMU Platform
- Enhanced Synch & Improved Cal

Gen 3
- Bias: 1°/hr (1σ), ARW: 0.1°/√h
- High- Reliability
- High-Precision

BGA Pkg

OpenIMU330BI
- 6-axis, 3x Redundant Arch.
- Open IMU Dev Platform
- SPI/UART Interface

In Production
In Development

AL Case Pkg

IMU381ZA
- 9-axis IMU
- Embedded FW
- SPI/UART Interface

OpenIMU300ZA
- 9-axis IMU
- Open IMU Dev Platform
- SPI/UART Interface

OpenIMU400
- 6-axis, Highly-Redundant
- OpenIMU Dev Platform
- SPI/UART Interface

Rugged Plastic Pkg

MTLT305D
- 6-axis Tilt Sensor
- Embedded FW
- CAN Interface

OpenIMU300RI
- 9-axis IMU Sensor
- OpenIMU Dev Platform
- CAN Interface

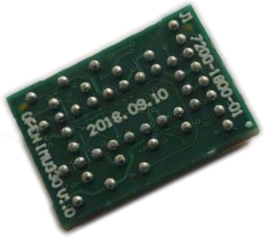
ACEINNA
POWERFUL SENSING SOLUTIONS

OpenIMU330- High Performance and Low Cost

Ready-to Use Algorithms	Outputs		
IMU	Calibrated Accel, Gyro		
VG-AHRS	Dynamic Roll, Pitch Heading		
INS	Position, Velocity, Attitude		
Angular Rate	**MIN**	**TYP[2]**	**MAX**
Range (°/s)	-400		400
Bias Instability (°/hr)[1]		2	
Bias Stability over Temp (°/s)		0.3	
Scale Factor Accuracy (%)		0.01	
Cross-Axis Error (%FSR)		0.02	
Angle Random Walk (°/√hr)[1]		0.2	
Configurable Bandwidth (Hz)	5		50
Acceleration	**MIN**	**TYP[2]**	**MAX**
Range (g)	-8		+8
Bias Instability (µg)[1]		15	
Bias Stability over Temp (mg)		3	
Scale Factor Accuracy (%FSR)		0.03	
Cross-Axis Error (%FSR)		0.03	
VRW (m/s/√hr)[1]		0.05	
Configurable Bandwidth (Hz)	5		50
Electrical	**MIN**	**TYP**	**MAX**
Input Voltage (V)	3.0		5.5
Current Consumption (mA)		20	
Interface	SPI or UART		
Output Data Rate – SPI (Hz)			200
Output Data Rate – UART (Hz)			100

Embedded Version:

- Triple Redundant Sensor Array
  - Better Performance & Better Quality
- Each Sensor has 3-axis Gyro, 3-axis Accel
- OpenIMU Development Platform
- ASIL B



High Performance:

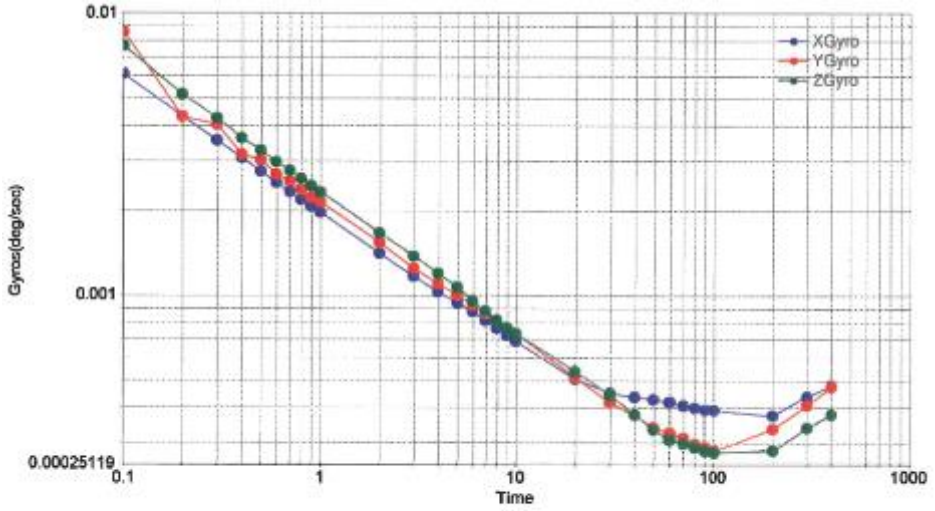
- Bias Instability: 2°/hr & 15µg (gyro/XL)
- ARW/VRW: 0.2°/√hr & 0.03m/s/√hr
- Calibrated over -40C to +85C

Low Cost, Small Packaging:

- 11mm x 15mm x3 mm
- 44 ball, BGA

ACEINNA
POWERFUL SENSING SOLUTIONS

OpenIMU330- Measured Results



ARW of Gyros (deg/rt-hr) with Limit(1.00): Pass
0.0985697293358447 0.107427046630389 0.116596562442133 0.107782682997214

