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Real-Time Software Receiver Using Massively Parallel Processors for GPS Adaptive Antenna Array Processing

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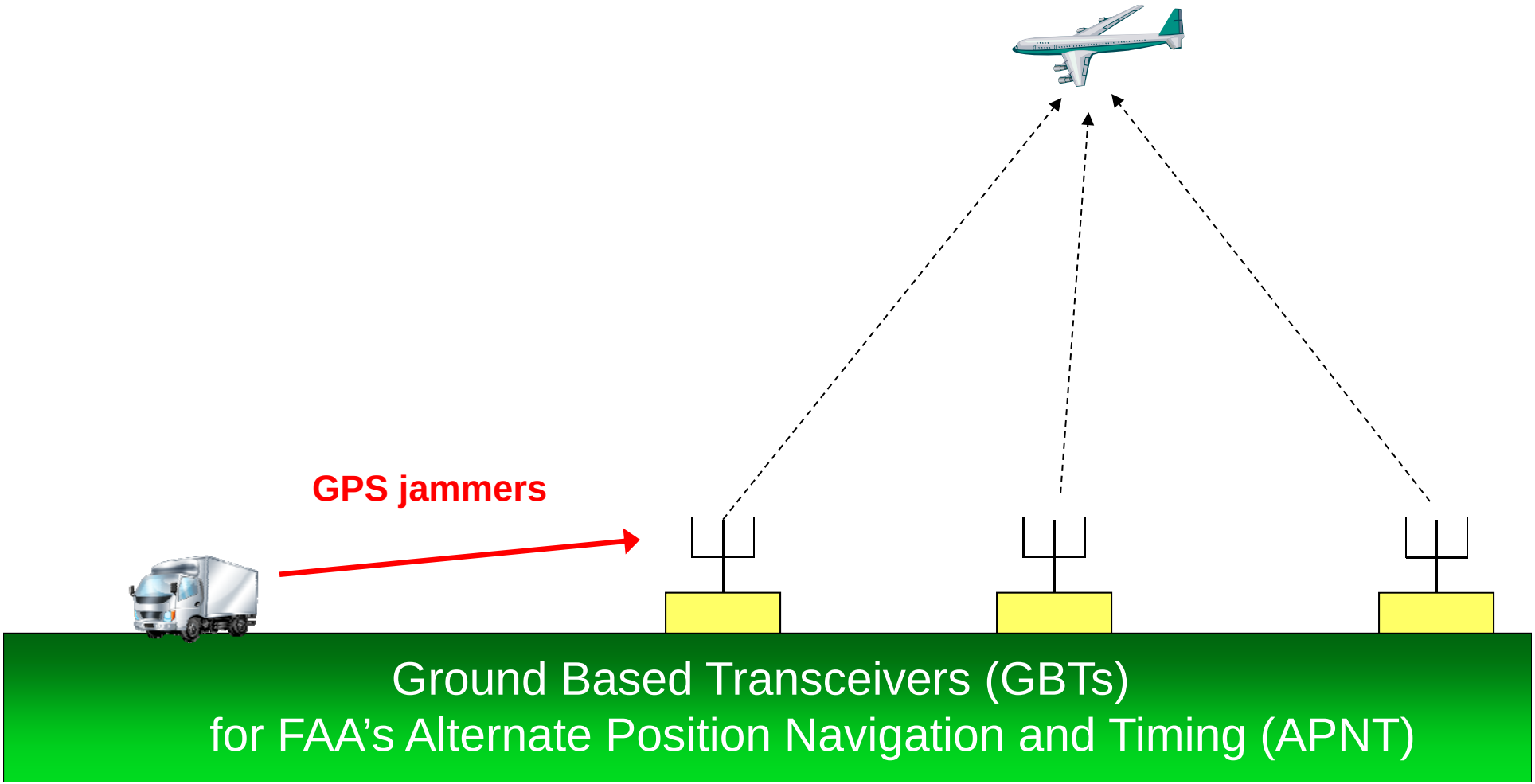
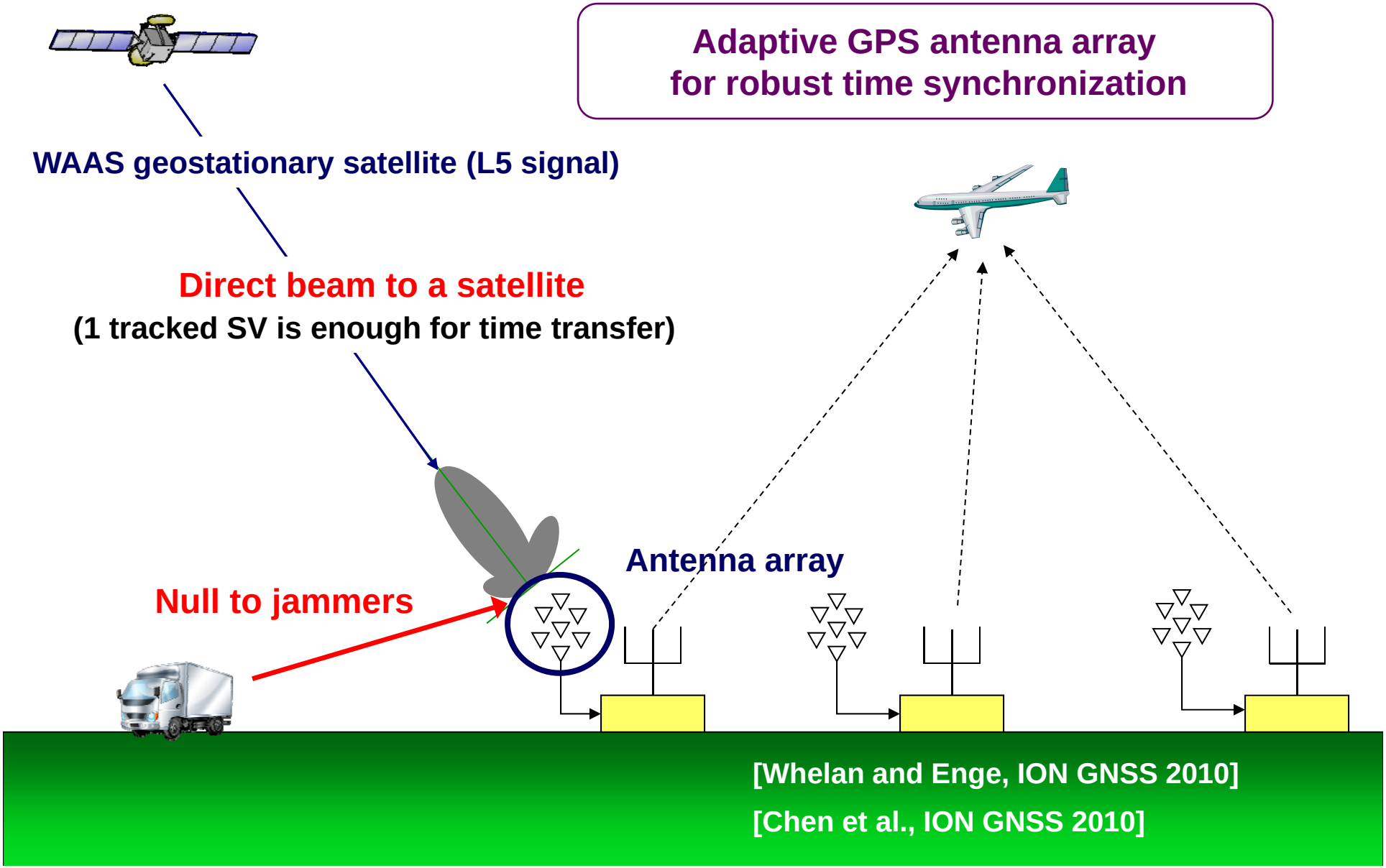
Motivation

