ITSF – 2010, Dublin

…some little known facts and stories, not in the GPS World magazine, May & June 2010 articles

The History of GPS

Hugo Fruehauf
001-714-724-7069
hugo.fruehauf@pepperdine.edu

- Conventional Targeting - World War II to Vietnam

Using WW II Allied Bombing for example:

Inside Germany: ~1.6 million tons of bombs
Euro Theater: ~2.8M tons
~4.4M tons Total

For Germany alone
~600,000 Civilian Casualties…
~95% of the Civil and War-machine Infrastructure destroyed
…Targeting cities and civilians was viewed as a psychological weapon to break the enemy's will to fight

- Targets – mainly cities of >80,000 population
- In the ’40s, ~100 cities/target areas
- Bombing mostly from 30,000 ft altitude, because of anti-aircraft fire
- It is estimated that only 10% of the bombs hit their target

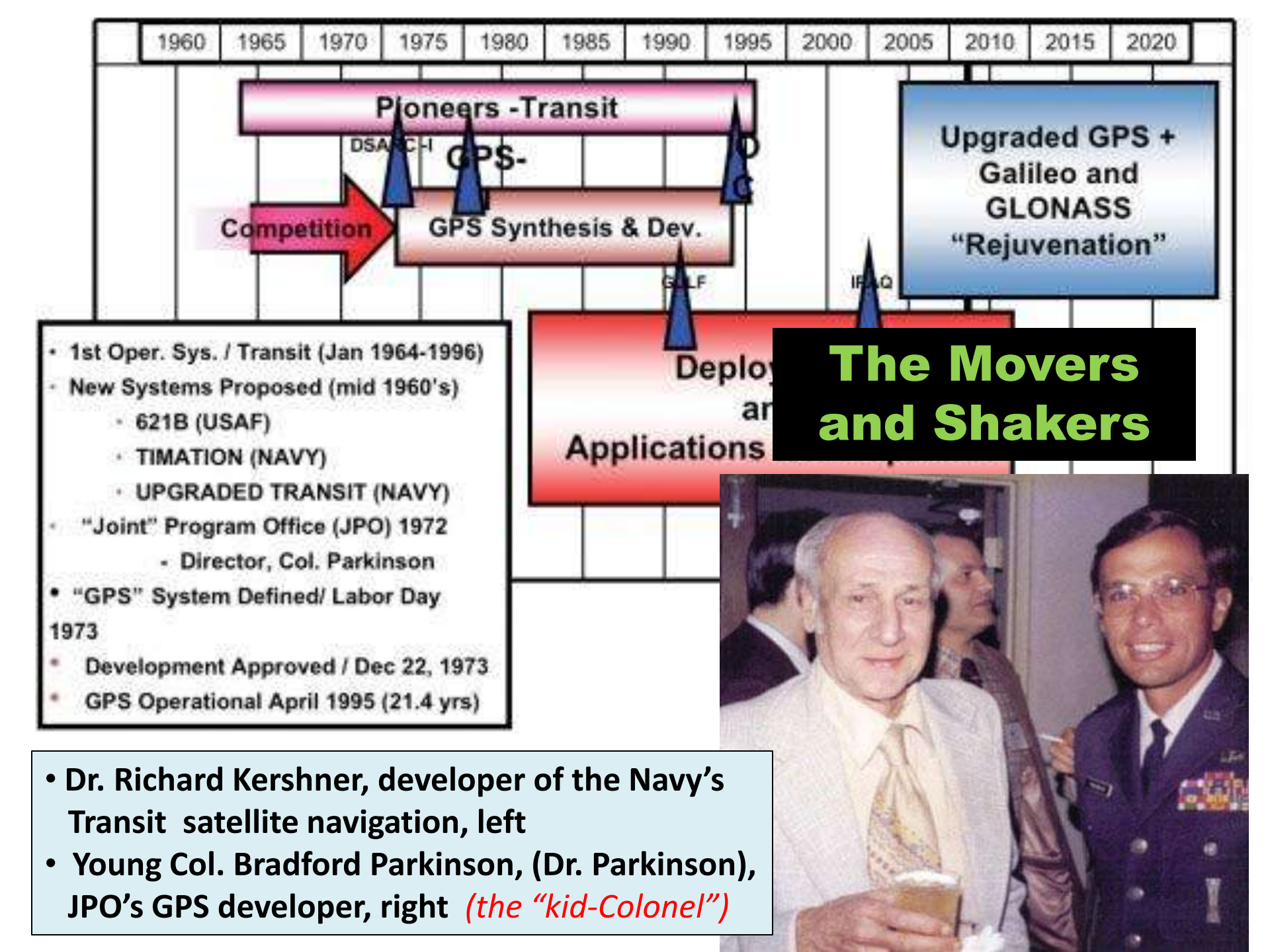
Nevertheless, for civilian intimidation and target destruction
…very successful indeed !

