

An Expurgated History of the GPS Revolution

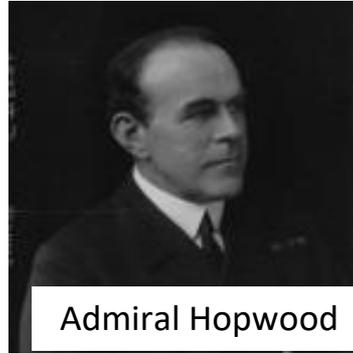
on the occasion of the 50th anniversary of its
initial approval in December of 1973

By Bradford Parkinson -
(There at the beginning)

Plebe "Knowledge" at US Naval Academy in 1953

"1898 -
Laws of the Navy" -

Law 5:



Admiral Hopwood

THE LAWS OF THE NAVY.
Dedicated to his comrades in the Service by the author,
Ronald A. Hopwood.

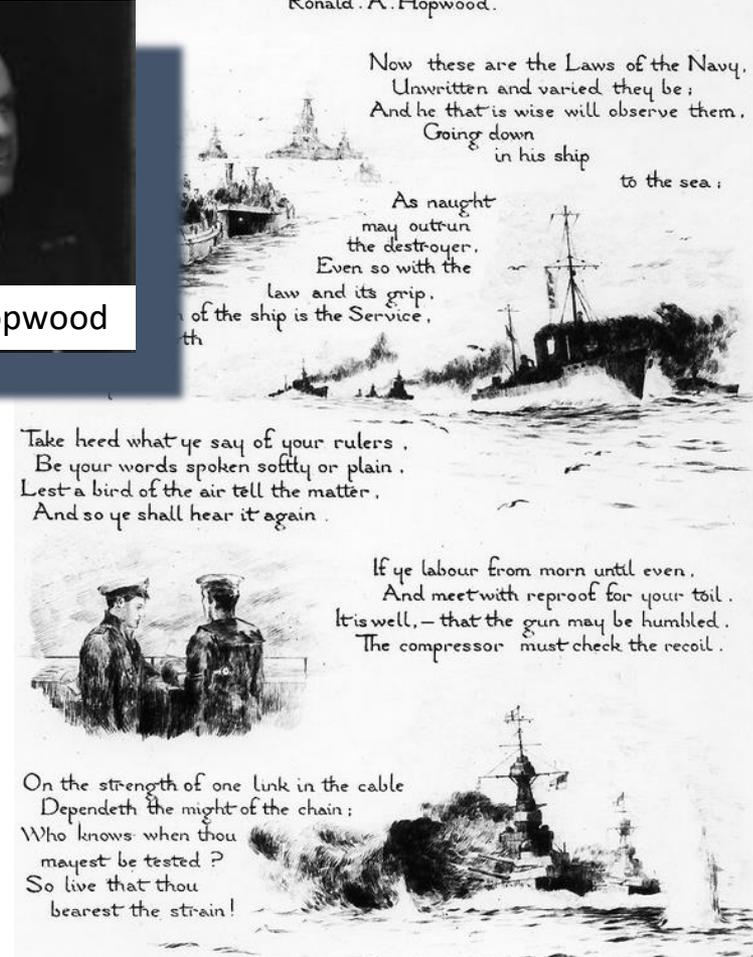
Now these are the Laws of the Navy,
Unwritten and varied they be;
And he that is wise will observe them,
Going down
in his ship
to the sea;

As naught
may outrun
the destroyer,
Even so with the
law and its grip,
of the ship is the Service,
th

Take heed what ye say of your rulers,
Be your words spoken softly or plain,
Lest a bird of the air tell the matter,
And so ye shall hear it again.

If ye labour from morn until even,
And meet with reproof for your toil,
It is well, — that the gun may be humbled,
The compressor must check the recoil.

On the strength of one link in the cable
Dependeth the might of the chain;
Who knows when thou
mayest be tested?
So live that thou
bearest the strain!

The page features several illustrations. At the top right, a ship is shown on the sea. Below that, two sailors in uniform are depicted in conversation. At the bottom right, another ship is shown navigating through rough, choppy waters.

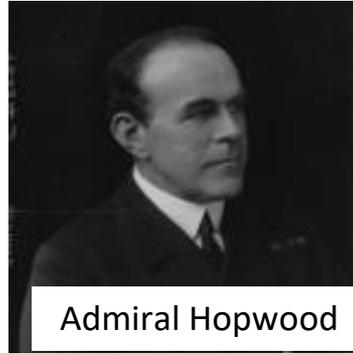
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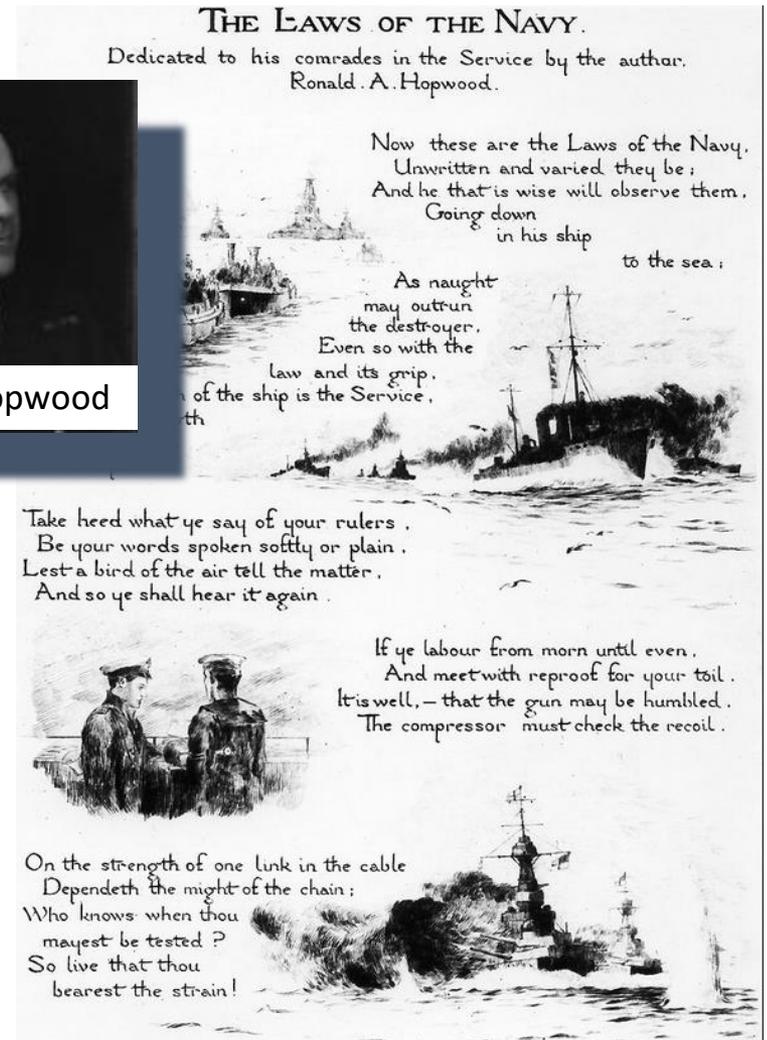
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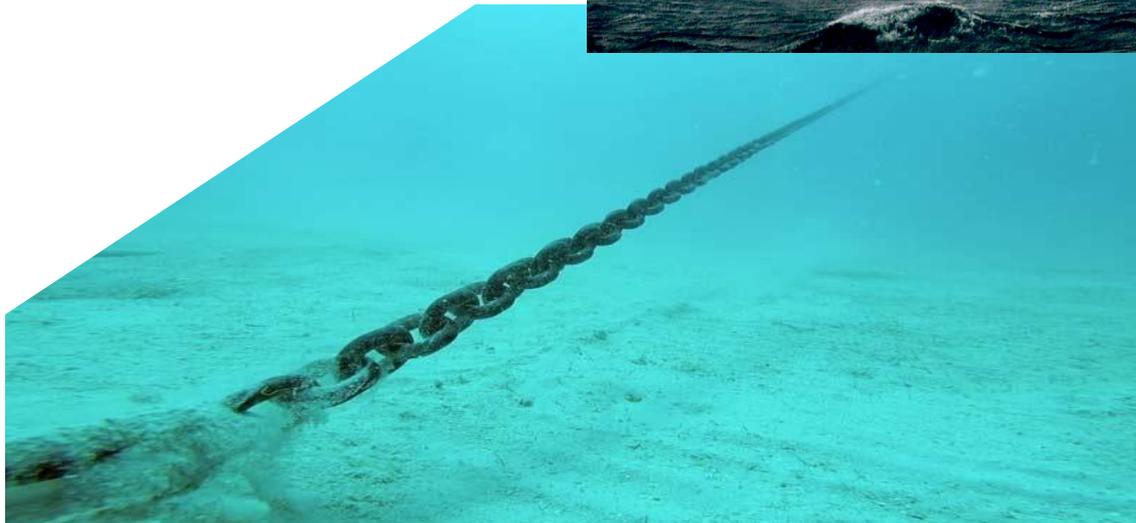
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GPS weathering *Protracted* *Storm* (1972 to 1978)



"On the strength of one link in the cable
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GPS weathering *Protracted* *Storm* (1972 to 1978)

The Anchor and the chain links had to hold in spite of:

- Multiple Technical Challenges,
- Complexity of Interface Management
(My Office was acting as Integration Managers)
- Attacks on the GPS budget,
- Extreme Hostility by the operational; Air Force



"On the strength of one link in the cable
dependeth the might of the chain; "

Setting the Scene : *The Ancient Era of 1966*

- There were no:
 - PCs
 - CDs and DVDs
 - Cell Phones/Text Messaging
 - Satellite TV
 - Internet
 - Streaming
 - Google
 - Facebook
 - eMail
 - iPODS
 - HDTV

Setting the Scene : *The Ancient Era of 1966*

- There were no:
 - PCs
 - CDs

• And there was no Monday night Football !!!

