An Expurgated History of the GPS Revolution

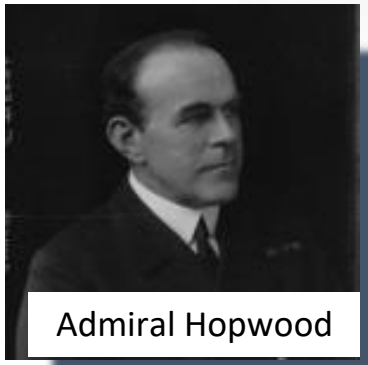
on the occasion of the 50th anniversary of its initial approval in December of 1973

By Bradford Parkinson –
(There at the beginning)

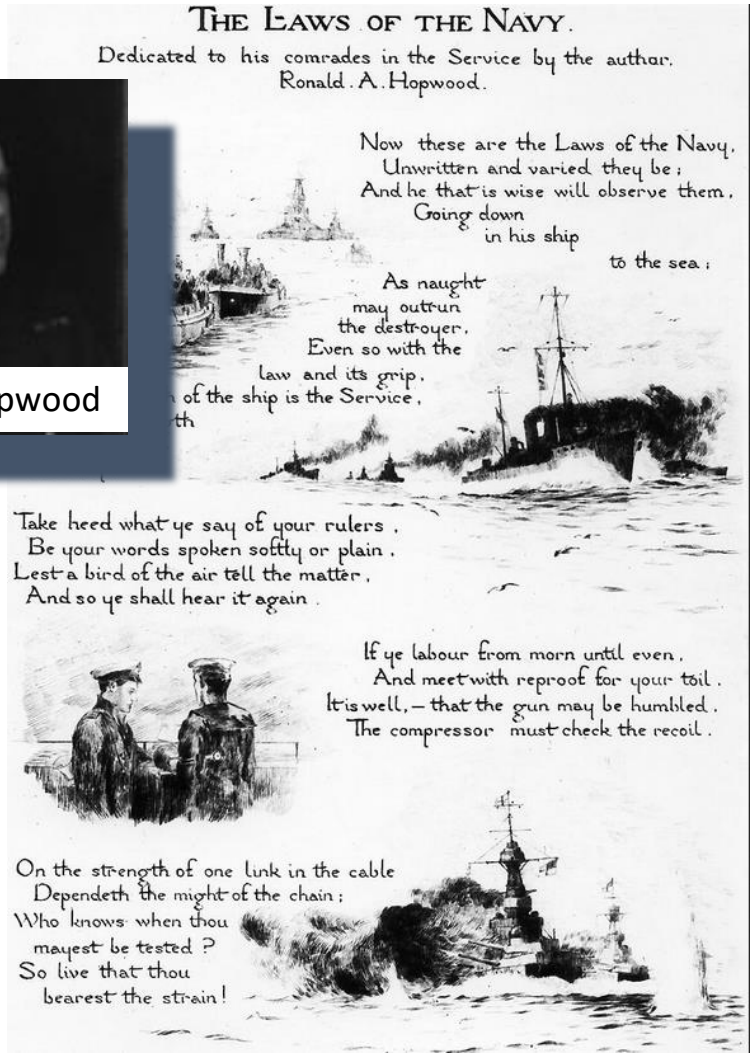
Plebe "Knowledge" at US Naval Academy in 1953

"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
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So live that thou
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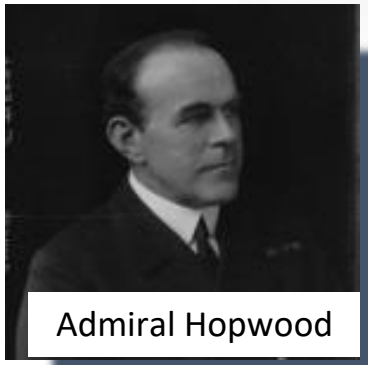
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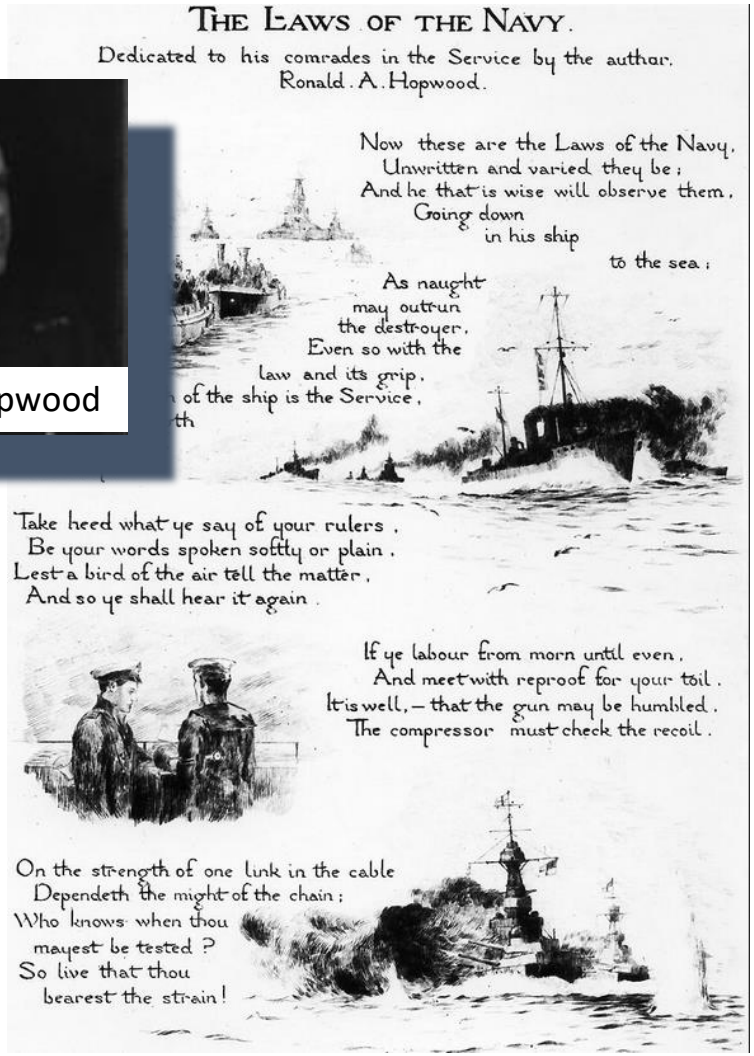
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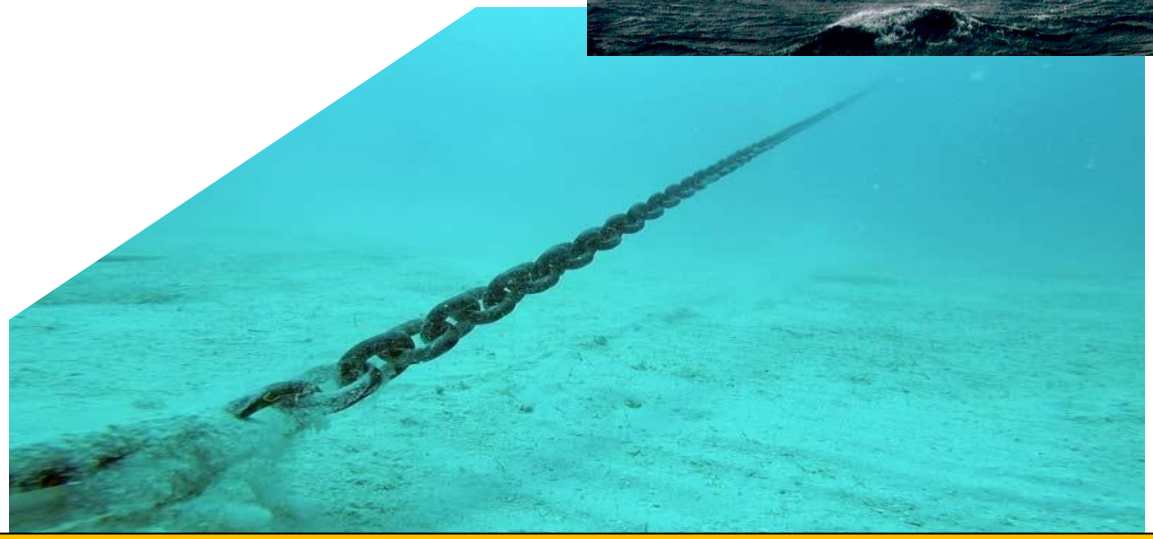
GPS weathering ***Protracted Storm*** (1972 to 1978)



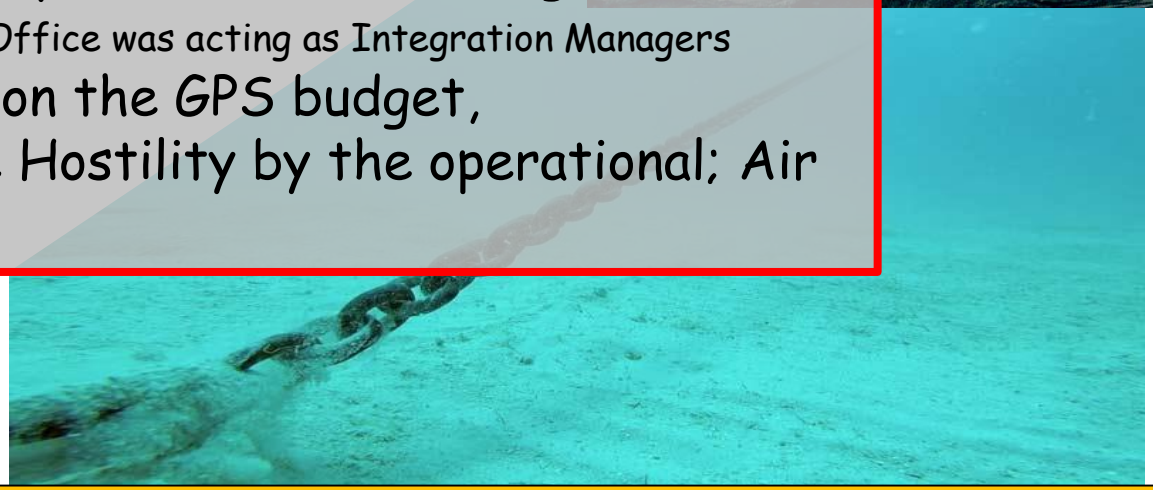
"On the strength of one link in the cable dependeth the might of the chain; "

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
  - iPODS
  - HDTV

- And there was no Monday night Football !!!
- Nor was there a GPS - but There **was** an existing Satellite-based Navigation System- USN Transit

