Project SEXTANT
New Thinking on Alternative PNT

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Explore Alternative PNT

- Identify and examine options
- Identify the key factors needed to catalyze development
- Develop a ‘way forward’ strategy
PNT Innovation Landscape

Resiliency Improvements
- M-Code
- Antennas
- RAIM
- Cyber

Alternative PNT
- Global-Coverage Sats
- Inertial (only)

GPS
- Modify
- Augment
- Substitute

New Paradigm

Increasing Disruptiveness
Project SEXTANT

Major Findings

- GPS is **vertically integrated**
- No obvious ‘**Drop-In**’ replacement
- Novel **combinations** of multiple approaches is fertile ground for **PNT innovation**
- An **independent** body is needed to **evaluate** and **coordinate** Alternative **PNT** concepts for critical functions

- Many experts have been working on GPS alternatives for some time with no clear consensus crystallizing on a path forward
GPS as a PNT Source
The Birth of GPS

(U) Briefing—Navigation Satellite Study

24 AUGUST 1966

Prepared by J. B. WOODFORD and H. NAKAMURA
System Planning Division

Prepared for COMMANDER SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
LOS ANGELES AIR FORCE STATION
Los Angeles, California

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By Authority of ADG 14

EL SEGUNDO TECHNICAL OPERATIONS • AEROSPACE CORPORATION
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Radionavigation from Space

<table>
<thead>
<tr>
<th>Location of Computation</th>
<th>Computation Performed by User</th>
<th>Computation Performed by Ground Station</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Navigation Radio Link</strong></td>
<td><strong>2 Way</strong></td>
<td><strong>1 Way</strong></td>
</tr>
<tr>
<td><strong>User Equipment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R = Receiver</td>
<td>T = Transmitter</td>
<td>X = Crystal Clock</td>
</tr>
<tr>
<td><strong>Applicable Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Sats PPH</td>
<td>✓</td>
<td>✓ (Altimeter)</td>
</tr>
<tr>
<td>3 Sats PPP</td>
<td>✓ (Altimeter)</td>
<td>✓</td>
</tr>
<tr>
<td>3 Sats ΔPΔP</td>
<td>✓ (Altimeter)</td>
<td>✓</td>
</tr>
<tr>
<td>4 Sats ΔPΔP</td>
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<tr>
<td><strong>User Active</strong></td>
<td>USER</td>
<td>USER</td>
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<tr>
<td><strong>User Passive</strong></td>
<td>USER</td>
<td>USER</td>
</tr>
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*Unclassified.*
Influence of Prevailing Technology on GPS

1966

- Simpler RF environment
- Focused mission applications
- Electronic components were large
- Processing power at its infancy
- Government at the forefront of technological innovation

2015

- Rich ambient RF ‘flora and fauna’
- Plethora of users
- Electronic component size is no longer an issue
- Intensive processing in portable devices is a reality
- Technology permeates all sectors with many sources of innovation
GPS Functional Decomposition

<table>
<thead>
<tr>
<th>Component</th>
<th>Position</th>
<th>Time</th>
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<tbody>
<tr>
<td>Processor</td>
<td>TOA</td>
<td>Kalman Filter</td>
</tr>
<tr>
<td>Receiver</td>
<td>User (RF)</td>
<td>User (RF)</td>
</tr>
<tr>
<td>Transmitter</td>
<td>Satellites (RF)</td>
<td>Satellites (RF)</td>
</tr>
<tr>
<td>PNT Data</td>
<td>Sat. Position</td>
<td>UTC</td>
</tr>
<tr>
<td>Reference</td>
<td>Orbital Motion</td>
<td>Atomic Clock</td>
</tr>
<tr>
<td>Phenomenon</td>
<td>Radionav.</td>
<td>Cesium Atom</td>
</tr>
</tbody>
</table>

- Vertically integrated
- Satellites act as a relay of PNT data (orbital position)
Basis for an Alternative-PNT Framework

**GPS**

**PNT Components**
Contribute to a PNT solution but cannot otherwise generate a solution alone

**PNT Concept**
A complete system capable of producing a PNT solution
Many PNT Components Identified

<table>
<thead>
<tr>
<th>PNT Components Identified</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>18</td>
</tr>
<tr>
<td>Receiver</td>
<td>12</td>
</tr>
<tr>
<td>Transmitter</td>
<td>23</td>
</tr>
<tr>
<td>PNT Data</td>
<td>16</td>
</tr>
<tr>
<td>Reference</td>
<td>15</td>
</tr>
</tbody>
</table>

- Over 100 PNT components identified and put into context
- Decomposing GPS into PNT Components gives us a new way to develop and describe alternatives
Innovating Alternative PNT
Inspiration from Other Sectors
Vertical to Horizontal Integration in PNT

Address Alternative PNT from the standpoint of transitioning from a vertical to a horizontal architecture

Vertical = tightly controlled
Horizontal = flexible

GPS
(Vertical Integration)
What We Can Learn From Other Sectors

There are several sectors that have relevant experience in vertical/horizontal transition

• **Telecom**
  – Ma Bell transitioned to cell phones

• **Media**
  – Early emphasis on controlling distribution (infrastructure) transitioned to content

• **Technology**
  – Tightly controlled desktop ecosystem transitioned to cloud computing
Creating a PNT Ecosystem

**GPS**
(Vertical Integration)

**Open-Source Alternative PNT**
(Horizontal Integration)

**Reference Phenomenon**
**Transmitter**
**Receiver**
**PNT Data**
**Reference**
**Phenomenon**
Open Source PNT

Alternative PNT Ecosystem

- Flexible horizontal architecture
- Creates a modular ecosystem for developing PNT components
- Dynamically integrates multiple types of PNT components
- Separates platform stewardship from application development
- Distributes PNT over many devices, technologies, and phenomenology
Resiliency Through Flexibility

Flexible Architecture serves as a ‘nudge’ to change behavior

- End users take on greater responsibility for PNT integrity
- Increased awareness with a “PNT Quality” indicator

= degraded quality

= tampering suspected
Alternative PNT Framework
Evaluating PNT Concepts

Which Combination of PNT Inputs To Choose?

- A framework for assessing user satisfaction is critical to support decision making

Open-Source Alternative PNT
Alternative PNT Assessment Workflow

The **Alternative PNT Framework** is the basis for an evaluation process:

- Identify and Evaluate **PNT Component Technologies**
- Develop and Integrate **Concepts**
- **Assess User Satisfaction**
The Alternative PNT Framework opens the aperture on future thinking

- The Open-Source PNT Concept illustrates the value of considering different business models

- The Framework highlights opportunities that may emerge from disaggregating the PNT user base

- Examining critical PNT functions across the DOD, civilian, and commercial sectors is worthy of investment to quantify user needs and options for satisfying them