

Launch Vehicle Mission Capability Enhancement through Global Positioning System Metric Tracking

Theodore C. Moore
United Launch Alliance
12257 S. Wadsworth Blvd1
MS T5009
Littleton, CO 80125
303-977-6973
ted.c.moore@ulalaunch.com

Michael A. Carr
United Launch Alliance
12257 S. Wadsworth Blvd1
MS H3400
Littleton, CO 80125
303-971-7444
michael.a.carr@ulalaunch.com

Henry D. Friesen
USAF AFSPC LRSW/EN
12782Court
Garden Grove, CA 92841
310-653-3725
henry.friesen@losangeles.af.mil

Abstract—United Launch Alliance (ULA) and their United States Air Force (USAF) Evolved Expendable Launch Vehicle (EELV) customer initiated operational flights of both the Atlas V and Delta IV launch vehicle families in 2002. Both Launch Vehicle families have provided 100% mission success since their respective inaugural launch and have demonstrated launch capability from both Vandenberg Air Force Base (VAFB) on the Western Range and Cape Canaveral Air Force station (CCAFS) on the Eastern Test Range. However, the current EELV fleet communications, tracking, & control architecture & technology, which date back to the origins of the space launch business, require support by a large and high cost ground footprint. The United States Air Force has embarked on an initiative known as Launch Enterprise Transformation (LET) that will significantly reduce Test Range Operations and Maintenance (O&M) cost by closing facilities and decommissioning ground assets. An important phase of the LET initiative is implementation of Global Positioning System Metric Tracking (GPS MT) on launch vehicles that use these ranges.

GPS MT is a way to leverage the existing GPS satellite base navigation system's capability in order to significantly reduce the costs of Test Range O&M. United Launch Alliance (ULA), in partnership with the U.S. Government, is engaged in project plan to evolve the EELV fleet from dependence on ground based range assets to a Space Based Range operational concept. The initial phase is development of the GPS MT System. ULA worked closely with the USAF to define and document the requirements for a GPS MT System for an EELV-class launch vehicle in the Range Commanders Council RCC324-1 document (RCC 324-01T-EELV, Global Positioning and Inertial Measurements Range Safety Tracking Systems' Commonality Standard Tailored for EELV).¹

The GPS MT System satisfies those requirements by establishing a common set of components to be implemented on Atlas V and Delta IV. The GPS MT System data output format is structured per the USAF Test Range GPS Metric Tracking Interface Control Document to

provide maximum mission flexibility. The GPS MT System will make its first flight in 2012. The certification of GPS MT System on Atlas and Delta is expected to be completed in 2013.

The GPS MT System will provide precise LV position, velocity and timing information that can replace ground radar tracking resource functionality. In its initial configuration, the GPS MT System will provide an independent position/velocity S-band telemetry downlink to support the current man-in-the-loop ground-based commanded destruct of an anomalous flight. To enhance cost effectiveness, the GPS MT System design is implemented using existing commercial parts, common test requirements for environments, and electrical/mechanical interface requirements for both EELVs. The EELV GPS MT System design is complete and the hardware is currently in functional and environmental qualification testing. The system utilizes a 50 channel all in view digital receiver with high dynamic environment compensation fed by antennas mounted diametrically opposed on the second stage airframe skin. An additional benefit of the GPS MT System implementation is the availability of a precise GPS time base on board the vehicle to provide tighter time correlation with external instrumentation and video along with the opportunity to better time synchronize vehicle dynamic and thermal analog data. Additional system flexibility such as the ability to power the transmitter and low noise amplifier from the Global Positioning Tracking Unit (GTU) is provided. The GTU also incorporates a modular construction which allows for easy modification for future system applications.

This paper summarizes the current development status, physical parameters and functional performance capabilities of the EELV GPS MT System.

¹ 978-1-4244-7351-9/11/\$26.00 ©2011 IEEE

² IEEEAC paper #1458, Version 3, Updated Jan 9, 2011

TABLE OF CONTENTS

1. INTRODUCTION..... 2
2. GPS MT OVERVIEW..... 2
3. DESIGN REVIEWS AND TEST..... 4
4. CONCLUSIONS 6
REFERENCES..... 7
BIOGRAPHY..... 7
ACKNOWLEDGEMENTS..... 7

ULA has teamed with our Air Force launch customer to plan and execute the EELV Space Based Range Project in support of the Air Force Space Command’s LET vision while enhancing the mission success and capabilities of the EELV fleet. The first phase is development of the Global Positioning System Metric Tracking System (GPS MT). The GPS MT System will provide precision LV position, velocity and timing information that can replace ground radar tracking resources. The GPS MT System will make its first flight in 2012 from Cape Canaveral. The GPS MT System will become operational in 2013.