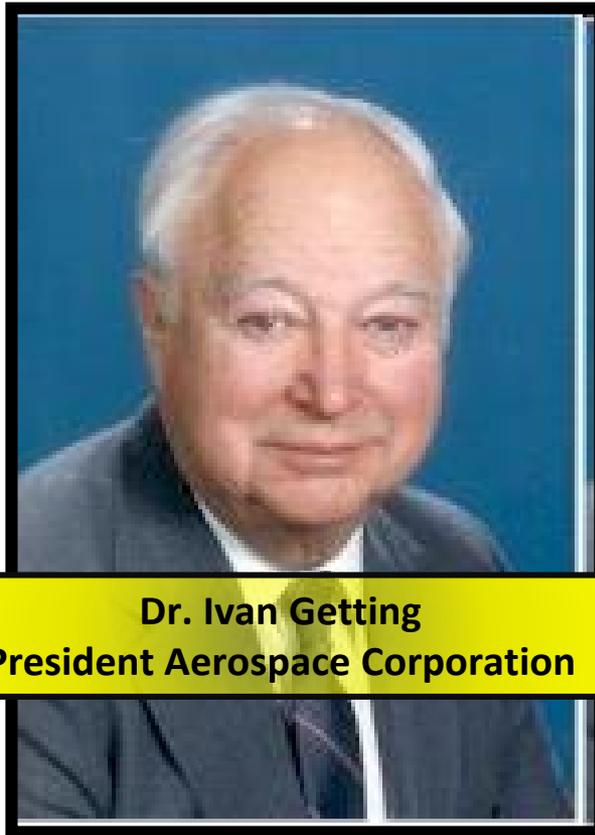
• Nor was there a GPS - but
There was an existing Satellite-based
Navigation System- USN Transit

- IPODS
- HDTV

Original "GPS" System Study- USAF 621B

The Woodford/Nakamura Secret System Study

Preliminary 1964 - Final Classified Report in 1966



Dr. Ivan Getting
President Aerospace Corporation

Original "GPS" System Study- USAF 621B

The Woodford/Nakamura Secret System Study

Preliminary 1964 - Final Classified Report in 1966

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System Planning Division

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FORM 1012

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



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6 years after GPS Definition

This was the real foundation of the decisions in the "Lonely-Halls" Pentagon Meeting

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Woodford and Nakamura Option # 12 Was the First of three great innovations that were the foundation of GPS:

Four Simultaneous Ranging measurements
to find 4-Dimensional Position

Essential Links - Support for the GPS Revolution -

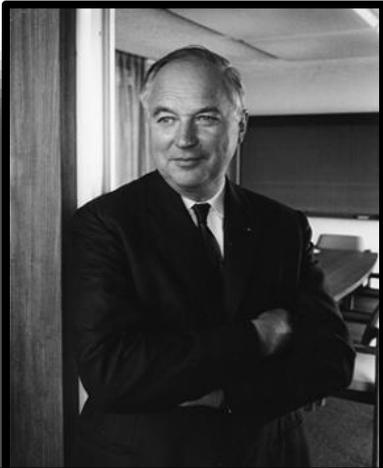
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The GPS Soothsayer

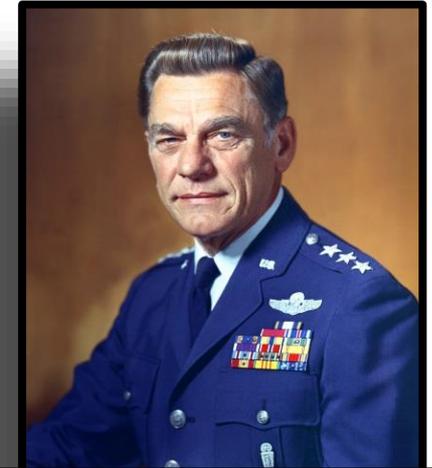
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The GPS

Air Force Sponsor

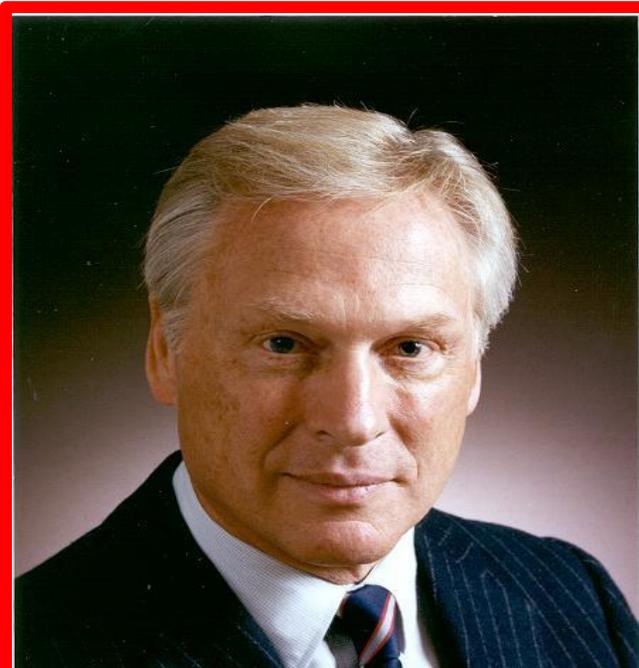
Lt.Gen Kenneth Schultz
Commander SAMS0

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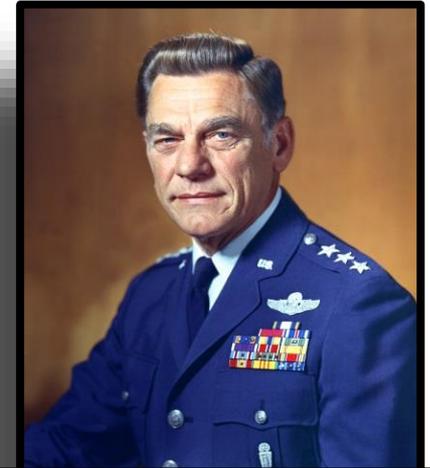
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The GPS "Godfather"

Dr. Mal Currie
Undersecretary of Research and
Engineering for the Office of
Defense



The GPS

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Lt.Gen Kenneth Schultz
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Failure

Early Links in the Chain - Defining GPS - The Lonely Halls Meeting - GPS "Architected" -

"Labor Day" Weekend (Saturday, 1 Sept. 1973 - Monday, 3 Sept. 1973)

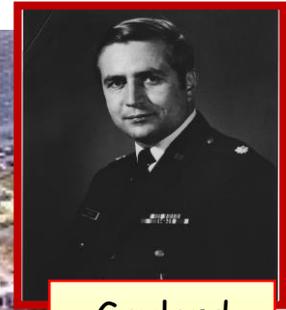


Brad Parkinson
USAF



Frank
Butterfield
Aerospace Corp.

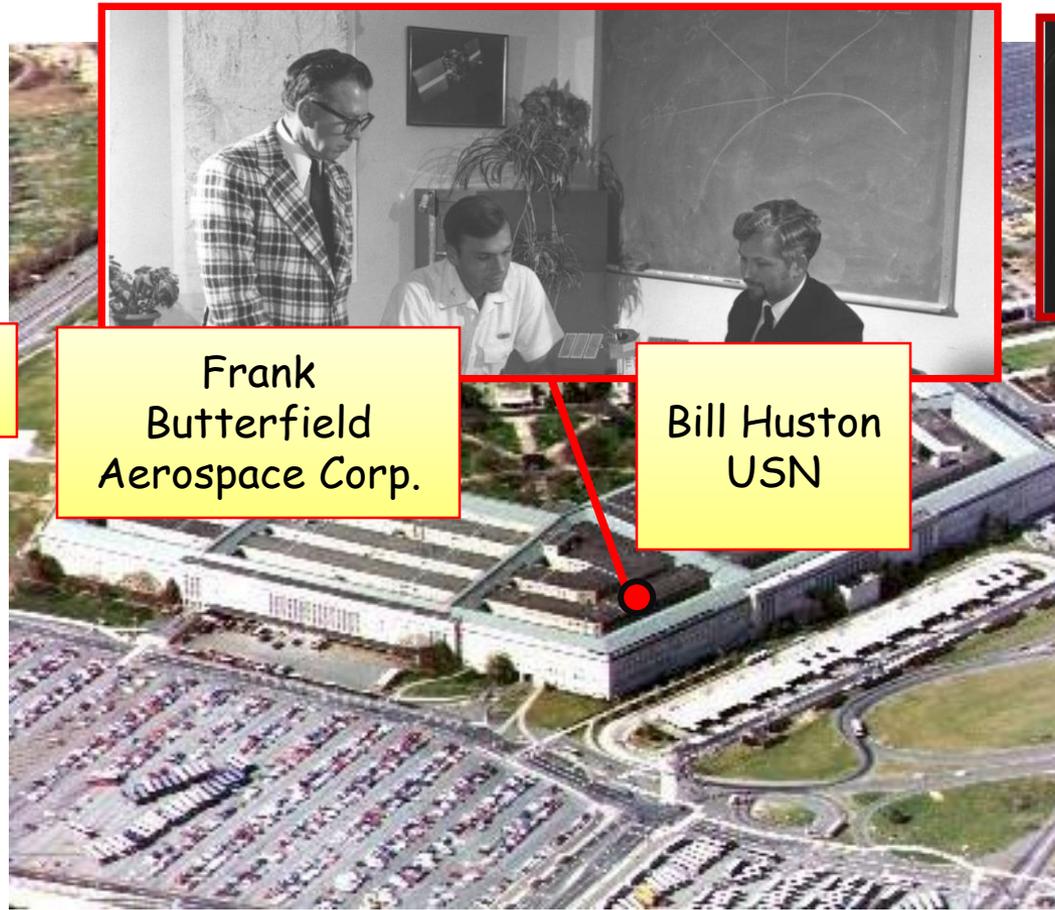
Bill Huston
USN



Gaylord
Green
USAF



Steve
Gilbert
USAF



Mel
Birnbaum
USAF

The Pentagon "Lonely Halls" System Design Meeting

Program Office/Aerospace in Attendance (~12 attendees)

