



Air Force Research Laboratory



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Advanced GPS Technologies (AGT)

1 May 2015

**Kevin Slimak
Program Manager**

**Space Vehicles Directorate
Air Force Research Laboratory**

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 01 MAY 2015		2. REPORT TYPE		3. DATES COVERED 00-00-2015 to 00-00-2015	
4. TITLE AND SUBTITLE Advanced GPS Technologies (AGT)				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory, Space Vehicles Directorate, 3550 Aberdeen Avenue SE, Kirtland AFB, NM, 87117				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Presented at the GPS Partnership Council 2015 (GPSPC15), held April 29 to May 1, 2015, at the Los Angeles AFB, CA.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 14	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			



Bottom Line Up Front



Briefing Purpose: Inform Partnership Council about AFRL technology investments to improve affordability and performance of the GPS Space Segment

Summary

- Working in close partnership with the GPS SPO to develop advanced technology options for future satellites
- Focus is on technologies with greatest payoff for our warfighters and the system
 - We're finding problems/risks now and solving/reducing them to minimize "technology discovery" during system development

Exploring/opening paths to the future!



AFRL Investments Supporting GPS Space Segment



- AFRL is investigating science and technology **options** for future GPS spacecraft (PNT Payloads and satellites)
 - To provide timely and cost-effective maturation of new technologies
 - Requirements pull (responding directly to identified AFSPC needs)
 - Tech Push
 - To enable
 - Improved performance
 - Reduced size, weight, power, and cost
 - Increased flexibility and resilience
 - Improved manufacturability
 - New concepts, architectures, and/or capabilities



GPS III



Developmental
Optical Clock



Deployable Antenna
Concept



Science and Technology for GPS Spacecraft



- AFRL has funded a portfolio of projects supporting next generation GPS spacecraft

Technologies	Capabilities
High efficiency GaN amplifiers	Lower-SWaP spacecraft OR higher power signals
On-orbit Reprogrammable Digital Waveform Generators	Increased signal flexibility after launch
New antenna concepts	Lower cost OR increased capability payload
Supporting electronics	Increased signal strength
Algorithms and new signal combining methods	Information assurance designed- in from the start
Satellite bus technologies for lower SWaP/ increased resiliency	
Advanced cyber technology	

SWaP = Size, Weight, and Power



Advanced L-Band Amplifier Technology for GPS



Objective:

- Design, fabricate, and characterize performance of advanced L-band power amplifier engineering development units
 - Space qualifiable/suitable for GPS

	Threshold	Objective
Increased η (%)	45%	60%
Increased Power (W RF_{out})	250	400

Payoff:

- Lower S/C power required for same signal strength
 - Less mass/cost for power system
- Reduces waste heat for same signal strength
 - Enables denser layout, decreases thermal subsystem requirement
- Increased signal strength for anti-jam
- Decrease part count in boxes

Acquisition Status:

- Three contracts awarded in June 2014
 - Ball, \$2.1M
 - Boeing, \$4.5M
 - Northrop Grumman, \$1M



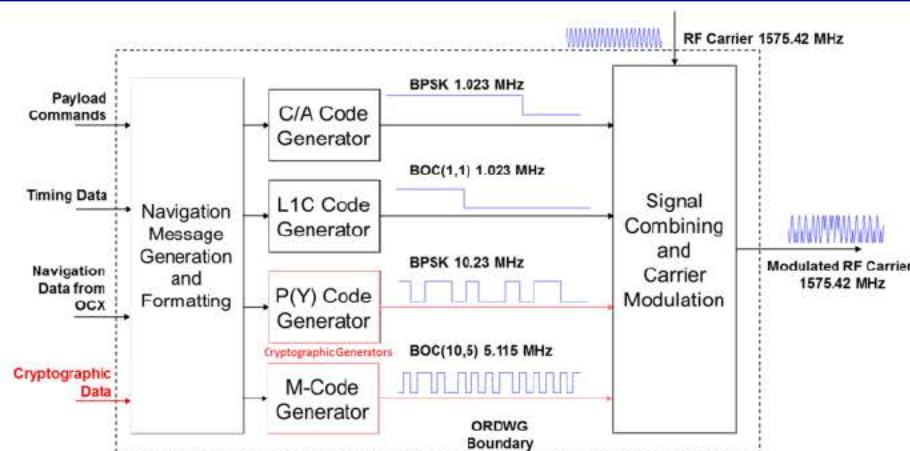
On-Orbit Reprogrammable Digital Waveform Generator Project



Develop & Demonstrate TRL 5+ technology to digitally produce GPS Signals

Payoff / Benefits

- Reprogrammable on orbit
 - Enables on-orbit up-dates/additions to waveforms
 - Enables shifting of power between modulations.
 - Enables pre-correction of signals
- Improves performance
 - Increased position/time accuracy
- Reduces part count, complexity, & expense
- Reduces mass & power consumption
- Reduces payload integration risk and schedule