1. INTRODUCTION

United Launch Alliance initiated operational flights of both the Atlas V and Delta IV launch vehicle families in 2002. Both LV families have provided 100% mission success since their respective inaugural launch and demonstrated launch capability from both Vandenberg Air Force Base on the Western Range and Cape Canaveral on the Eastern Test Range. However, the current EELV fleet communications, tracking, & control architecture & technology, which date back to the origins of the space launch business, require support by a large and high cost ground footprint. The United States Air Force has embarked on an initiative known as Launch Enterprise Transformation (LET) that will significantly reduce Test Range Operations and Maintenance (O&M) cost by closing facilities and decommissioning ground assets.

2. GPS MT OVERVIEW

The Global Positioning System Metric Tracking (GPS MT) System is being developed to satisfy the requirements established by the Air Force (AF) in the Range Commanders Council 324-1 (RCC 324-1) titled Global Positioning and Inertial Measurement Range Safety Tracking Systems’ Commonality Standard as tailored for EELV. This document establishes the performance and verification requirements for the GPS MT System.

The GPS MT System will be one of three independent range tracking sources to assist the AF Range Officer to determine the trajectory health of the vehicle. The three sources of tracking data will include Telemetered Inertial Guidance (TMIG), Launch Head Skin Track Radar and GPS MT System as depicted in Figure 1.

