A GPS Receiver for LEO, GEO and Beyond

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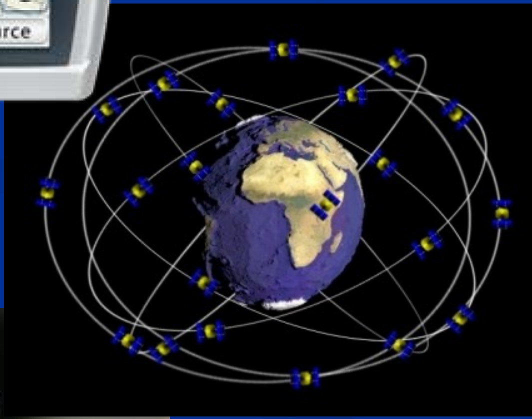
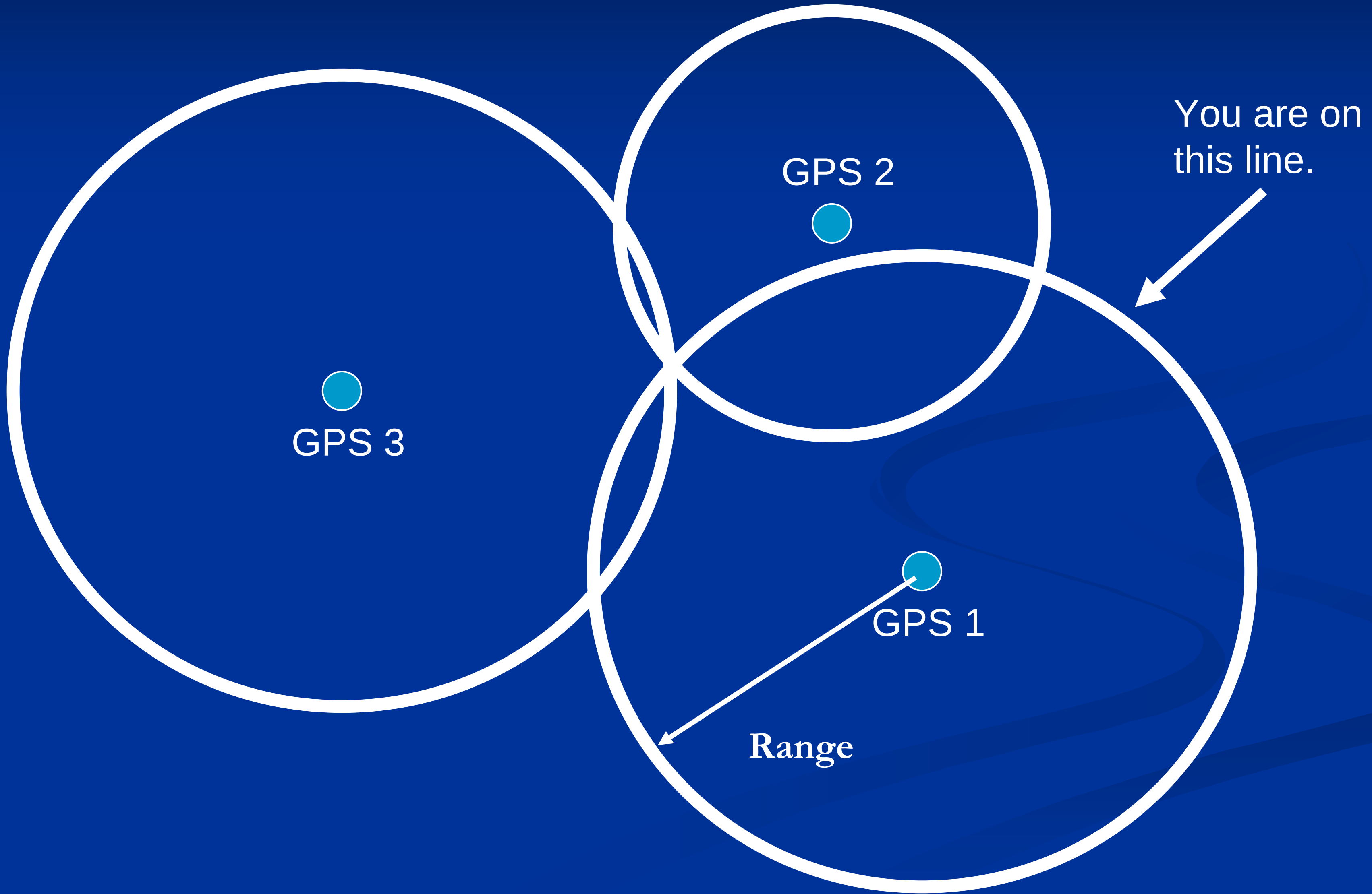
What is GPS?