Synchronize time between GBTs under GPS interference?
(Stanford's effort)



Our Previous Work

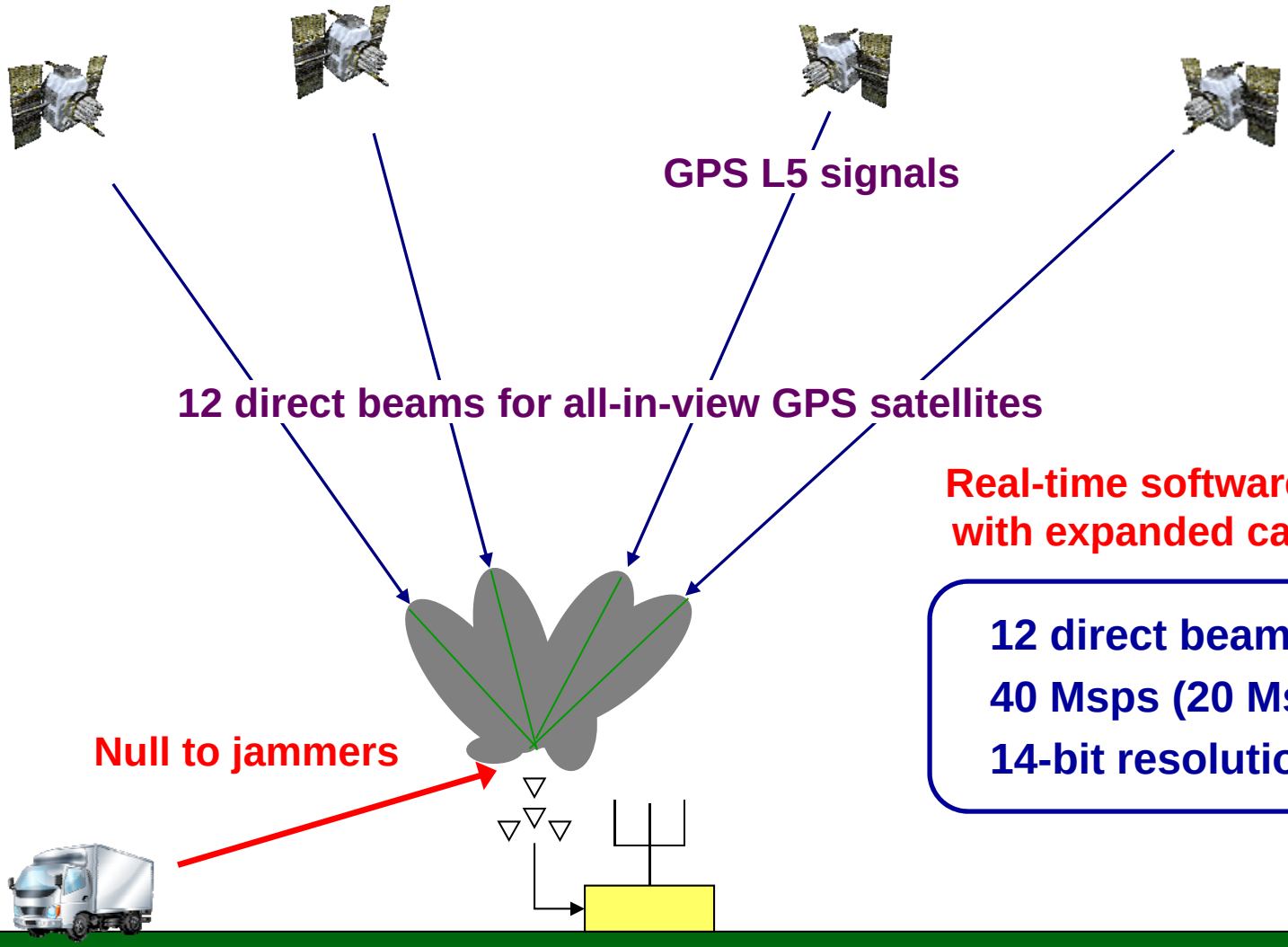
Adaptive GPS antenna array for robust time synchronization



[Whelan and Enge, ION GNSS 2010]

[Chen et al., ION GNSS 2010]