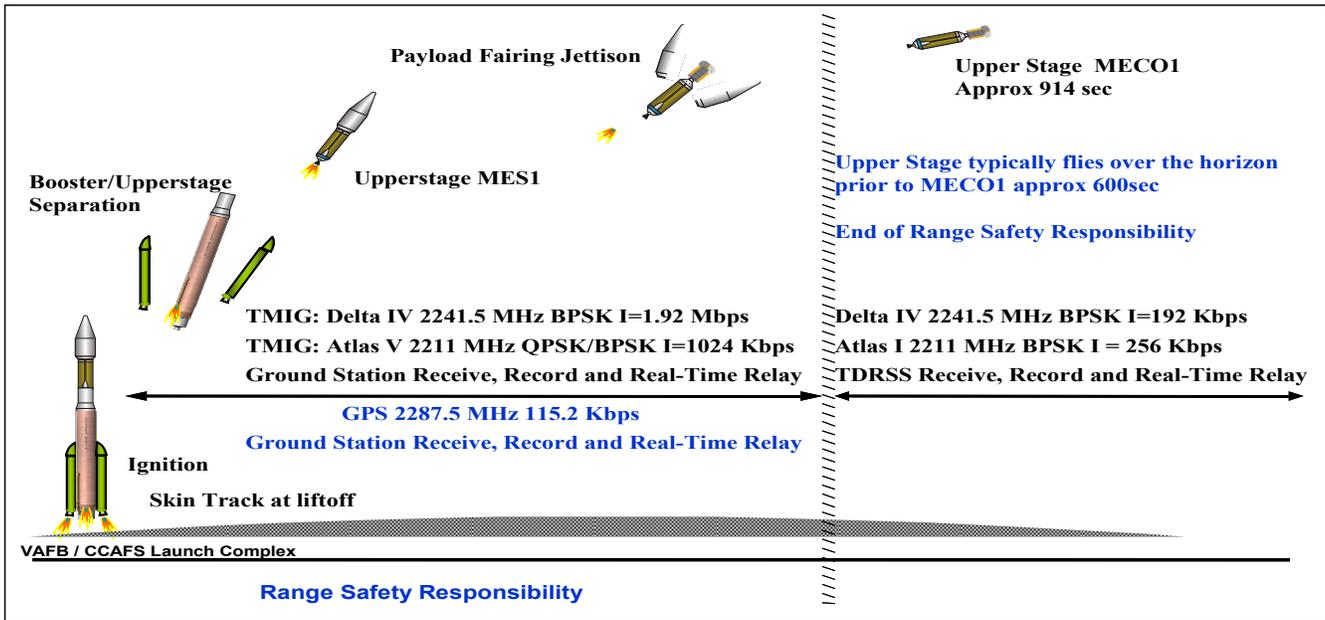


Figure 1: GPS MT Signal telemetered thru End of Range Safety Responsibility

The GPS MT System will utilize signals from the NAVSTAR GPS constellation for computing state vectors. The resulting state vector data (position, velocity vectors and time) will be transmitted to ground based S-Band telemetry receivers and processed by ULA Mission Control and cognizant Range Safety organizations at the Eastern and Western flight test ranges. The GPS MT System will be operational from pre-launch activities thru Range Safety responsibility. The end of Range Safety responsibility coincides with the vehicle going over the horizon which is approximately 600 seconds into flight and prior to the end

of the first engine cutoff of upper stage propulsion as depicted in Figure 1.

The GPS MT System will be used on both the Atlas V and Delta IV series of EELV launch vehicles. The system hardware is comprised of newly designed and tested L-band antennas (Haigh Farr), Low Noise Amplifiers (Delta Microwave), Global Positioning System Tracking Unit (GTU) (Space Vector Corporation (SVC)), S-band transmitter (Microwave Innovations), RF Multiplexer (L-3 Narda) as shown in Figure 2.