Functions of an L1 band On-Orbit Reprogrammable Digital Waveform Generator

Status & Projected Schedule:

- ~\$31M over 3 years
- BAA released April 2015
- Expect multiple contract awards



Advanced Clock Technologies for GPS Spacecraft



Goal: Develop manufacturable, highly-stable timing for GPS satellites

- **Cold atom atomic clock (cesium)**

- Leverage clocks used by NIST & USNO – develop low SWAP, space-compatible version
- Addressing manufacturability and reliability
- Expect 5X performance headroom over GPS III clocks
- Status:

- Built/ tested more-manufacturable microwave cavity
- Laser system build – in progress

- **Vapor cell optical clock (rubidium)**

- Similar to current GPS clocks, except lamp and OCXO are replaced with manufacturable telecom lasers & Rb vapor cell
- Effort began in 2013:
 - Demonstrated 3X performance over GPS III clocks for times less than a few seconds
 - Working to extend useful time and developing packaging options

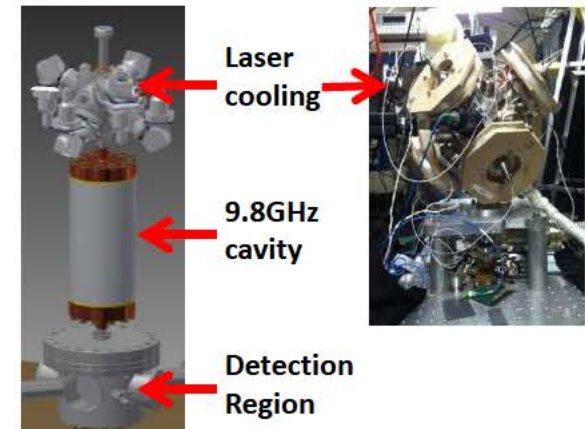
OCXO = Oven-Controlled Crystal Oscillator

Distribution A

Cold Atom Cs clock

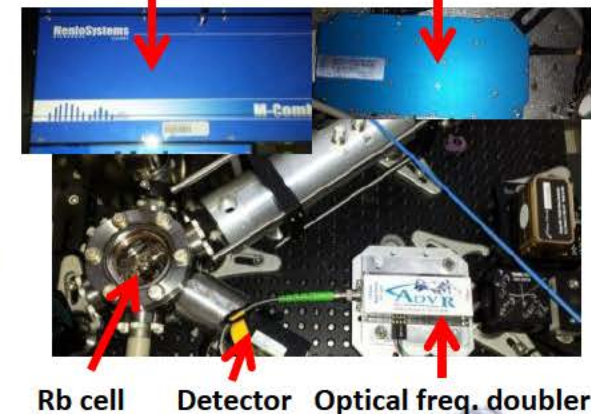
Next Gen

Current Prototype



Optical Rb Clock

Oscillator replaced with COTS probe laser and frequency comb





GPS Military High Gain Antenna



Developing Options for Ground Testing

1) Deployable phased array

- Low profile element
- High efficiency phase shifters at each element
- Leverages legacy payload amplifier and diplexer
- Heritage deployment mechanism



2) Electronically steerable Earth deck array

- Features construction modularity and high efficiency
- Minimum S/V mass impact
- Eliminates triplexer and high gain amplifier
- Replaces legacy Earth coverage array



3) Deployable reflector with phased array feed

- Modular 3-step construction
- Minimum assembly tooling
- Passive deployment mechanisms
- Compact composite shell folding scheme