Current Work



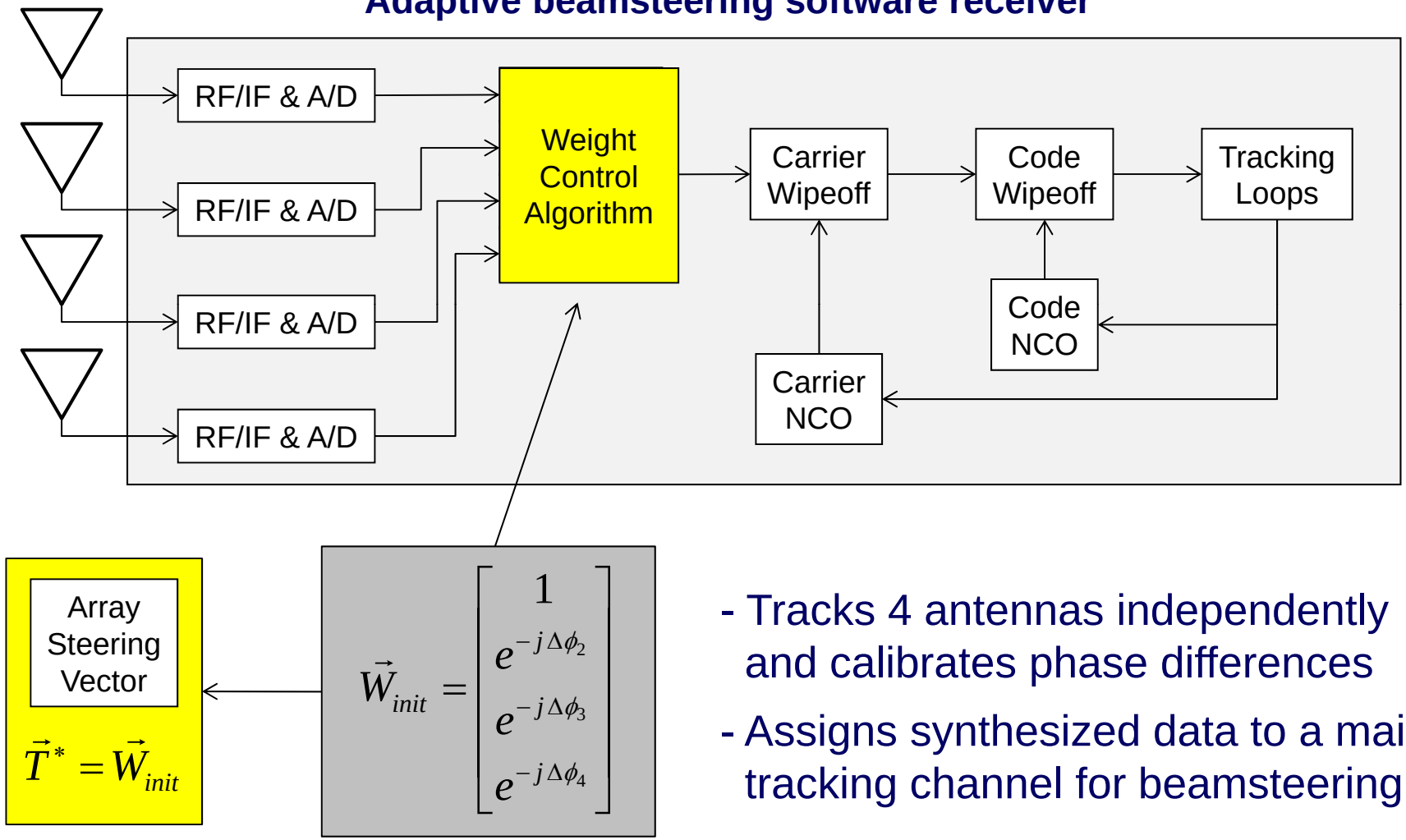
Real-time software receiver with expanded capabilities

- **12 direct beams**
- **40 Msps (20 Msps I & Q)**
- **14-bit resolution data**

Possible aviation application: Protecting GBAS ground facility

Receiver Architecture: Initial Phase Alignment

Adaptive beamsteering software receiver

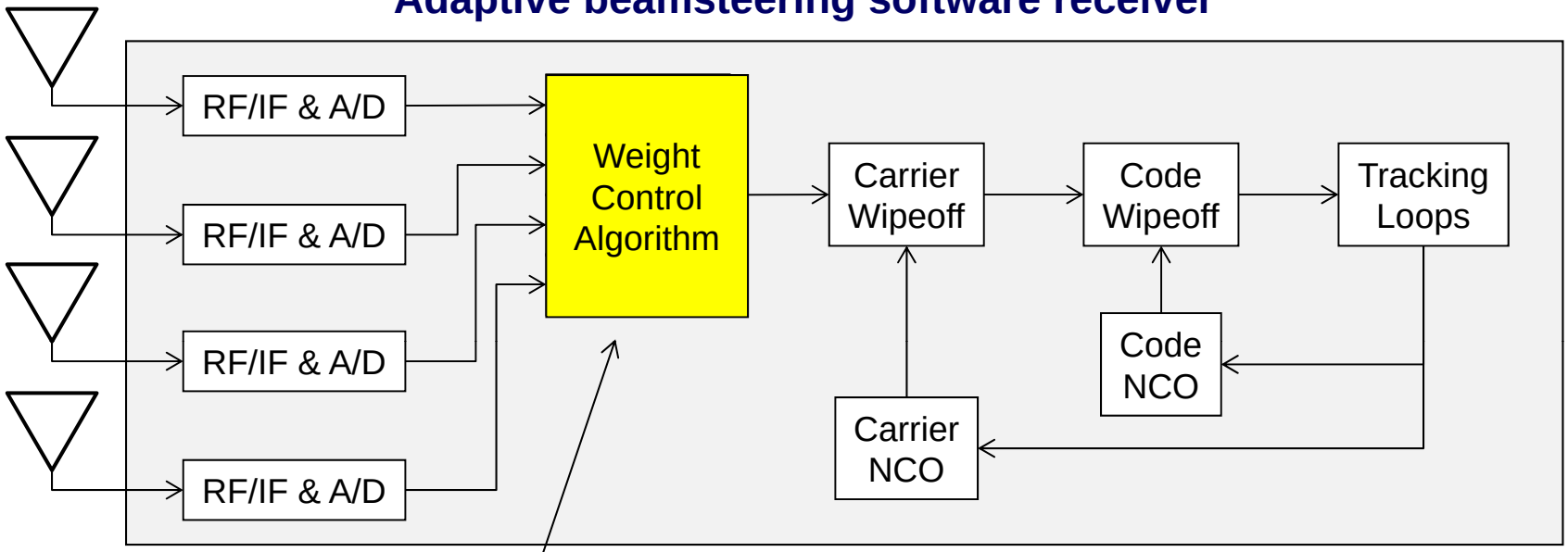


- Tracks 4 antennas independently and calibrates phase differences
- Assigns synthesized data to a main tracking channel for beamsteering

[De Lorenzo et al., ION GNSS 2010]

Receiver Architecture: Adaptive Beamsteering

Adaptive beamsteering software receiver



MVDR Adaptive Array Processing

$$\mathbf{\Phi}_n \equiv E\left\{\vec{X}^* \vec{X}^T\right\}$$

$$\Delta\vec{W}_n = \gamma\left[\mu\vec{T}^* - \mathbf{\Phi}_n\vec{W}_n\right]$$

$$\vec{W}_{n+1} = \vec{W}_n + \Delta\vec{W}_n$$

MVDR (Minimum Variance Distortionless Response)