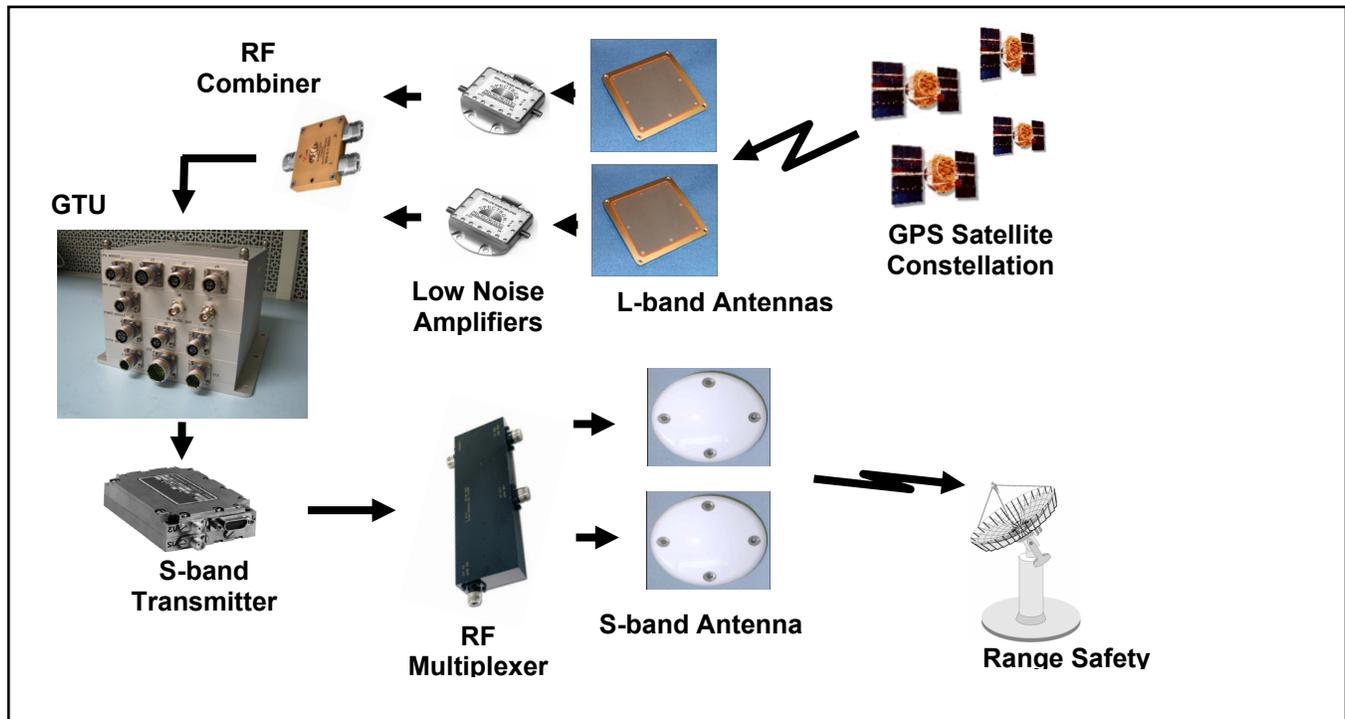


Figure 2: The GPS MT System Hardware

The heart and soul of the GPS MT System is the GTU. The GTU utilizes signals from the NAVSTAR GPS constellation for computing position and velocity state vectors. At altitudes less than 230,000 ft, the position error is required to be less than 250 ft Root Sum Squared (RSS) 3 sigma and the velocity error is required to be less than 3 ft/sec 3 sigma. Above altitudes of 230,000 ft, the position and velocity error limits remains the same but with a statistical confidence of 1 sigma. GPS MTS data is telemetered to the ground receiving antenna over a single in-phase channel on the S-band frequency using Binary Phase-Shift Keying (BPSK) encoding format and Pulse Code Modulation (PCM) per the IRIG 106, class 2 standard. The detailed listing of the data that is telemetered from the launch vehicle to the launch base appears in an Air Force:

Launch Vehicle –to– Range Interface Control Document (ICD). This ICD can be requested from the Air Force.

SVC utilized a stackable module design in developing the GTU. The GTU consists of four stackable modules (CPU/communication module, GPS module, Power supply module, Filter module) as shown in Figure 3. The module approach allowed SVC to provide additional GTU interfaces to accommodate both Atlas V and Delta IV unique power and ground interfaces such that the design is universal to either vehicle as well as taking advantage of the commercial off the shelf components (COTS). The COTS receiver and processor modules were easily ruggedized for the launch vehicle environments. Interfaces were added for control ground power (28 vdc) and vehicle power (28 vdc) control. DC excitation voltage for the LNAs will be provided on the

center conductor of the coax cable from the GTU via the RF combiner. GTU health data as a function of voltage and

current monitors are provided to the ground operation for monitoring via the vehicle telemetry formatter.