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

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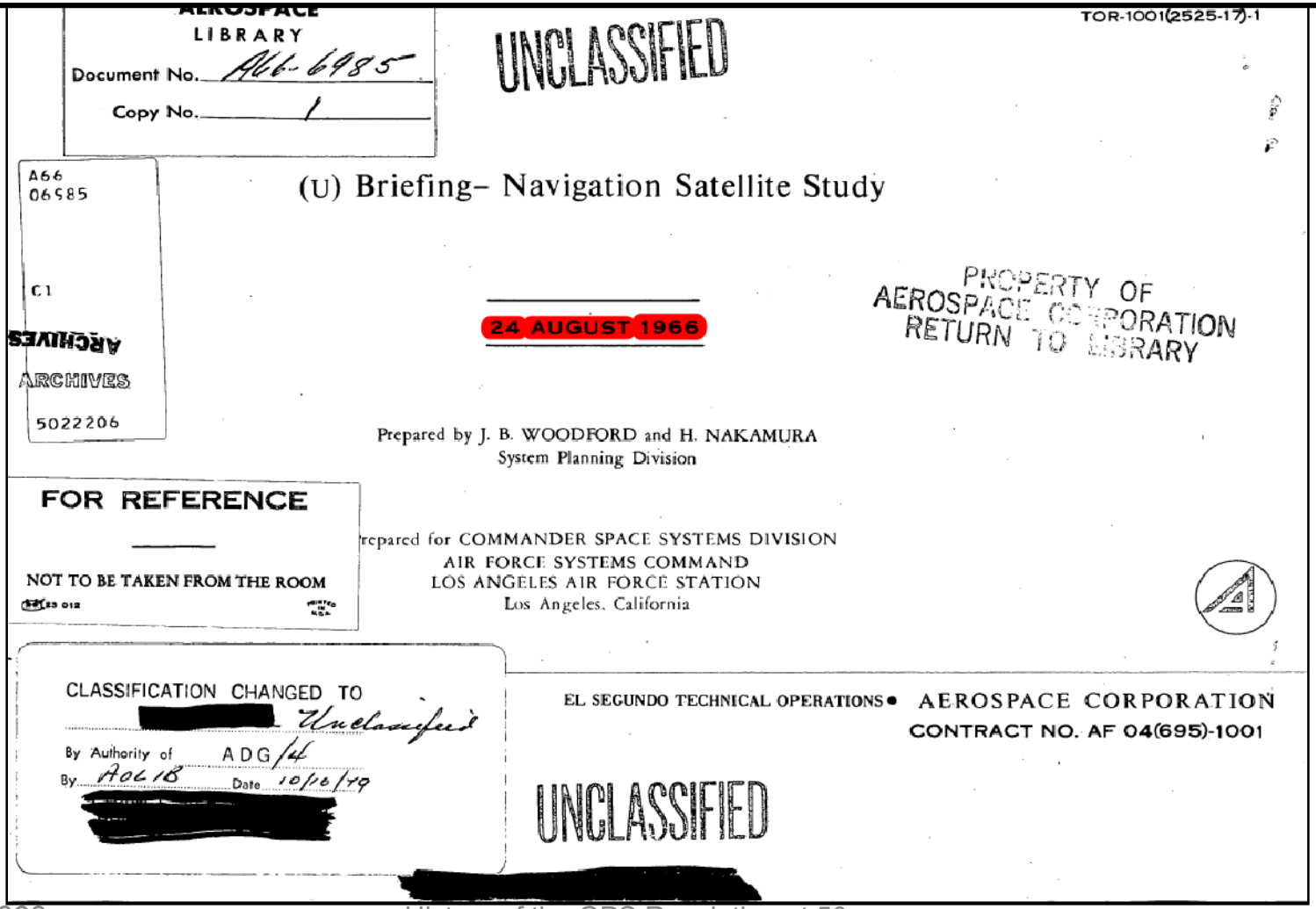

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By [redacted] Date 10/16/79

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(U) Briefing– Navigation Satellite Study

24 AUGUST 1966

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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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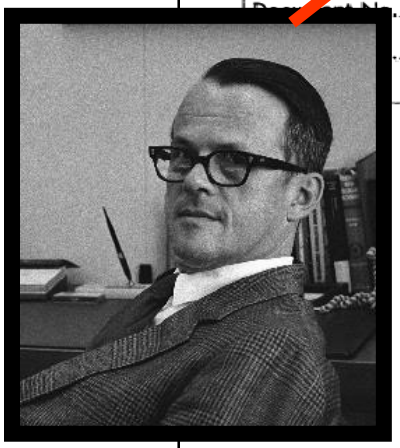

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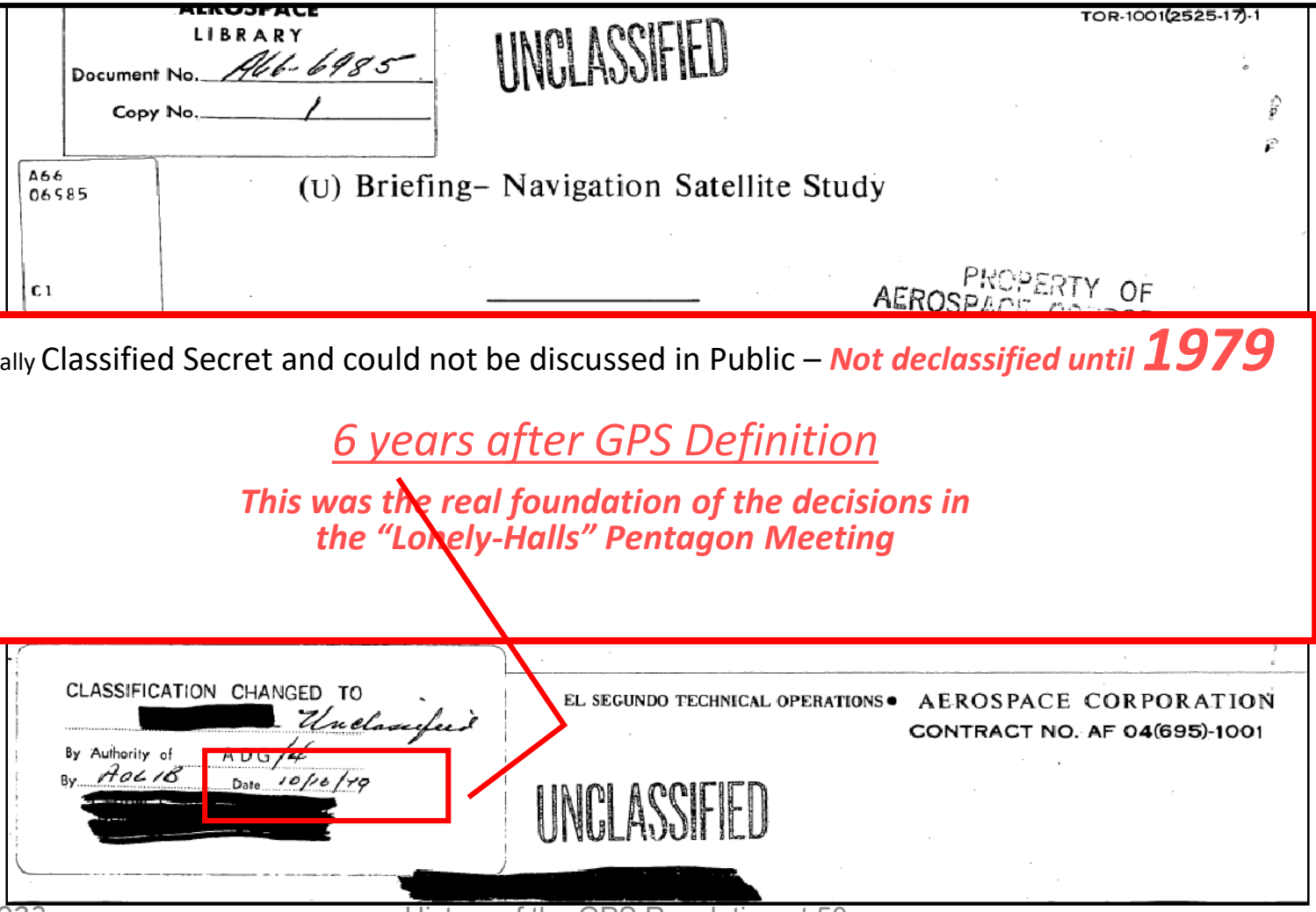

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6 years after GPS Definition

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

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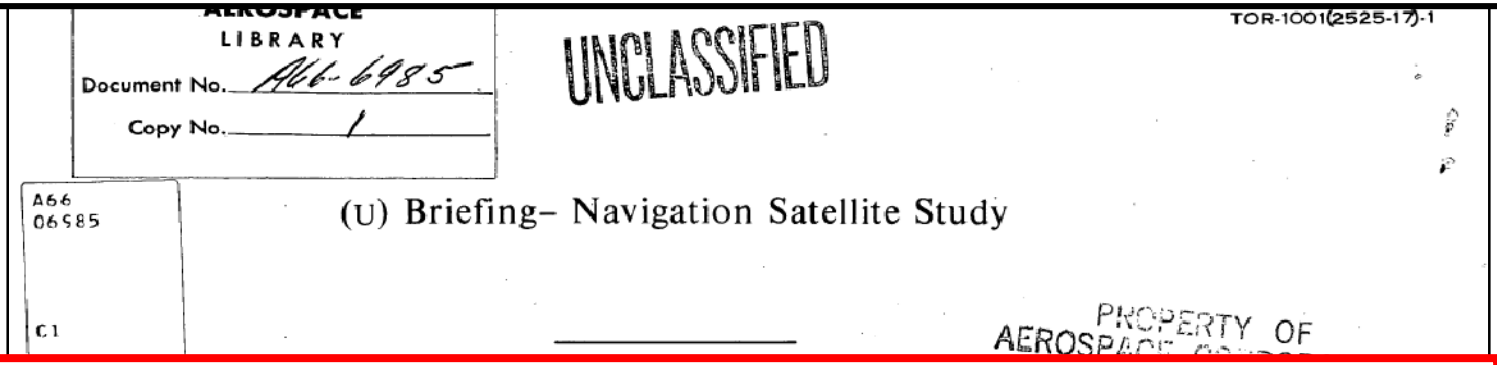
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Woodford and Nakamura Option # 12 Was the ***First*** of three great innovations that were the foundation of GPS:

Four Simultaneous Ranging measurements to find ***4-Dimensional Position***

Essential Links - Support
for the GPS Revolution –

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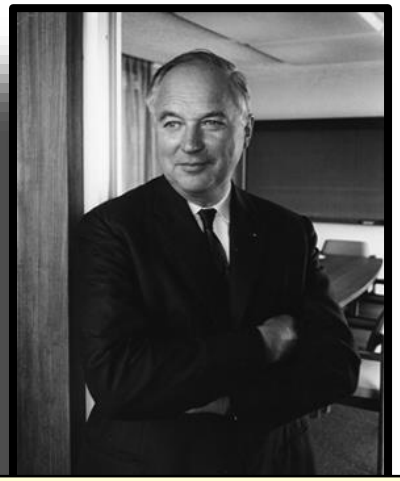

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Dr. Ivan Getting

President and CEO

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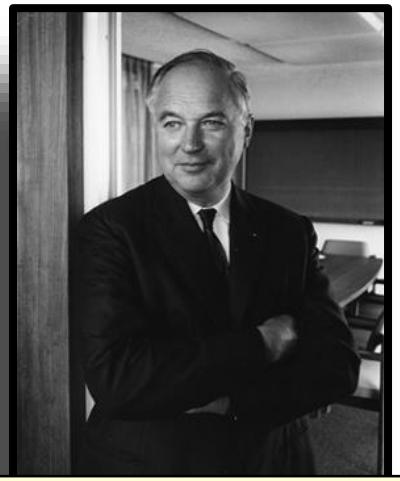

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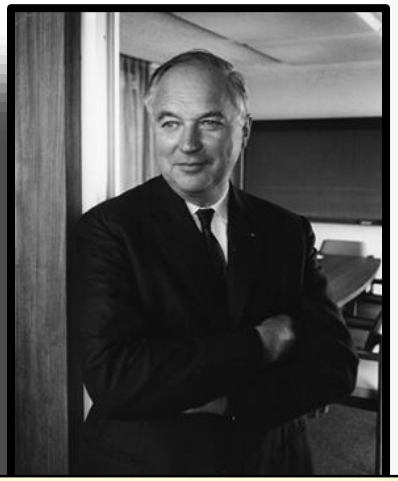