Ref: Wikipedia and a host of other websites

Future Warfare Strategy

- Such carnage in future warfare has become unimaginable
- Tactical, rather than Strategic / Continental conflicts considered most likely
- War with Rogue / Turbulent Regimes, not “a People” as the future military strategy
- Collateral casualties / damage political suicide
- **However, such would require:**
  - Global Coverage
  - 24/7 Availability
  - Precision 3D Navigation and Positioning
  - 2σ Targeting Dependability
  - Precision Timing and Synchronization
- In the ‘60s, the US Military began to wake up to these realities

hence… the birth of Transit (2D), then GPS (3D)



- Dr. Richard Kershner, developer of the Navy's Transit satellite navigation, left
- Young Col. Bradford Parkinson, (Dr. Parkinson), JPO's GPS developer, right *(the "kid-Colonel")*

Requirements for the initial GPS System

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Adding to the previous requirements:

- CONUS satellite updates
- Universal Coordinated Time (UTC)
- Relativity Compensation
- Low cost User Set (no atomic clock) – needs 4 Sats for 3D
- Spread Signal format to meet ITU requirements:
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- Military control of GPS sats and ground control segment

Clearly - the precision Clock was and is still the key technology that makes GPS possible

The Key GPS Technology Effort: ...the Atomic Clock Search

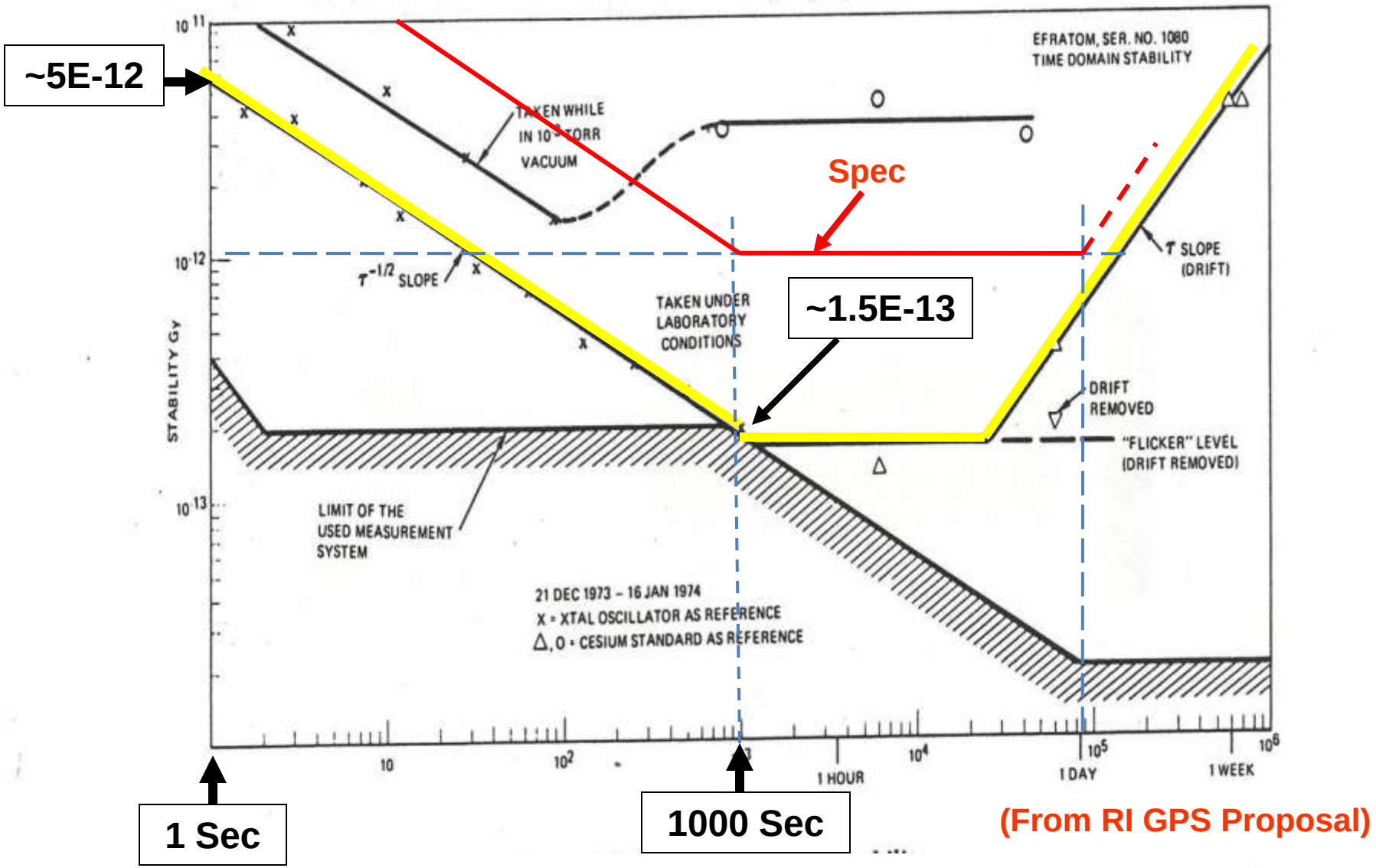
Space Division
Rockwell International

(From RI GPS Proposal)