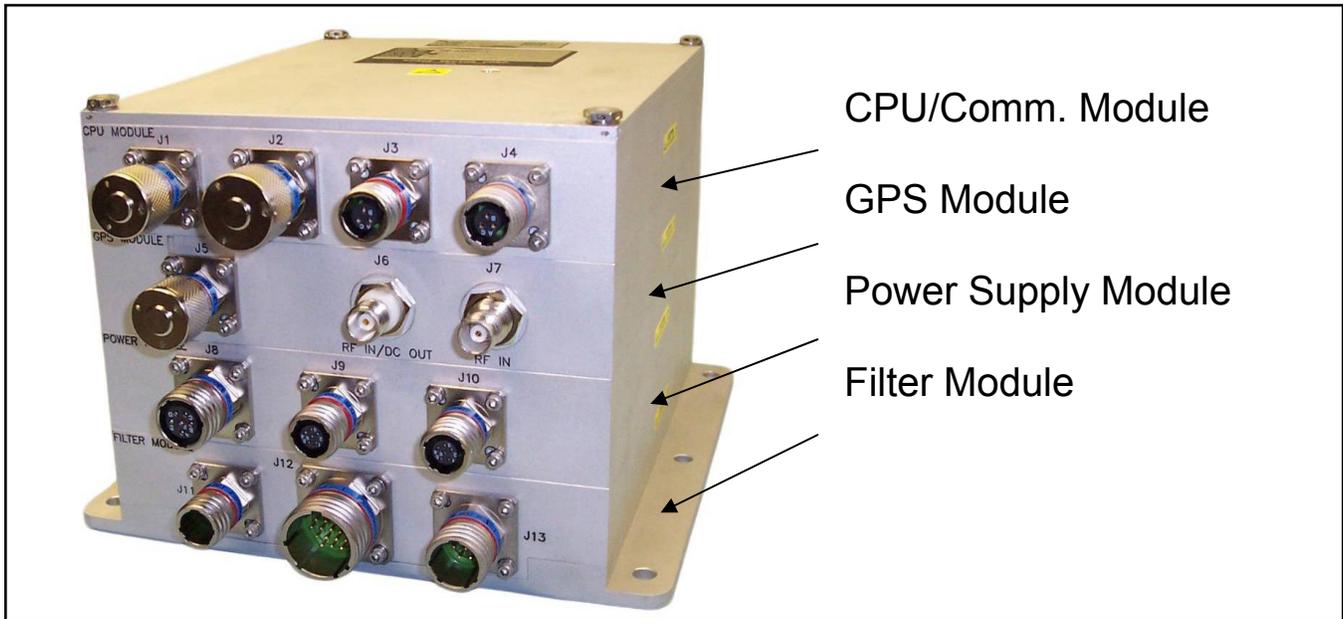


Figure 3: The GTU Stackable module design

Prior to lift off a single skyward facing antenna, external to the rocket will be routed through an RF switch internal to the GTU and will be used instead of the vehicle antennas until approximately 4 minutes before liftoff. The external antenna will be used to improve constellation visibility and will allow the GPS receiver to acquire the ephemeris data for all satellites in view for several hours. In flight, the signals from two L-band antennas located 180° apart on the circumference of the vehicle will each routed thru the LNAs for amplification and combined in the RF combiner prior to being received by the GTU.

The GPS S-Band Transmitter is a dedicated 5 watt BPSK transmitter for the GPS MT System. The GPS transmitter will telemeter position and velocity state vectors to ground based S-Band telemetry receivers where the data will be processed by ULA Mission Control and by cognizant Range Safety organizations at the Eastern and Western flight test ranges.

3. DESIGN REVIEW AND TESTS

A series of design reviews, development and qualification tests, and system integration tests were required to implement the GPS MT System on both vehicle

configurations as depicted in Figure 4 to reduce the risks to launches. The System Requirements Review (SRR) was conducted prior to the start of the GPS MT System hardware design or vehicle modifications. The review evaluated the allocation and verification methodology of the RCC 324-1 technical requirements assigned to the existing Atlas V and Delta IV vehicle design. A preliminary system architecture, vehicle interface modifications and component environments were defined. The information from this review was then flowed to the suppliers via component specifications.

A series of component Preliminary Design Reviews (PDR) were conducted. The suppliers PDR provided a preliminary design synthesis of the hardware including schematics, mechanical layout, environmental analysis, part selection criteria, test philosophy, and configuration control processes. Design Evaluation Tests (DET) were conducted by the suppliers. The DET test program provided the suppliers with an early opportunity to evaluate their design, manufacturing processes, test equipment, and test procedures against the specified requirements. The suppliers built test units using processes that would be implemented on the production unit and then exposed the units to dynamic and thermal environments at qualification levels. Design and test issues were resolved via analysis or design modifications and the tests re-executed.

A series of component Critical Design Reviews (CDR) were conducted where the suppliers demonstrated the adequacy of their detailed design to satisfy the component

specification via the released electrical and mechanical drawings, worse case analyses, and test results from the DETs..

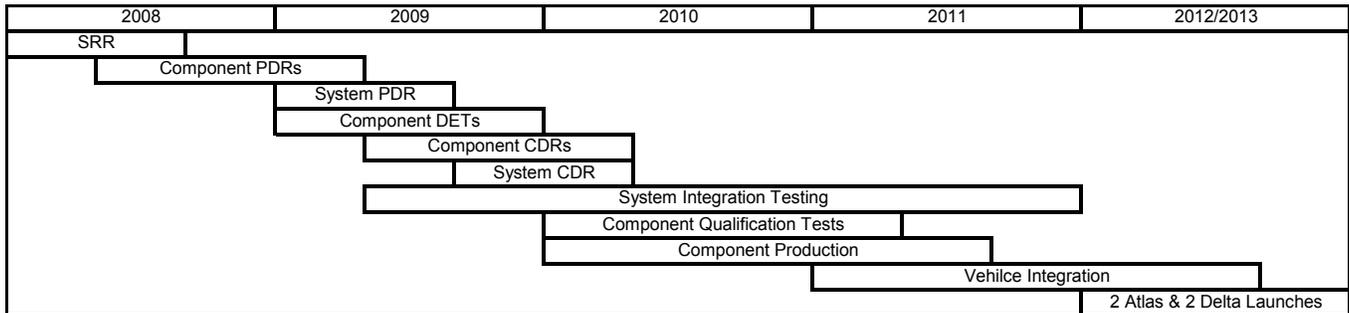


Figure 4: GPS MT System Risk reduced thru a series of reviews and tests

The first production unit authorized for development was submitted to a series of Qualification tests. These tests demonstrated that the final design and manufacturing processes had a minimum of 6dB margin above the expected flight environments with the exception of the velocity specification which was demonstrated to have 3dB

of margin during vibration. The defined environments enveloped both the Atlas and Delta vehicle environments. ULA qualification program is based on years of Atlas and Delta lessons learned as well as MIL-STD-1540. The tests executed as part of the qualification program are shown in Table 1.