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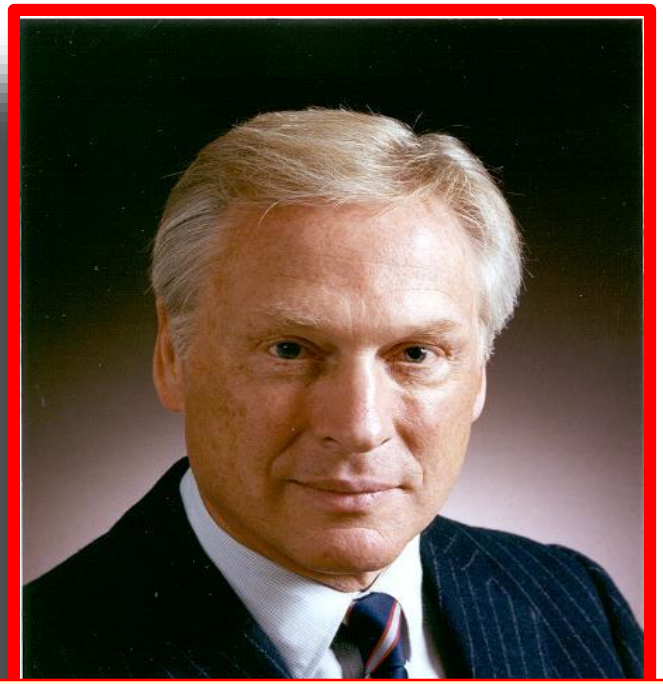

The GPS "Godfather"

Dr. Mal Currie

Undersecretary of Research and Engineering for the Office of Defense

The GPS Air Force Sponsor

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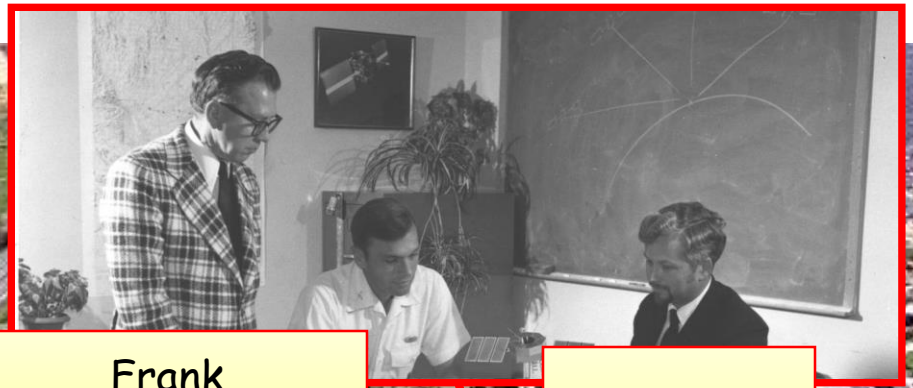
Commander SAMSO

Failure

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

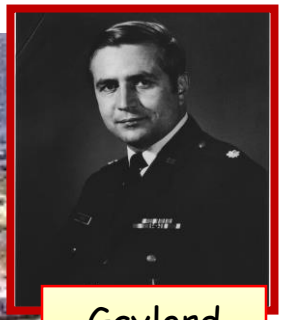
"Labor Day" Weekend ***(Saturday, 1 Sept. 1973 – Monday, 3 Sept. 1973)***

Brad Parkinson
USAF



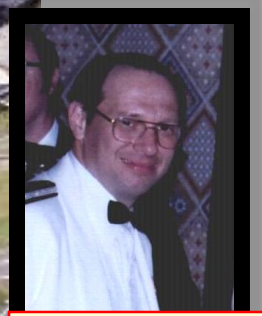
Frank
Butterfield
Aerospace Corp.

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)

Design: Confirmation of Fundamental 621B concept (4 Sats in view)

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Machiavelli on Innovation

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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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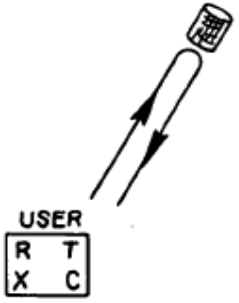
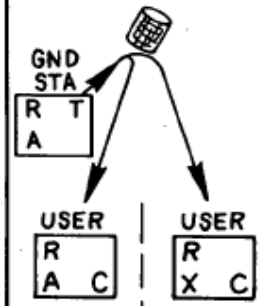
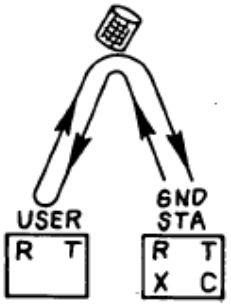
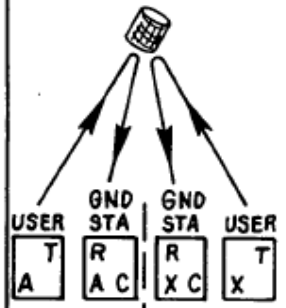
And I testified to congress that we were offering the Receiver Signal Spec to the public.
First civil set **locked up on GPS within 24 hours of first broadcast (students at Leeds - 1978)**
But the signal was *not* guaranteed!

Highlighting

The Three Major Innovations

First Essential Link in the Chain - The GPS System Concept

RANGE AND RANGE DIFFERENCE SYSTEMS

LOCATION OF COMPUTATION	COMPUTATION PERFORMED BY USER		COMPUTATION PERFORMED BY GROUND STATION	
NAVIGATION RADIO LINK	2 WAY	1 WAY	2 WAY	1 WAY
USER EQUIPMENT R = RECEIVER T = TRANSMITTER X = CRYSTAL CLOCK A = ATOMIC CLOCK C = COMPUTER				
APPLICABLE MEASUREMENTS 2 SATS ppḣ 3 SATS ppp 3 SATS ΔPΔḣ 4 SATS ΔPΔPΔP	✓ (ALTIMETER) ✓	✓ (ALTIMETER) ✓ ✓ (ALTIMETER) ✓	✓ (ALTIMETER) ✓	✓ (ALTIMETER) ✓ ✓ (ALTIMETER) ✓
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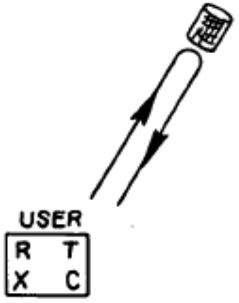
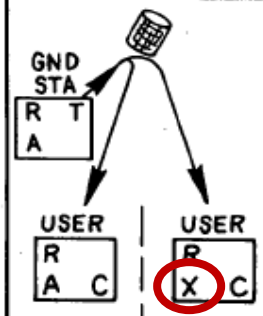
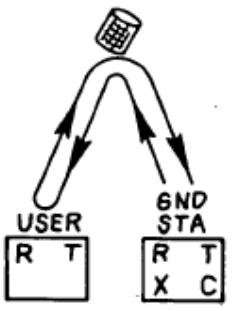
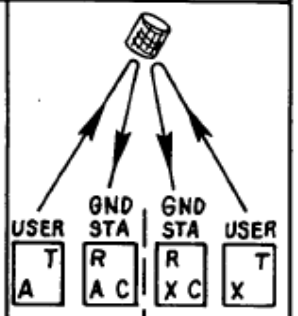
USER EQUIPMENT R = RECEIVER T = TRANSMITTER X = CRYSTAL CLOCK A = ATOMIC CLOCK C = COMPUTER				
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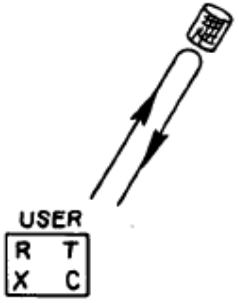
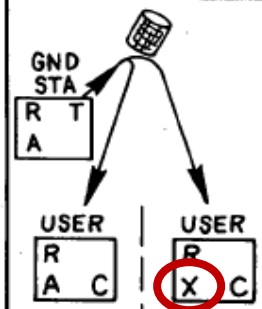
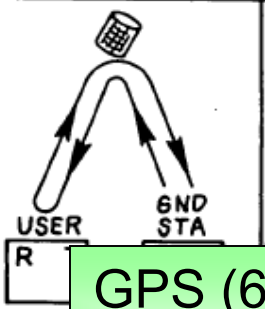
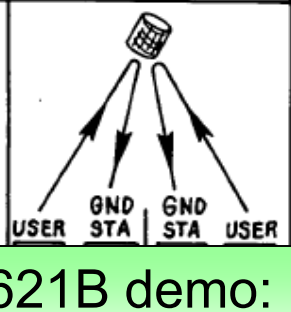
USER EQUIPMENT R = RECEIVER T = TRANSMITTER X = CRYSTAL CLOCK A = ATOMIC CLOCK C = COMPUTER				
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	USER ACTIVE	USER PASSIVE	USER ACTIVE	USER ACTIVE

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

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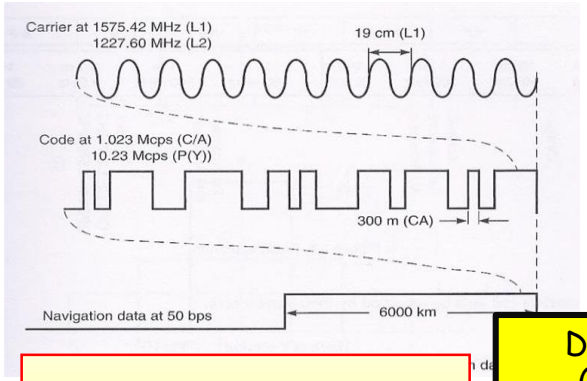
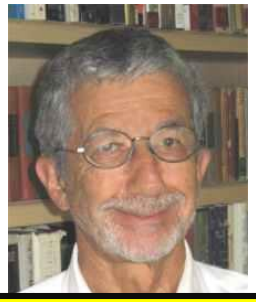


The "new" GPS signal (1972)

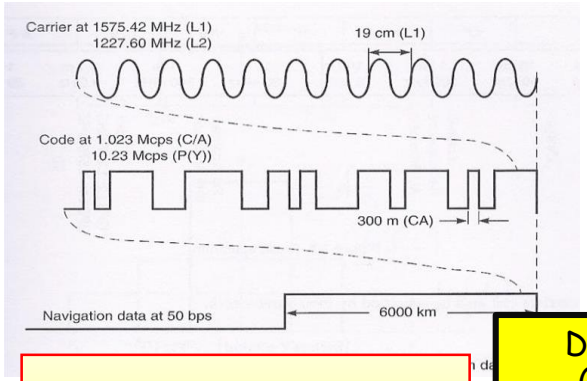


Dr. Robert Gold (Consultant to Magnavox in 1967)

Charlie Cahn Magnavox

Jim Spilker Stanford Telecom

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



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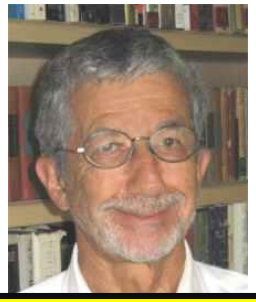

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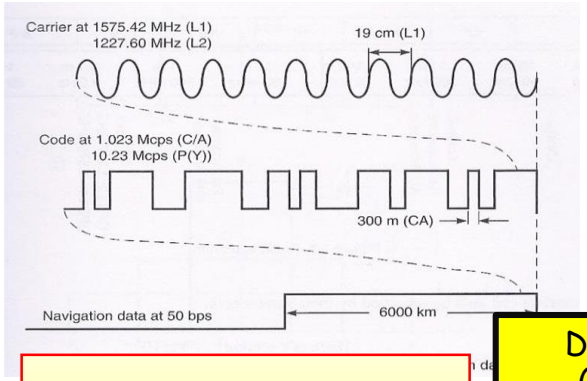

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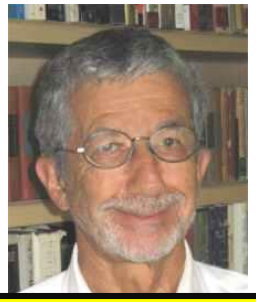