Manufacturer	Model No.	Stability	Size (in.)	Weight (lb)	Input Power (Wdc)	Notes
Rubidium Standards						
Efratom	FRK	1×10^{-10}/MO 5×10^{-11} (τ = 1 sec)	4 x 4 x 4	3	13	Commercial available
HP	5065A	1×10^{-11}/MO 5×10^{-12} (τ = 1 sec)	16-3/4 x 18-3/8 x 5-7/32	34	35	Commercial available
Tracor	308A	3×10^{-11}/MO 2×10^{-11} (τ = 1 sec)	12 x 5-1/4 x 17-1/3	20	50	Commercial available
Collins Radio		2×10^{-11}/MO 5×10^{-11} (τ = 10 sec)	19 x 5-1/2 x 9	44	35	Not presently in production
Cesium Standards						
HP	5061A	3×10^{-12}/MO 5.6×10^{-12} (τ = 1 sec)	16-3/4 x 18-3/8 x 8-3/4	67	27	16-in. tube unit, commercial available
HP	5062C	1×10^{-11}/MO 7×10^{-11} (τ = 1 sec)	16-3/4 x 19 x 5-7/32	45	30	Not available till mid-74, 6-in. tube
Freq & Time Sys			7-5/8 x 4-7/8 x 19	30	20	Not available till late 74
Hydrogen Maser						
Smithsonian JPL Goddard		1×10^{-14}/MO	30 x 30 x 30	75+	50	Custom design for NASA, experimental unit
Crystal Oscillators						
FEI	FEI 800D FEI 800DS	2×10^{-11}/day 8×10^{-13} (τ = 1 sec)	3.5 in. x 4.5 in. x 9.25 in.	6.5	1.8	For FLEETSATCOM, space-rated

Clock Search for GPS, early 1974

Initial GPS Clock Performance Requirements



(From RI GPS Proposal)

DNSDP (GPS) Proto-type Rad Hard Rb - Performance, RI-Efratom FRK-Rb, 1974, D. Ringer, C. Wheatley, W. Weidemann, Hugo Fruehauf

▲ **A.J. VAN DIERENDONCK** helped define "GPS Time."

▲ **ED MARTIN,** one of the key systems engineers at Magnavox.

▲ **ERNST JECHART (LEFT) AND GERHARD HUEBNER,** developers of the commercial rubidium clock. They later teamed with Rockwell to develop the first successful GPS clock, the only working clock on the first four GPS vehicles.

▲ **HUGO FRUEHAUF,** chief engineer for the design and development of the first GPS satellites. His oversight was essential to produce the first GPS atomic clocks.

▲ **RON BEARD** of NRL, a staunch supporter of GPS over many years.