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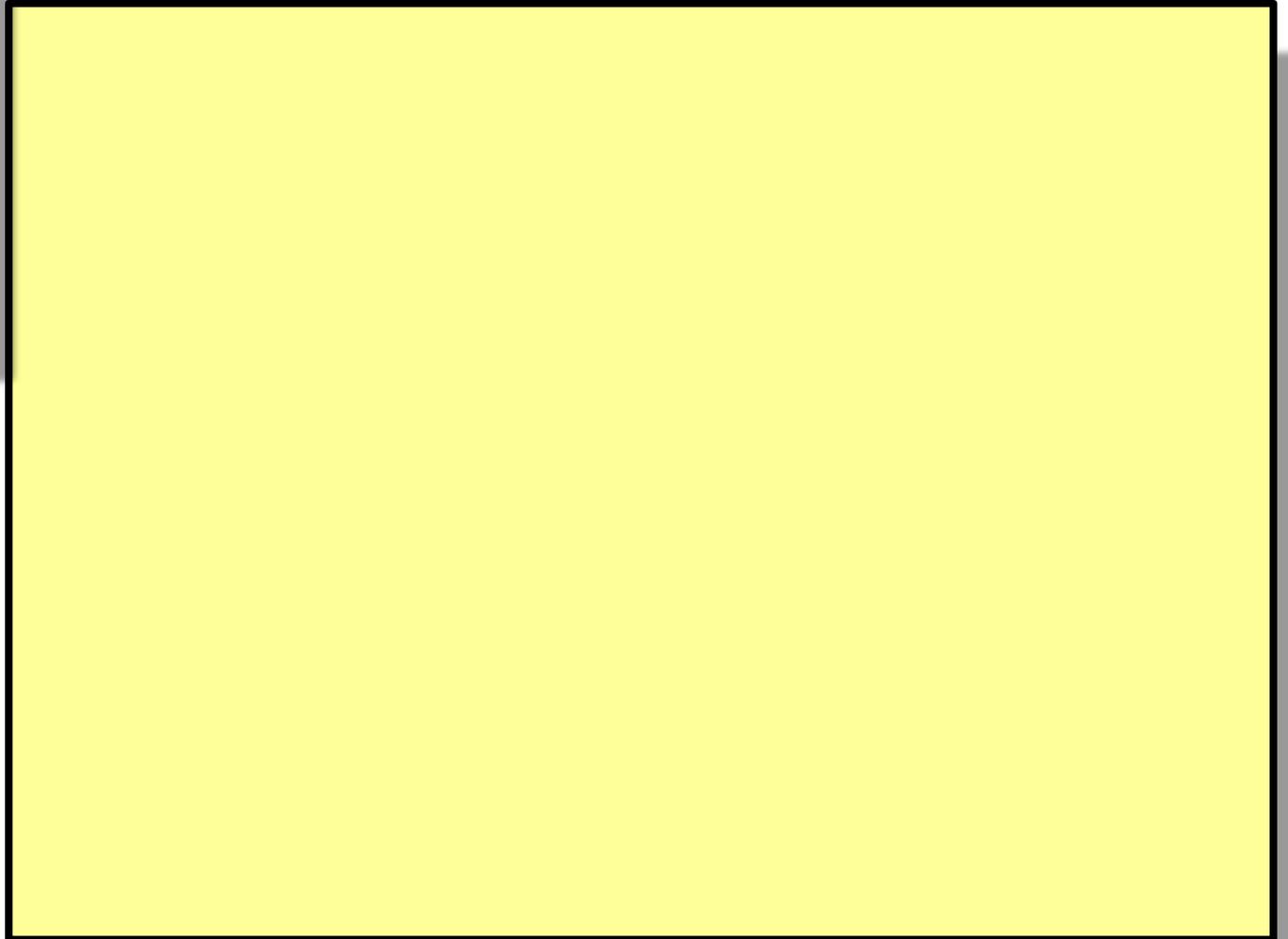
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Machiavelli on Innovation

(1513 The Prince-Ch. VI)





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Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new.



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This coolness arises partly from fear of the opponents..., and partly from the incredulity of [people], who do not readily believe in new things until they have had long experience with them."

50 Years Ago, Success:

Phase-One Demonstration Approved December 1973
- Civil use offered, but at risk

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- Budget about \$150M (1973\$), and included:
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 - Ground Master Control and 6 worldwide monitors
 - 7 Kinds of User Equipment
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And I testified to congress that we were offering
the **Receiver Signal Spec to the public.**

First civil set locked up on GPS within 24 hours of first
broadcast (students at Leeds - 1978)

But the signal was not guaranteed!

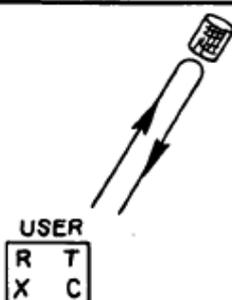
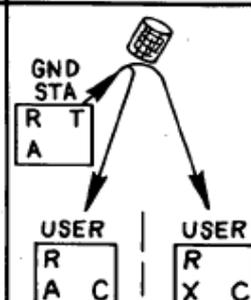
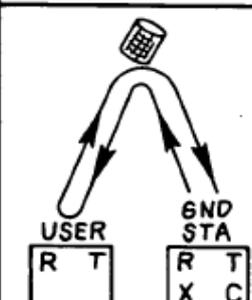
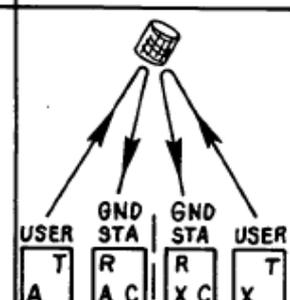
Highlighting The Three Major Innovations

First Essential Link in the Chain - The GPS System Concept



USAF/621B Woodford Study - Alt. Passive Ranging Techniques

RANGE AND RANGE DIFFERENCE SYSTEMS

LOCATION OF COMPUTATION	COMPUTATION PERFORMED BY USER		COMPUTATION PERFORMED BY GROUND STATION	
	2 WAY	1 WAY	2 WAY	1 WAY
NAVIGATION RADIO LINK 				
USER EQUIPMENT R = RECEIVER T = TRANSMITTER X = CRYSTAL CLOCK A = ATOMIC CLOCK C = COMPUTER		 	 	   
APPLICABLE MEASUREMENTS 2 SATS PPH 3 SATS PPP 3 SATS $\Delta P \Delta P h$ 4 SATS $\Delta P \Delta P \Delta P$	✓ (ALTIMETER) ✓	✓ (ALTIMETER) ✓ ✓ (ALTIMETER) ✓	✓ (ALTIMETER) ✓ ✓ (ALTIMETER) ✓	
	USER ACTIVE	USER PASSIVE	USER ACTIVE	USER ACTIVE

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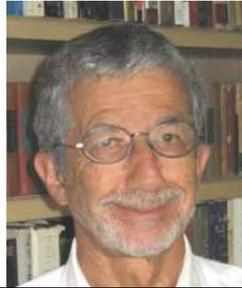
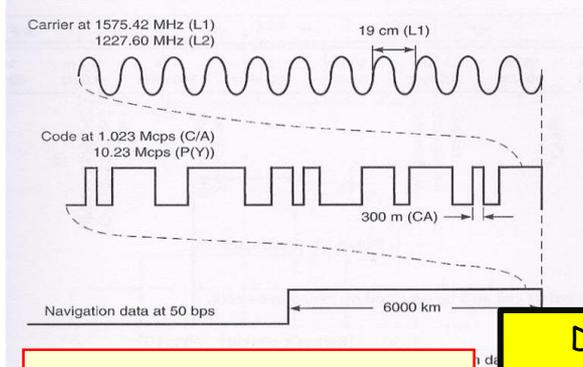
GPS (621B demo: 1971/73)



Another Essential Link in the GPS Anchor Chain: The Second Essential GPS Innovation: The Unique GPS Signal (CDMA) - now the Worldwide Standard



design



Dr. Robert Gold
(Consultant to
Magnavox in 1967)

The "new"
GPS signal (1972)



Charlie Cahn
Magnavox

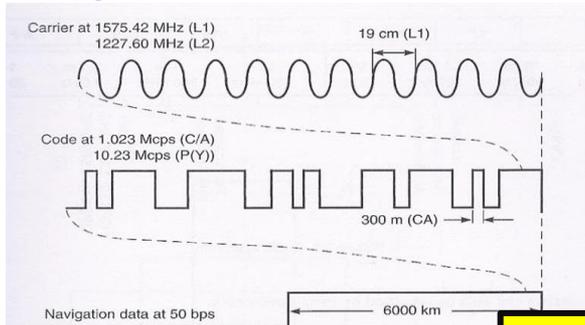


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Stanford
Telecom

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Verifying the
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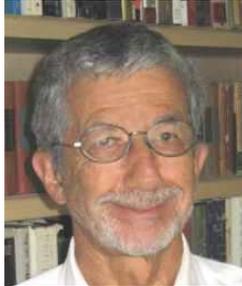
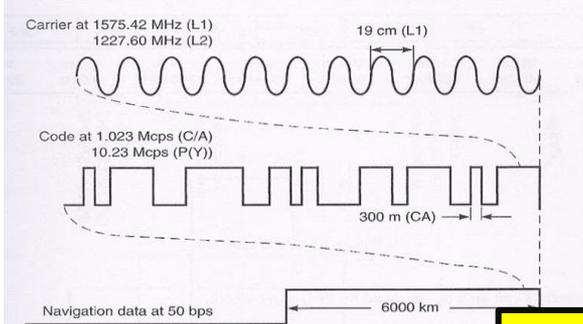


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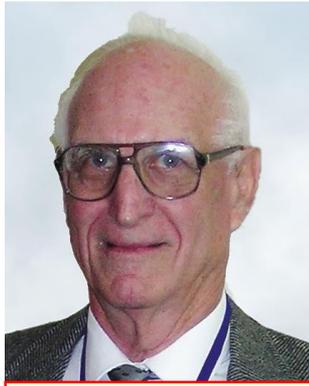


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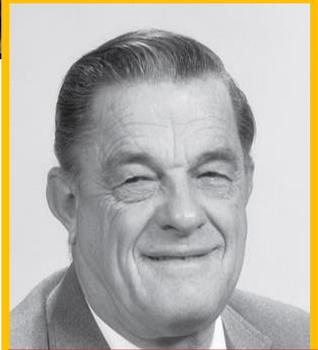
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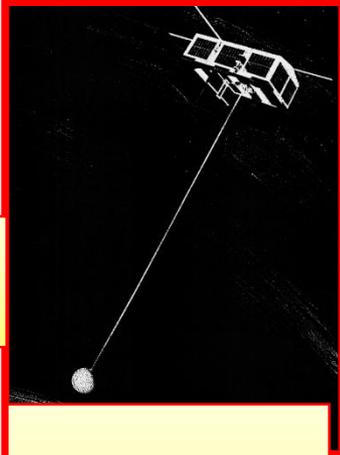
Bill Fees
Aerospace

The Third Essential Link - Space Hardened Atomic Clocks & the Link Contributors

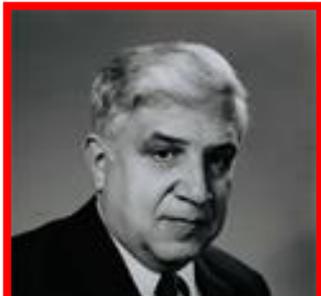
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Pete Wilhelm
NRL