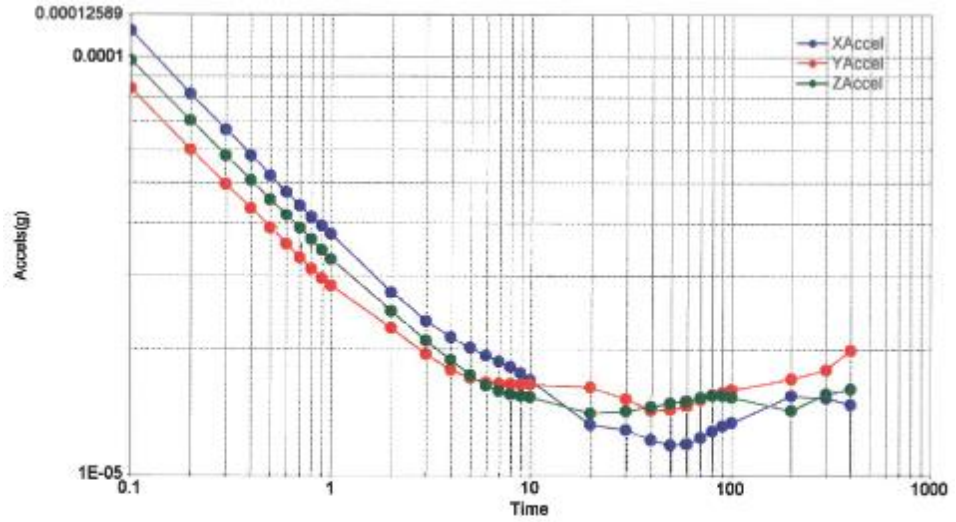
BIAS INSTABILITY of Gyros (deg/hr) with Limit(20): Pass
1.35361641086646 1.01431193062081 0.997369328257413 1.13370361428784

Gyro Results:

- Measured Gyro Bias Instability: 0.997 – 1.35 °/hr
  - Spec is 2 °/hr typical
- Measured Gyro ARW: 0.098 – 0.117 °/√hr
  - Spec is 0.2 °/√hr typical

Accel Results:

- Measured Accel Bias Instability: 11.85 – 14.3 ug
  - Spec is 15ug typical
- Measured Accel VRW: 0.014 – 0.018 m/s/√hr
  - Spec is 0.05 m/s/√hr typical



VRW of Accels (m/sec/rt-hr) with Limit(0.10): Pass
0.0184614892581636 0.013916226458288 0.016092214095073 2 0.016262915881941 5

BIAS INSTABILITY of Accels (ug) with Limit(100): Pass
11.8535239004895 14.3178194081604 14.0868375661162 13.4653255199954

RTK/INS Solutions

Gen 1

- Position Accuracy: 2 cm (RTK)
- Heading Accuracy: 0.1°, Attitude Accuracy: 0.05°
- Velocity Accuracy (horiz,vert): 0.01 m/s, 0.02 m/s

Gen 2

- Position Accuracy: <10 cm (RTK)
- Enhanced Synch & Improved Cal
- 30cm error after 10s drive test

INS1000

- RTK Inertial Navigation Systems
- Dual-band GPS/GLO/GAL/BDS
- Dual Antenna
- USB/Ethernet/CAN and RS-232

OpenRTK330

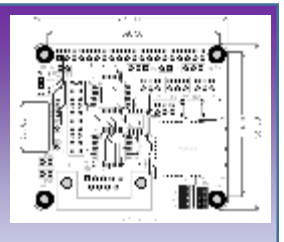
- Dual-band (L1/L2 or L1/L5)
- GPS/QZSS/GLO/GAL/BDS
- Teseo V, 3x-Redundant IMU
- RTK/Embedded FW
- SPI/Serial/CAN/Ethernet Interface
- LGA64, 30mm x 30mm pkg

INS1000 Dev Kit

- Rover, Base station
- 3 Antenna
- Cabling

Pi3 Hat Eval Board

- Teseo V Chipset
- 3x-Redundant IMU
- Convenient Network Connectivity
- Flexible for data logging, algorithm development



OpenRTK330

- **ST TESEO V GNSS Receiver**
  - Dual Band: L1/L2 with L1/L5 Option
  - Global Constellations
    - GPS (L1 C/A, L2C and L5)
    - BeiDou (B1I, B2I)
    - Galileo (E1, E5a, E5b, E6)
    - GLONASS (L1OF, L2OF)
    - NAVIC
  - 80 tracking channels
- **Integrated Triple-Redundant IMU**
  - Precise IMU performance
  - High Reliability – reject faulty sensors
  - ASIL B – redundant sensors
- **Accuracy**
  - Horizontal Position Accuracy (RMS)
    - RTK – 2cm
    - 10s GNSS Outage – 30cm
  - Heading Accuracy (RMS) 0.5°
  - Attitude Accuracy Roll/Pitch, RMS) – 0.1
- **Interface**
  - CAN, Ethernet, SPI and UART
- **OpenRTK**
  - RTK/PPP Lite Embedded FW
  - RTK/PPP Correction Solution
  - Open Sensor GNSS/INS Fusion Algorithm
- **3.3V to 5V DC Supply**
- **50-pin, 31mm x 33.5mm LGA Package**