Ernst Jechart

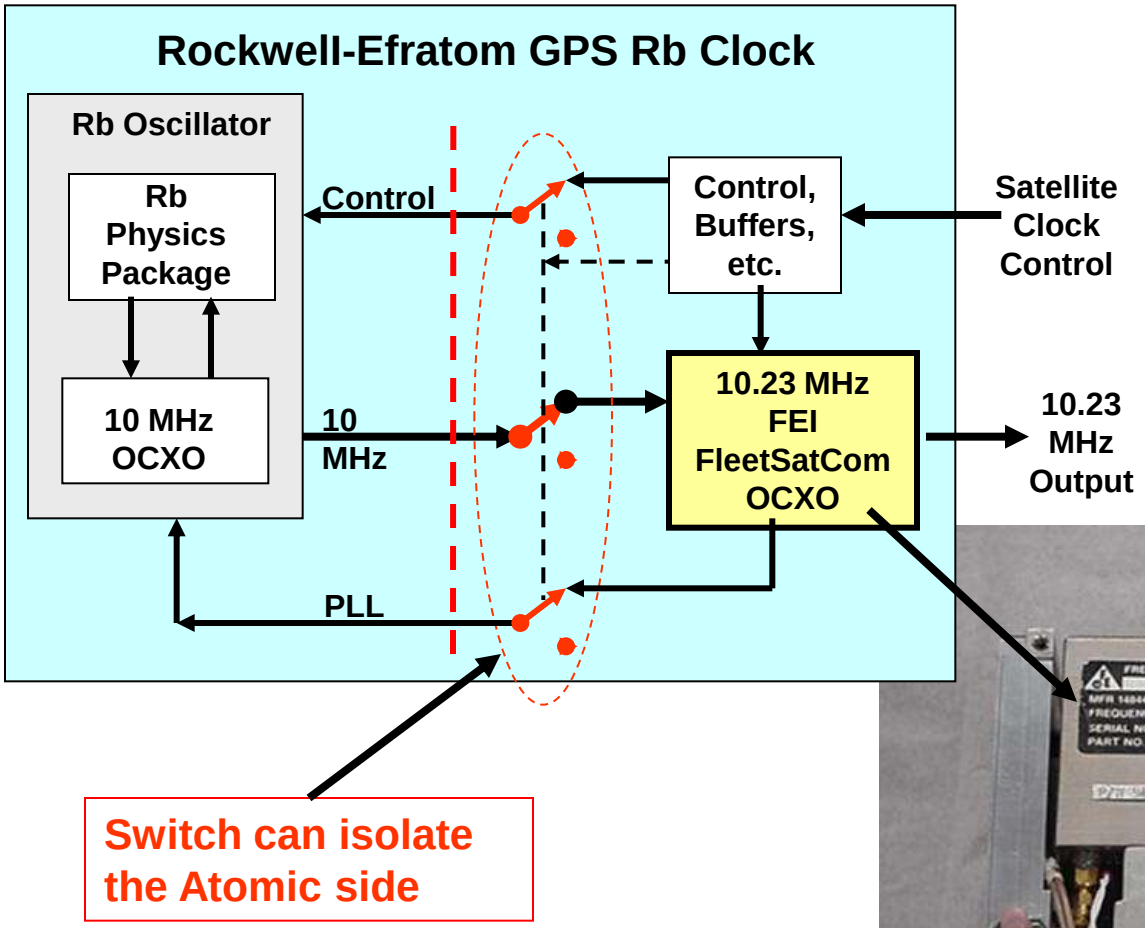
Gerhard Hübner

Werner Weidemann

The Clock Players

The brains behind the Efratom GmbH, Munich, Miniature Rubidium Vapor Oscillator, that became the 1st GPS Space Clock from Efratom Inc., California (RI-Efratom Team)

Efratom Rb & FEI Qz in the GPS Space Clock



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MAJOR GAYLORD GREEN. His innovations included design of the modified orbits that ensured daily test time at the instrumented Yuma range.

WALT MELTON, early leader of

ED LASSITER was the Aerospace program manager under Brad Parkinson for the latter stages of Pha skilled with r experience, he was especially skilled at early identification and solution to

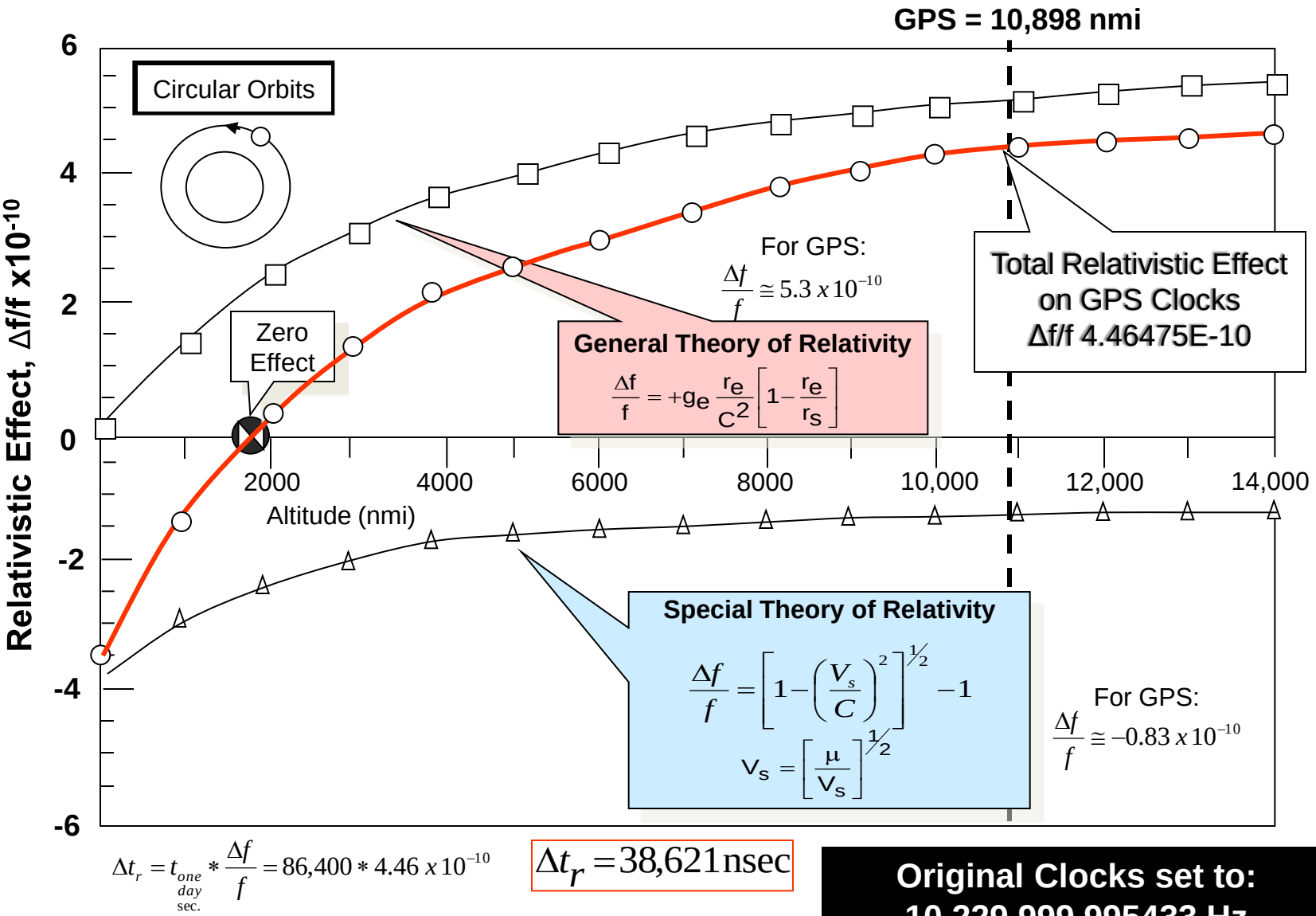
DR. MALCOLM CURRIE. As the number 3 man in the Pentagon, his support was essential g om