- Determines your position based on your distance from GPS satellites and knowledge of time
- Installed in phones, cars and planes
- Designed for earth's surface, but can be used in space
- Many LEO satellites use GPS



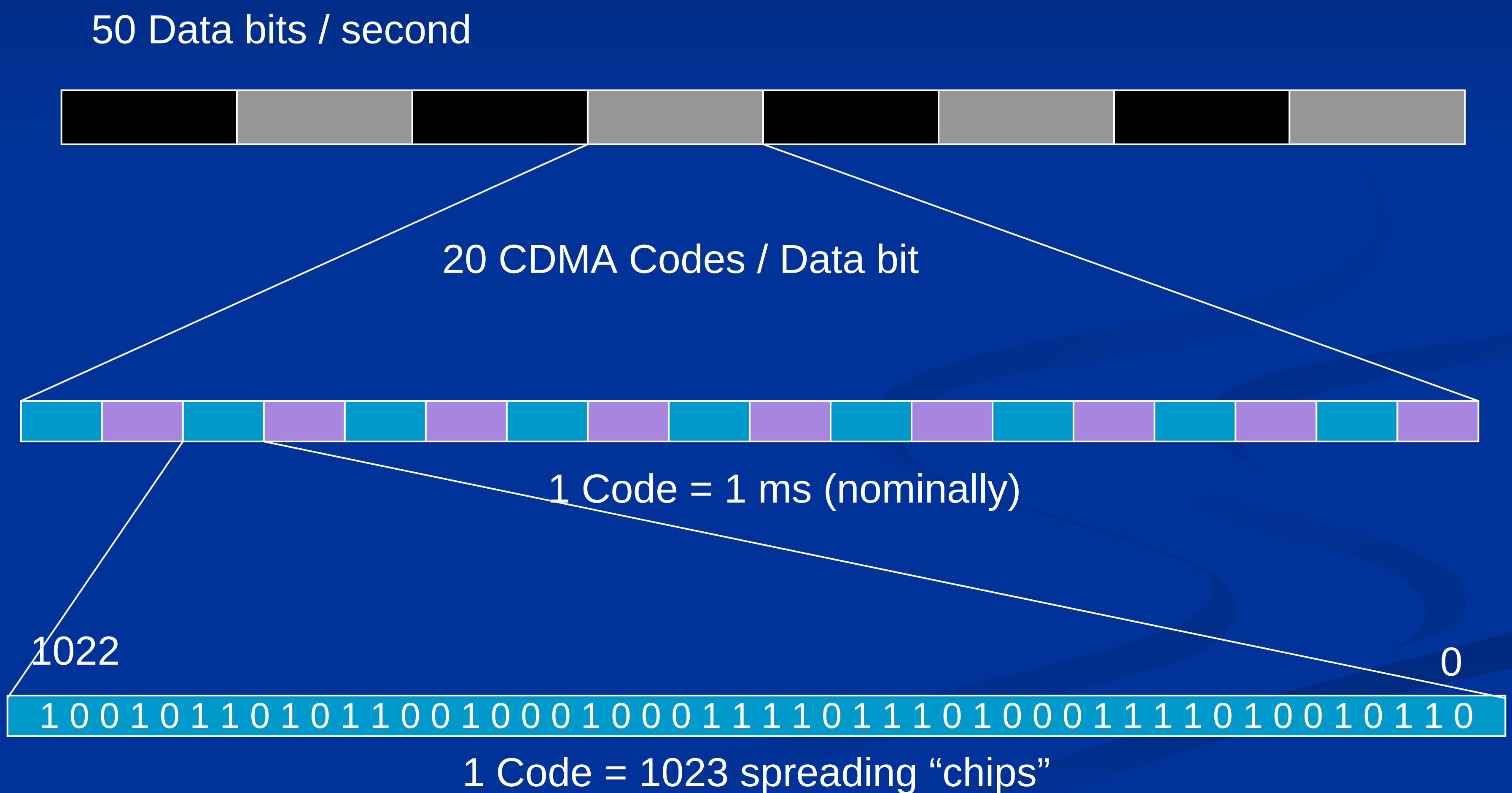
Where are you?