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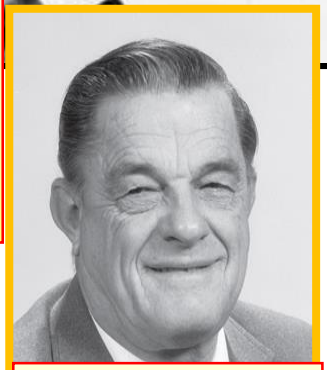

Bill Fees Aerospace

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

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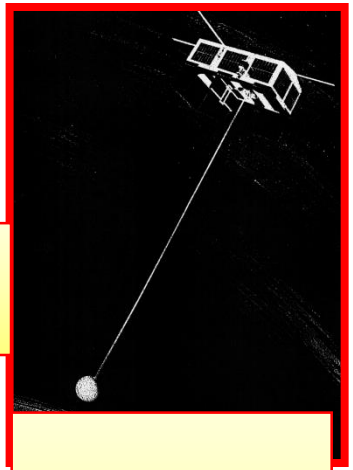
Pete Wilhelm
NRL



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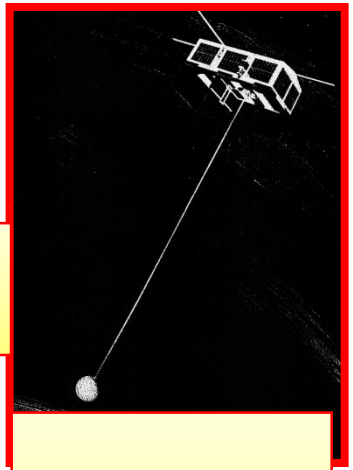

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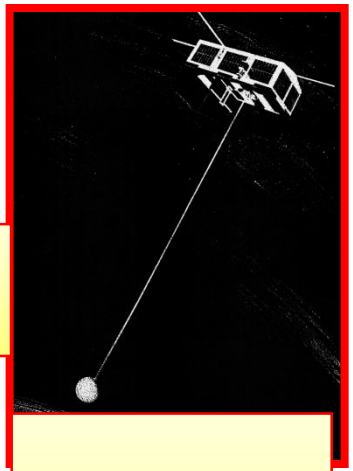

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Dick Schwartz
Led Satellite
Development -
Rockwell

First Space-
Qualified Atomic
Clock –
Efratom/ Rockwell

Hugo Fruehauf
Rockwell

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*(Critical Development Links That **had** to work)*

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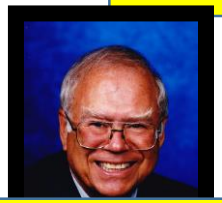
5. Evolutionary test concept based on 621B (the "Inverted Range")

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

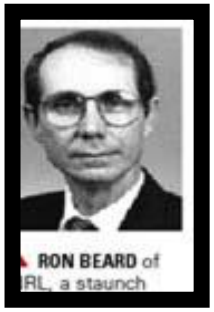


Walt Melton
Led Development of Ground Control and User Equipment General Dynamics

Sherm Francisco
Control Software
IBM

Dr. Bob Cooper

Dr. Bob Rennard



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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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- 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)

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- **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 over-ruled attempt!

Two Defining Events

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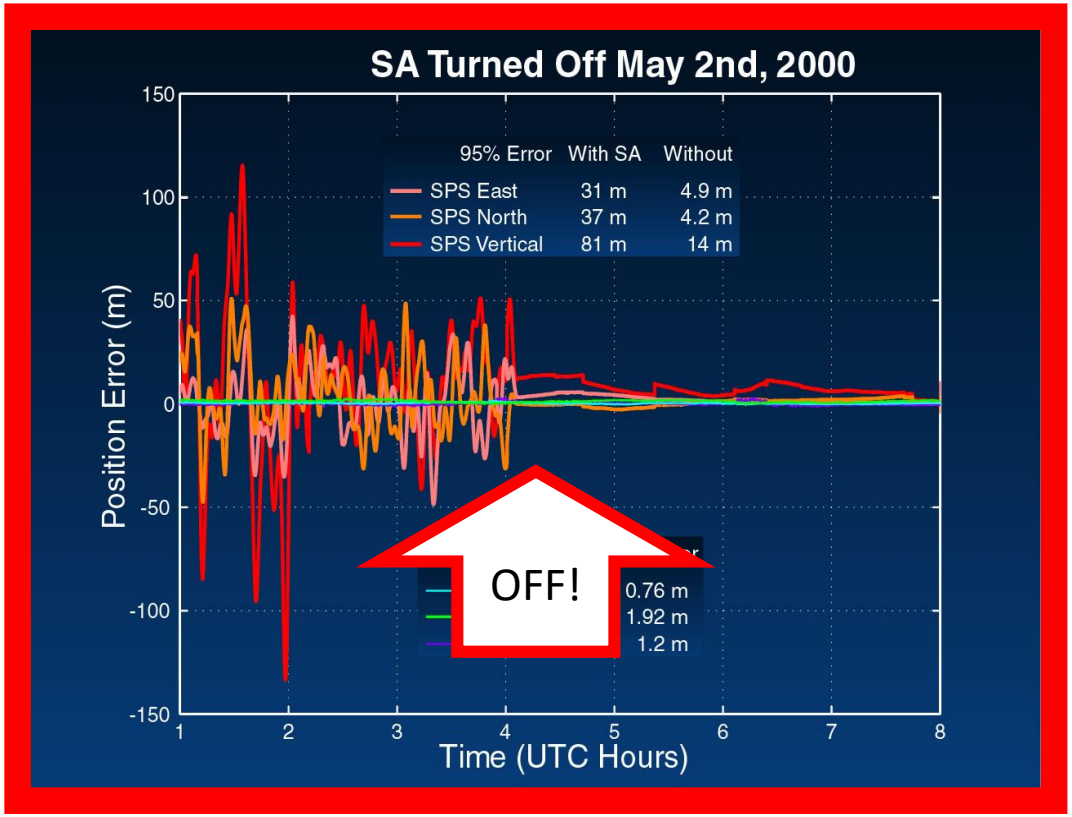
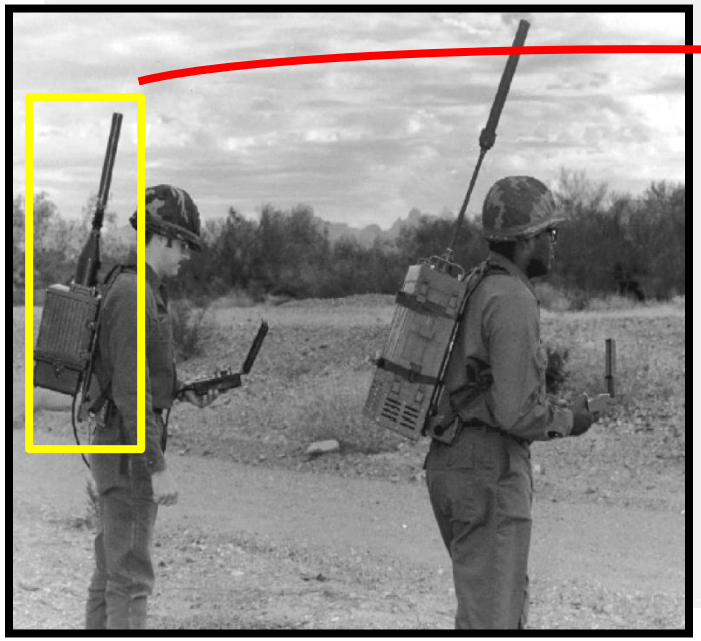
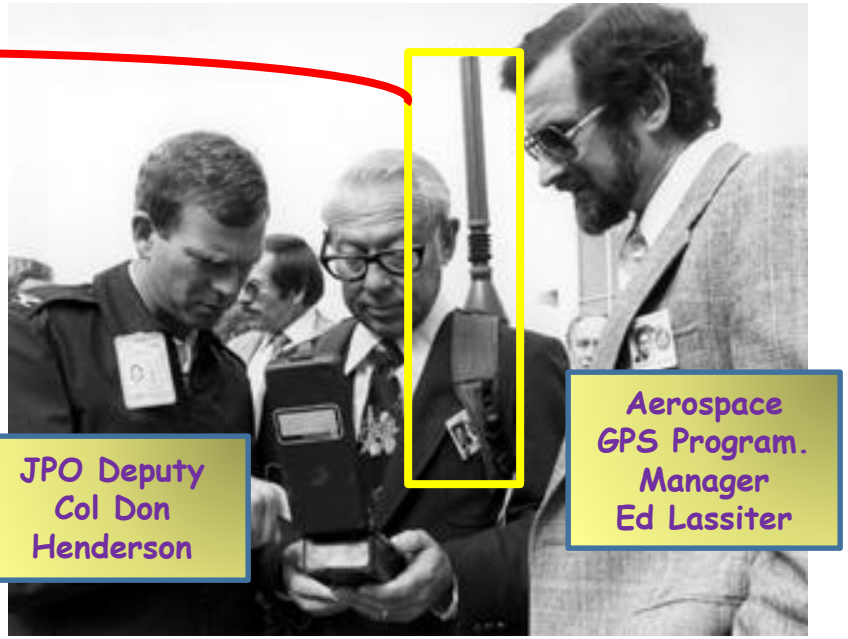


And an Allied Defining Development: The Integrated Circuit





1978 "Manpack"

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

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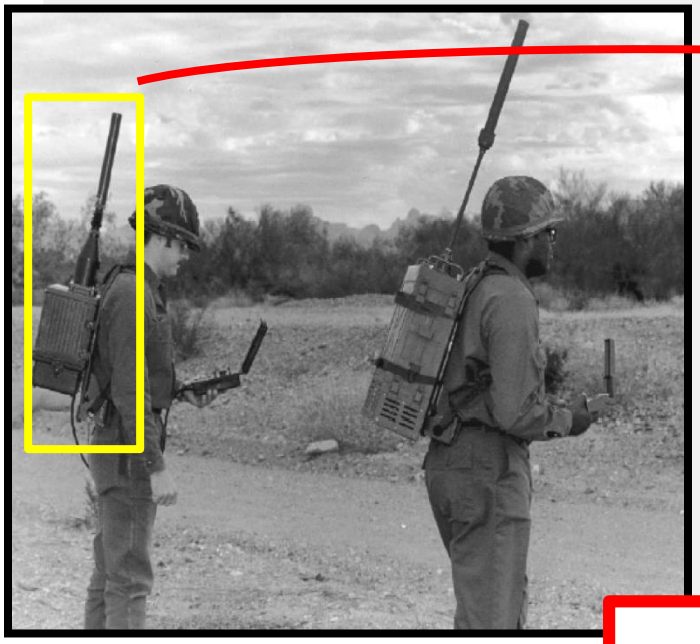

