A High G, MEMS Based, Deeply Integrated, INS/GPS, Guidance, Navigation and Control Flight Management Unit

Timothy M. Buck – Honeywell International
Jason Wilmot – Honeywell International
Michael J. Cook – Rockwell Collins

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Presentation Overview

- System Architecture
- MEMS Technology
- SAASM GPS and A/J Technology
- Ultra Tightly Coupled INS/GPS Architecture
- System Performance
- IEEE 1394b Bus Architecture
- ECTOS™ IIc Software Architecture
- Future Generation FMU – DIGNU3
- Summary

BG1930 FMU Overview

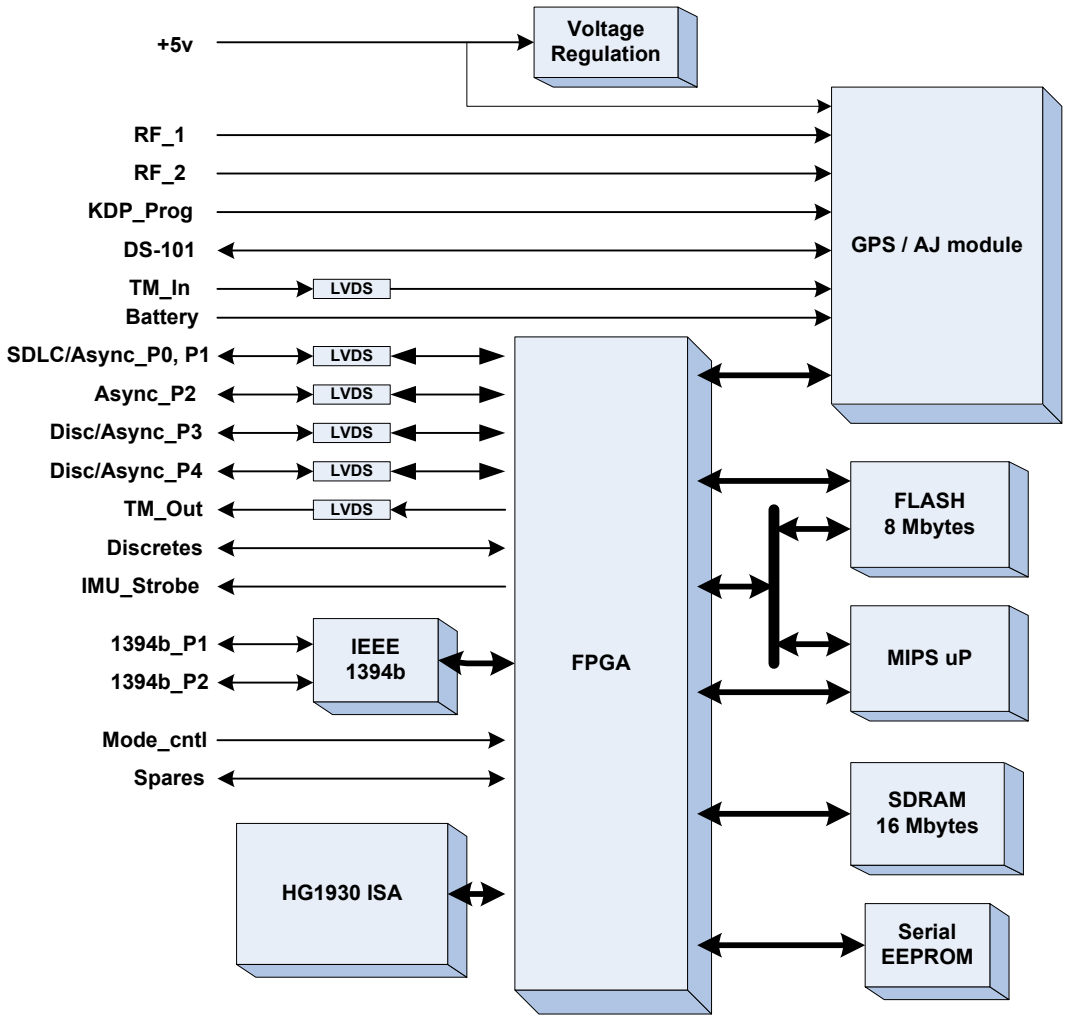
Features

- 2-Channel Digital Nuller Anti-Jam Capability
- SAASM L1/L2 Dual Frequency GPSR
- PMC-Sierra RM7035C MIPS Processor
- MEMS Digital Inertial Sensor Assy (ISA)
- Small Size: 13.7 in^3 (2.75”D x 2.3”H)
- Weight: < 1 Lbs
- +5V input
- Power: < 9 W

Performance

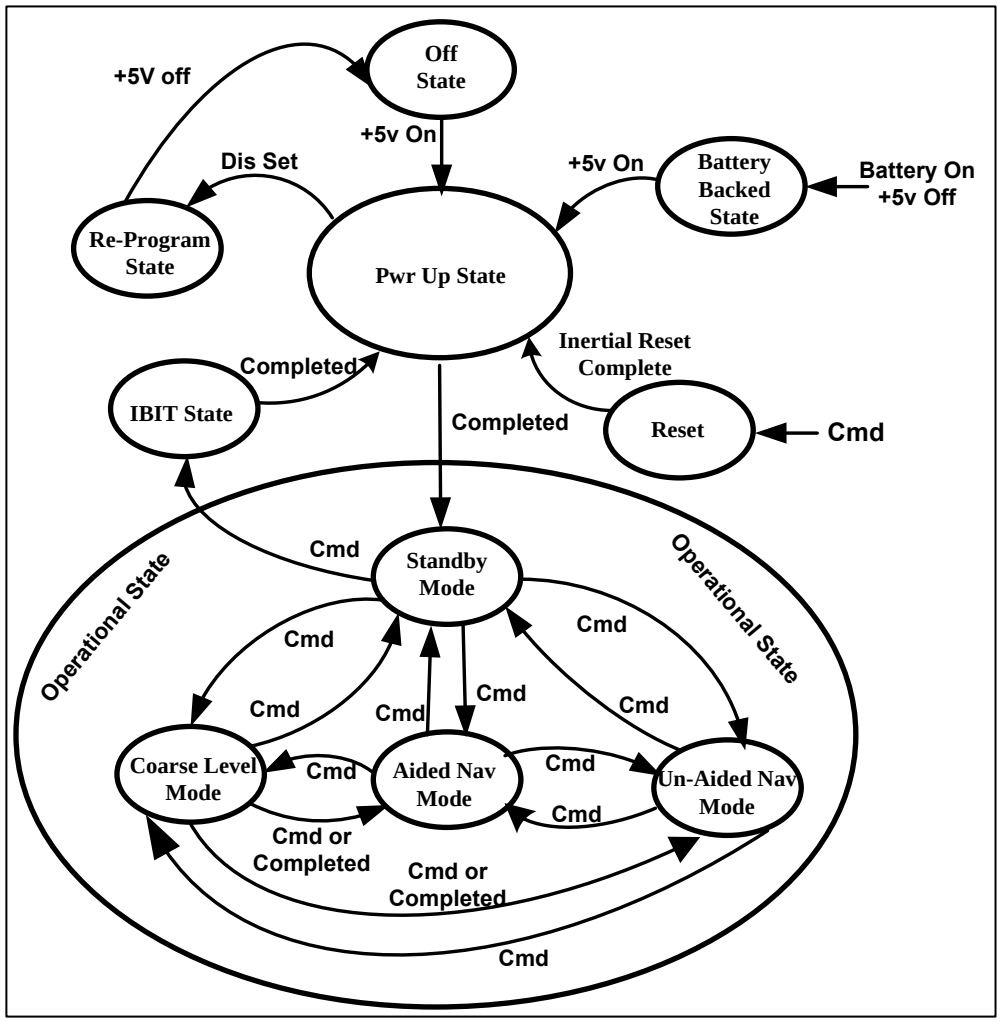
- Aided-INS Outputs
  - Attitudes (roll, pitch, heading)
  - Velocity Vector (3-Dim)
  - Present Position (3-Dim)
- CEP < 5m, Vertical Err < 8m, 1sigma
- Tightly coupled or Ultra Tightly coupled INS/GPS Integrated Navigation
- Capable of Hosting G&C Software
- Outputs Flight Control Sensing Data
- 89dB J/S BB/CW (Tracking)