- Signal covariance should be calculated

[De Lorenzo et al., ION GNSS 2010]

Computational Cost

	Single-antenna L1 receiver		4-antenna adaptive beamsteering L5 receiver
Sampling rate	4 Msps	x 10	40 Msps
Number of channels	12	x 5	60
	T: Computational cost for 12-channel L1 software receiver		50 T → 100 T
Synthesis of 4-antenna data	None	Correlation cost / Beamforming	1.7 T x 12 beams = 20 T
Covariance calculation	None	Adaptive processing	15 T
Sample resolution	2 bits	Dynamic range / No bit-wise parallelism for anti-jamming	14 bits
		(About twice faster [Ledvina et al., 2003])	

Objective & Challenges

Objective: Real-time 4-antenna adaptive beamsteering L5 software receiver
(85 of integer-correlation L1 receivers;
135 of bit-wise-parallel-correlation L1 receivers)

Don't: Have hardware support such as FPGA or ASIC

Do: Use a desktop computer with commercial-off-the-shelf processors

Desktop Parallel Processing

Desktop Parallel Processors

Commercial-off-the-shelf desktop parallel processors

CPU
(Central Processing Unit)

Intel Core i7 950
($300)

4 cores

GPU
(Graphics Processing Unit)

NVIDIA GeForce GTX 480
($500)

480 cores

Hardware Setup

Raw IF data collection setup (4 sets)

Trimble Antenna

USRP2 (Universal Software Radio Peripheral)