What must a GPS receiver do?

- In order for a GPS receiver to work it must perform 4 tasks
  - Find GPS signals (frequency, code phase)
  - Track/Demodulate the message from each GPS satellite (at the same time)
  - Calculate the position based on distances to the satellites
  - Calculate the correction to your local clock

GPS Signal Structure



Tracking the Signal

To decode message, receiver must line up with the start of code

Incoming Signal

1 0 0 1 0 1 1 0 1 0 1 1 0 0 1 0 0 0 1 0 0 0 1 1 1 1 0 1 1 1 0 1 0 0 0 1 1 1 1 0 1

1023 chips

1 0 0 1 0 1 1 0 1 0 1 1 0 0 1 0 0 0 1 0 0 0 1 1 1 1 0 1 1 1 0 1 0 0 0 1 1 1 1 0 1

Local Code

XOR

1 0 0 1 0 0 0 1 0 1 1 0 1 0 1 1 0 0 1 0 0 0 1 0 0 0 1 1 1 1 0 1 1 1 0 1 0 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Correlation

Correlation

<u>Total</u>
Ones: 0
Zeros: 1023
Excellent Correlation

<u>Total</u>
Ones: 478
Zeros: 545
BAD Correlation

Search Space

Traditional Search

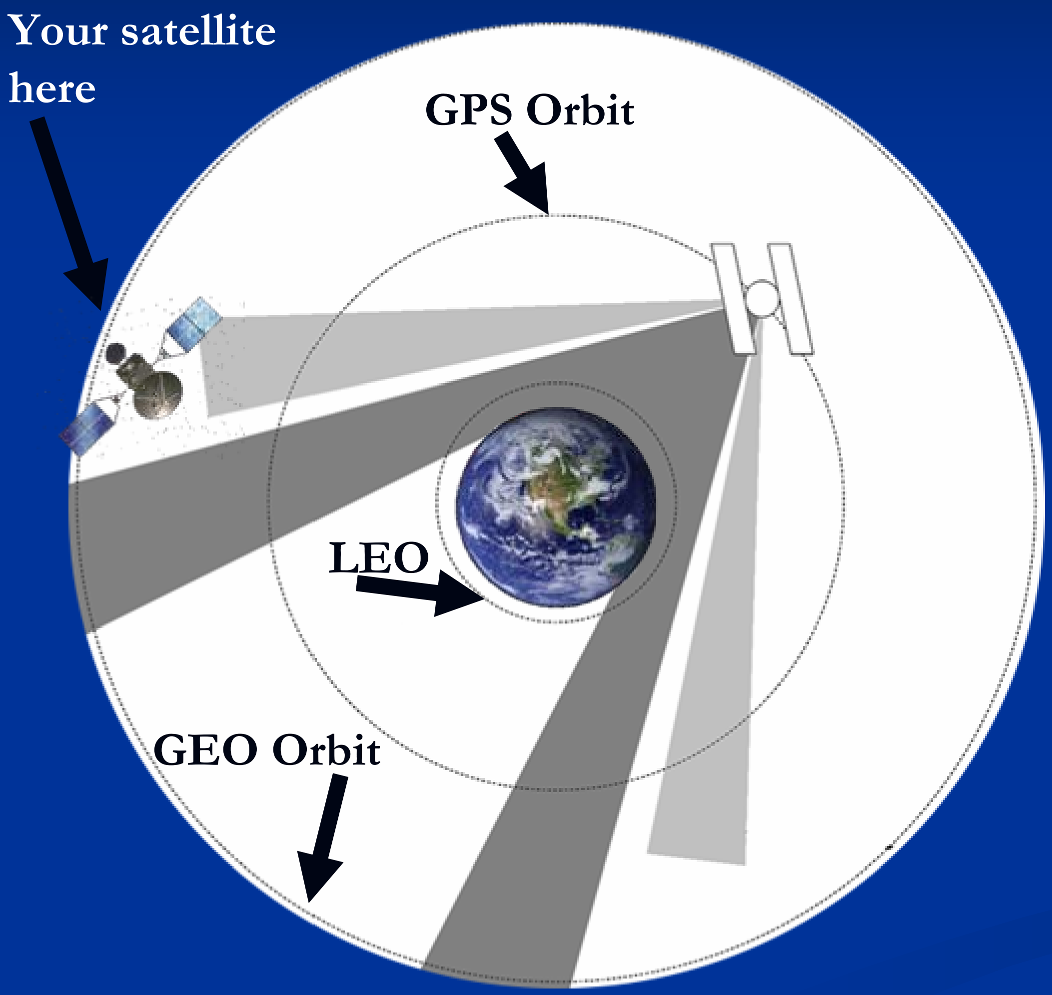
Strong: 35 dB-Hz: 10 KHz * 2 secs/500 Hz = 400 seconds (~7 minutes)