System Architecture



Size	2.75"Dx2.3"H 13.7 cuin
Weight	<1 lbs
Power	+5v Primary, < 9W +3.3v Battery Backup, <0.11W
GPS	SAASM L1 AND L2
Interface	1 Async Port (LVDS) 1 SDLC / Async port (LVDS) 2 -port IEEE-1394b Bus 4 Prog Discrete I/O 4 Prog Discrete I/O / 2 Async ports (LVDS) DS-101 (LVCMOS) Time Mark In/Out (LVDS) IMU Strobe Mode Control
A/J	89 dB BB/CW Track
Processor	MIPS PMC7035C
Cooling	Passive
Memory	SDRAM - 16 Mbytes FLASH - 8 Mbytes
Performance	UTC INS/GPS 5m CEP aided 26m CEP (60 sec Free Inertial)
Environment	Temp -40 to 63 C Temp Shock ±5 degC/min Set Back Shock 15,750 g Set Forward Shock 7,875 g Altitude 120,000 ft
MTBF	8,500 hrs
Software	VxWorks RTOS ECTOS IIc Hosts Customer Code - Flight Control, Guidance and Mission Management

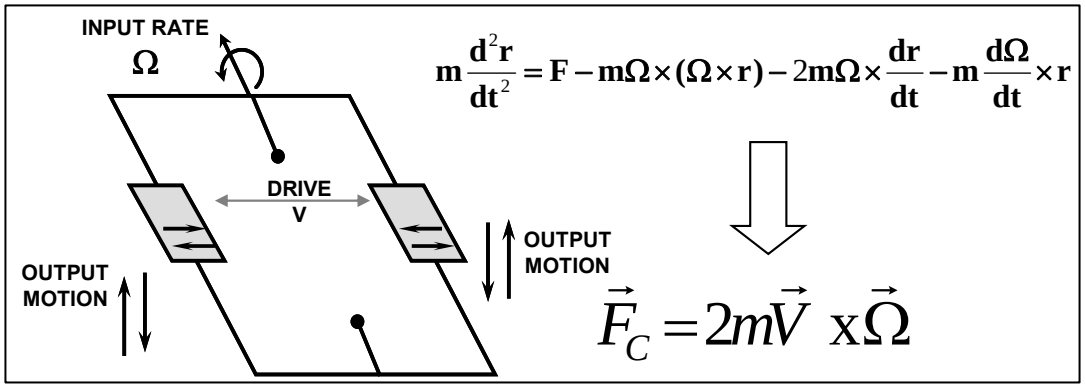
System Architecture



KF Aiding Sources

- Course level alignment
- GPS aided navigation
  - PVT
  - Pseudo Range
  - Delta Range
  - Vector Tracking Loop (VTL)
- Zero integrated velocity aided nav
- Zero heading change aided nav
- Position match aided navigation
- Velocity match aided navigation
- Attitude match aided navigation

MEMS Technology



- **Based on the principle of Coriolis force**
  - **Electrostatic force drive 2 proof masses at resonance**
  - **Rotation about input axis causes Coriolis force normal to the drive plane**
  - **Output is sensed via capacitive pickoffs**
    - ★**Amplitude is proportional to input angular rate**
- **Robust error model minimizes errors**
  - **Automatic calibration procedure allows the errors to be observed and decoupled**
  - **A minimum variance estimation technique is used to compute the compensation model**
    - ★**Allows the data to be weighted based on measurement uncertainty**

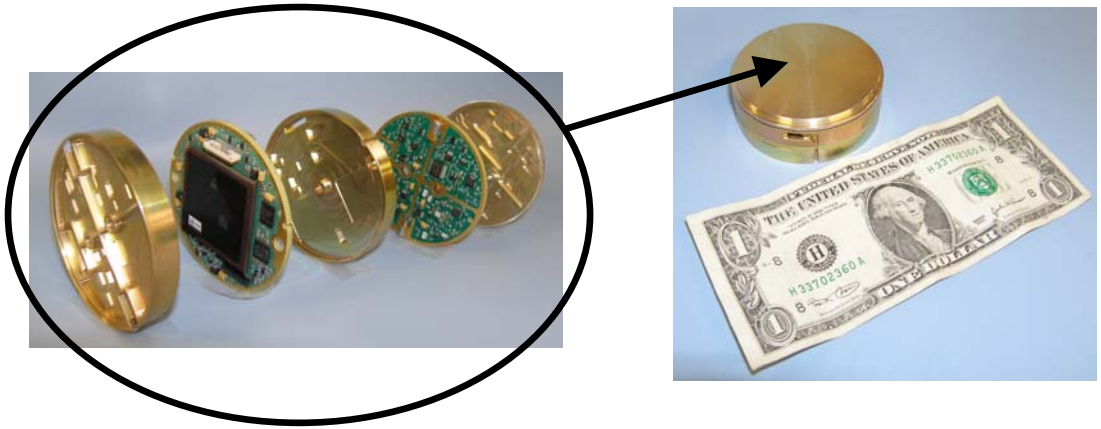
MEMS Technology

Parameter	ISA Performance			
		Realized		
	Goal	Mean	Stdev	Units
Gyro				
Bias Repatability	20	17.1	9.6	deg/hr
Bias (High G Shift)	20	100	---	deg/hr
Bias In-Run Stability	5	15.7	11.4	deg/hr
Scale Factor Repeatability	350	270.5	76.2	ppm
Scale Factor (High G Shift)	350	4000	---	ppm
Scale Factor In-Run Stability	50	268.1	74.3	ppm
Random Walk	0.125	0.09	0.055	deg/√hr
VRC	1	0.0084	0.757	deg/hr/g^2
Noise	12	1.2	0.6	mrad/s
Axis Misalignment	500	277.9	343.2	µrad
Axis Orthogonality	200	34.3	41.1	µrad
Accel				
Bias Repatability	4	1.2	0.66	mg
Bias (High G Shift)	4	40	---	mg
Bias In-Run Stability	0.8	0.5	0.25	mg
Scale Factor Repeatability	700	427.5	225.4	ppm
Scale Factor (High G Shift)	700	4000	---	ppm
Scale Factor In-Run Stability	100	230.2	122	ppm
Random Walk	0.03	0.03	0.006	m/s/√hr
VRC	50	2.01	72.15	µg/g^2
Noise	19	6.1	4.7	mg
Axis Misalignment	500	295.9	365.5	µrad
Axis Orthogonality	200	118.4	91.7	µrad

ISA Performance

- Sample space = 36 sensors
- Includes temperature effects
  - - 40 to 85 C
- In-run stability based on 1 minute averages
- Alignment errors do not include mount to mount
- VRE is mean bias shift from quiescent to 6grms
- Noise is standard deviation of 600Hz flight control data