The Relativity Story

Government JPO Principal Engineer

Dr. Edward Teller,
Lawrence Livermore National Laboratory, California

Relativistic Effect on GPS Clocks



$\Delta t_r = t_{\substack{one\\day\\sec.}} * \frac{\Delta f}{f} = 86{,}400 * 4.46 \times 10^{-10}$

$\Delta t_r = 38{,}621 \text{nsec}$

Original Clocks set to: 10,229,999.995433 Hz

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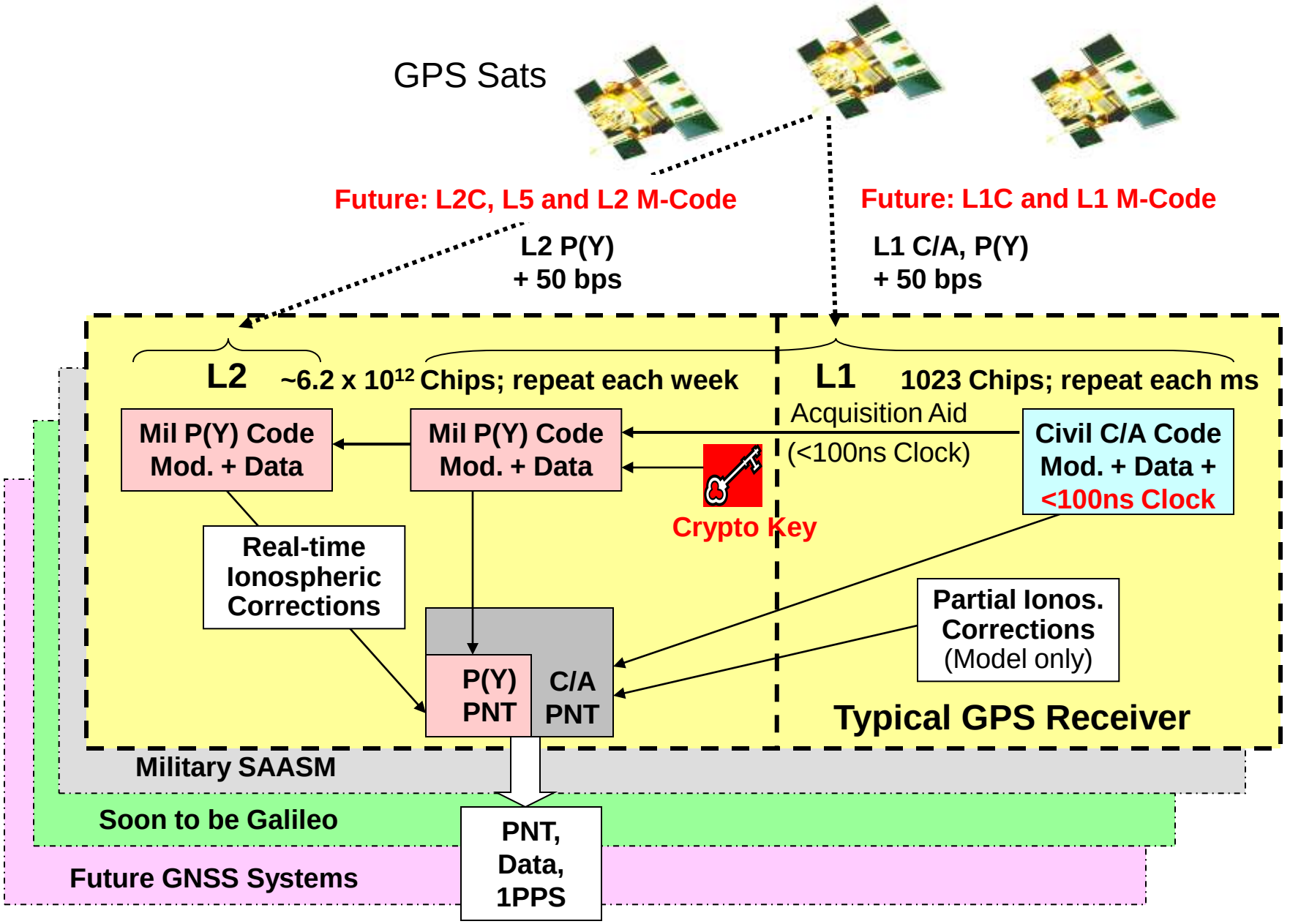
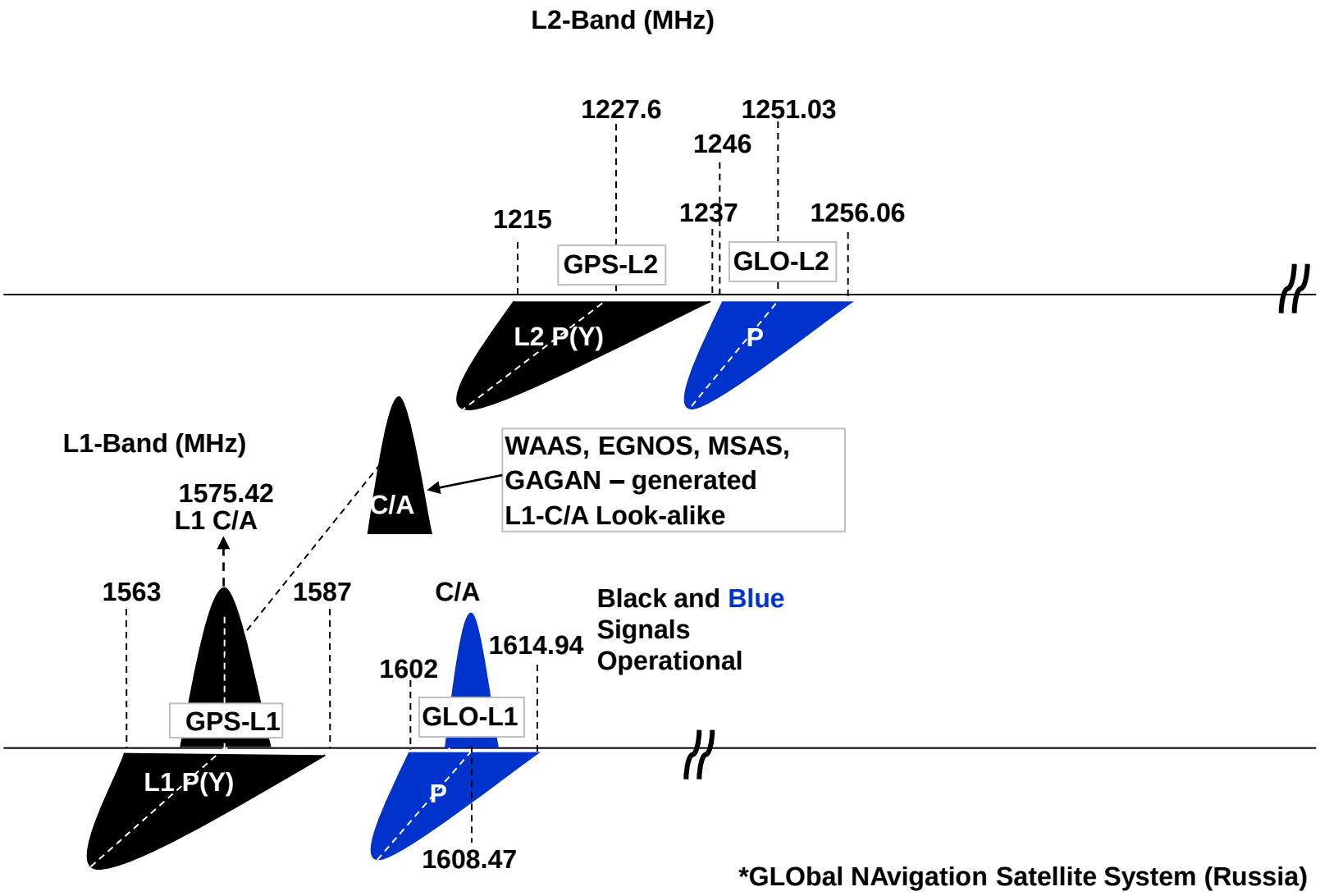
Civil and Military Signal Relationships