Timation
First Efforts
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Roger Easton
NRL

First Miniaturized Atomic Clock -
Efratom



Ernst Jechert
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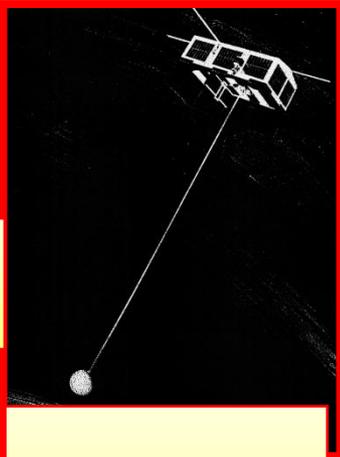


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Ernst Jechert
Efratom



Gerhard Huebner
Efratom



Dick Schwartz
Led Satellite
Development -
Rockwell



First Space-
Qualified Atomic
Clock -
Efratom/ Rockwell



Hugo Fruehauf
Rockwell

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Additional *Engineering Challenges*
(*Critical Development Links That had to work*)

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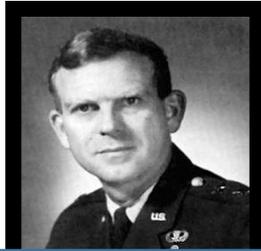
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5. **Evolutionary test concept** based on 621B (the "Inverted Range")

More Links in a Chain that would not break



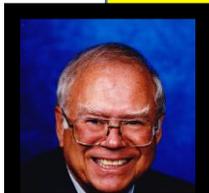
Don Henderson
Deputy Program
Director



Ed Lassiter
Led Aerospace
Support



Brock Strom
Chief Engineer for Program
Office



Walt Melton
Led Development of
Ground Control and User
Equipment General
Dynamics



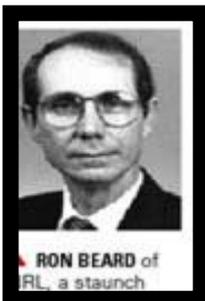
Sherm Francisco
Control Software
IBM



Dr. Bob Cooper



Dr. Bob Rennard



**▲ RON BEARD of
RL, a staunch**



**▲ A.J. VAN
DIERENDONCK**
helmet design



▲ PHIL WARD
developed the



**▲ MAJOR WALT
LARKIN, one of the**

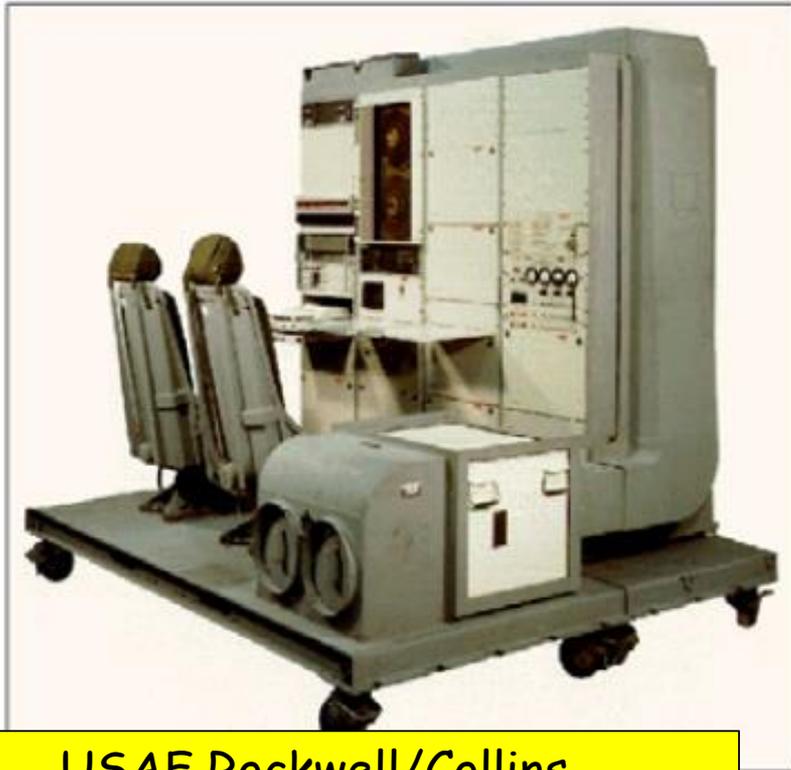
Responding to another Major Design Issue: Jamming - The Phase One A/J demonstrator

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Original Hi Anti-jam set

- Multi element antenna
- Inertial coupling
- Long averaging time

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USAF Rockwell/Collins
General Development Model
Operational 1978 (45 years ago!)

Responding to another Major Design Issue: Jamming - The Phase One A/J demonstrator



USAF Rockwell/Collins
General Development Model
Operational 1978 (45 years ago!)

Original Hi Anti-jam set

- Multi element antenna
- Inertial coupling
- Long averaging time

1978 Test Demonstrated
Ability to fly directly over
10kW jammer with no
effect...

Aside: Are civil sets currently available with full system A/J?

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NO!

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NO!

- L5 is not yet operational

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NO!

- L5 is not yet operational
- ITAR forbids more than 3 elements in civil GPS antennas
 - Although this technology at L band has been known and used for over 60 years
 - Inexpensive A/D devices are off-the shelf
 - A Turkish company is advertising a GPS antenna with 16 elements (and claimed 50 dB of improved Jam resistance, but not backed up with data)

A few additional innovations...

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- **First JPO: Deputy PMs from all services**

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- **Our motto: "Drop 5 bombs in the same hole"**

A few additional innovations...

- **First JPO: Deputy PMs from all services**
- **Contracts: Award and Incentive fees**
- **Refurbished Atlas F (ICBM) as Booster**
- **User equipment competition**
- **Our motto: “Drop 5 bombs in the same hole
and build a cheap set that navigates”**

Then What?

- First launch of GPS February 1978 -
44 months after contract award.
- Extensive testing confirmed all capability promises made in 1973...
- In 1979, US Air Force still tried to cancel development, but Civil leadership overruled attempt!

Two Defining Events

(Insured Availability of an accurate, worldwide system)

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- Pres. Reagan Commits GPS to the World (1983)

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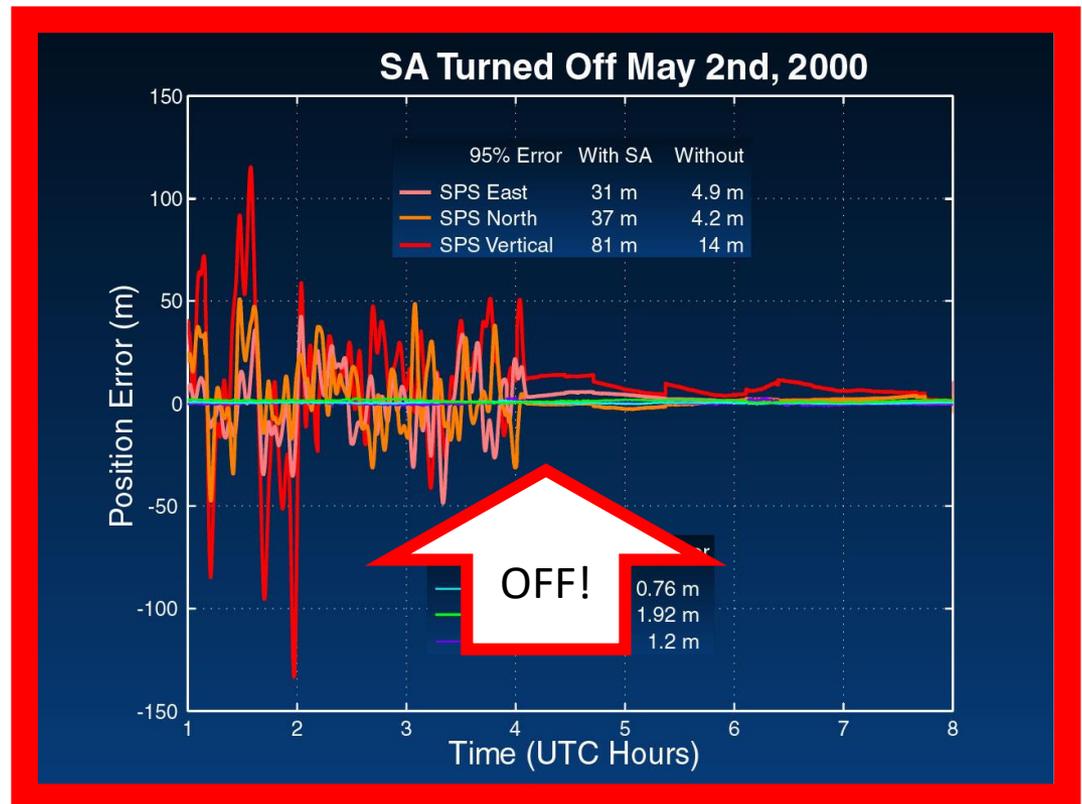
- Pres. Bill Clinton
orders
Deliberate Errors
(SA) turned off
at midnight
May 1, 2000 (UTC).