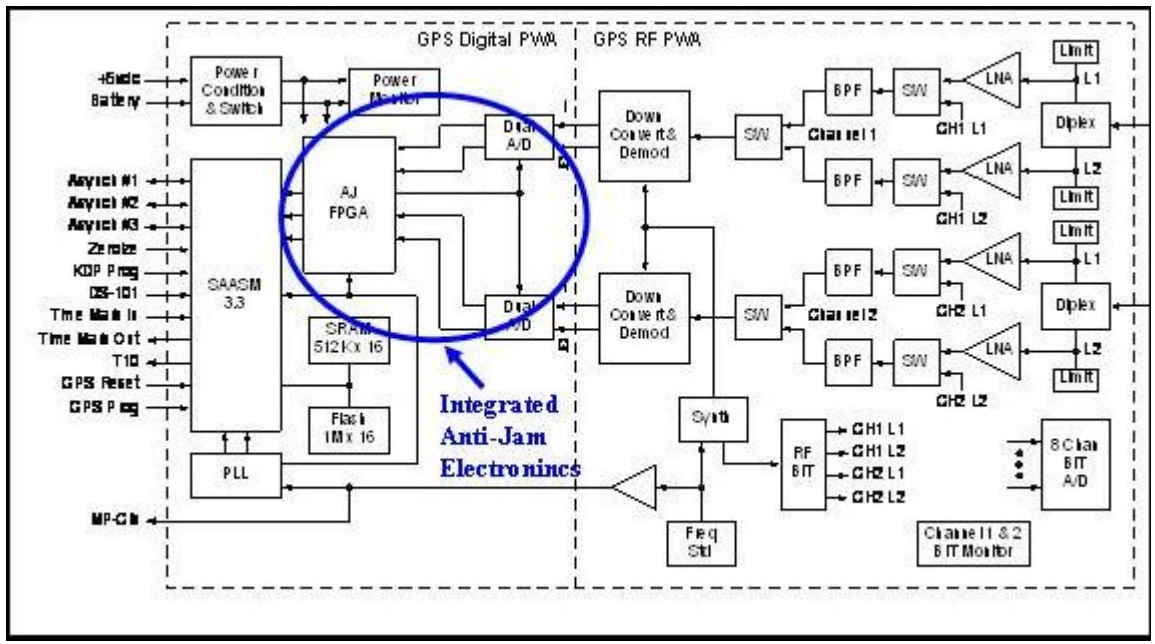
SAASM GPS and AJ Technology



NavStorm+ GPSR

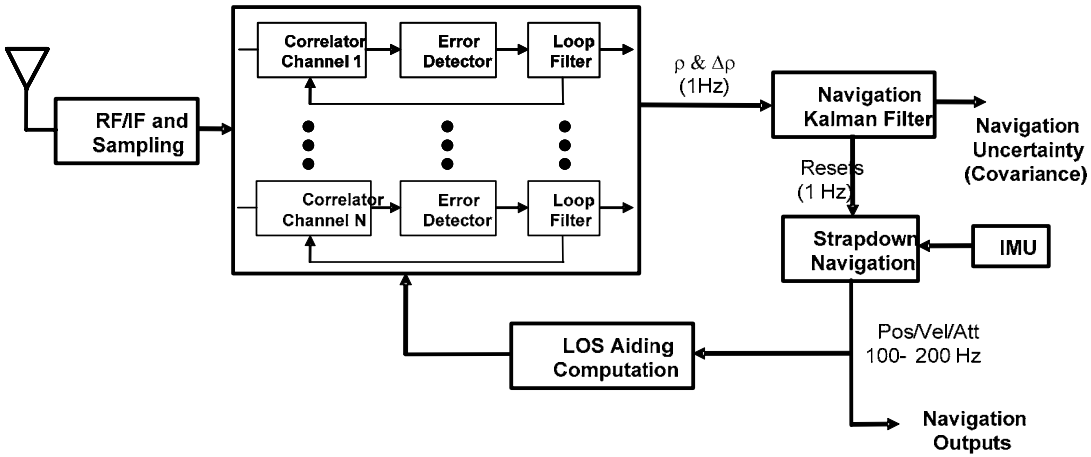
- Utilizes cutting edge packaging
  - 75% TCXO size reduction realized
  - 95% RF filter size reduction realized
- SAASM 3.3 technology
  - Direct Y capable
- L1 AND L2 capable
- Proven gun-hardness to 20 kG
- Integrated digital spatial nuller

SAASM GPS and AJ Technology



- Dual independent RF channels
  - Interfaces with any FRPA
- 2 element digital AJ
  - 23 dB BB J/S enhancement
  - 30 dB CW/NB J/S enhancement
- Designed with a DI interface
- Realizes a 10 sec TTFM

UTC Architecture

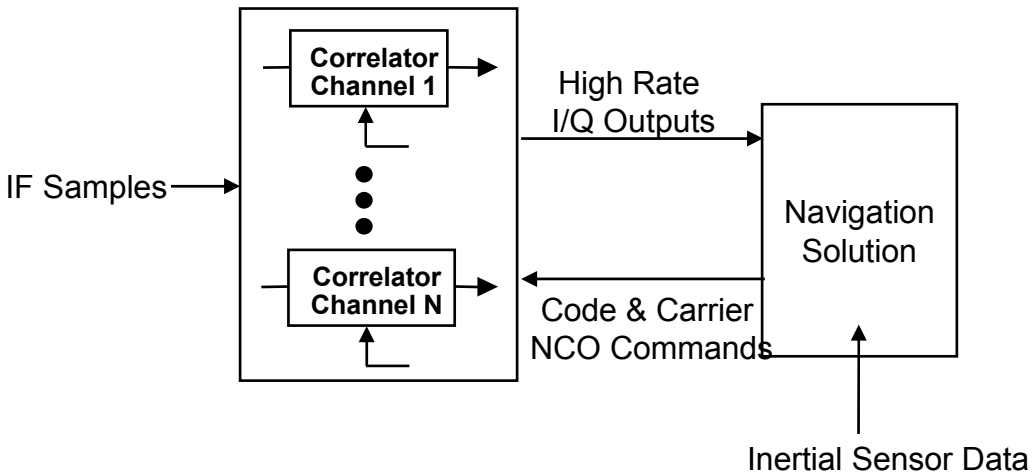


Today's Approach

Satellite tracking loops closed on an individual satellite basis

Receiver provides low-rate pseudorange and deltarange outputs

Dynamics of tracking loop closure generally unknown/unmodeled by Kalman filter



VTL Approach

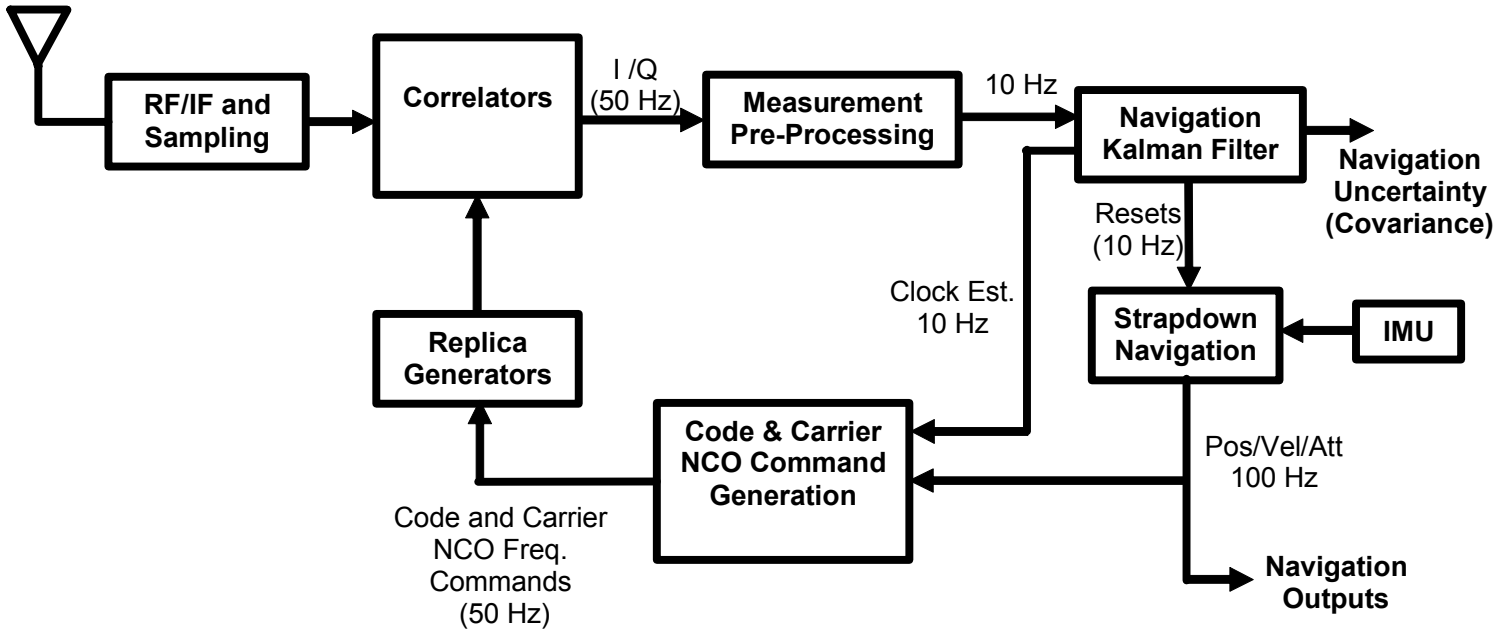
Vector tracking loop closure through the navigation solution

Improved tracking under high interference conditions (jamming)