Gigabit Ethernet

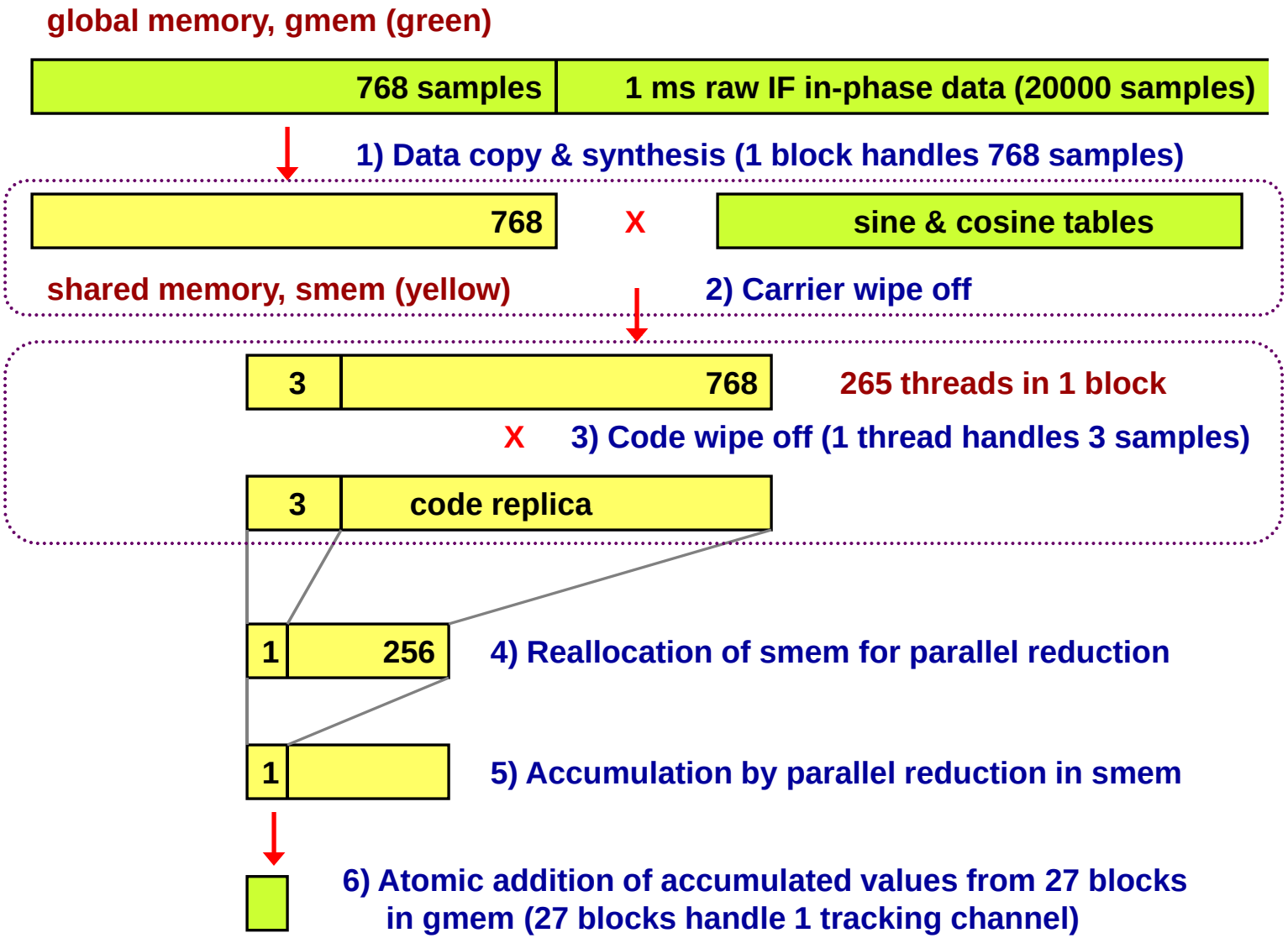
14-bit, 40 Msps

Solid State Disk in a Linux box

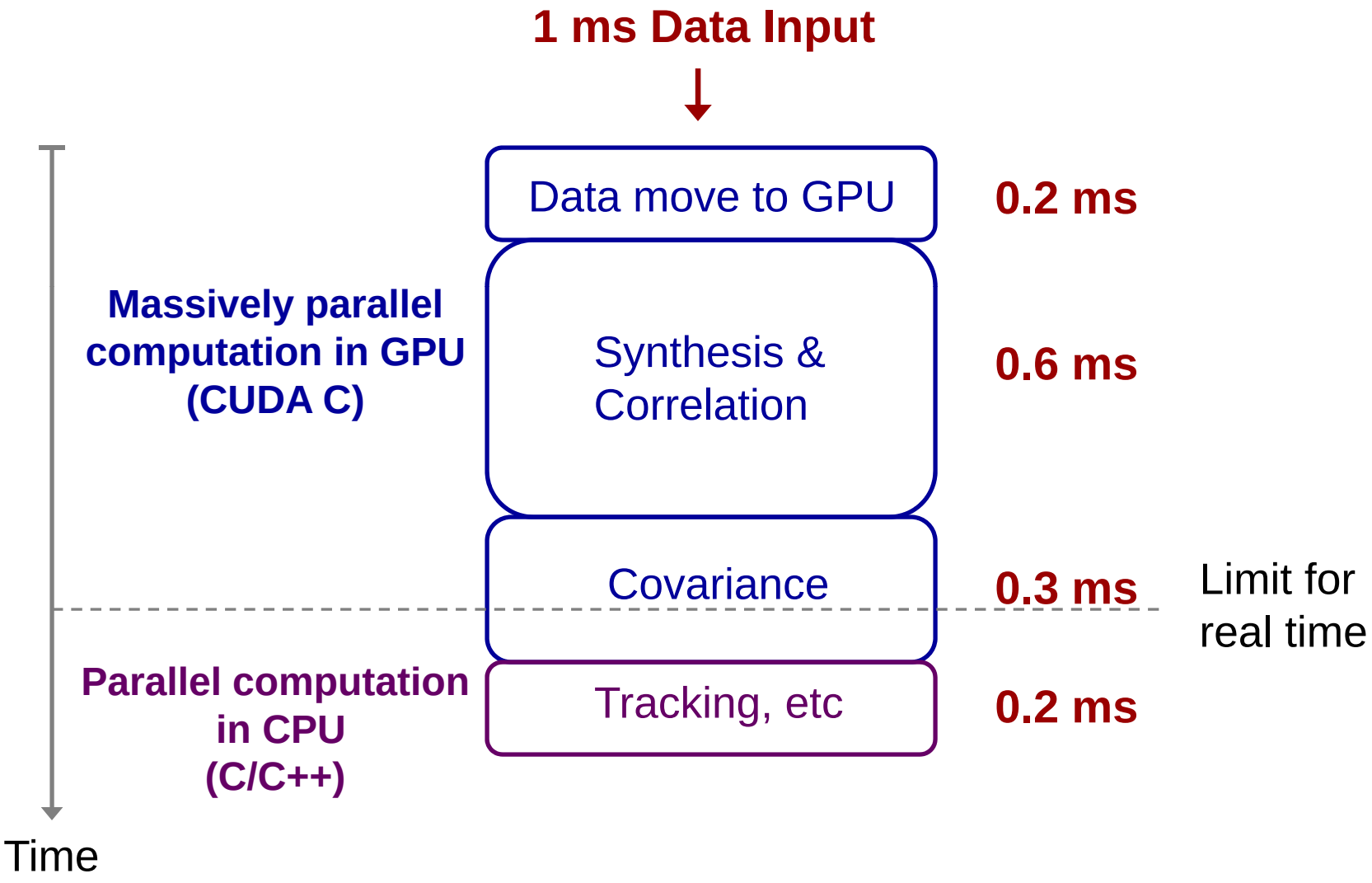
Demonstrate real-time computational capability for L5 processing