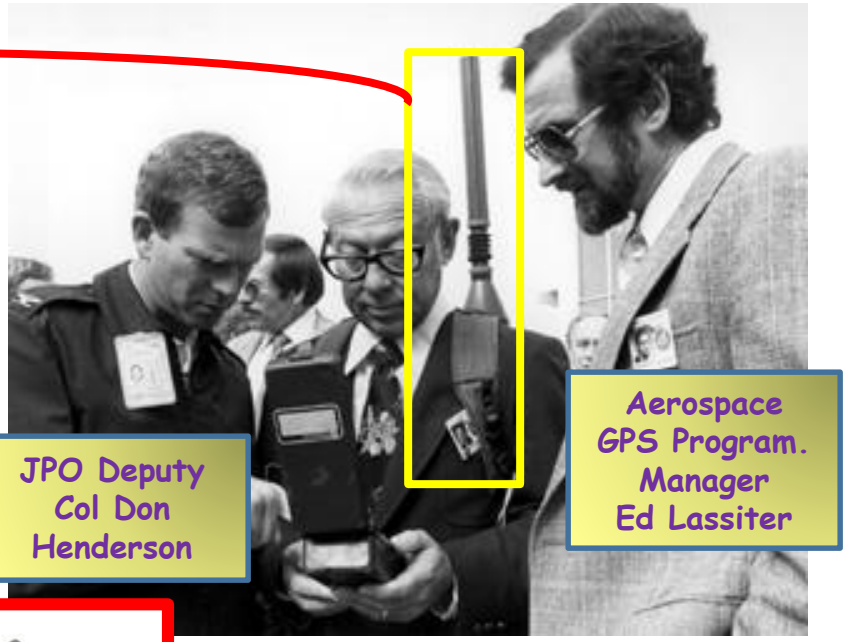

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A Modern Chip

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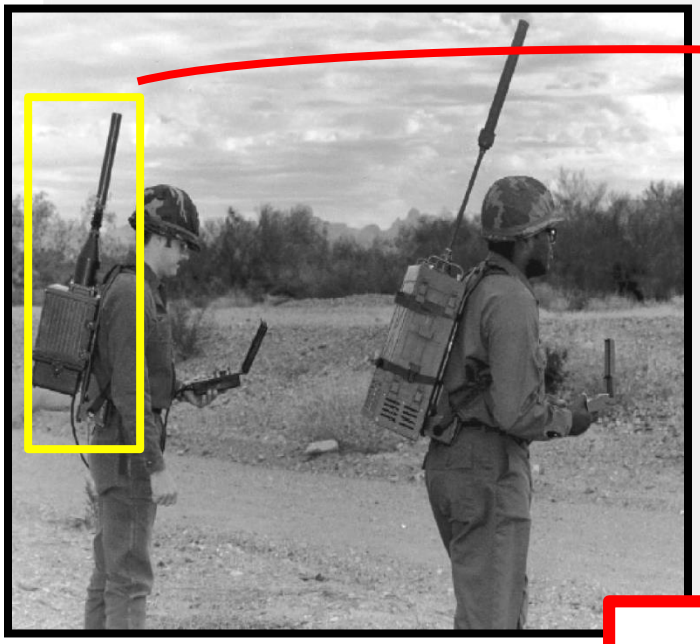

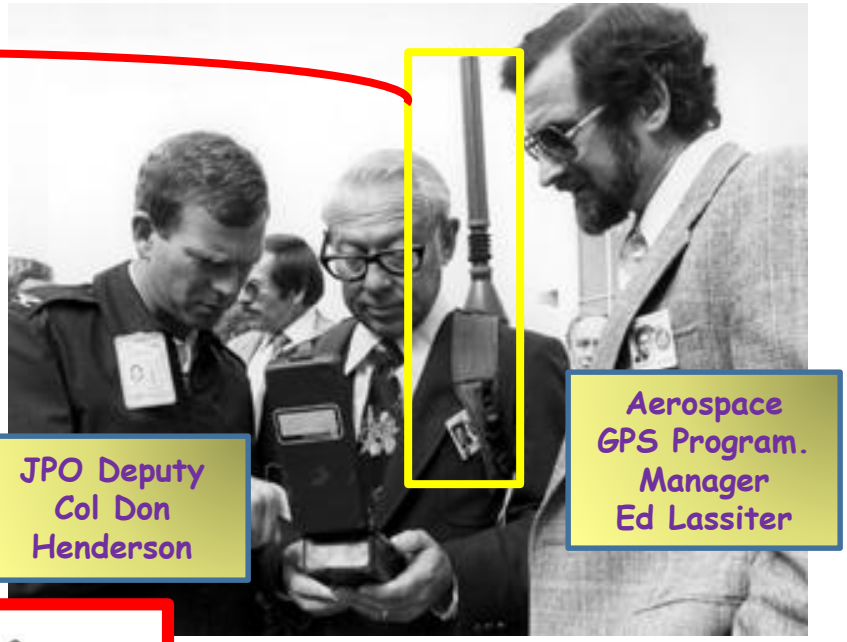

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A Modern Chip

- 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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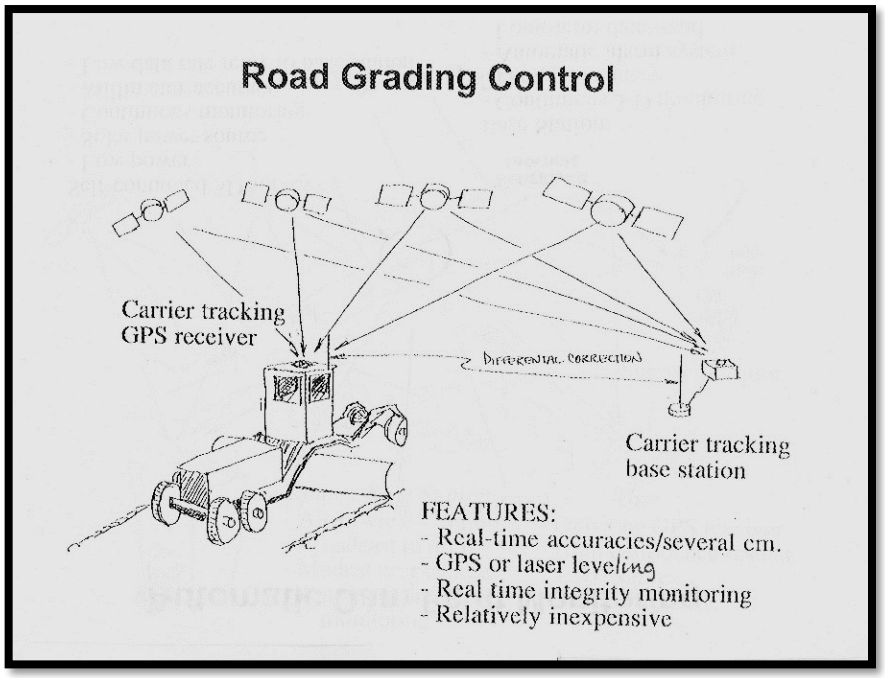

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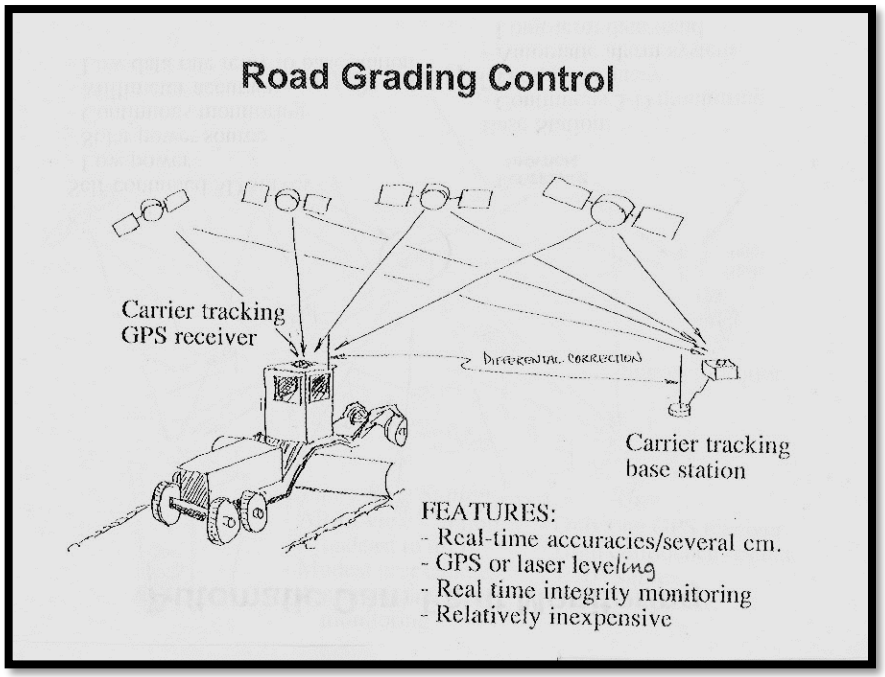

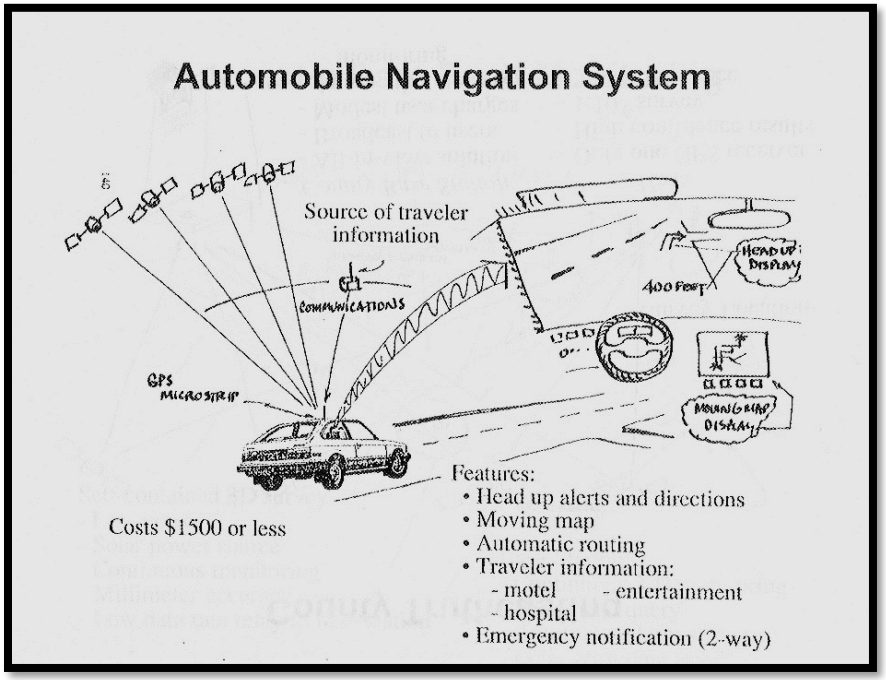

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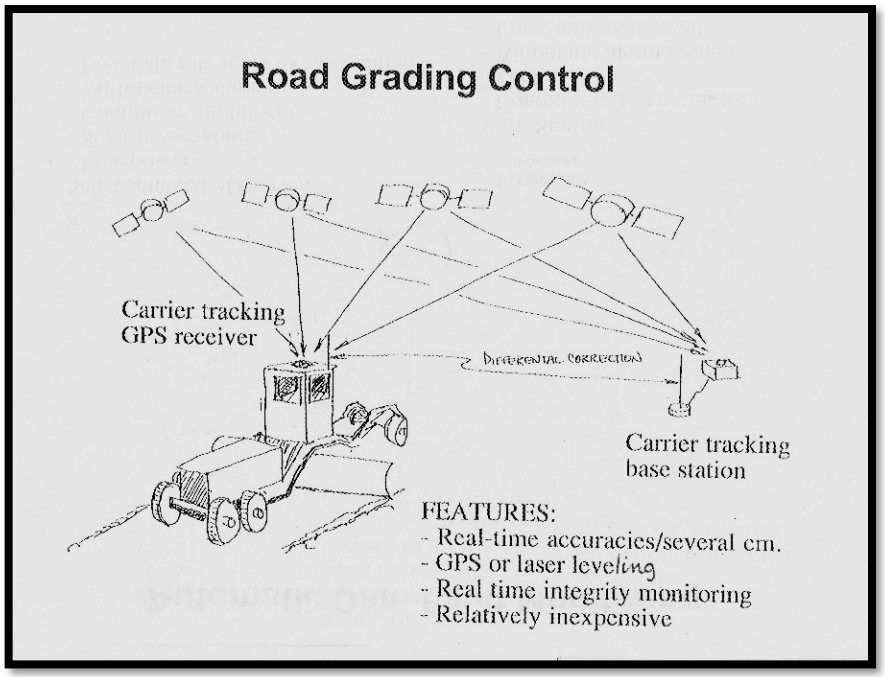