UTC Architecture

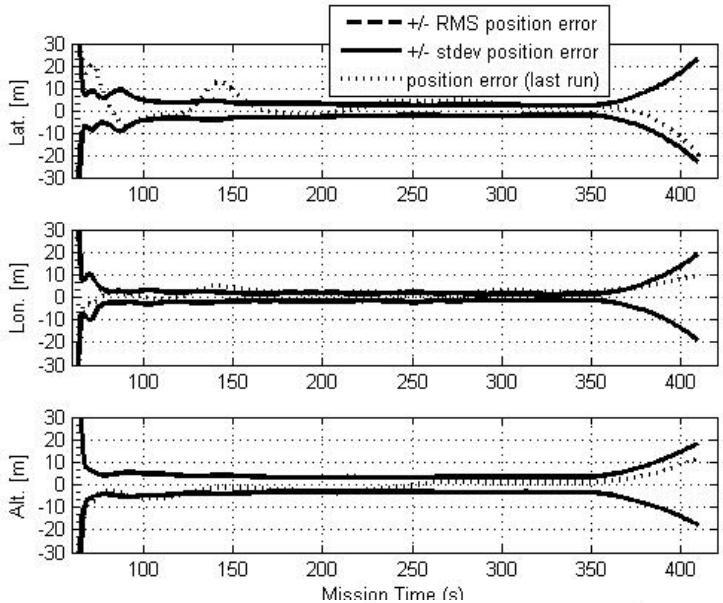
- Key feature is GPS tracking loop closure through the navigation solution
  - I and Q outputs for all satellites are used to generate the tracking loop closure commands for each satellite
  - Approach takes advantage of the inherent coupling of the line-of-sight dynamics among multiple satellites
    - N pseudorange or carrier phase measurements, but only 4 primary degrees of freedom (position & time)
    - Provides effective signal-to-noise ratio enhancement
  - I/Q measurements from each satellite are appropriately weighted in navigation Kalman filter based on estimated signal to noise ratio
- Replaces conventional GPS receiver code and carrier tracking loops when operating in deep integration mode

UTC Architecture



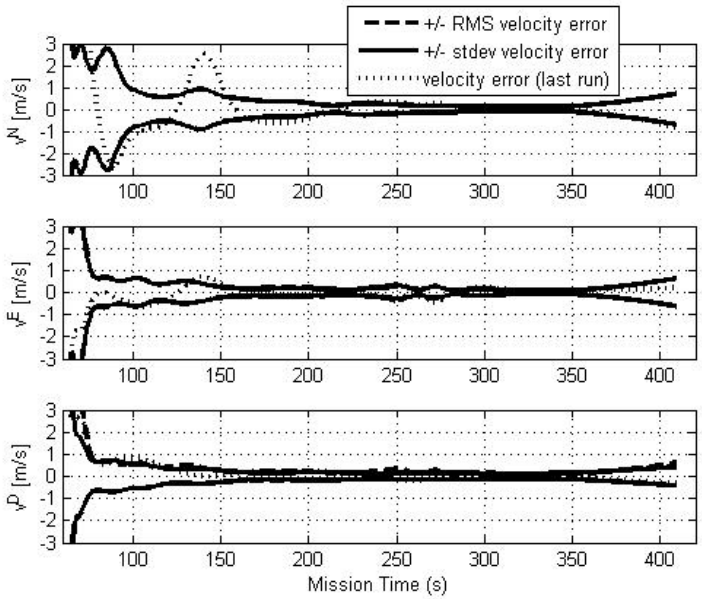
- **VTL Benefits**
  - Enhanced signal to noise ratio
  - increases likelihood that tracking loop keeps errors small enough to stay within linear region of operation
  - Improved anti-jam capability
- **More effective integration of GPS with inertial and/or other sensors**
  - No cascading of GPS tracking loop filters with navigation Kalman filter
  - No measurement processing rate limitations based on stability concerns
- **Improved reacquisition following brief loss of tracking**

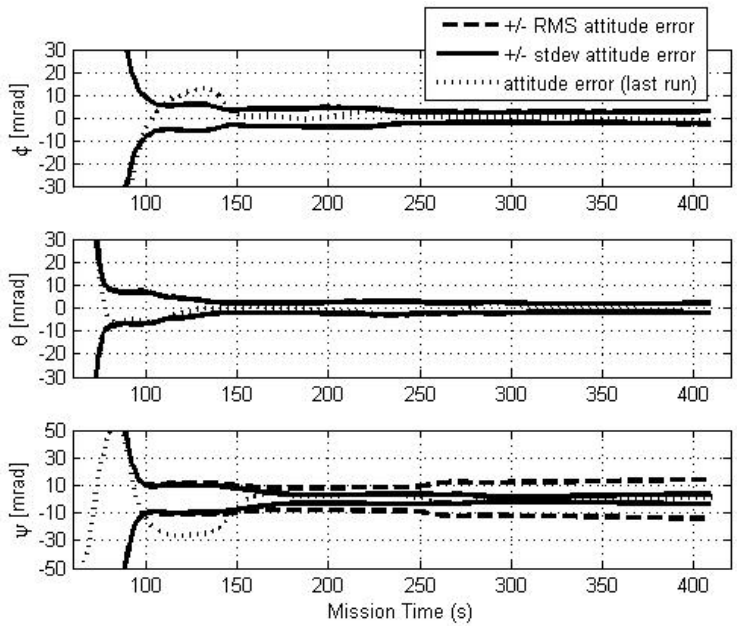
System Performance - Sim



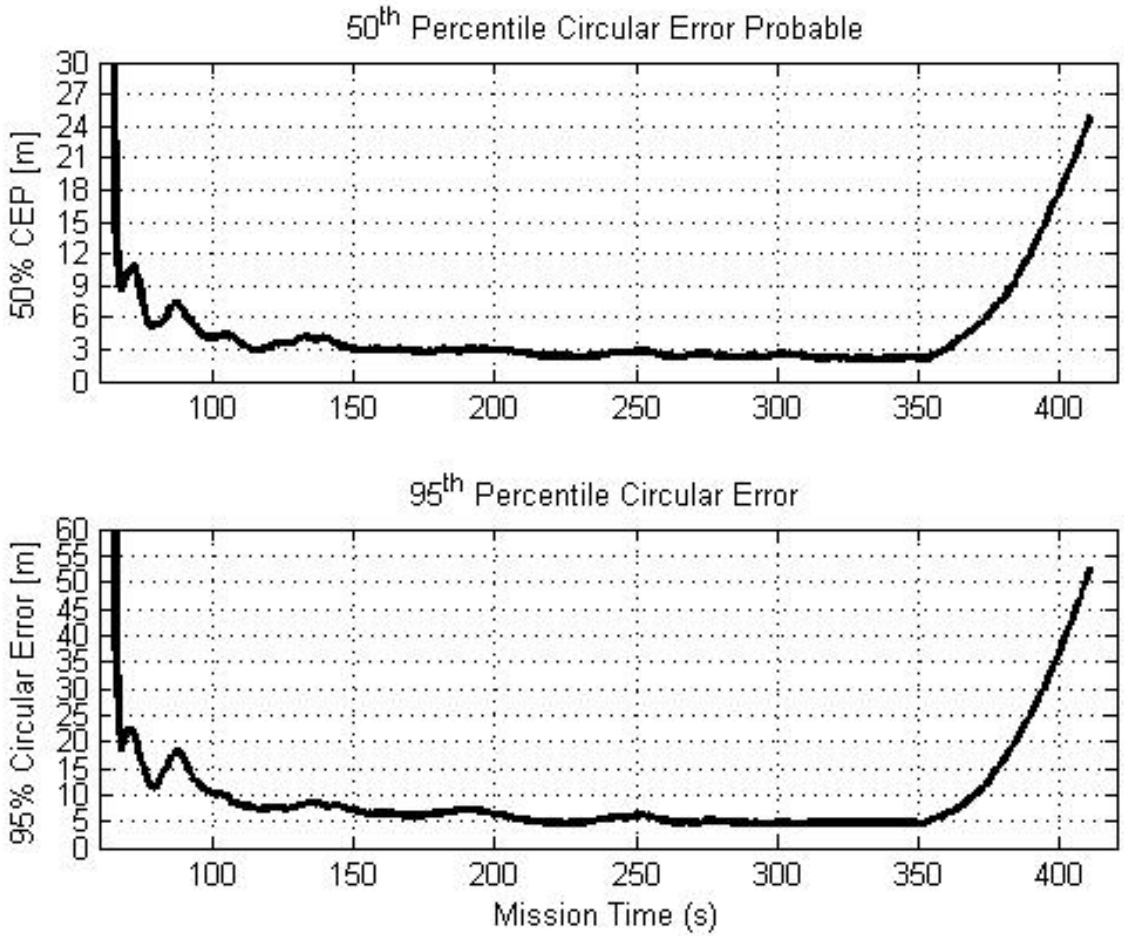
Scenario Definition

- Gun launched
- Constant 25 Hz roll rate during first minute
- Constant 0 Hz roll rate after first minute
- Maximum altitude of 29 km
- Total Downrange of 200 km
- Total Cross-range of 37 km
- Total flight time of 7 minutes
- DI aided
- No jamming