4-antenna, 14-bit, 40 Msps (20 Msps I & Q), L1 data

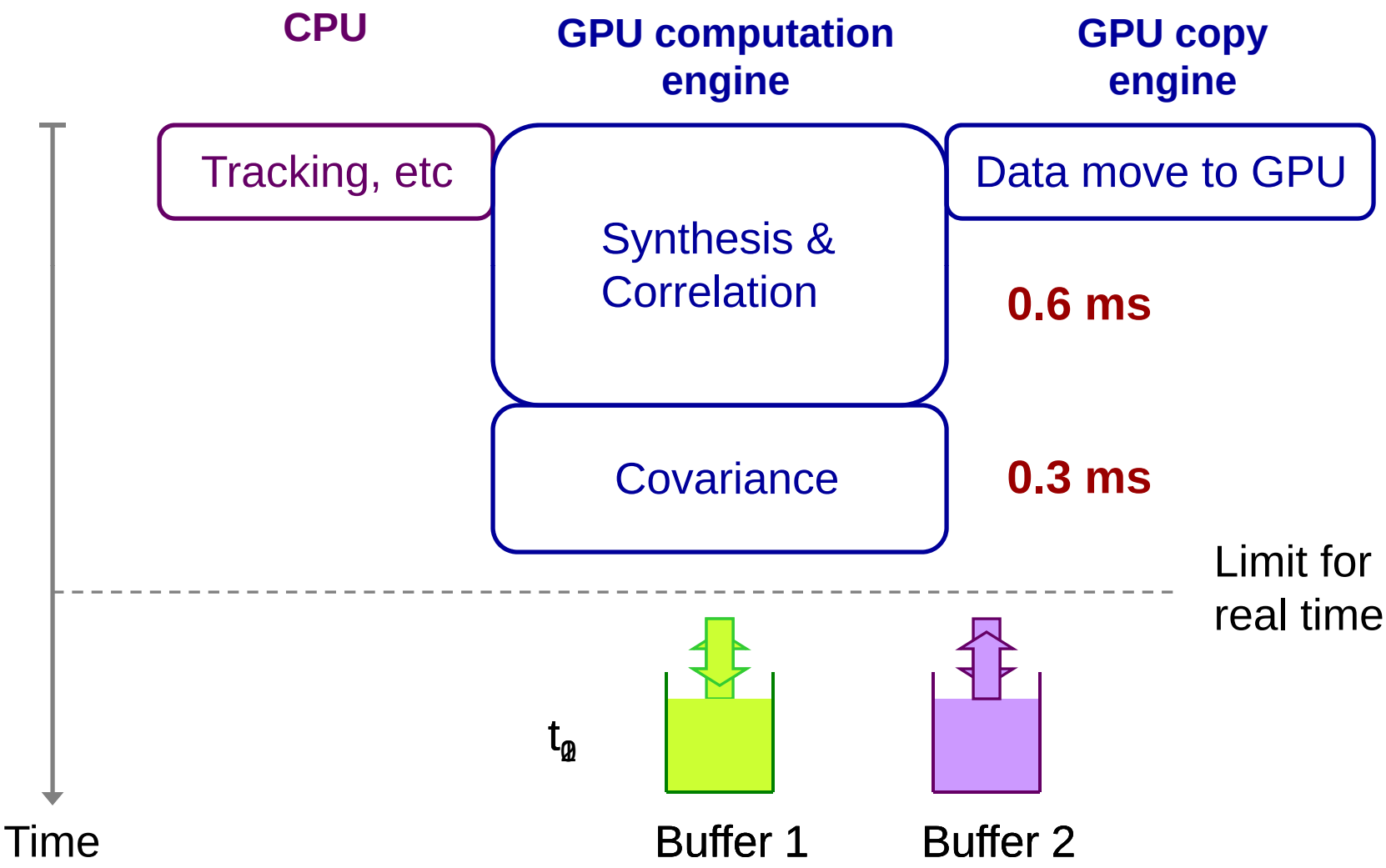
GPU-Based Parallel Correlator



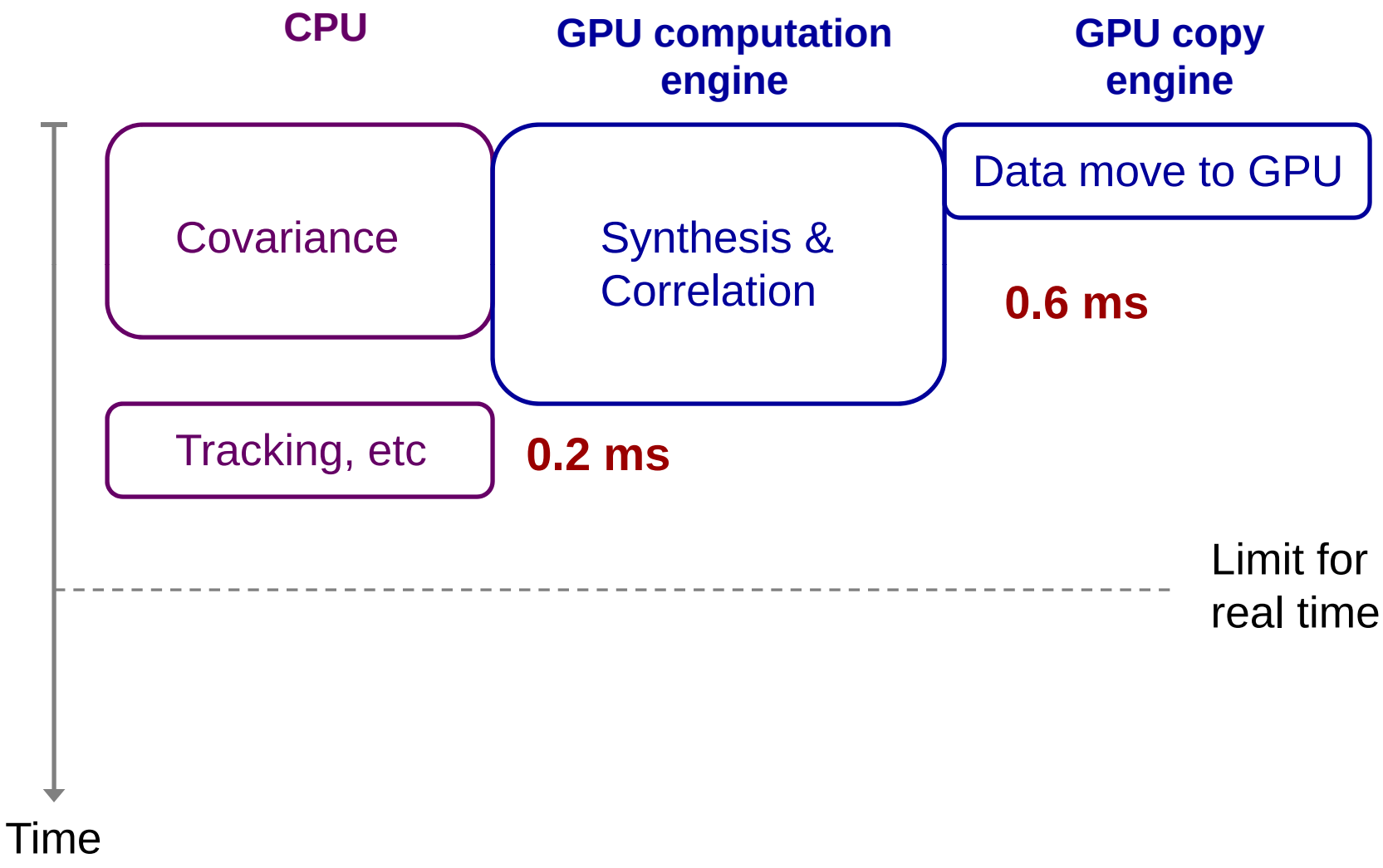
Timing Diagram of Initial Design



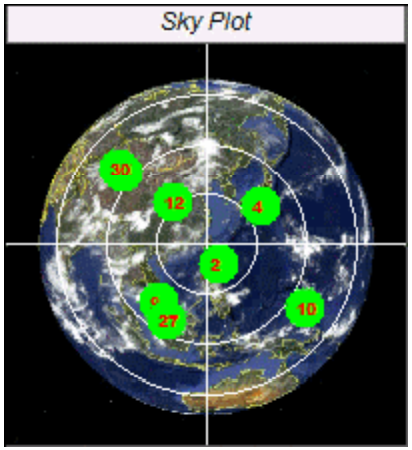
Hardware Parallelism



Load Balancing Between CPU & GPU

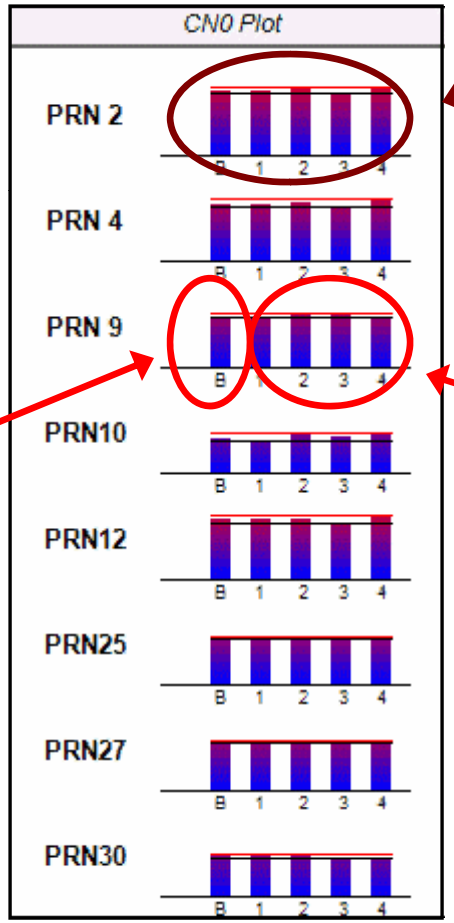


Anti-Jamming Capability



8 satellites in view

Tracking without beamsteering



5 tracking channels for 1 satellite

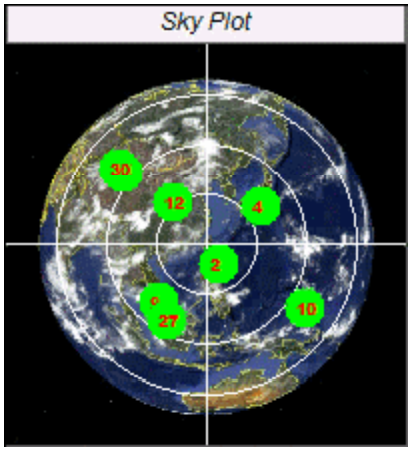
Beamsteering channel

(same as 1st antenna channel)