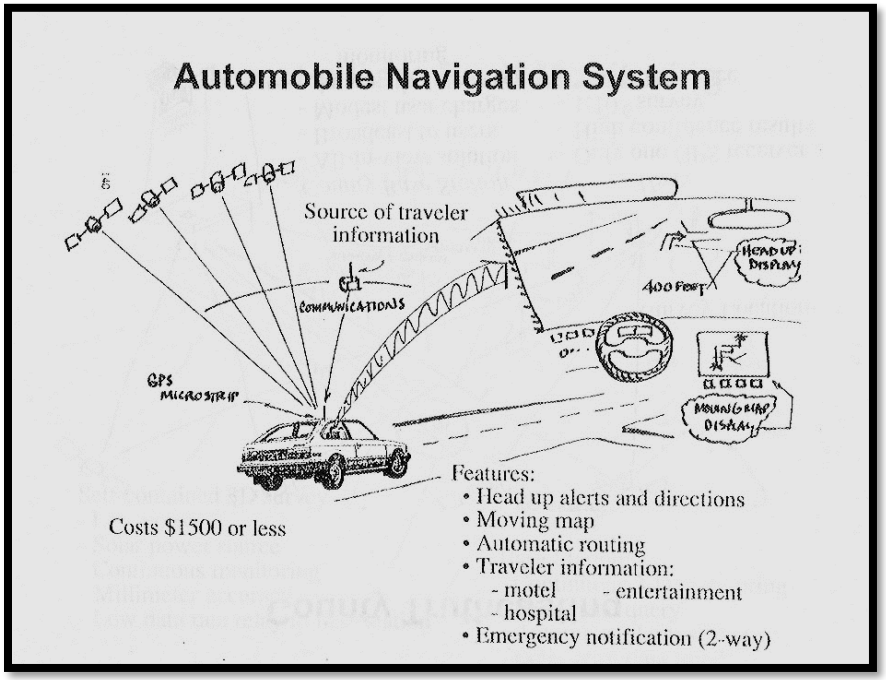

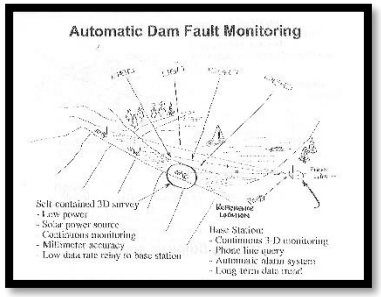

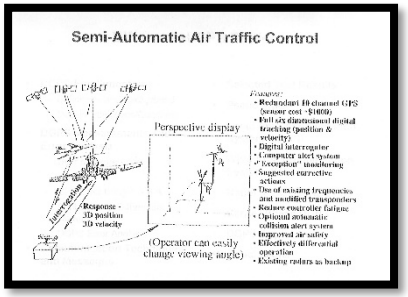

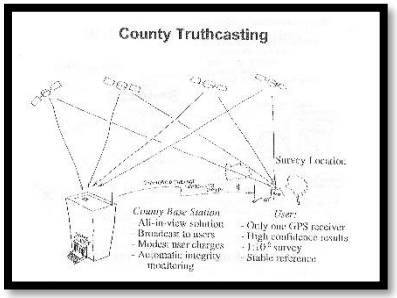

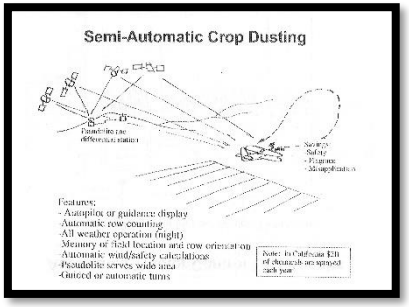

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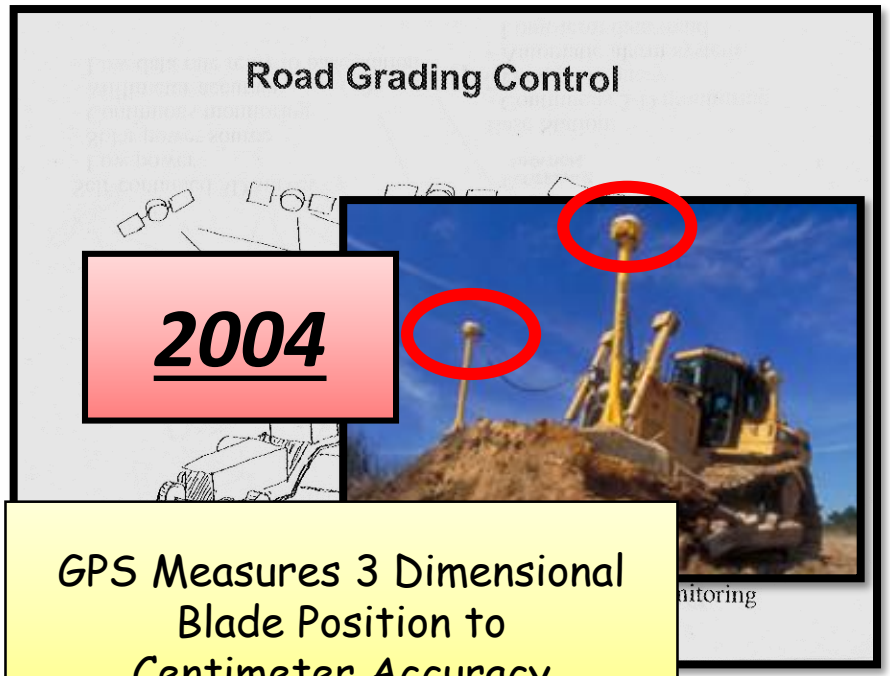

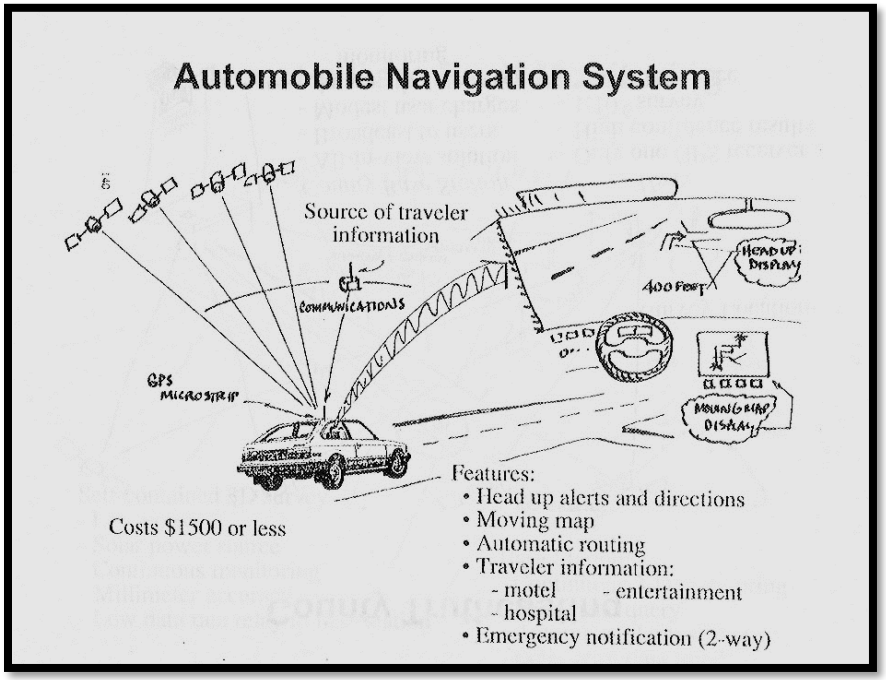

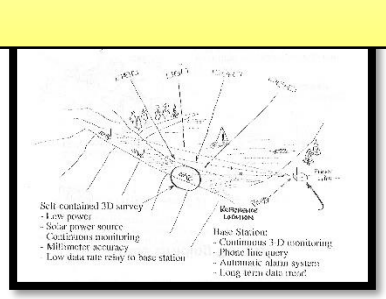

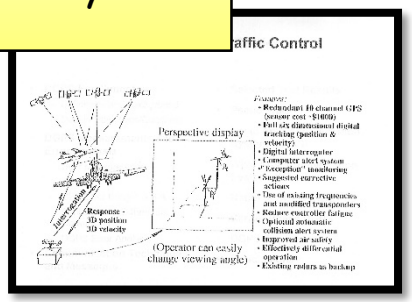

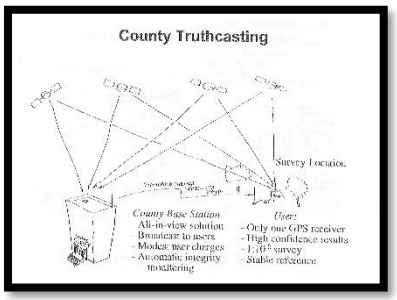

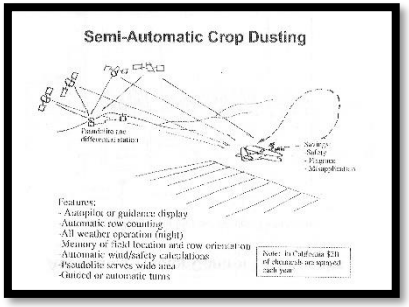

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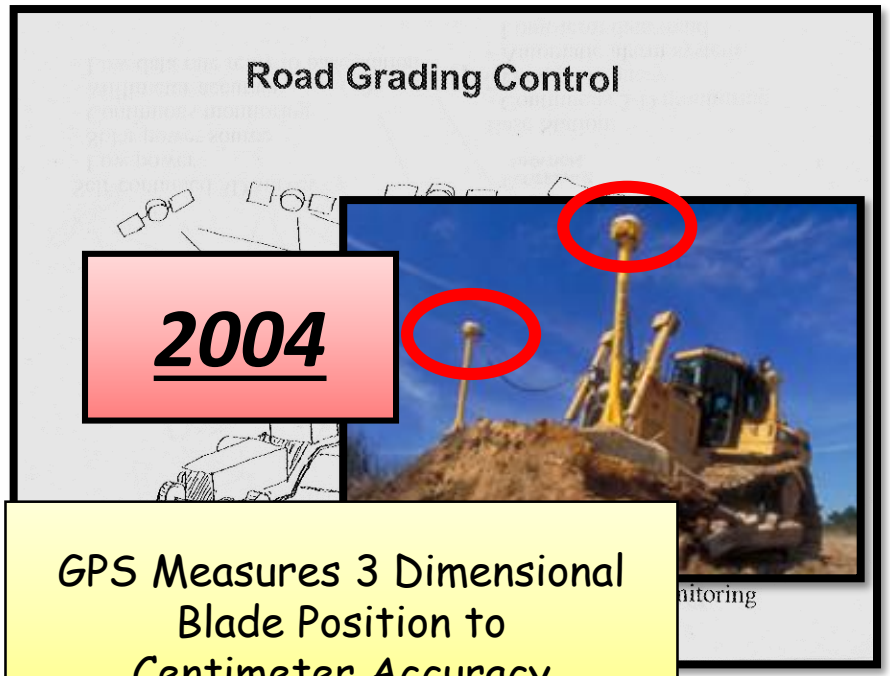