Table 1: GPS MT Qualification Tests

Test	GTU	Transmitter	LNA	Antennas	RF MUX	Combiner
Functional Performance	x	x	x	x	x	x
Handling Shock	x	x	x	x	x	x
Transportation Shock	x	x	x	x	x	x
Pyrotechnic shock	x	x	x	x	x	x
Vibration	x	x	x	x	x	x
Thermal Cycling	x	x	x	x	x	x
Thermal Vacuum	x	x	x	x	x	x
Humidity	x	x	x	x	x	x
Bonding	x	x	x	x	x	x
Electromagnetic Interference	x	x	x	x	x	x
Electrostatic	x	x	x	x	x	x
Post Disassembly Examination	x	x	x	x	x	x
Salt Atmosphere				x		

ULA conducted a System CDR once the suppliers completed the DET and component CDR. The System CDR integrated the supplier design solutions and test results into vehicle electrical and mechanical designs. ULA demonstrated vehicle compatibility via electrical,

mechanical, thermal, and dynamic analysis. RF link analyses were based on nominal mission trajectories.

ULA created three labs for system integration and verification as shown in Figure 5: System Integration Labs

(SIL) verify design. There are unique SILs for an Atlas V and Delta IV configuration. The third lab is dedicated to the GTU receiver referred to as a GPS Simulation Lab.

The Atlas V SIL and Delta IV SIL are built to vehicle schematics and utilize functional equivalent flight units. The SIL testing validates the harness pin-pin configuration, vehicle grounding, power drop and current draw limits, telemetry measurements, and ground computer control. The SIL functionality is also used to verify day of launch

procedures, to provide training for launch site operators and to assist with vehicle anomaly resolution.

The GPS Simulation Lab is used to evaluate key phase and code lock loop, multipath mitigation, bandwidth of filter, fast reacquisition time, and tuning parameters. GPS MT telemetry data has been created and sent to the East and West coast Range Safety groups for verification of range safety hardware and software.