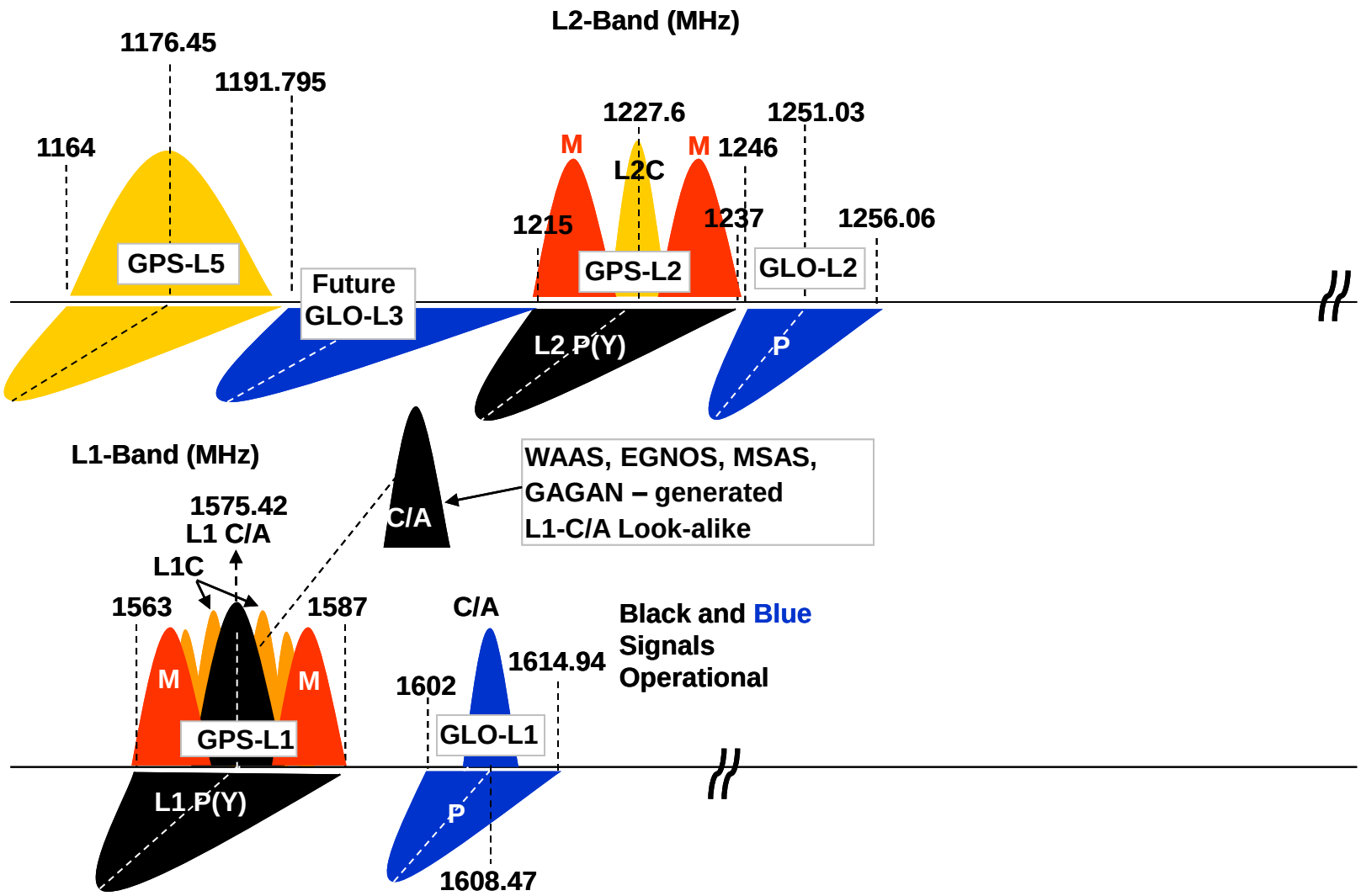


Operational Signals – GPS and GLONASS



*GLObal NAvigation Satellite System (Russia)