Weak: 25 dB-Hz: 10 KHz * 300 ms/bin * 2000 bin/25 Hz * 40 = 66 hrs!

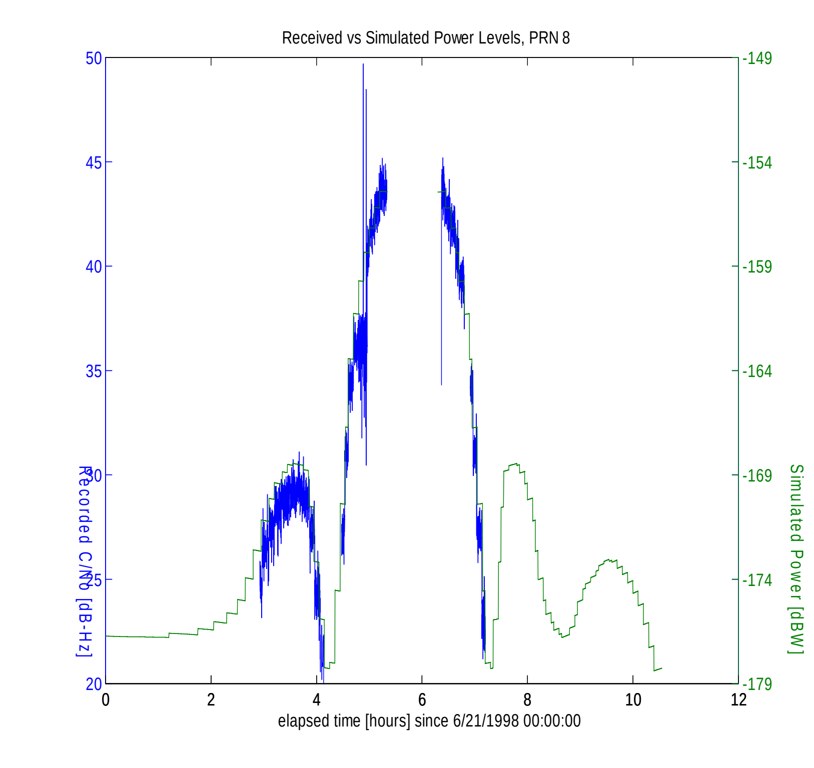
What makes GPS tough in Space?

- GPS in LEO satellites is common
  - Under the GPS canopy
  - Doppler shifts are much higher than on the ground
- In GEO, HEO and cis-lunar
  - Signal strengths are much weaker
  - Signals are only present for brief times