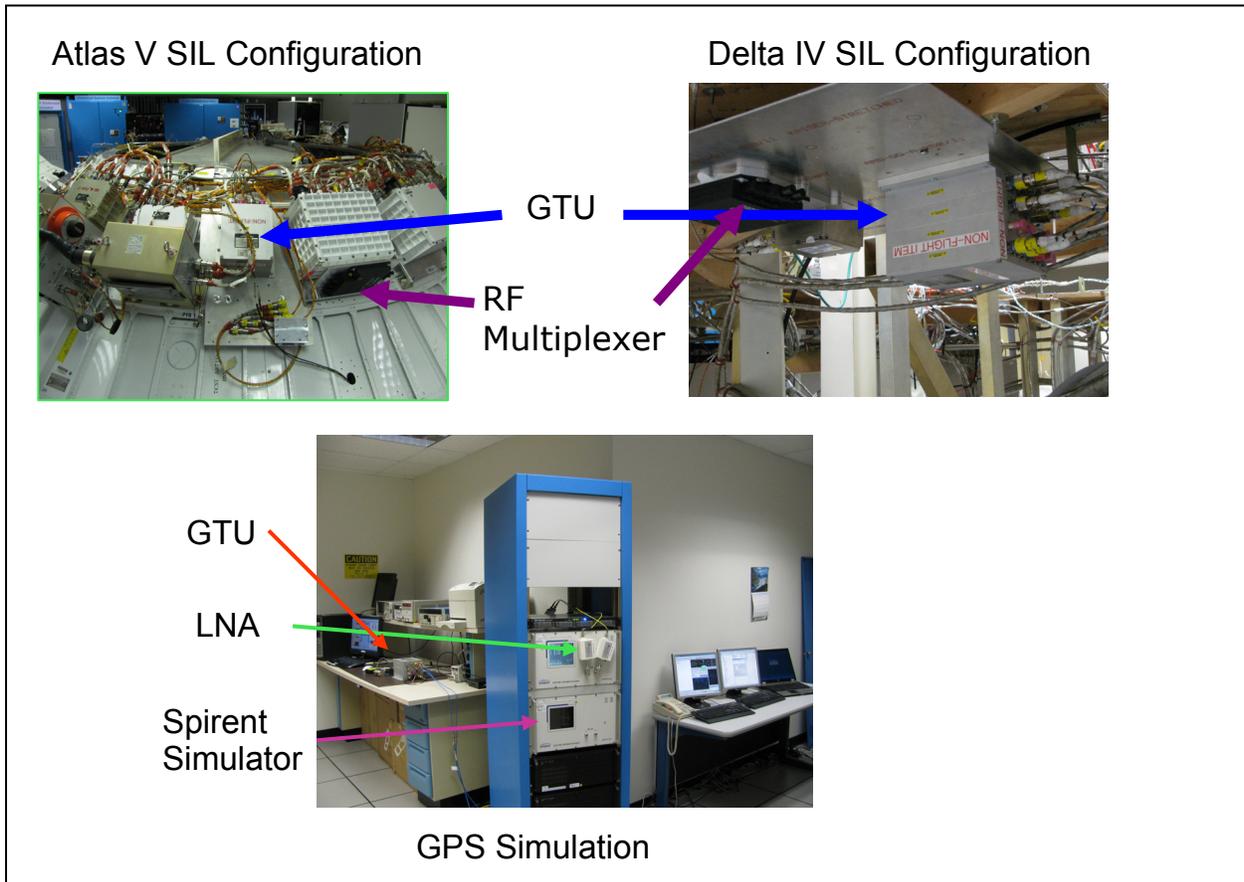


Figure 5: System Integration Labs verify design

4. CONCLUSION

United Launch Alliance and the Air Force have initiated the initial phase of the Launch Enterprise Transformation with the implementation of the GPS MT System. This system will enhance the test range operation and maintenance capabilities. The GPS MT System was designed with interfaces and tested to common environments to be interchangeable with the Atlas V and Delta IV

configurations. The System also has implemented a modular design to support future LET initiatives. The development and qualification tests of the GPS MT components have been successfully completed. Production and vehicle integration will continue thru 2011 with the first launch scheduled for early 2012. The GPS MT System will complete the certification phase in 2013.

REFERENCES

[1] RCC 324-01T-EELV, Global Positioning and Inertial Measurements Range Safety Tracking Systems' Commonality Standard Tailored for EELV, April 2008.

Elliot (ULA), Dr. Hanchu Li (ULA), and Tim Gray (Space Vector) for their technical review and comments.

BIOGRAPHY

Ted Moore has worked on Atlas, Titan, Galaxy Express, and Delta product lines since 1982. He has lead design teams in the development of tools used for ground and flight software verification, and power distribution system for Centaur. Ted has held various leadership positions as subcontract manager of major suppliers, final assembly of Centaur and Avionics System Manager. In his current position as GPS MT Program Manager he is responsible for the development, integration and certification of the GPS MT System for both Atlas V and Delta IV Programs in support of the United States Air Force Launch Enterprise Transformation Initiative.

Mr. Carr has worked in the military avionics industry for over 30 years. After working as a design engineer in the area of radar intercept/signal processing and homing/inertial system integration, he has held various leadership positions including Avionics Manager on the High Endoatmospheric Interceptor and Ground Based Tracking and Surveillance Programs, Director of Communications and Tracking for the International Space Station, Global Missile Defense Interceptor Chief Engineer, and Delta II/IV Avionics Director. In his current position as ULA's Director, Space Based Range, he is responsible for evolution of the Delta & Atlas fleet to space based communications and tracking architecture consistent with the United States Air Force Launch Enterprise Transformation Initiative.

Henry Friesen has spent 15 years working at McDonnell-Douglas, Boeing and ULA. He worked on the Delta II launch vehicle as a controls engineer and in trajectory analysis. He has spent the last 2 years as a civilian government employee at Los Angeles Air Force Base as the U.S. Air Force GPS MT Program Manager. He is responsible for the integration and certification of the GPS MT System for both Atlas V and Delta IV programs in support of the United States Air Force Launch Enterprise Transformation Initiative.

ACKNOWLEDGEMENTS

The authors would like to thank our colleagues Dr. Diane Sakaguchi (Aerospace), Dr. Andrei Doran (Aerospace), Jim