Two Defining Events

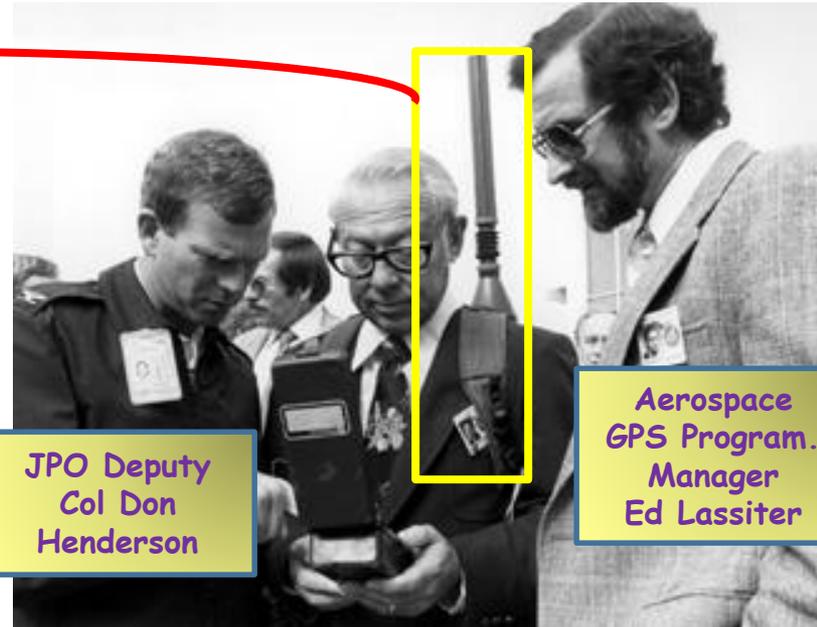
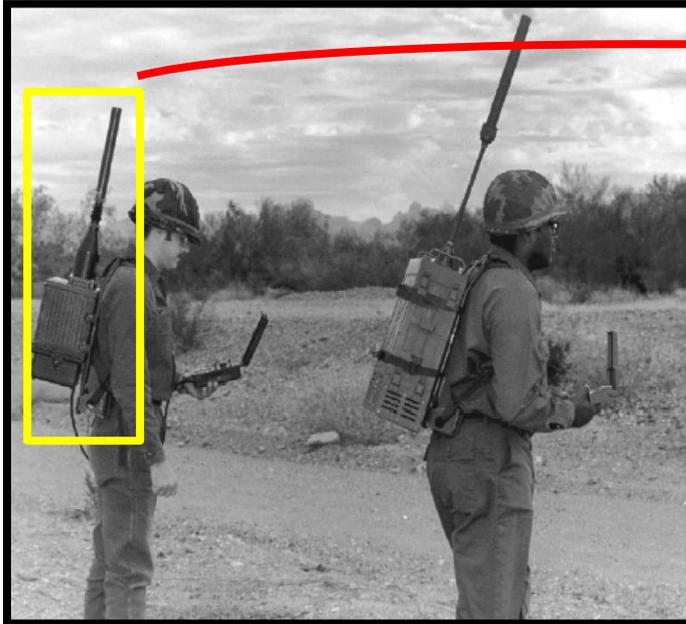
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And an Allied Defining Development: The Integrated Circuit



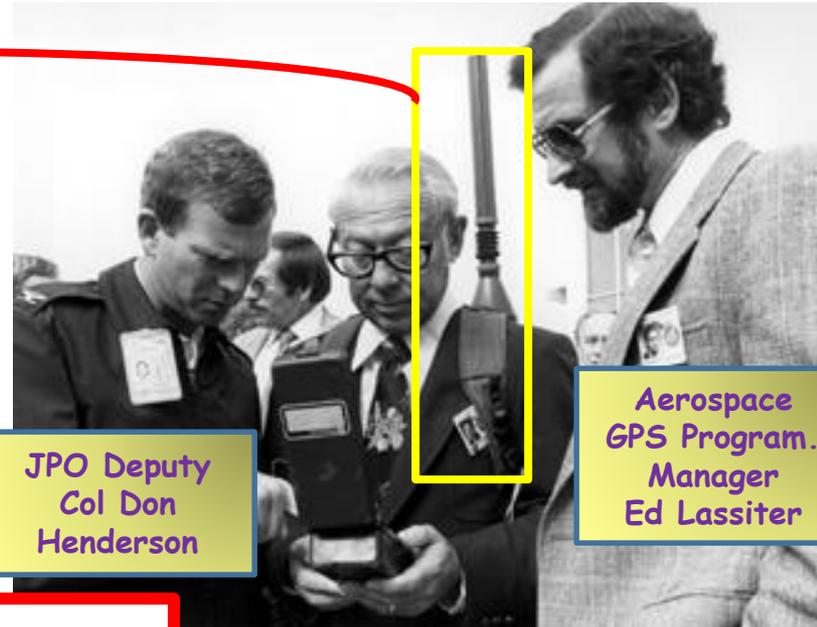
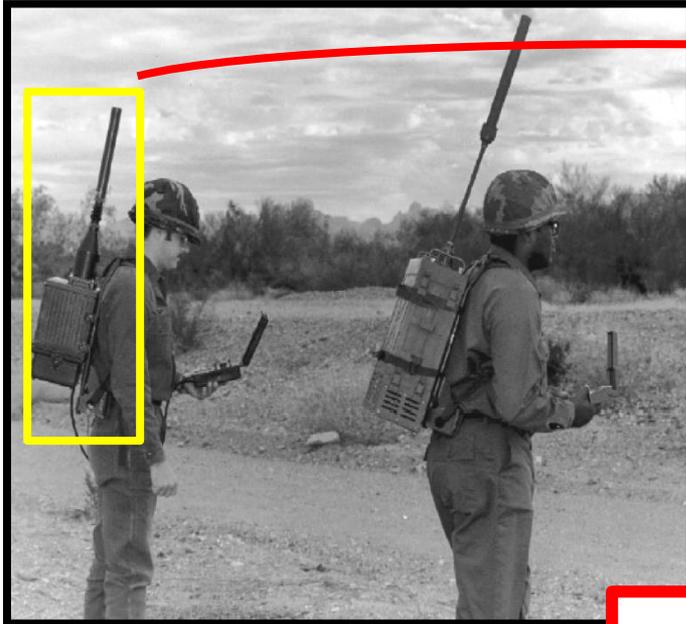
JPO Deputy
Col Don
Henderson

Aerospace
GPS Program.
Manager
Ed Lassiter

1978 "Manpack"

- "Discrete Transistors
- About 40#
- One Channel/frequency
- Batteries lasted about 6 hours
- About 10 m accuracy

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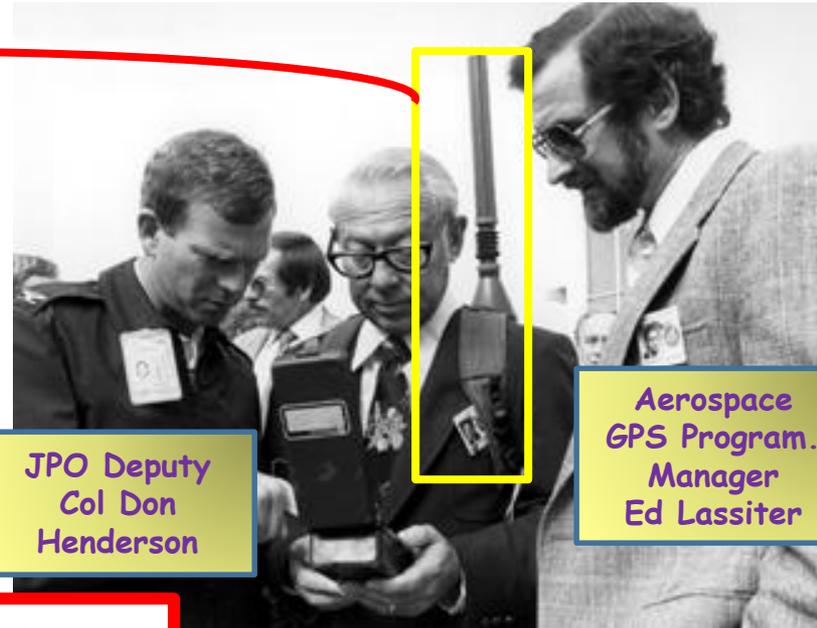
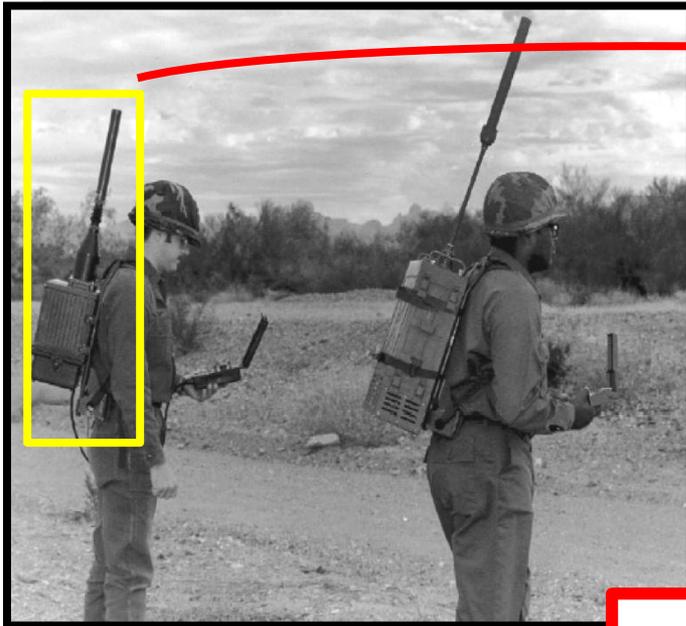
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A Modern Chip

And an Allied Defining Development: The Integrated Circuit



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A Modern Chip

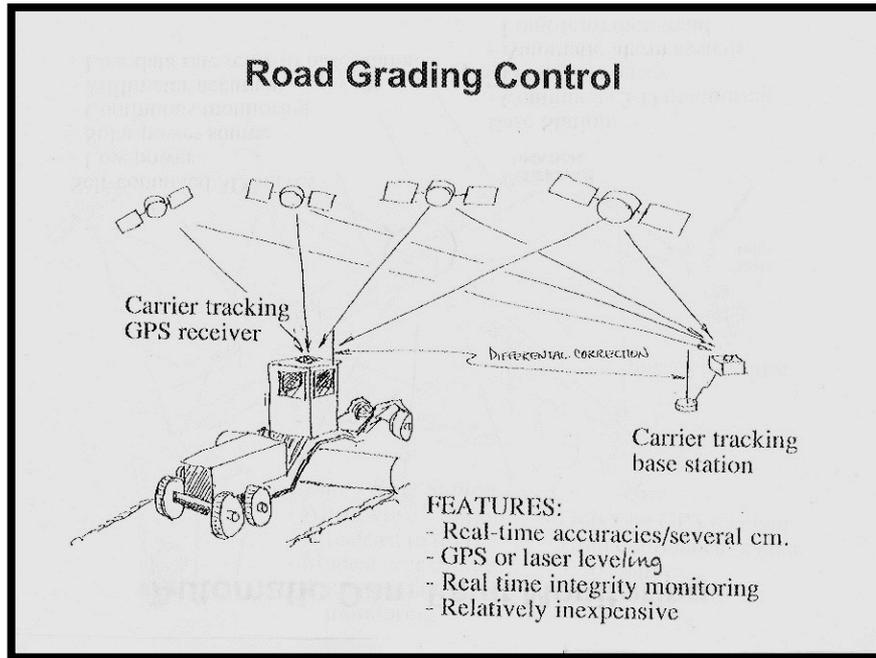
- Support 135-channel GNSS
- Dual-frequency and multi-constellation RTK positioning
- Support GPS, GLONASS, GALILEO, BEIDOU and QZSS
- Capable of SBAS (WAAS, EGNOS, MSAS, GAGAN)
- Low power consumption