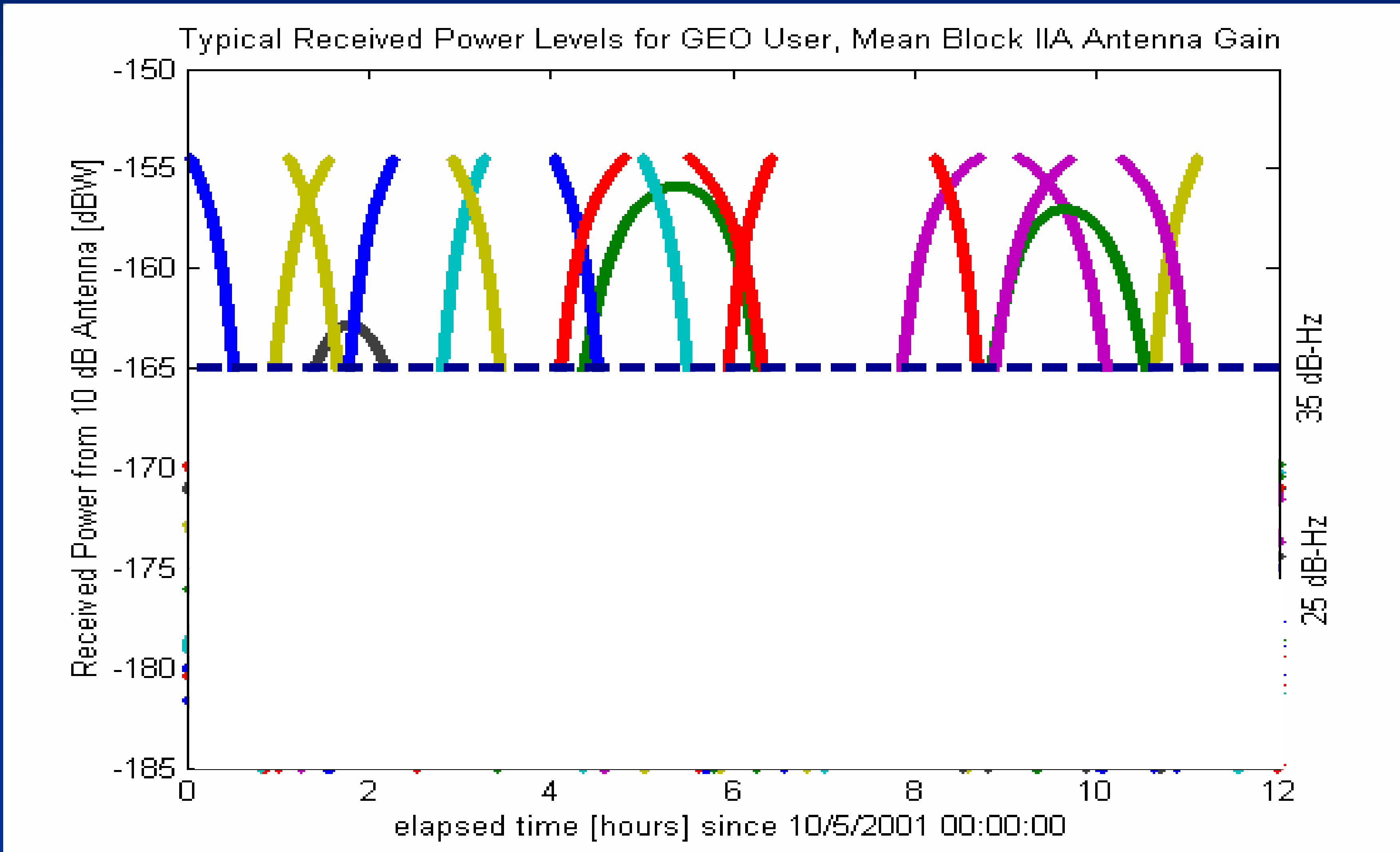
Working Above the Constellation



- Signals can rotate out of view



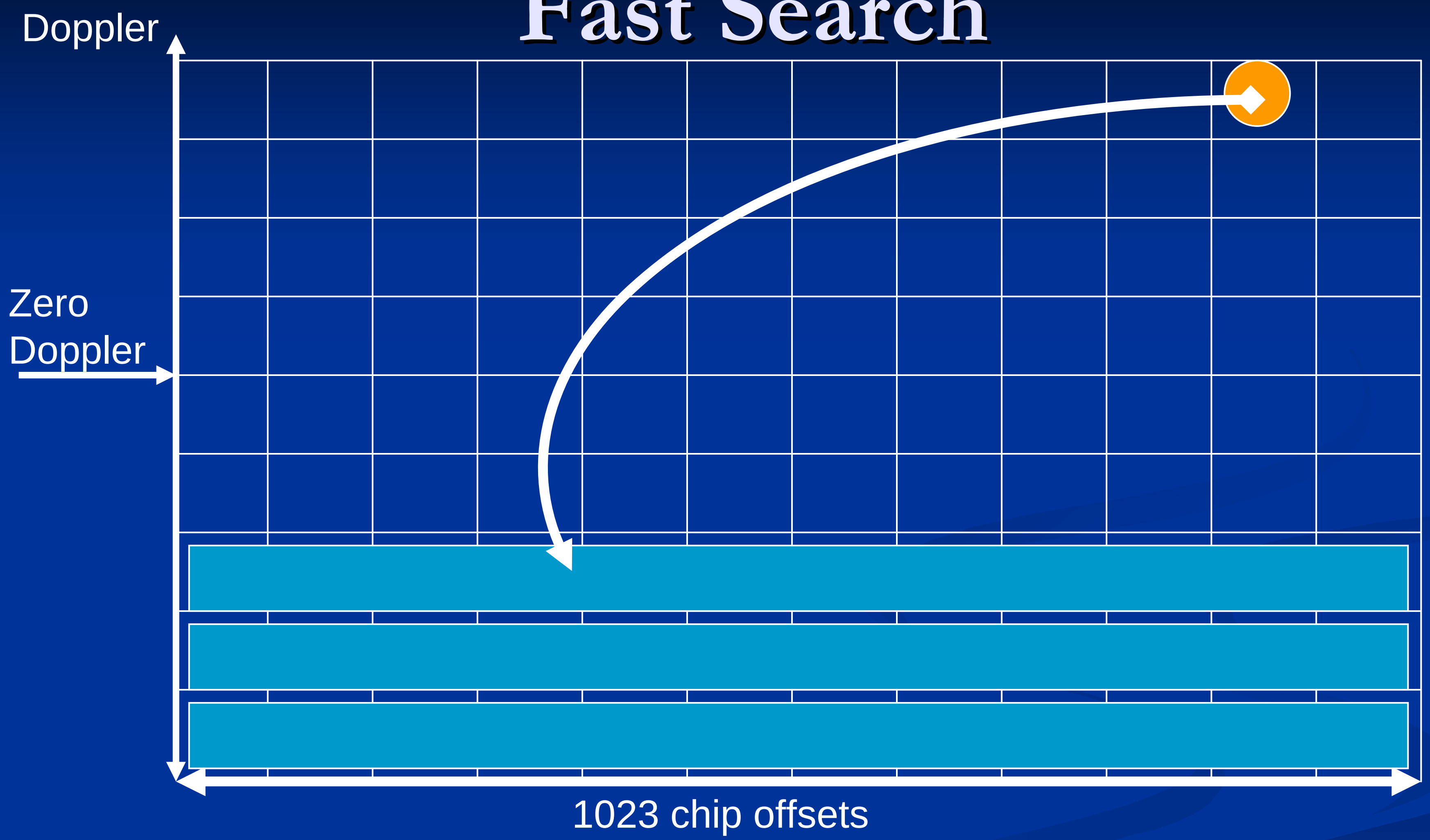
Signal Availability at GEO



How do we find it faster?

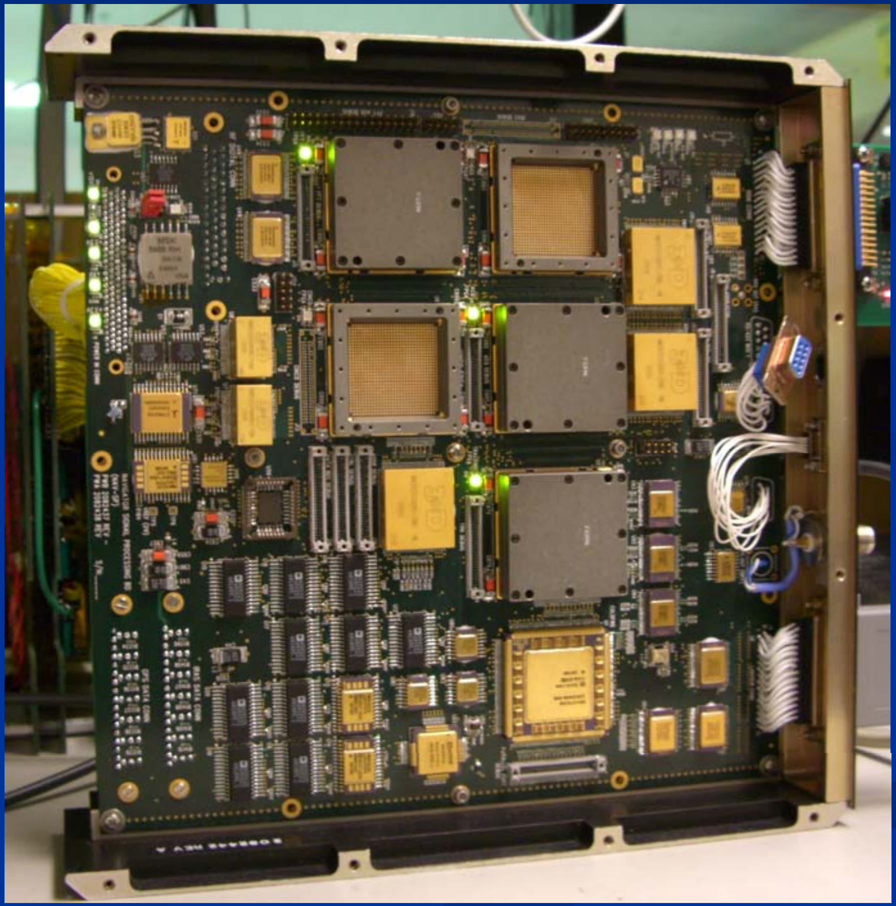
- Need a more parallel search!
  - “Frequency Domain Correlation” provides faster searches.
  - Allows every offset to be searched in 1 ms (strong GPS)
  - Optimizations allow multiple frequencies to be searched at once
  - Roughly 2000 times improvement over traditional
  - Requires an FFT to convert to/from frequency domain
- Relatively straight-forward algorithm
  - IFFT(FFT(x) * FFT(pn_sequence)) = Correlation(x,pn_sequence)