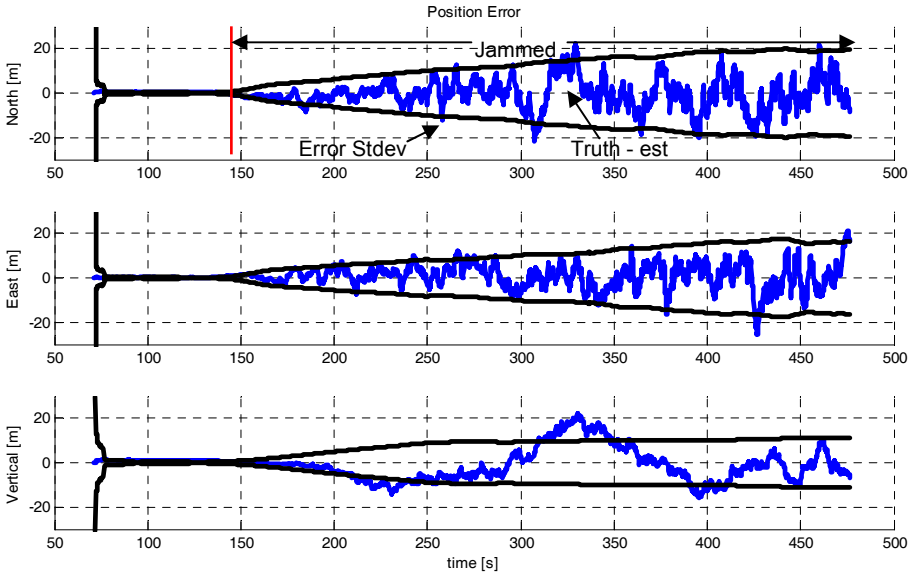




System Performance

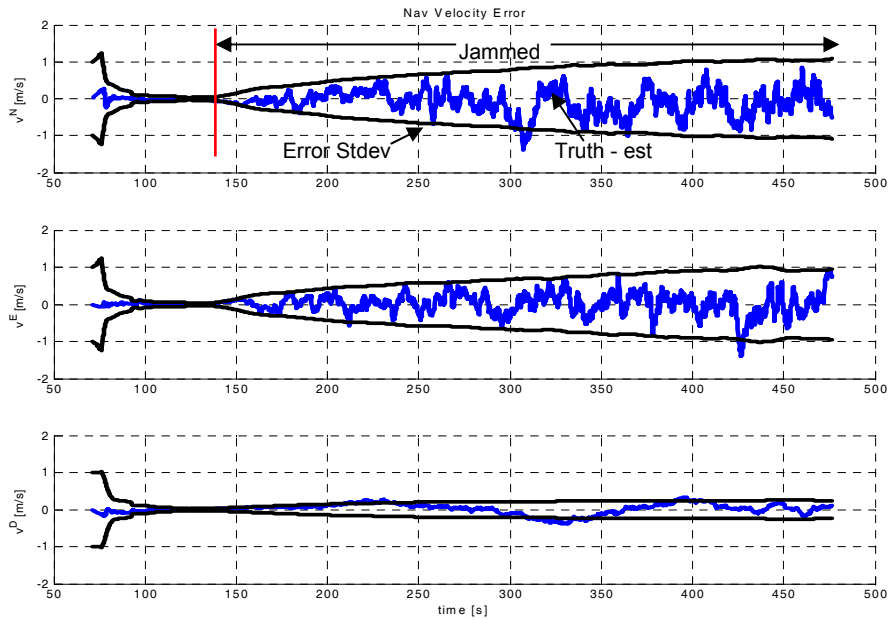


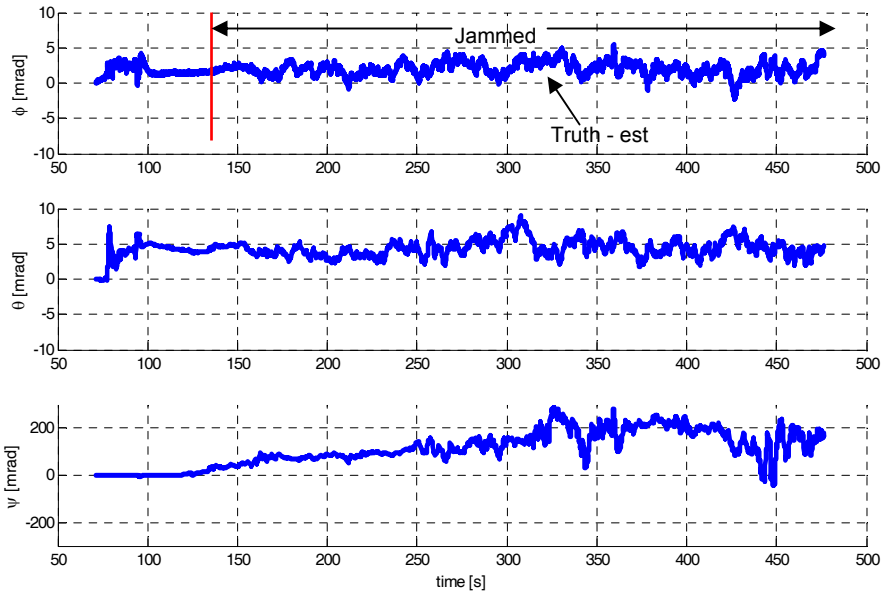
System Performance - Test



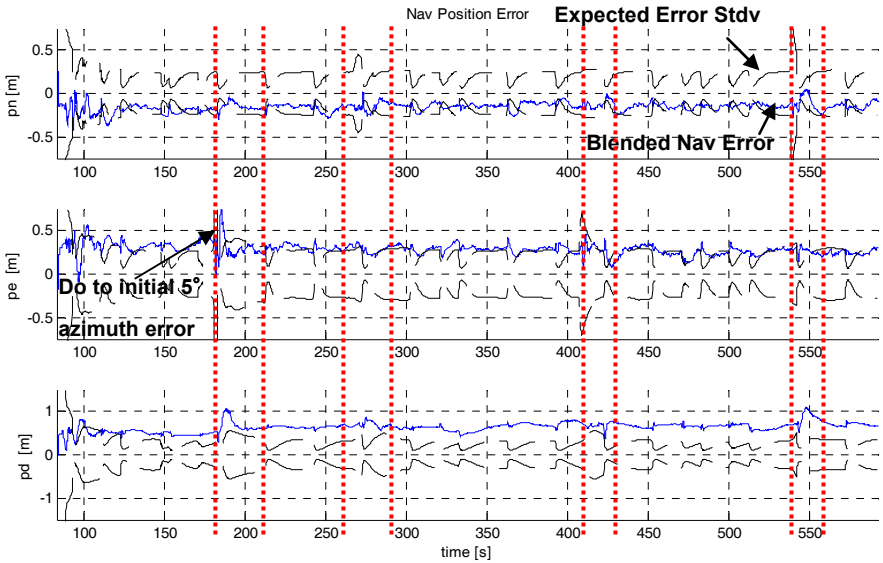
Static Jamming Performance

- **HW AJ Off**
- **Broadband Noise**
- **66 dB J/S**



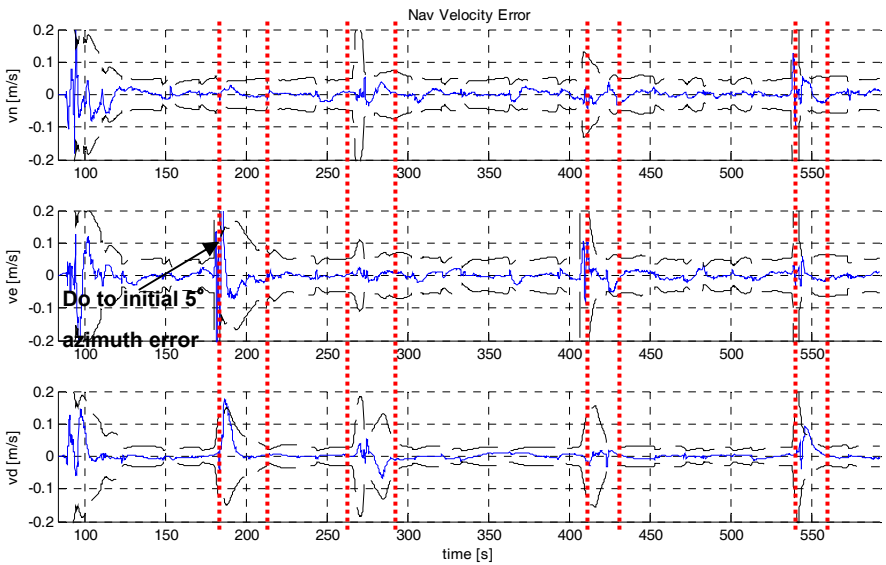


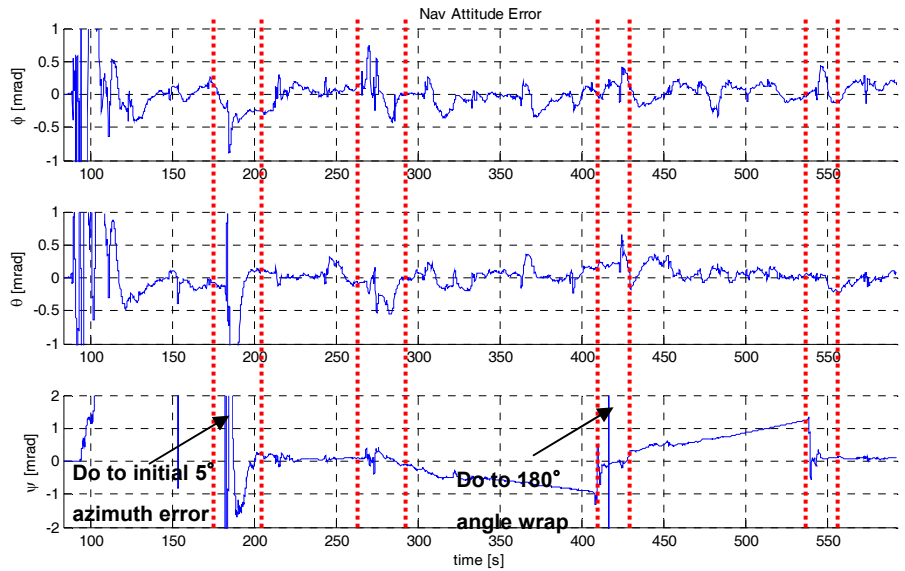
System Performance - Test



Dynamic Performance

- 1g linear accel
- 2, 4, 8 g turns
- Un-Jammed



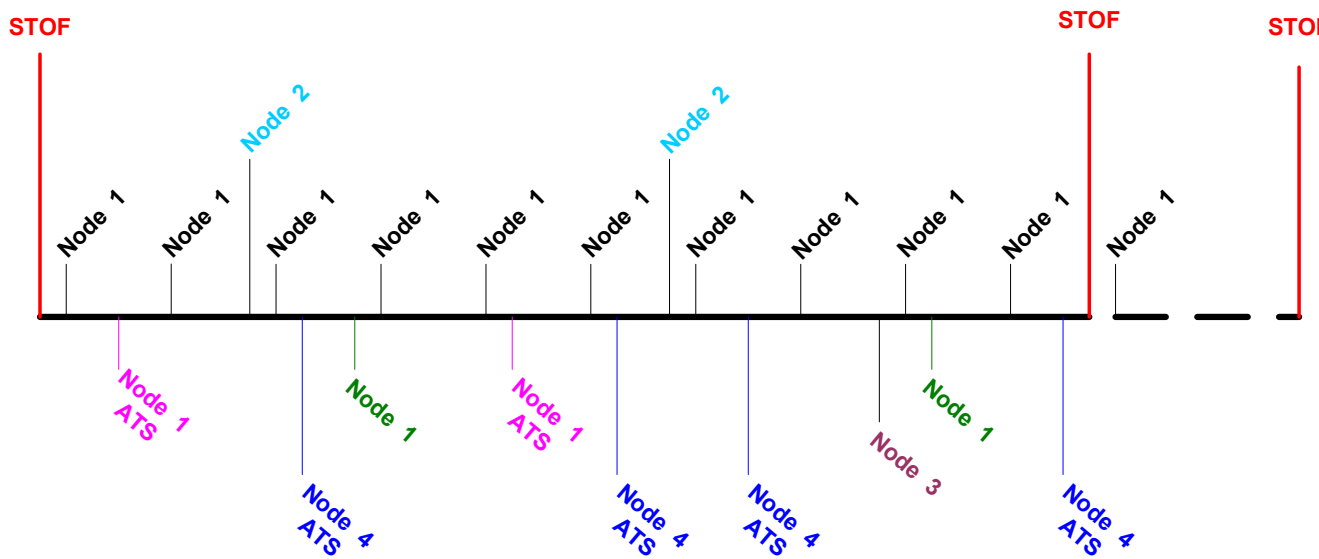