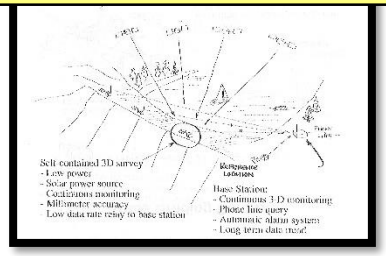

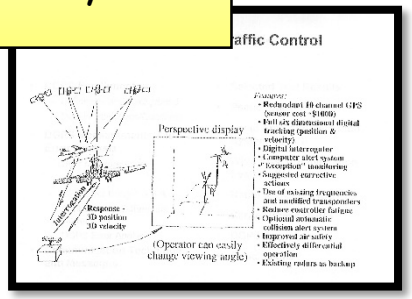

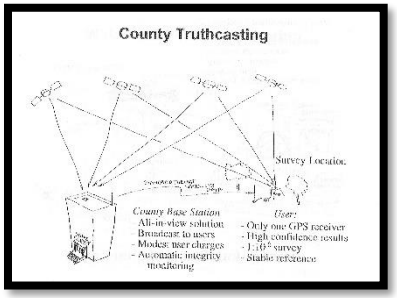

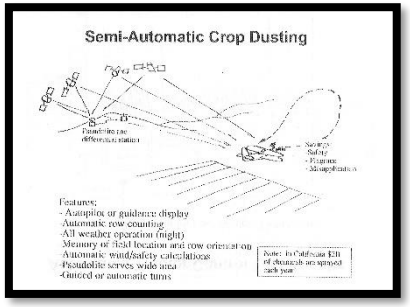

GPtS Applications have Proliferated

- Civil
  - Transportation
    - Aviation
    - Automobile
    - Maritime
    - Rail Control
  - Public Services
  - Timing & Frequency
  - Surveying
  - Surveillance
  - Other
- Military

GPS Watch – helps find your way home!

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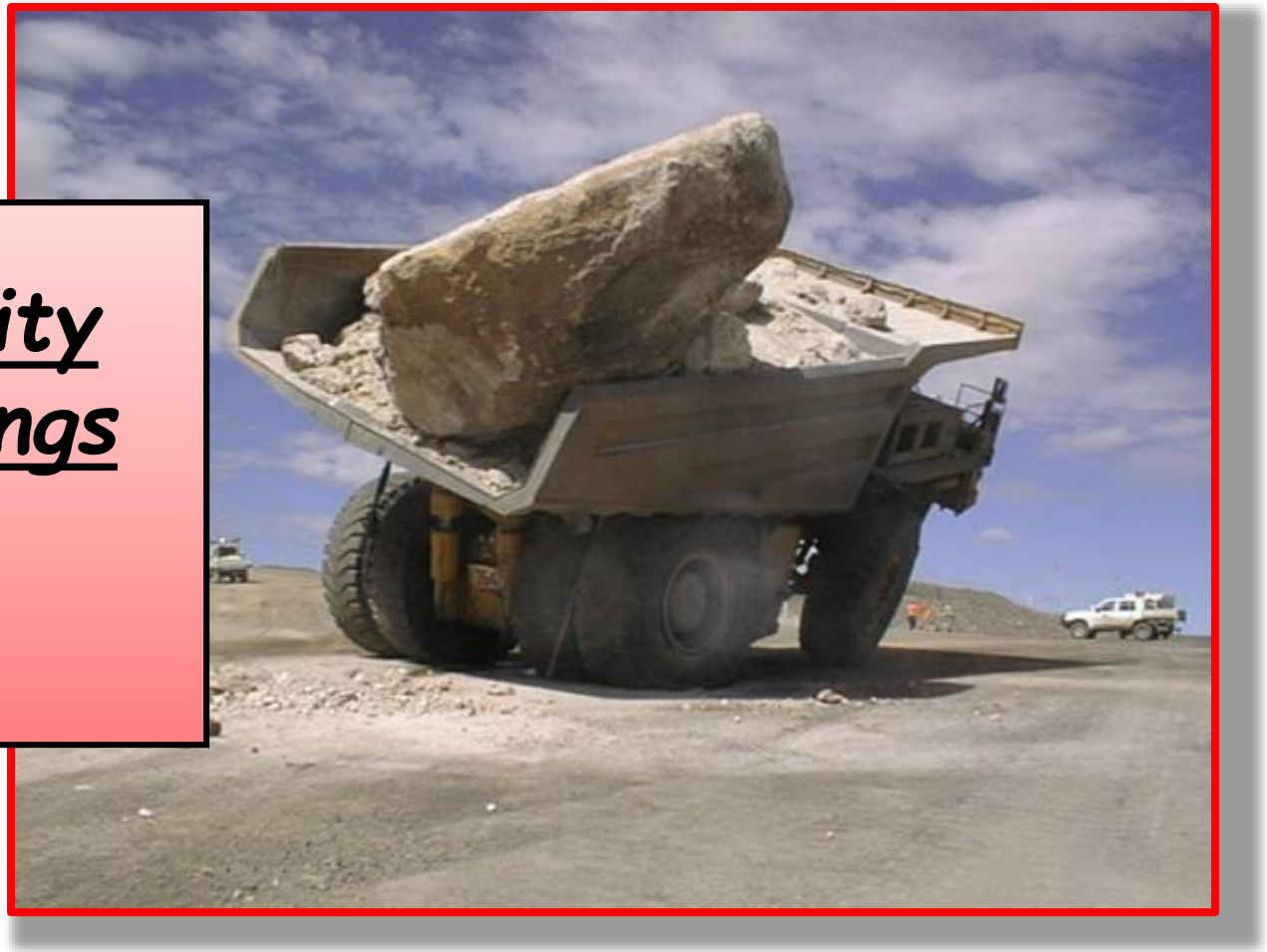
And it "watches" you –
If you haven't been active recently – ***tells you to "Move"***

GPS Robotically Guided Trucks
- Wheels 3 meters high

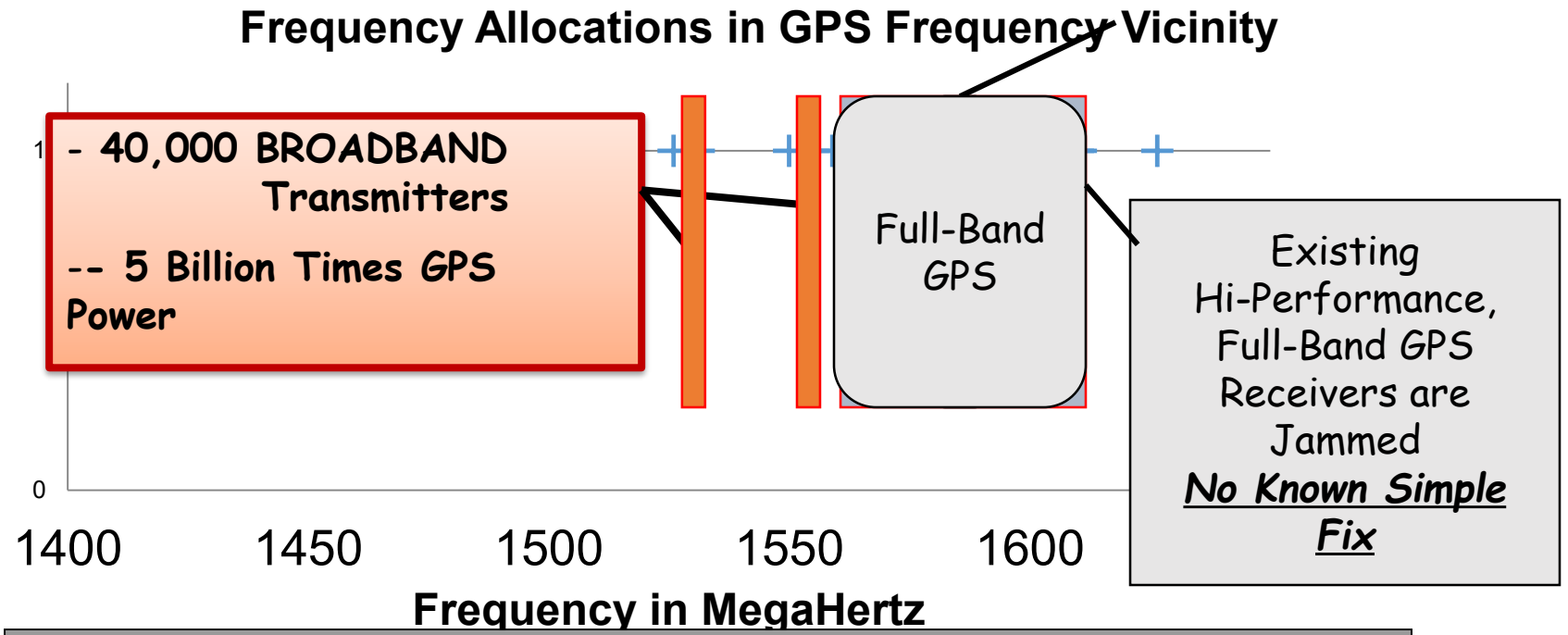
Productivity Savings

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



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

The sincerest form of Flattery… 4 Global GNSS

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GP(t)S
(USA)

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

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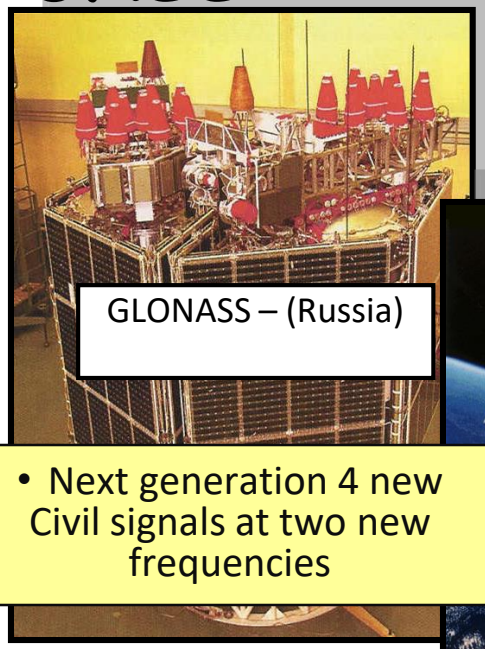

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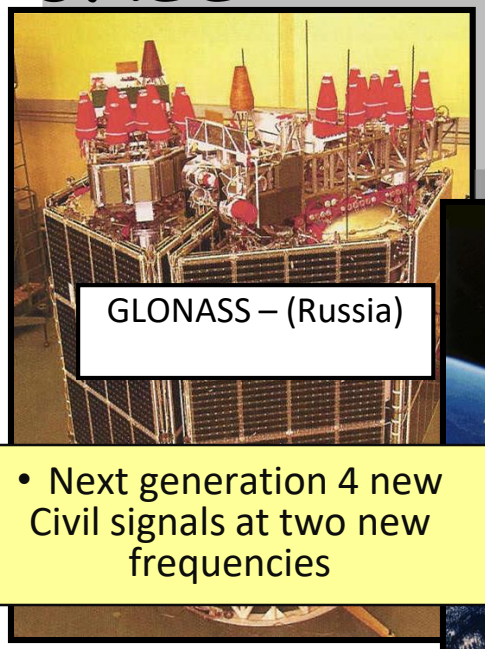