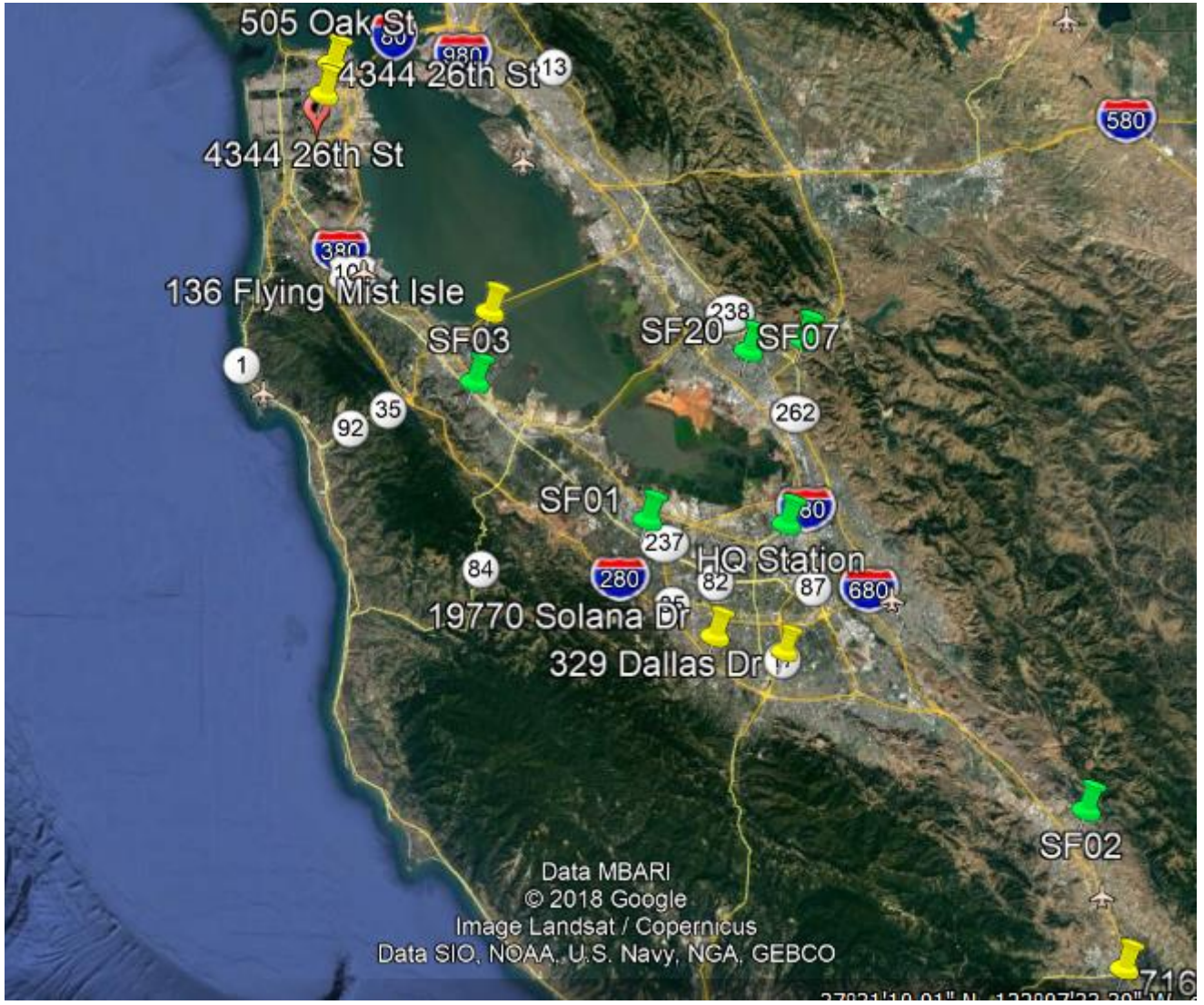
OpenRTK330 Dynamic Test

- ACEINNA OpenRTK330 vs Competitor
  - Car Mounted
  - Parking Lot with Trees
  - Same Antennae
  - RTK Service
    - Aceinn’a’s Silicon Valley RTK Network
- ACEINNA RTK Engine
  - 98.3% Fix Rate

Delta (cm)	68%	95%	99%
Horizontal	2.5	5.2	6.0
Vertical	2.1	4.5	5.1

Free Dense RTK Network in Silicon Valley

- FREE
- All Constellations
  - GPS, BeiDou, Galileo, Glonass
  - All Channels (L1, L2, L5…)
- Deploying Beta Network in SF Bay Area
- Dense: Stations every 20km
- Cellular correction delivery



Conclusion

- ST is a leader in both Sensor and GNSS solutions
- In partnership with Aceinna
  - A range of highly precise IMU modules with industry leading performance and price
  - Industry leading INS/RTK solution based on ST IMU and GNSS