IEEE 1394b High Speed Bus

- FMU supports asynchronous and asynchronous stream transactions

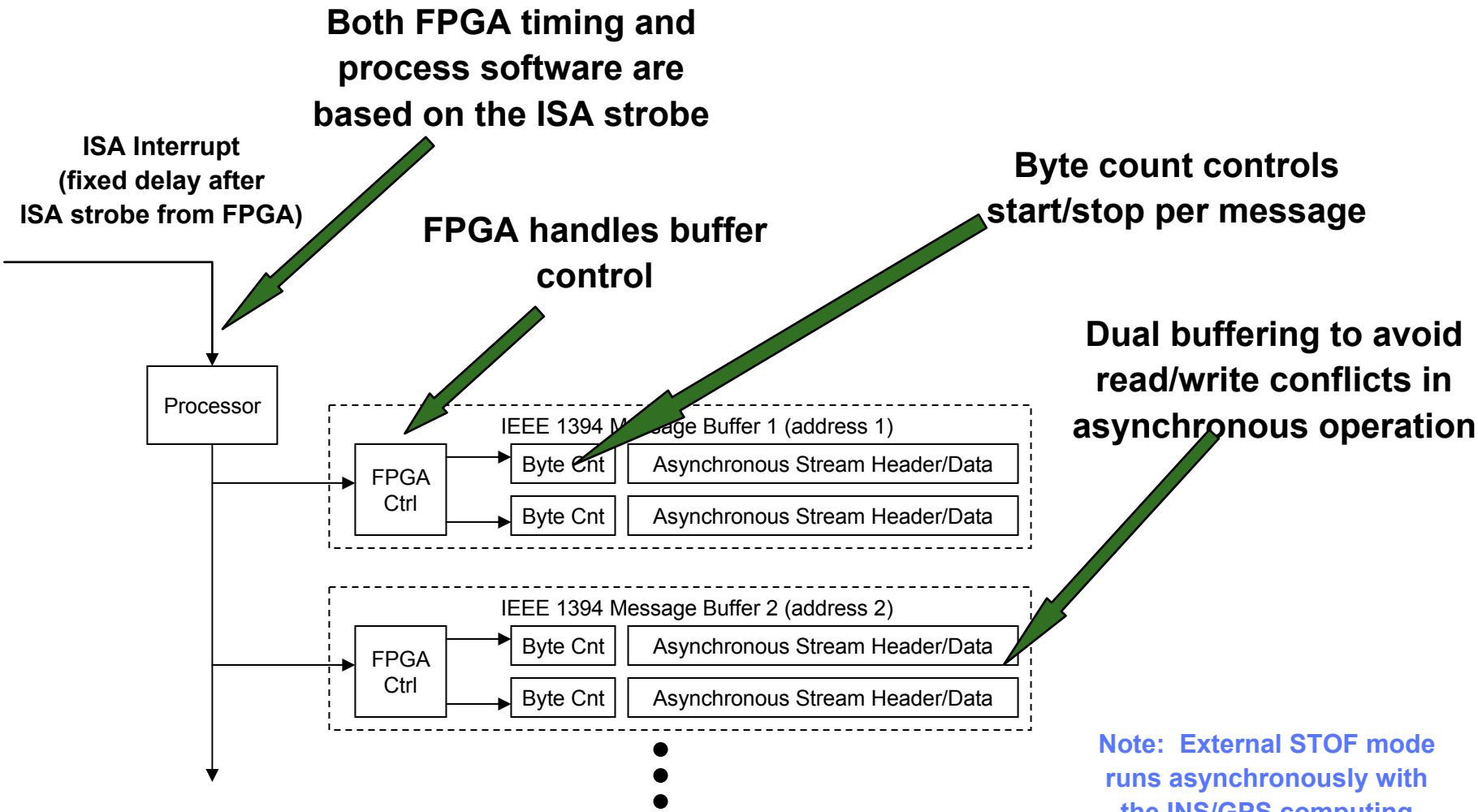
- Baseline FMU protocol (per SAE AS-1A-3 Standard)
  - Designed for a highly deterministic, low jitter interface
  - Uses asynchronous stream transactions only
    - Isochronous packets
      - Broadcast messages with no re-transmission in asycnc BW
    - Asynchronous arbitration
      - Subaction gap (message gap)
      - Arbitration reset gap (fairness interval)
    - No isochronous bandwidth used