BP Hand drawn Applications (1978)

(Some just slightly ahead of their time)

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BP Hand drawn Applications (1978)

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Road Grading Control

Carrier tracking GPS receiver

Differential correction

Carrier tracking base station

FEATURES:

- Real-time accuracies/several cm.
- GPS or laser leveling
- Real time integrity monitoring
- Relatively inexpensive

Automobile Navigation System

Source of traveler information

COMMUNICATIONS

GPS MICROSTRIP

HEAD UP DISPLAY

400 FEET

MOVING MAP

MOVING MAP DISPLAY

Features:

- Head up alerts and directions
- Moving map
- Automatic routing
- Traveler information:
 - motel
 - entertainment
 - hospital
- Emergency notification (2-way)

Costs \$1500 or less

Automatic Dam Fault Monitoring

Self contained 3D survey

- Low power
- Solar power source
- Calculations assembling
- Millimeter accuracy
- Low data rate relay to base station

Response - 3D position 3D velocity

Operator can easily change viewing angle

Semi-Automatic Air Traffic Control

Perspective display

ADVANTAGES:

- Reduced 3D classed GPS sensor cost (\$1000)
- Full six dimensional digital tracking position & velocity
- Digital altimeter
- Computer alert system
- "Cooperative" maneuvering
- Suggested corrective actions
- Use of existing frequencies
- Not limited to transponders
- Reduce controller fatigue
- Optimal automatic collision alert system
- Improved air safety
- Effective differential operation
- Existing radars in backup

County Truthcasting

Survey Location

County Base Station

All-in-view solution

Broadcast to users

- Makes user charges
- 1,10° survey
- Automatic integrity monitoring

Users:

- Only one GPS receiver
- High confidence results
- 1,10° survey
- Stable reference

Semi-Automatic Crop Dusting

Features:

- Azimuth or guidance display
- Automatic row counting
- All weather operation (night)
- Memory of field location and row orientation
- Automatic wind/drift calculations
- Pseudolite serves wide area
- Guided or automatic turns

Note: In Outline Kit of research on spread each row

BP Hand drawn Applications (1978)

(Some just *slightly* ahead of their time)

Road Grading Control

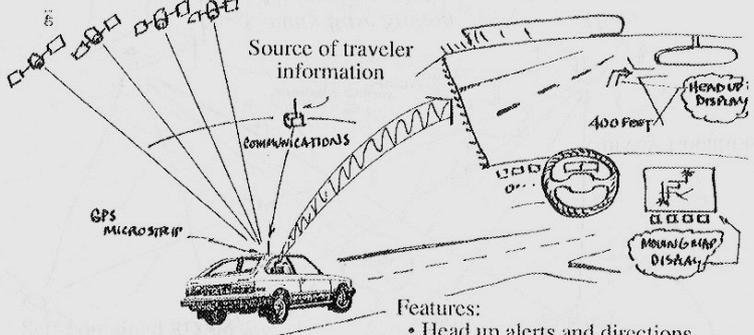


2004

Monitoring

GPS Measures 3 Dimensional Blade Position to Centimeter Accuracy

Automobile Navigation System



Source of traveler information

COMMUNICATIONS

GPS MICROSTRIP

400 FEET

HEAD UP DISPLAY

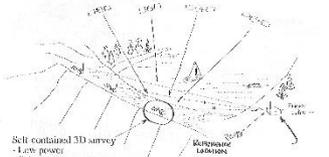
DRIVING DISPLAY

Features:

- Head up alerts and directions
- Moving map
- Automatic routing
- Traveler information:
 - motel
 - entertainment
 - hospital
- Emergency notification (2-way)

Costs \$1500 or less

Traffic Control



Self contained 3D survey

- Low power
- Solar power source
- Calculations assembling
- Millimeter accuracy
- Low data rate relay to base station

Response latencies

- Have Standard
- Continuous 3D monitoring
- Phone line query
- Automatic alarm system
- Long term data trace

Traffic Control



Perspective display

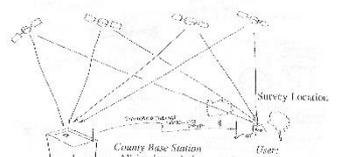
Response - 3D position 3D velocity

(Operator can easily change viewing angle)

Advantages:

- Reduced 3D classed GPS sensor cost (\$1000)
- Full six dimensional digital tracking position & velocity
- Digital integrator
- Computer aided system or "cooperative" maneuvering
- Suggested corrective actions
- Use of existing frequencies and unutilized frequencies
- Reduce counterforce
- Optimal automatic collision alert system
- Improved air safety
- Effectively differential operation
- Relative refers to backup

County Truthcasting



County Base Station

Survey Location

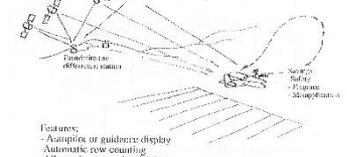
County:

- All-in-view solution
- Broadcast to users
- High confidence results
- 1.0" survey
- Automatic integrity monitoring

Users:

- Only one GPS receiver
- High confidence results
- 1.0" survey
- Stable reference

Semi-Automatic Crop Dusting



GPS

Dustbin

Sprayer

Features:

- Azimuth or guidance display
- Automatic row counting
- All weather operation (night)
- Memory of field location and row orientation
- Automatic wind/drift calculations
- Pseudorange serves wide area
- Guided or automatic turns

Note: In Outdoor Kit of research on spread each row

BP Hand drawn Applications (1978)

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Road Grading Control

2004

Monitoring

GPS Measures 3 Dimensional Blade Position to Centimeter Accuracy

Automobile Navigation System

2015

\$149!

Emergency notification (2-way)

Traffic Control

Self contained 3D survey

- Low power
- Solar power source
- Calculations downloading
- Millimeter accuracy
- Low data rate relay to base station

Response time

- Has 3 channel
- Continuous 3D monitoring
- Phone line query
- Automatic alarm system
- Long term data trace

Traffic Control

Perspective display

Response - 3D position 3D velocity

(Operator can easily change viewing angle)

Features:

- Multichannel 3D channel GPS sensor cost - \$1000
- Full 3D dimensional digital tracking position & velocity
- Digital altimeter
- Computer aided system
- "Geometric" mapping
- Suggested corrective actions
- Use of existing frequencies
- Not limited to roadways
- Reduce controller failure
- Optimal automatic collision alert system
- Improved air safety
- Effectively differential operation
- Relative refers to backup

County Truthcasting

Survey Location

County Base Station

Features:

- All-in-view solution
- Broadcast to users
- 1, 10⁶ survey
- Automatic integrity monitoring

Costs:

- Only one GPS receiver
- High confidence results
- 1, 10⁶ survey
- Stable reference

Semi-Automatic Crop Dusting

Survey Location

Features:

- Azimuth of guidance display
- Automatic row counting
- All weather operation (night)
- Memory of field location and row orientation
- Automatic wind/factor calculations
- Pseudorange serves wide area
- Guided or automatic turns

Note: In outdoor use EIRP of beacon is spread each way

GPtS Applications have Proliferated

- **Civil**

- **Transportation**

- **Aviation**
 - **Automobile**
 - **Maritime**
 - **Rail Control**

- **Public Services**

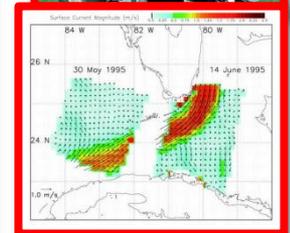
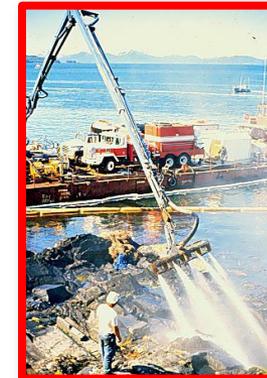
- **Timing & Frequency**

- **Surveying**

- **Surveillance**

- **Other**

- **Military**



GPS Watch - helps find your way home!



GPS Watch - helps find your way home!

And it "watches"

you -

If you haven't been
active recently -
tells you to "Move"

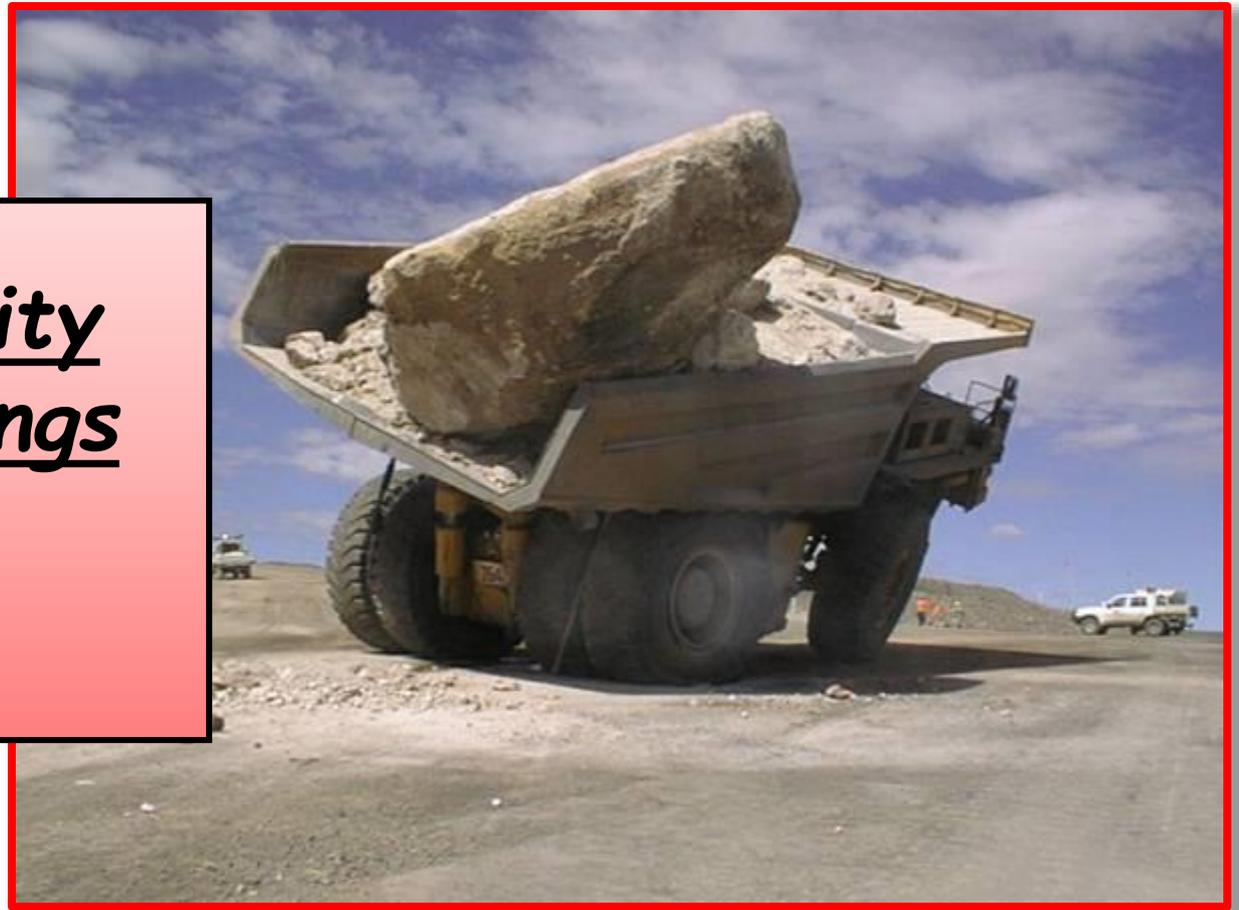


GPS Robotically Guided Trucks

- Wheels 3 meters high

Productivity
Savings

But...