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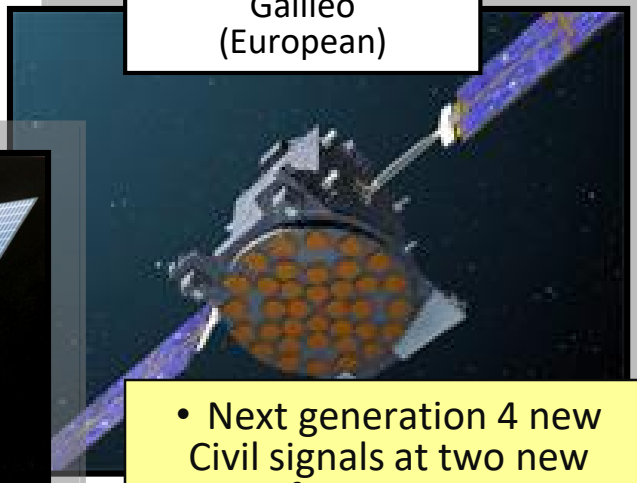

Galileo (European)

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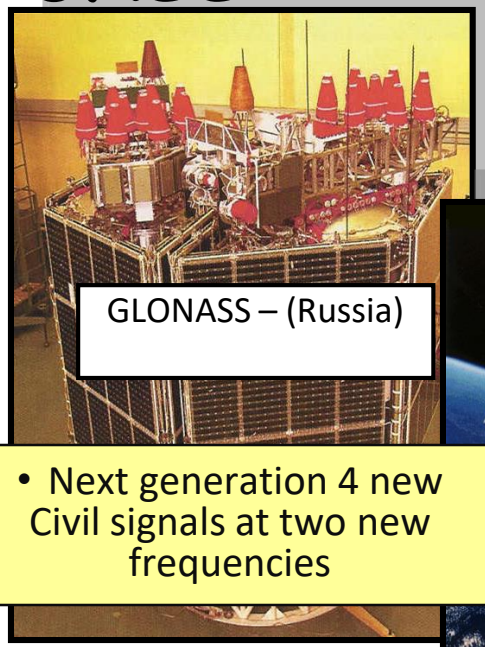
The sincerest form of Flattery… 4 Global GNSS



GLONASS – (Russia)

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- First Operational Civil Signal
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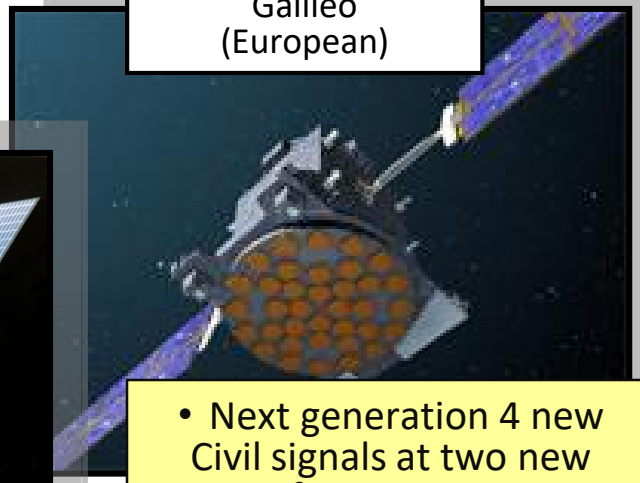

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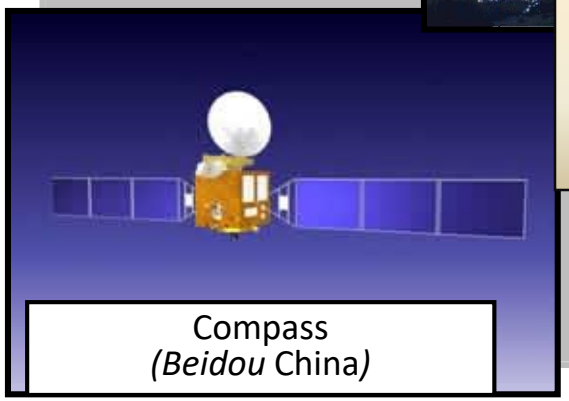

Compass *(Beidou* China*)*

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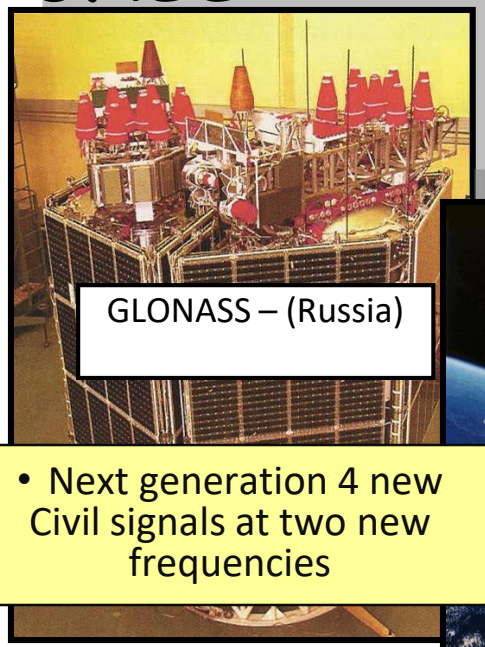

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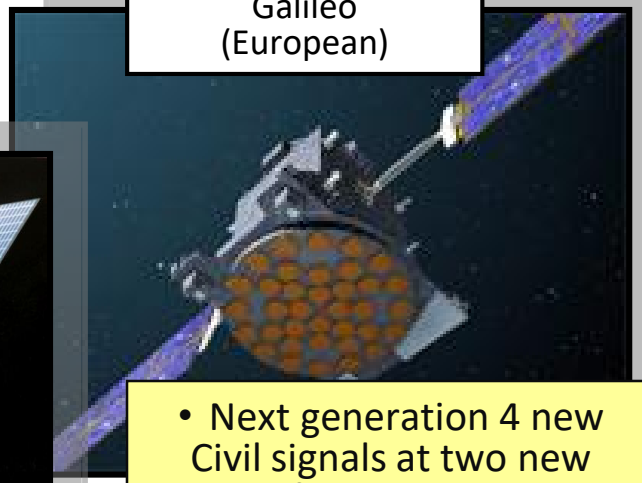

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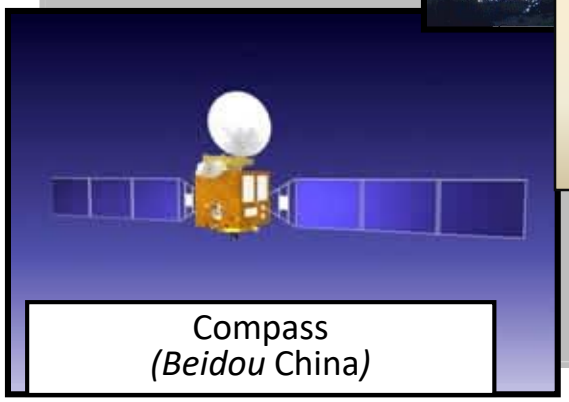

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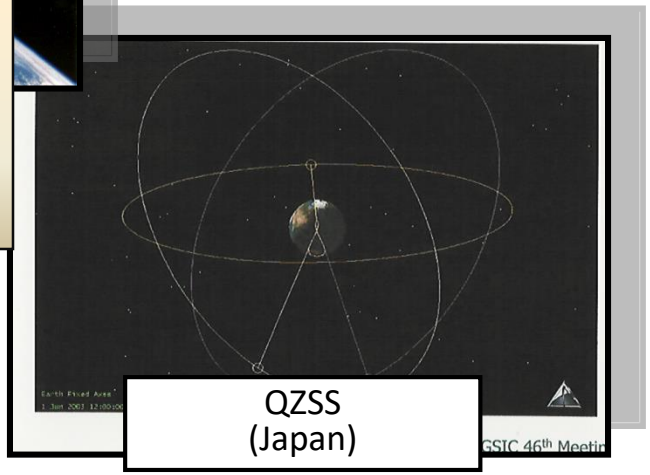

QZSS (Japan)

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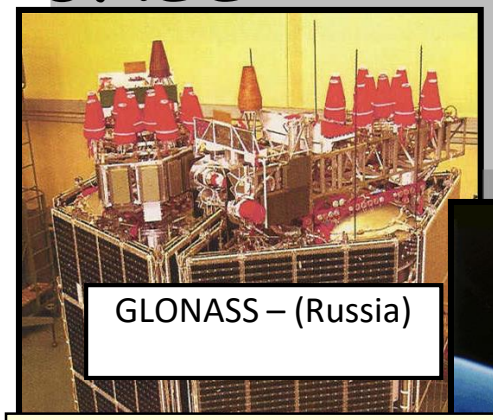


GLONASS – (Russia)

Galileo
(European)

- 10 New Civil Signals –

(Including L5 and a new ***International Signal*** called L1C)

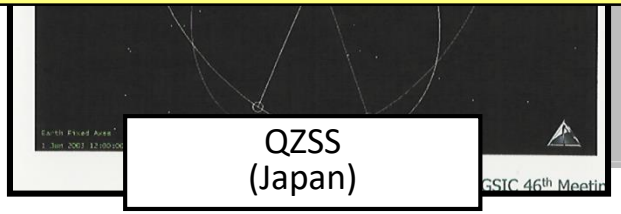
- This will provide Interchangeability

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

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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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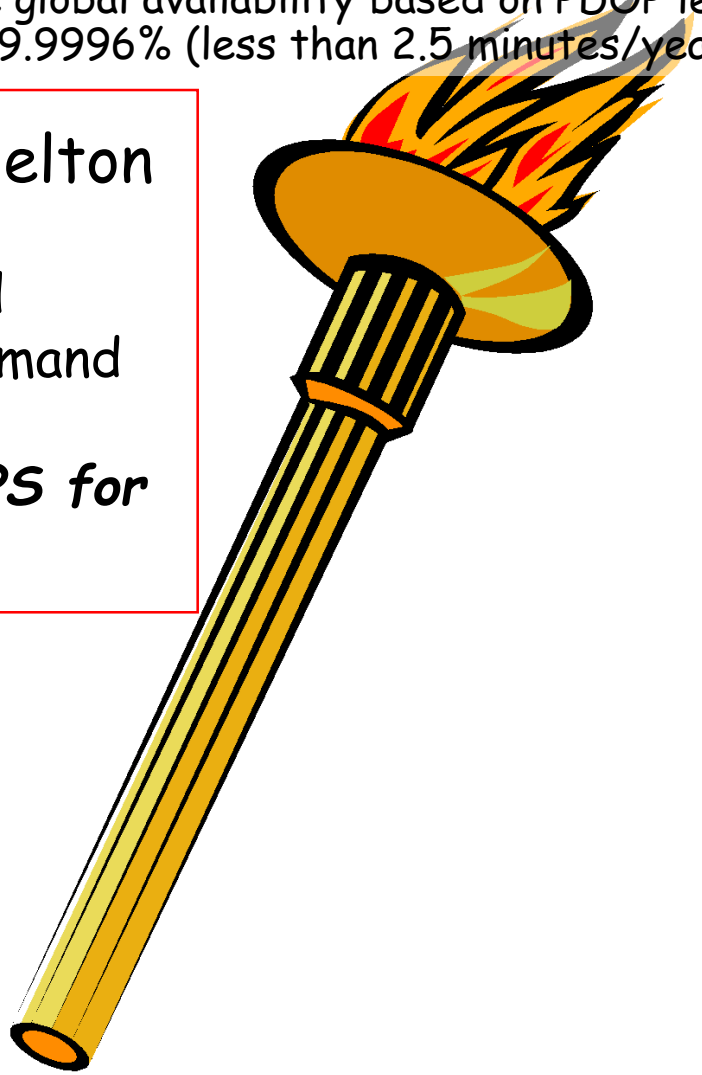

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"mission will include safeguarding civil Position, Navigation and Timing signals". (Sept. 2022)

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

The Anchor ***and the chain links held***!!

Thank you!

Questions?