IEEE 1394b High Speed Bus



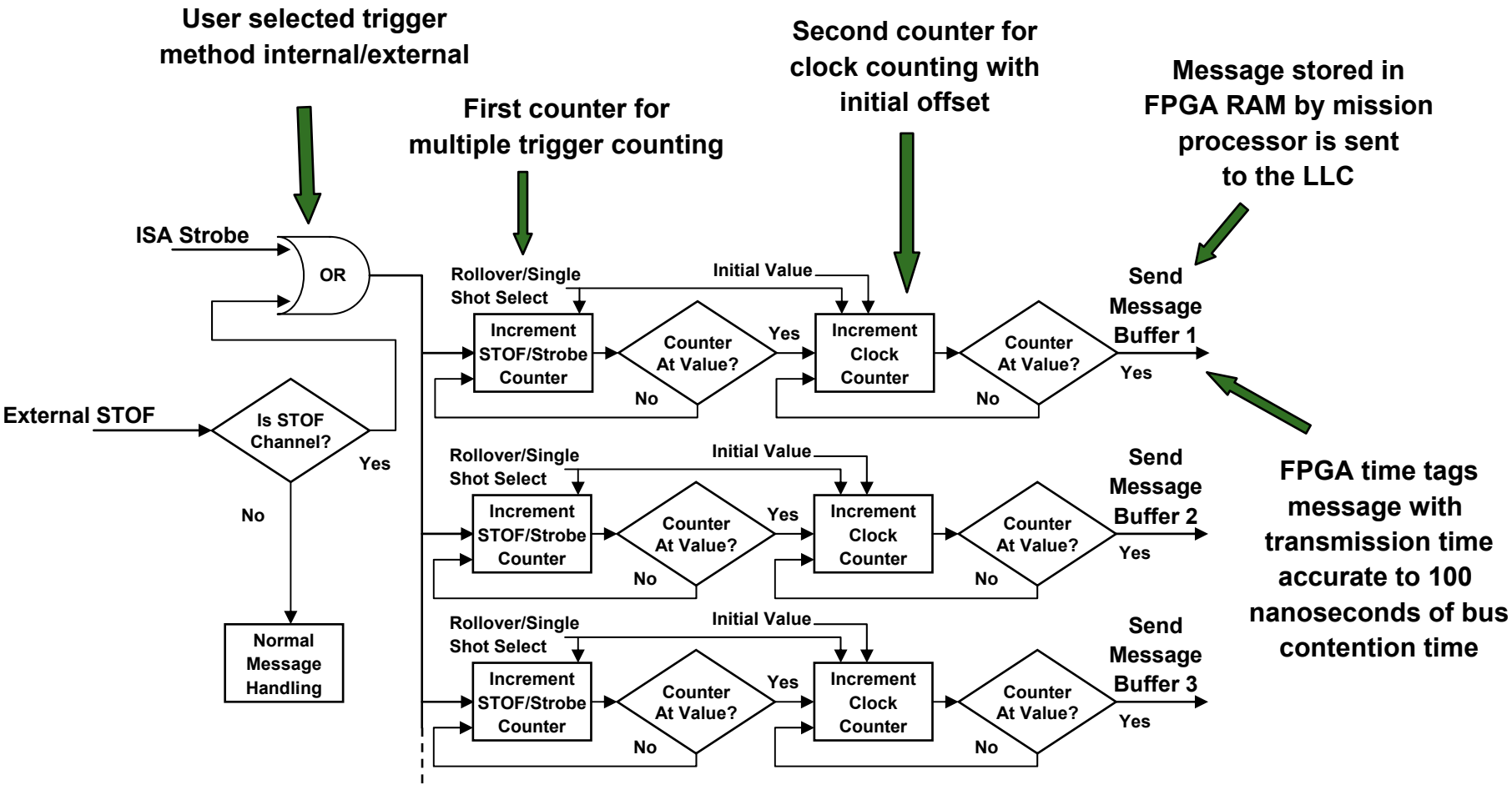
- Incorporates rigidly deterministic messaging
  - Every node assigned a time slot within a specified time frame
    - ★ A STOF is used to synch all subsystems
      - ➢ Supports variable rates
    - ★ Specified time frame is determined by STOF packet
    - ★ Each node is specified a time slot(s) at offsets to STOF
      - ➢ Multiple time slots allows for higher frequency messaging
    - ★ Each slot is specified a certain bandwidth
    - ★ Channel numbers a pre-assigned
    - ★ Nodes listen to specific channel numbers

IEEE 1394b High Speed Bus



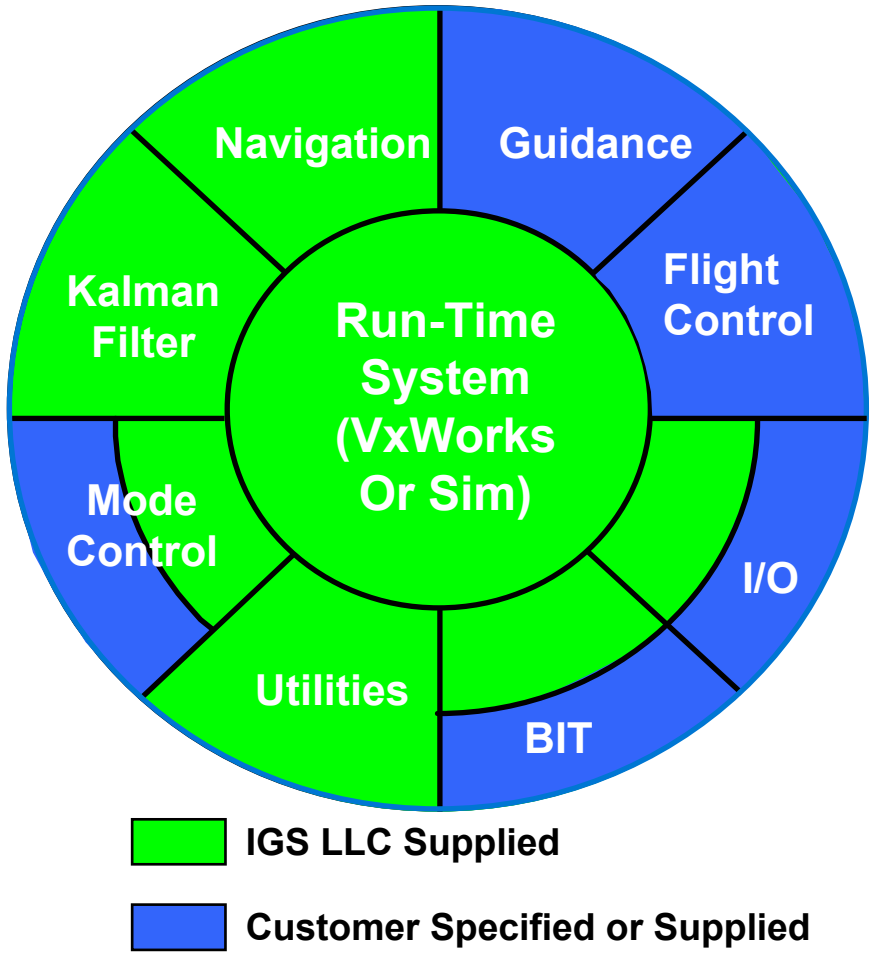
Note: External STOF mode runs asynchronously with the INS/GPS computing