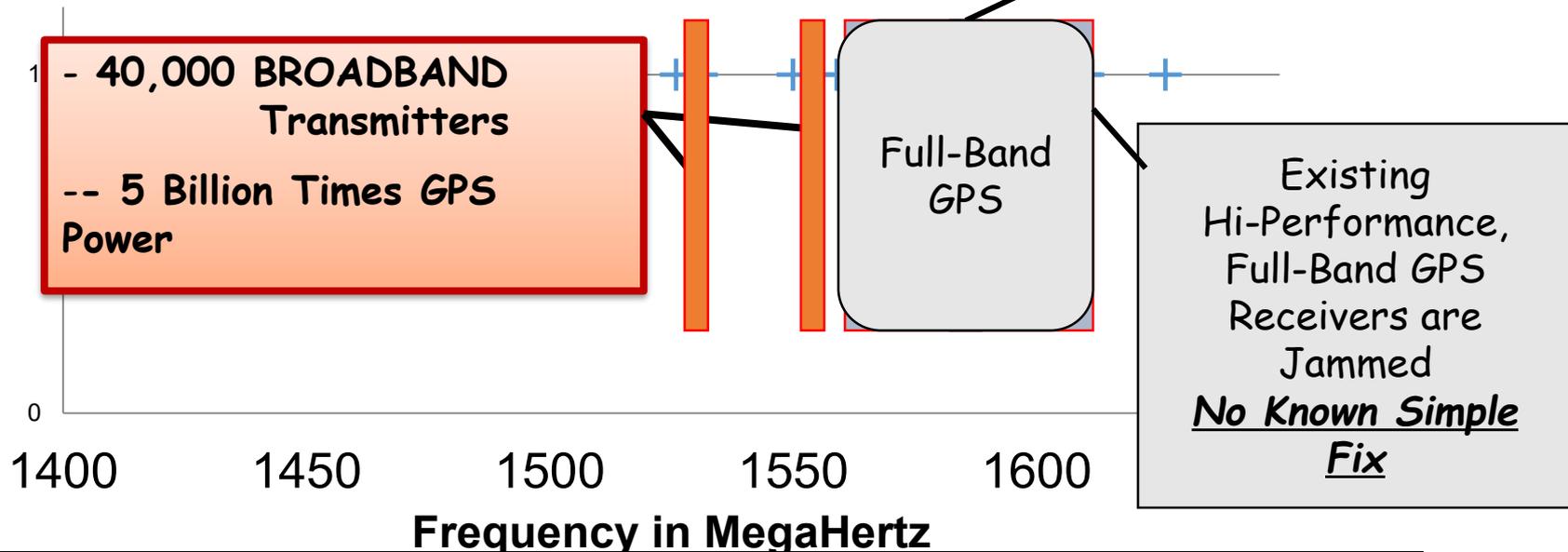


A Reminder: GPS can guide, but don't select the wrong path...



An Existential Threat to GPS - FCC Re-allocation of Nearby Band to Higher Power

Frequency Allocations in GPS Frequency Vicinity



The Ligado Problem:
Proximity (geographic and RF spectrum)
and Power

The sincerest form of Flattery... 4 Global GNSS



The sincerest form of Flattery... 4 Global GNSS



The sincerest form of Flattery... 4 Global GNSS



GLONASS – (Russia)

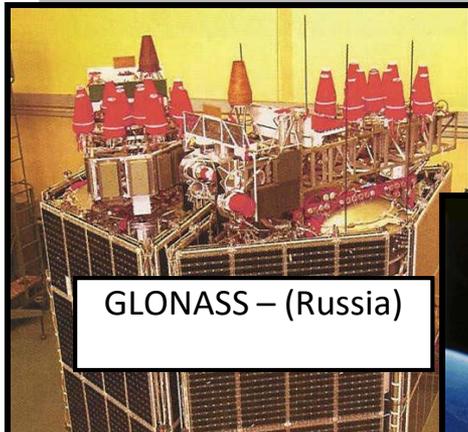
- Next generation 4 new Civil signals at two new frequencies



GP(t)S
(USA)

- First Operational Civil Signal
- Next generation 4 new signals at two new frequencies

The sincerest form of Flattery... 4 Global GNSS



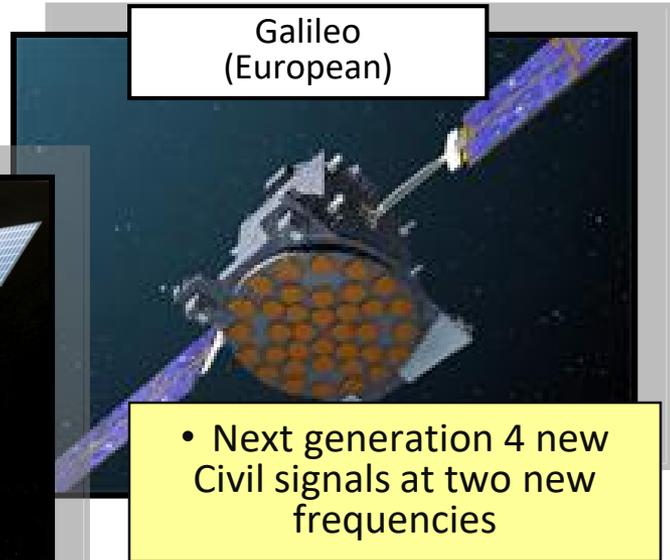
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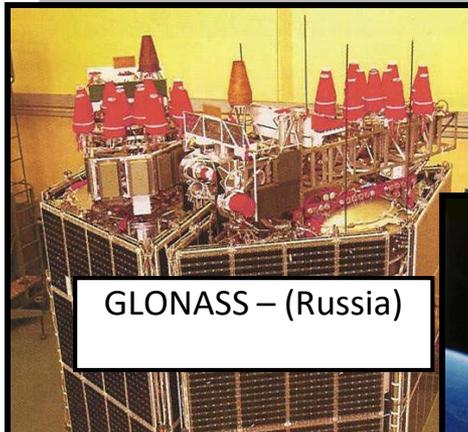
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Galileo
(European)

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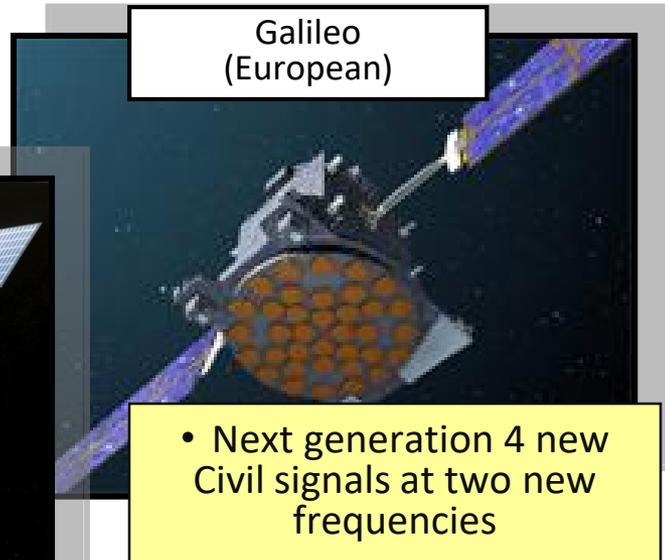
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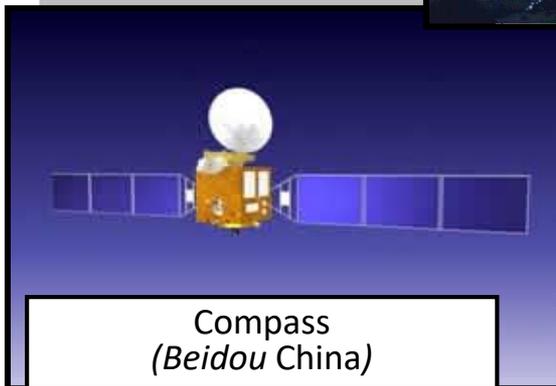
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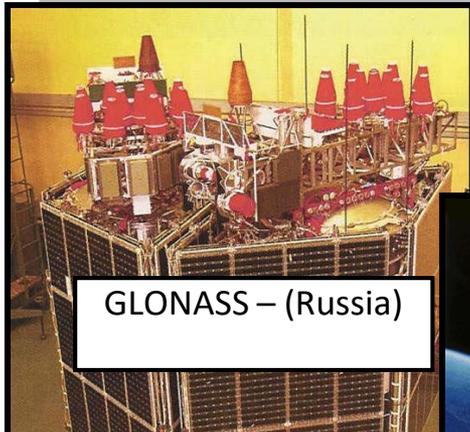
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Compass
(Beidou China)