4 channels tracking 4 antennas independently

(for real-time phase calibration; Calibration data are stored as a lookup table)

Anti-Jamming Capability



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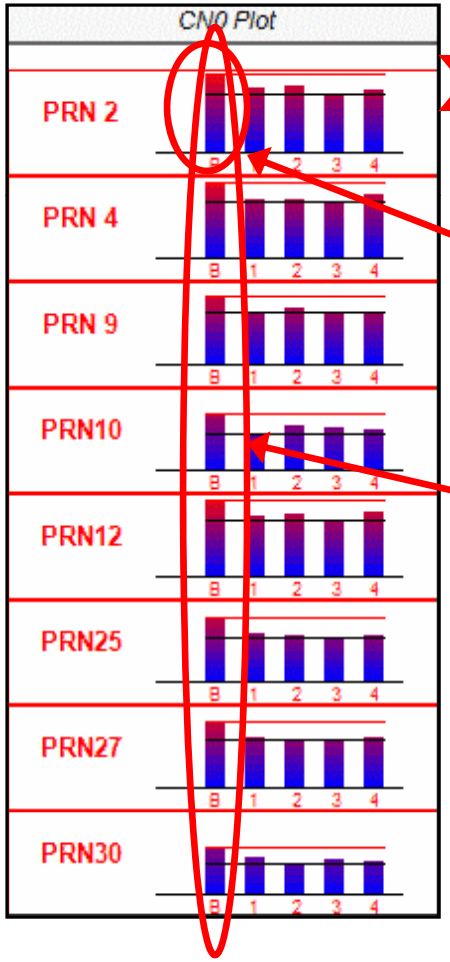


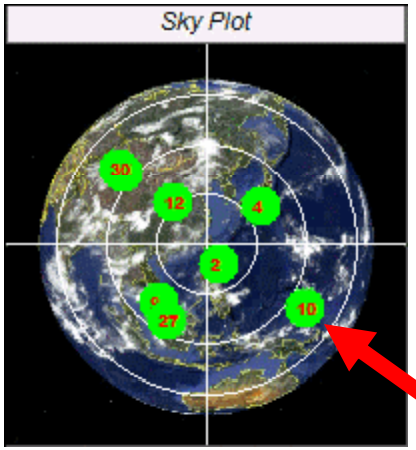
About 6 dB C/N_0 enhancement in beamsteering channel

(benefit from a direct beam)

C/N_0 enhancement for all satellites

(synthesized IF data 12 times with 12 different weight vectors to make 12 direct beams)

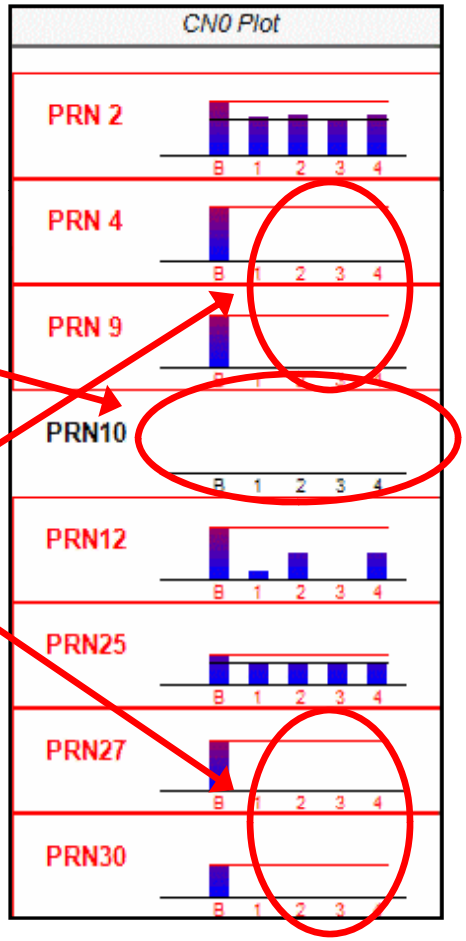
Anti-Jamming Capability



Simulated CDMA jamming in the direction of PRN 10

(40 dB J/S, PRN 168 as CDMA jammer)

Tracking under simulated CDMA jammer



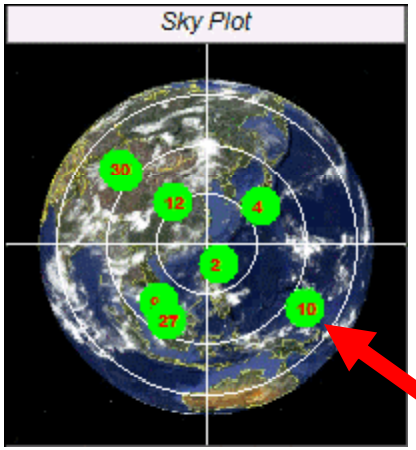
PRN 10 is completely lost

Most single antenna channels are lost

(Calibration data is already stored as a table by the real-time calibration scheme;

Satellite ground tracks repeat)