IEEE 1394b High Speed Bus



ECTOS™ IIc Overview

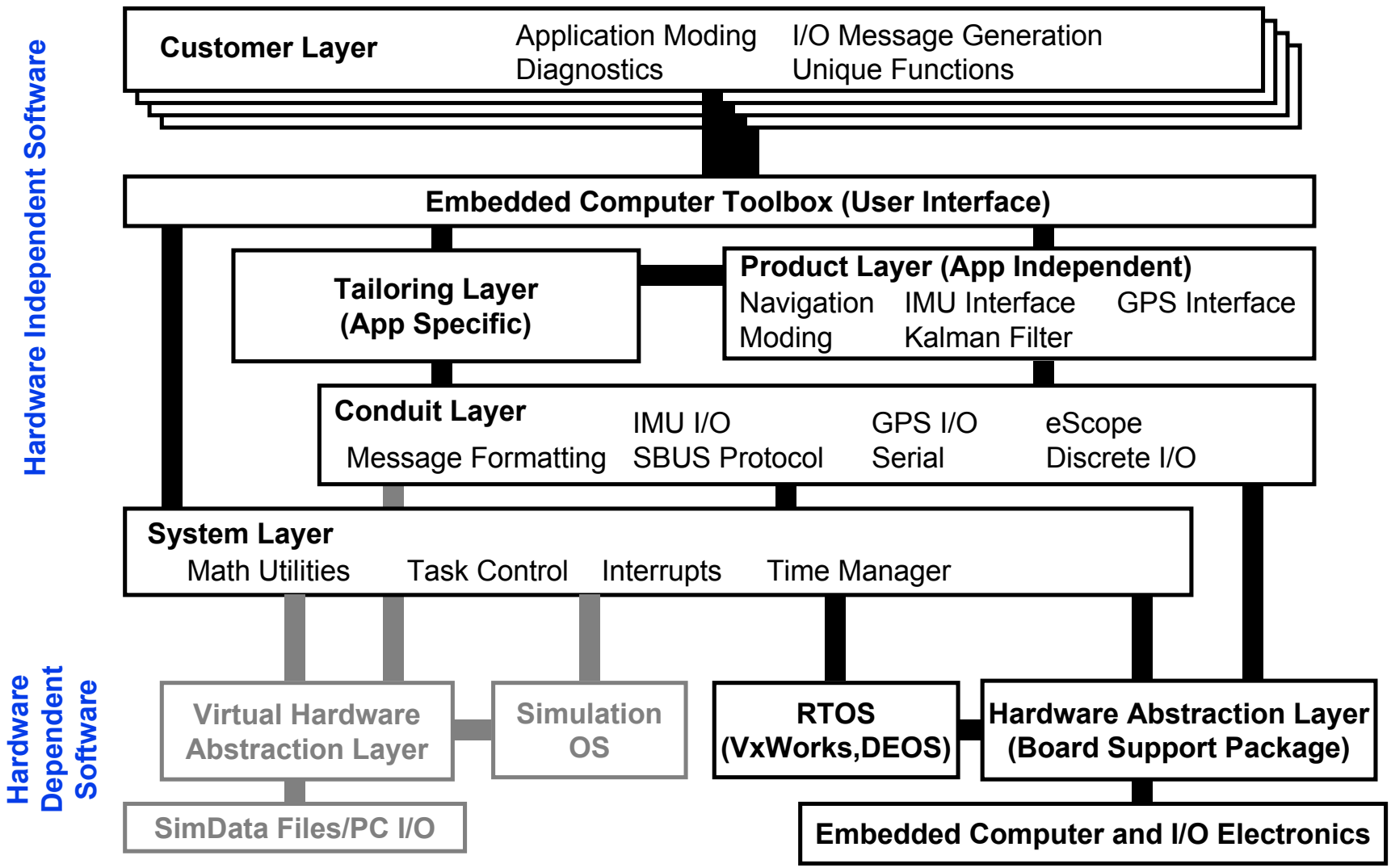
- Provides the necessary operating system and tools
  - Navigation
  - Guidance
  - Control
- Major Functions
  - Real-time Tasking Executive
  - Navigation
  - Aiding Kalman filter
  - Mode control
  - I/O interface software
  - Diagnostics and BIT
- Includes User's Manual describing APIs and their use



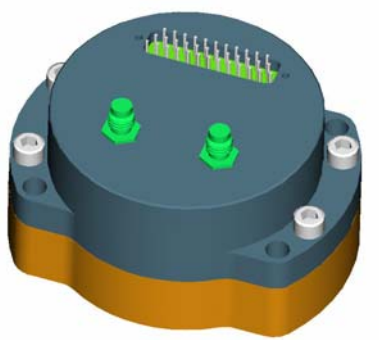
ECTOS™ IIc Overview

Integrated Guidance Systems LLC

Honeywell Rockwell Collins



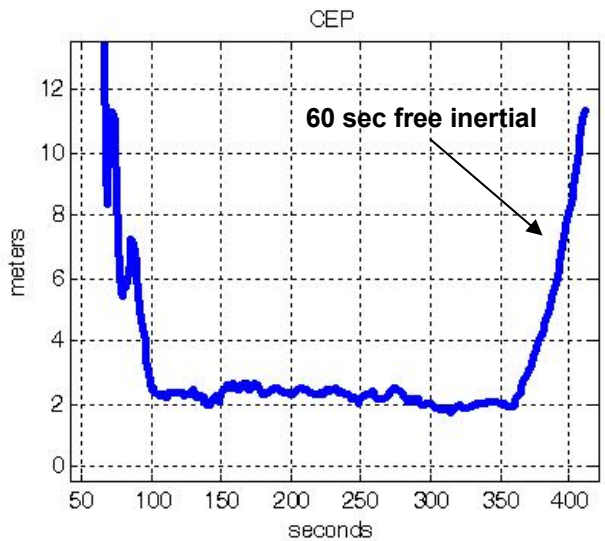
Future Generation – DIGNU-3



Parameter	Gyro		Accel	
	Perf (1σ)	Units	Perf (1σ)	Units
Operating Rate Range	1440	°/sec	70	g's
Scale Factor Repeatability	150	ppm	300	ppm
Scale Factor (In-Run Stability)	150	ppm	150	ppm
Scale Factor Asymmetry	---	ppm	100	ppm
Scale Factor Linearity	---	ppm	15	ppm/g
Bias Repeatability	1	°/hr	1	mg's
Bias (In Run Stability)	1	°/hr	0.4	mg's
Bias Static g Sensitivity	0.5	°/hr/g		
Bias g^2-Sensitivity	0.5	°/hr/grms^2	10	μg/grms^2
Axes Alignment stability	1200	μrad	1200	μrad
Axes Alignment Stability, (non-orthogonality)	200	μrad	200	μrad
Random Walk	0.12	deg/rt-hr	0.07	m/sec/rt-hr

Features

- 4.5 cuin
- +5 v input / 5 watts
- ARM 11 processor
- ZSP 540 processor
- SDLC interface
- 1394b interface
- UARTS
- Discrete I/O
- TM in/out
- DS101 interface



Summary

- IGS LLC's next generation INS/GPS guidance system is designed for the emerging demands of military applications
  - Gun hardened – tested to 20 kg
  - Enhanced AJ capability - 89 dB J/S
    - Hardware AJ
    - Ultra tightly coupled algorithms
  - Small volume - 13.7 in^3
  - Low power - < 9 w
  - Configurable hardware and software
    - Capable of hosting customer guidance, control and flight management code
  - Militarized high speed IEEE 1394b bus architecture
  - Proven performance
- The future generation INS/GPS guidance system will realize enhanced performance in a smaller volume at reduced power