The sincerest form of Flattery... 4 Global GNSS



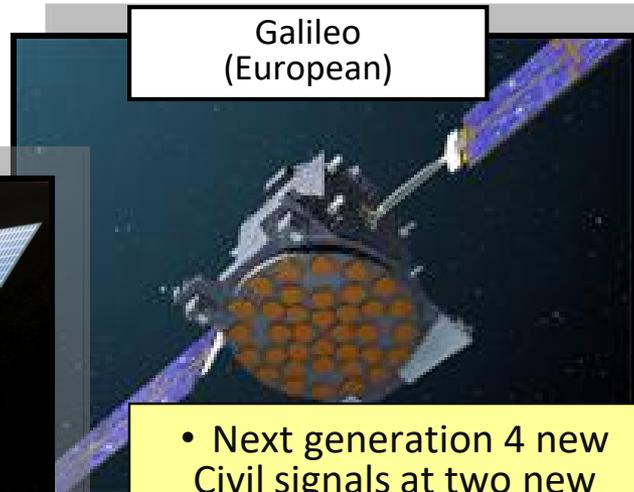
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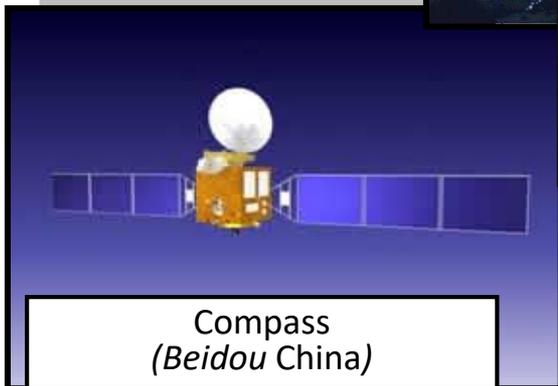
GP(t)S
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- First Operational Civil Signal
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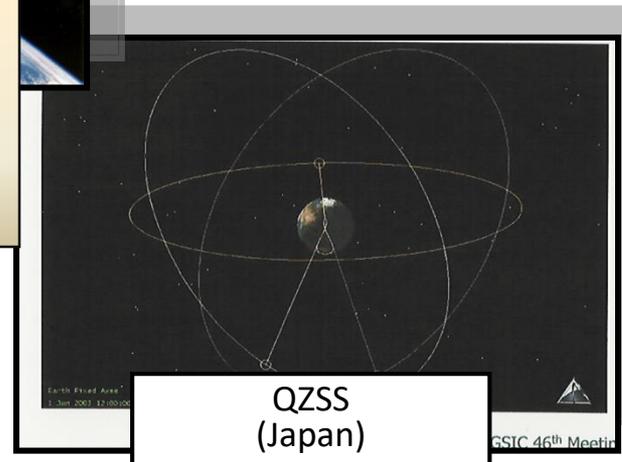


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(European)

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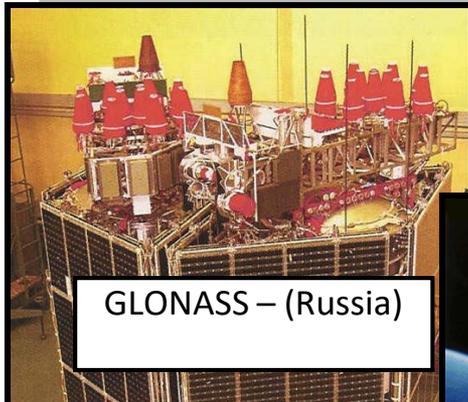


Compass
(Beidou China)



QZSS
(Japan)

The sincerest form of Flattery... 4 Global GNSS



GLONASS – (Russia)

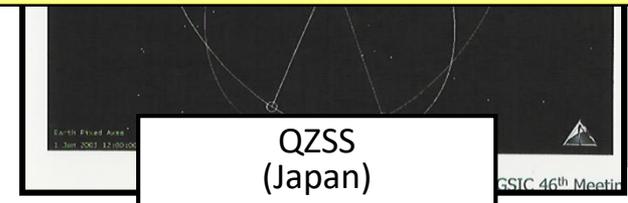


Galileo
(European)

- 10 New Civil Signals -
(Including L5 and a new International Signal called L1C)
 - This will provide Interchangeability
for All Navigation Satellite Signals
 - And there will be over 60 satellites on orbit!
- Result: Even Better Accuracy, Availability**



Compass
(Beidou China)



QZSS
(Japan)

A glimpse of the Future?

The World's First Self-Driving Semi-Truck Hits the Road (May 2015)

- “The Freightliner”
- Daimler-Benz Prototype
- GPS *plus*
- Stereo Camera Reads Lanes
- Short and Long Range Radars



Future: My Three Current GPS Issues

1. **FCC attempting to place high-powered signals in an adjacent frequency band**
 - Shown to be harmful
 - Extensive Opposition

Future: My Three Current GPS Issues

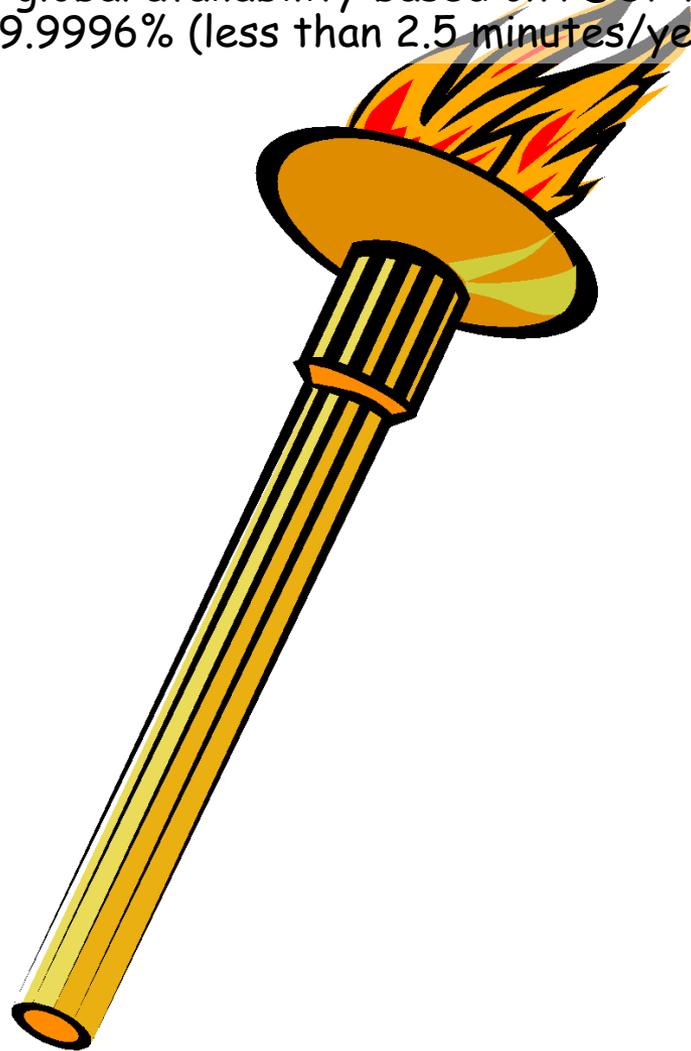
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 - Can enable integrated receivers to be virtually jamproof
 - First demonstrated 45 years ago

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1. **FCC attempting to place high-powered signals in an adjacent frequency band**
 - Shown to be harmful
 - Extensive Opposition
2. **ITAR restrictions on well-known, multi-element A/J enhancements.**
 - Can enable integrated receivers to be virtually jamproof
 - First demonstrated 45 years ago
3. **Lagging in GPS system development**
 - E.g. laser cross links, operational L5
 - Need an affordable, proliferated MEO design to reduce physical vulnerability
 - L5 signal operational

And a tribute to USSF: Carrying the Torch for GPS

FAA Annual Evaluation: the global availability based on PDOP less than six for CONUS was 99.9996% (less than 2.5 minutes/year)



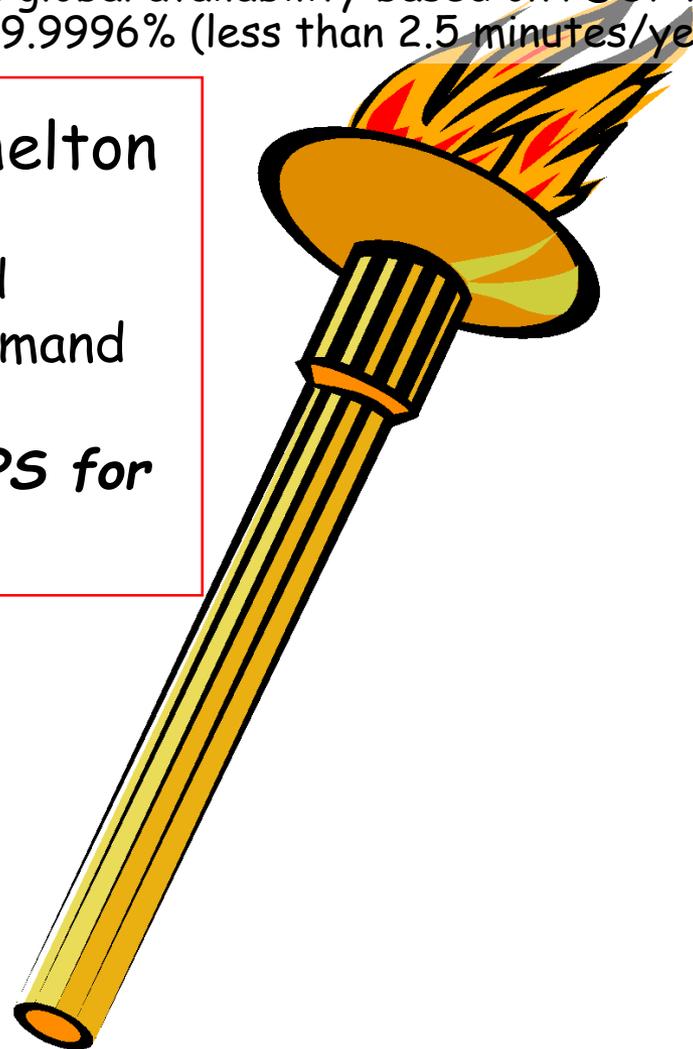
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General William Shelton

Recently Retired
CMDR US Space Command

*"Chief Steward of GPS for
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5/3/2023



• Current Operators

LCol Robert Wray
2nd Space
Operations Squadron
(GPS) Cmdr.



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5/3/2023



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*"mission will include safeguarding civil
Position, Navigation and Timing signals".
(Sept. 2022)*

*So, about 50 years ago,
GPS weathered
the Protracted Storm (1972 to 1978)*



*The Anchor and
the chain links held!!*

Thank you!

Questions?