Oscillating Heat Pipe (OHP) Based Chip Carrier



Phase I Moly-licked OHP Chip Carrier Photos

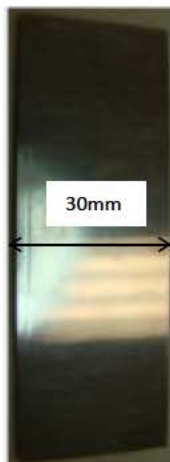
Before Sealing

After sealing

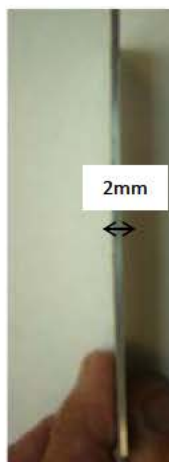
Side view



100mm



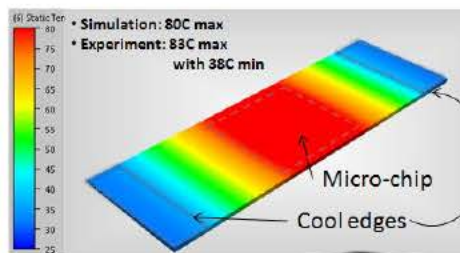
30mm



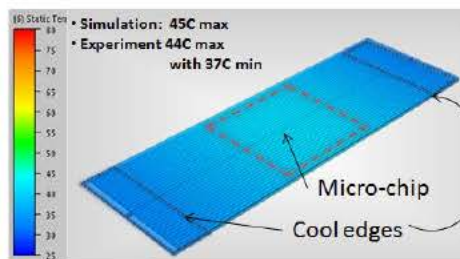
2mm

Technical Benefits and Commercialization Potential

- Durable, coefficient of thermal expansion matched die attach
- Ultra-high thermal conductivity
- Ideal for high-power/high-flux thermal management
- Manufacturable in a variety of materials, fluids, sizes



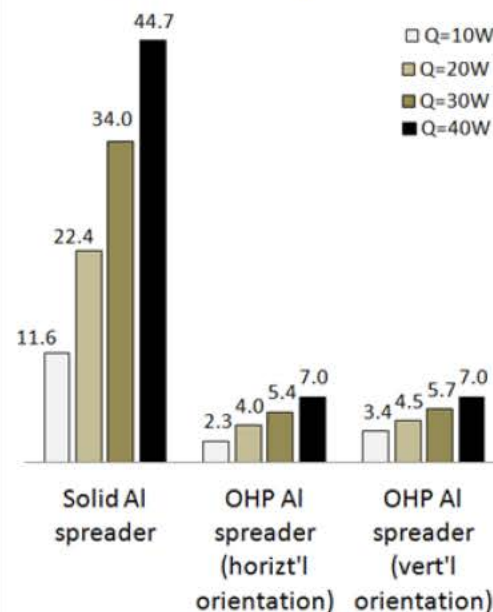
(i) Al-solid spreader



(ii) OHP-embedded spreader

(a) Finite element modeling

$$\Delta T = T_{\text{chip_interface}} - T_{\text{edges_interface}}$$



(b) Experimental measurements





Array Technologies - ROSA



High specific power / lightweight, compact stowage volume and user-friendly profile, broad re-configurability, high strength / stiffness, reliable elastic deployment with no motors or complex mechanisms, modular construction, broad scale-ability, high TRL, affordable / low cost

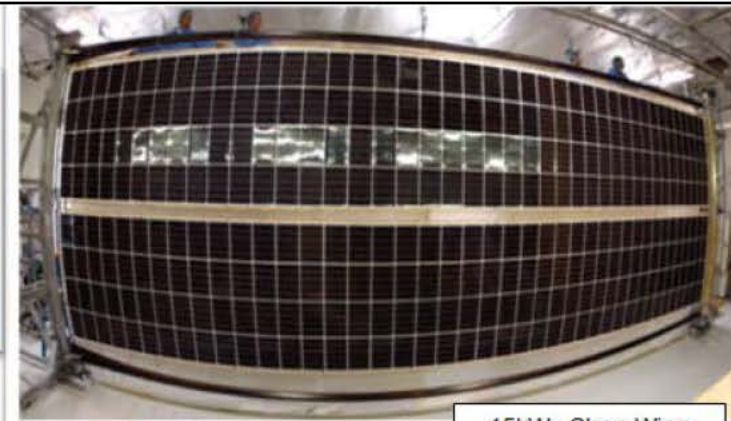
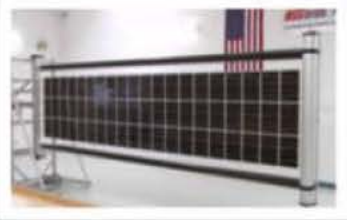
3kW-6kW Class Wing



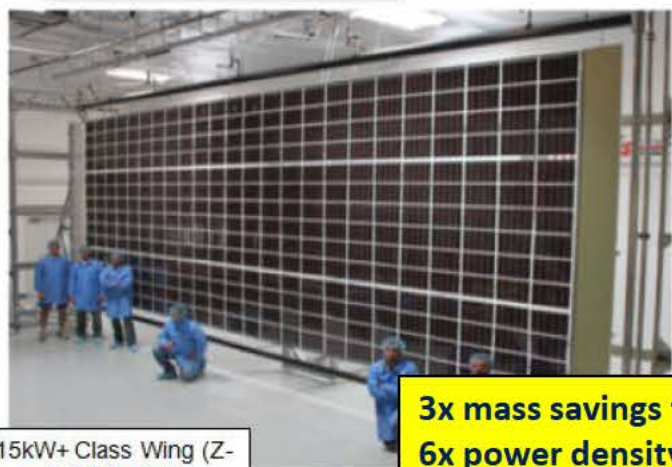
1kW-3kW Class Wing
(Retractable)