Future Signals – GPS and GLONASS



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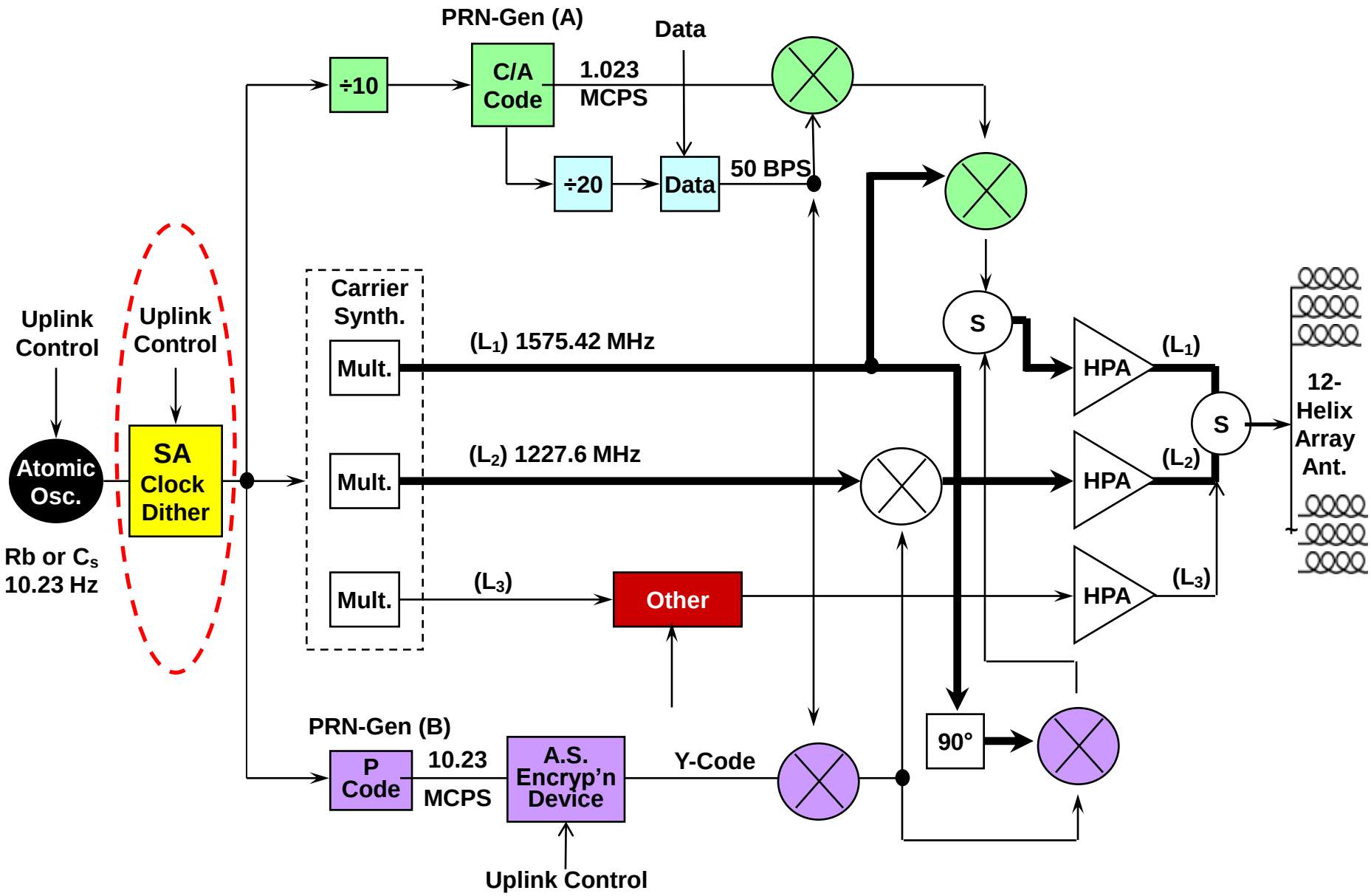
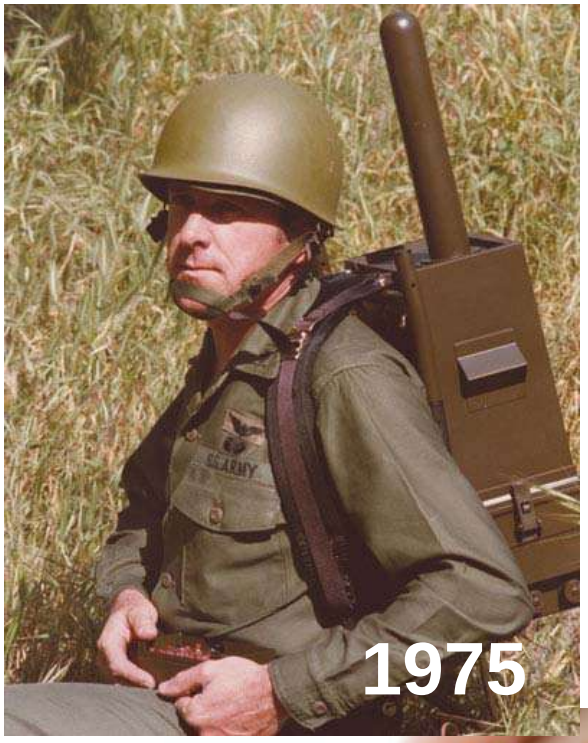
GPS C/A accuracy better than xpected: The birth of Selective Availability



GPS Receivers



We have come a long way and changed our world forever…

GPS rivals the most famous and well know brand name _____

GPS Navigation, Positioning, and UTC has become a global utility, along with:

- Water
- Energy
- Communications
- and Sanitation

GPS-related sales:

- 2009, > $50B
- 2020, expect GPS+GNSS, > $1T

~ 1 billion Nav and Timing Rcvrs in use today, out of ~ 6.8B global population

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What about a GPS World War II ?

A GPS WW II Bombing Campaign in Germany, w/o the civilian targeting strategy

…my rough estimate based on:

~100 cities/target areas
(3) targets each area
(4) yrs of bombing, weekly
(1) ton bombs
(2σ) targeting accuracy

Results:
< 1000 vs.~600,000 Civilian Casualties
> 95% of the Targets destroyed

< 60K tons with GPS vs. ~1.6M tons in WW II

The original Rockwell GPS Proposal that won the contract, late 1974...

and the engineering model of the first 100 (or so) RI/Efratom Rb Space Clocks

...here on the front table