Anti-Jamming Capability



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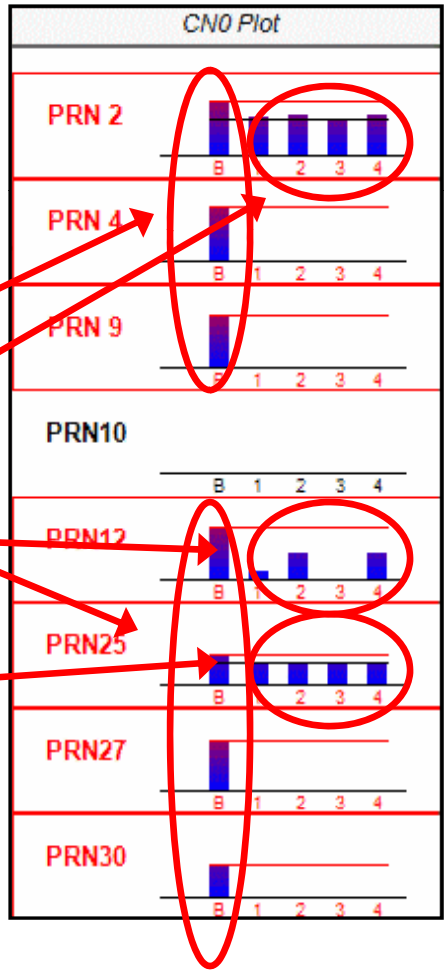
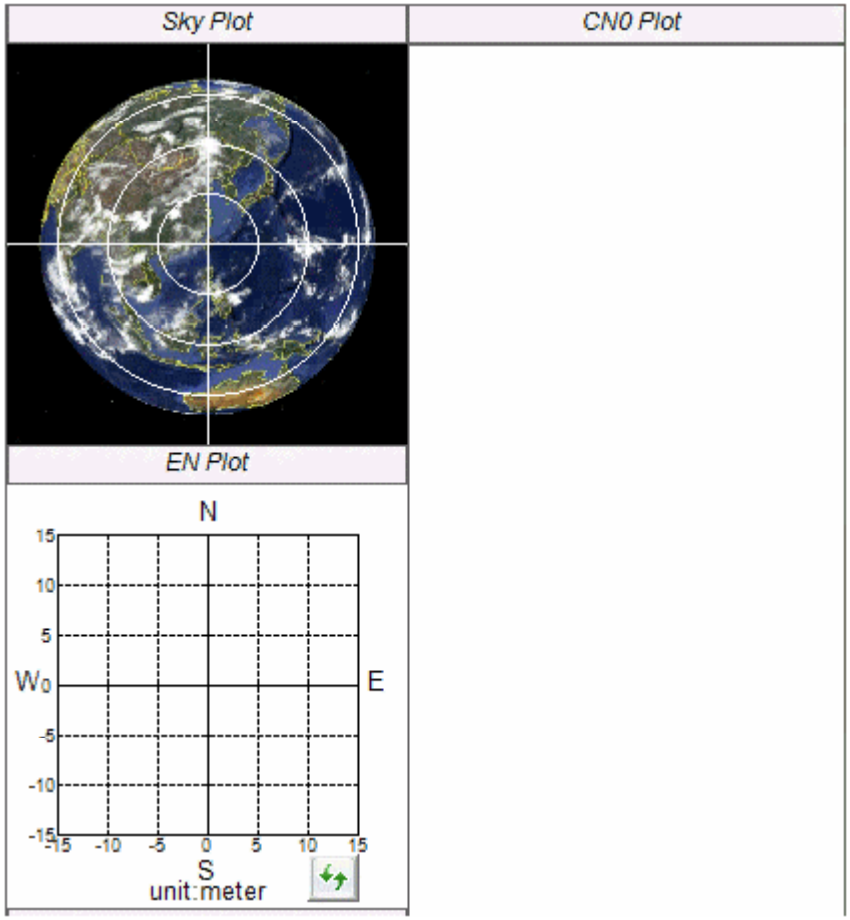


Beamsteering channels are still tracking!

Some single antenna channels are good, but lower C/N_0

Single antenna channels of PRN 25 track the jammer!

Real-Time Receiver Demo (Recorded)



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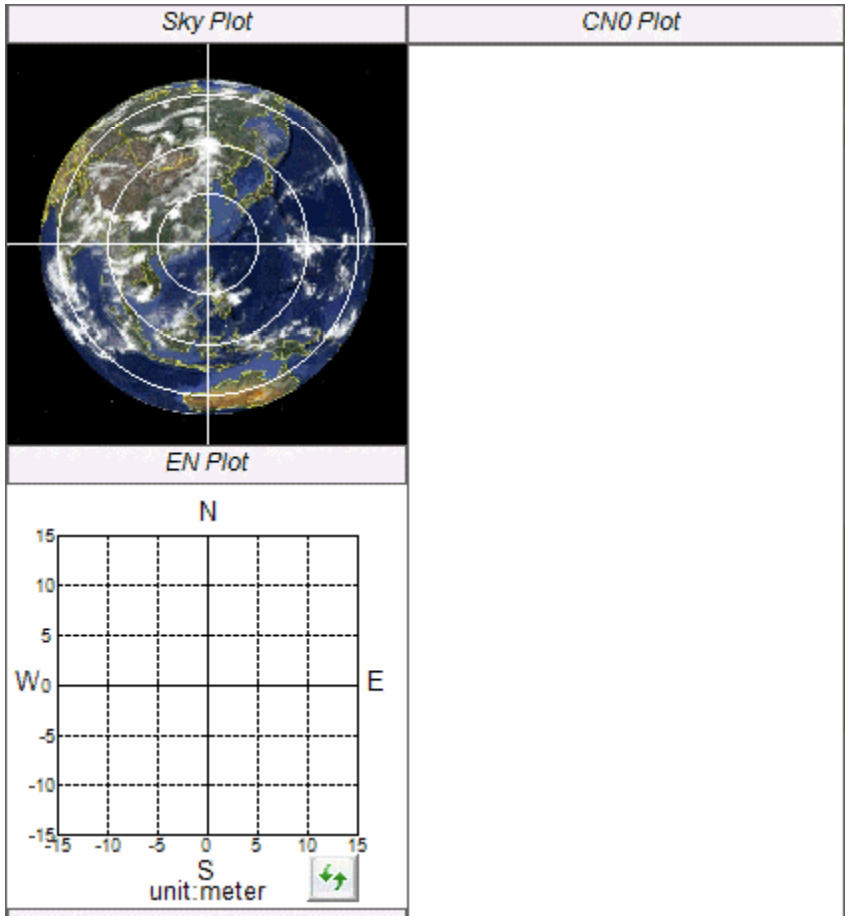

Summary

Objective:

- Real-time, 4-antenna, all-in-view, adaptive beamsteering GPS software receiver capable of L5 signal processing and running on a desktop computer

Results:

- Developed an optimized parallel computation architecture for the beamsteering receiver on cost-efficient CPU & GPU
- Confirmed real-time computational capability and anti-jamming performance under a synthetic CDMA jammer
- Demonstrated that cost-efficient commercial-off-the-shelf hardware and processors would be enough to implement an adaptive beamsteering GPS receiver

END