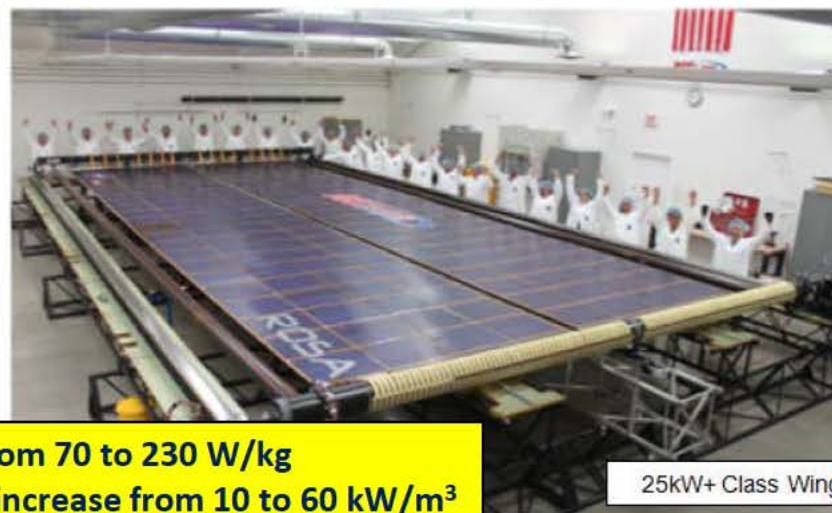
Patented and Multiple
Patents Pending



15kW+ Class Wing



15kW+ Class Wing (Z-
Fold Blanket)



25kW+ Class Wing

3x mass savings from 70 to 230 W/kg
6x power density increase from 10 to 60 kW/m³
4x improvement in wing stiffness



GPS-Focused SBIR Thrust

14.1 Summary



Title	Ph 1 Awards	Ph 2 Awards
Power Aware GPS User Equipment	2	↑
Secure Time Delivery to Military GPS Receivers Using Existing Wireless Networks	4	↑
M-Code External Augmentation System	0	Not solicited
GPS Receiver Cryptography Key Delivery Leveraging NSA Key Management Infrastructure	3	
Selective Availability Anti-Spoofing Module (SAASM) Compliant GPS Receiver for GEO	2	Not solicited
GaN Technology for L-Band Power Amplification	4	
Advanced Space Antenna for GPS	4	
L-Band Wide Bandwidth Multiplexer	4	
Radiation-Hardened, Non-Volatile Memory	4	
On Orbit Reprogrammable Waveform Generator	6	
Compact Precision Atomic Clock	2	
Optical System for Clocks and Stable Oscillators	5	
GPS PNT Flexible Satellite	3	
PNT, Comm, Architecture, Mission Design	5	
Disruptive Military Navigation Architectures	11	
Alternative Control Architecture for Residual GPS IIA Spacecraft	0	
Total	59	20

User Equipment	Payload Components	Clocks	Architecture	Ground System
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Distribution A





Developing a Concept for an AFRL Space Flight Experiment



GPS technology ideas under consideration:

Test advanced payload technologies

- Advanced Amplifiers
- ORDWG (Digital Waveform Generator)
- Active array
- Advanced clocks
- High power, directional signals

Ground segment experiments

- Uplink ranging
- Control of hosted payloads

Crosslink experiments

Experiments with alternate signals

- Binary coded signals
- Composite BPSK
- Sinusoidal offset carrier
- Multilevel coded spreading symbols
- Prolate spheroidal wave functions

**Other
Ideas
??**

Other potential experiments

- LEO to MEO via electric propulsion
- Advanced User Equipment Concepts

Also:

- Quantify how well advanced signal generation and transmission meets
 - Current GPS requirements
 - Future needs
- Measure ground systems' performance

Goal: Solidify a GPS experiment concept for consideration as AFRL's next space flight experiment (~2020-2022)



Colonel Goldstein Wants YOU!



- GPS PNT Payload Technology development is a relatively new area for AFRL
- But we plan to make it a long term, core competency
- To that end, we are looking for a few good men/ women who want to explore new GPS PNT Payload technologies and concepts with us!



Interested? Contact me after the briefing or.....

- Kevin Slimak, l.slimak@us.af.mil, 505-846-1925
- Misty Crown, misty.crown@us.af.mil, 505-853-2558
- Tom Roberts, thomas.roberts.6@us.af.mil, 505-846-7039



Summary



- AFRL is funding a portfolio of science and technology efforts to provide **options** for future GPS spacecraft
 - Working in close partnership with the GPS SPO
- The goal of these efforts is to provide options for:
 - Smaller, less costly space vehicles
 - Performance improvements at affordable cost
 - Flexibility in future spacecraft