Fast Search



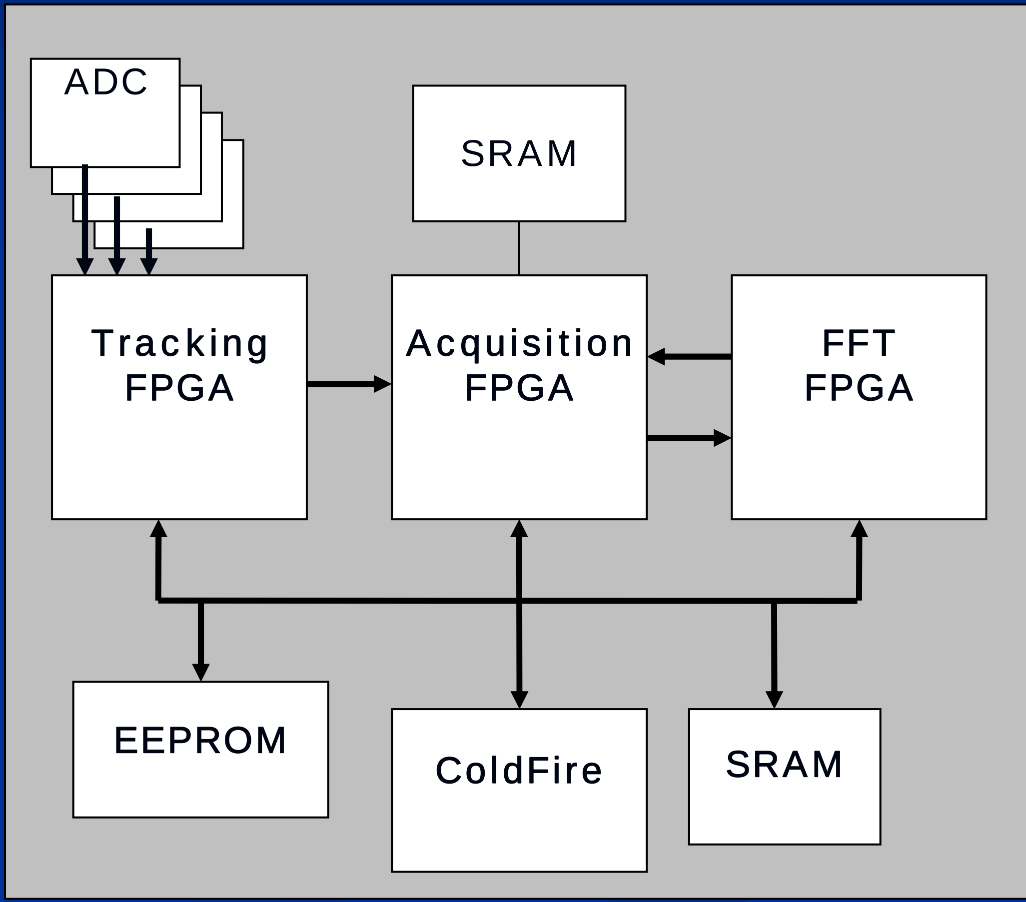
Navigator Signal Processing Card

- GPS + crosslink transceiver
- 5 RTAX-2000 FPGAs
  - 3 used for GPS
- Rad-hard ColdFire
  - 65.536 MHz
- Total dose > 100 kRad
- RS422, RS644, Space wire

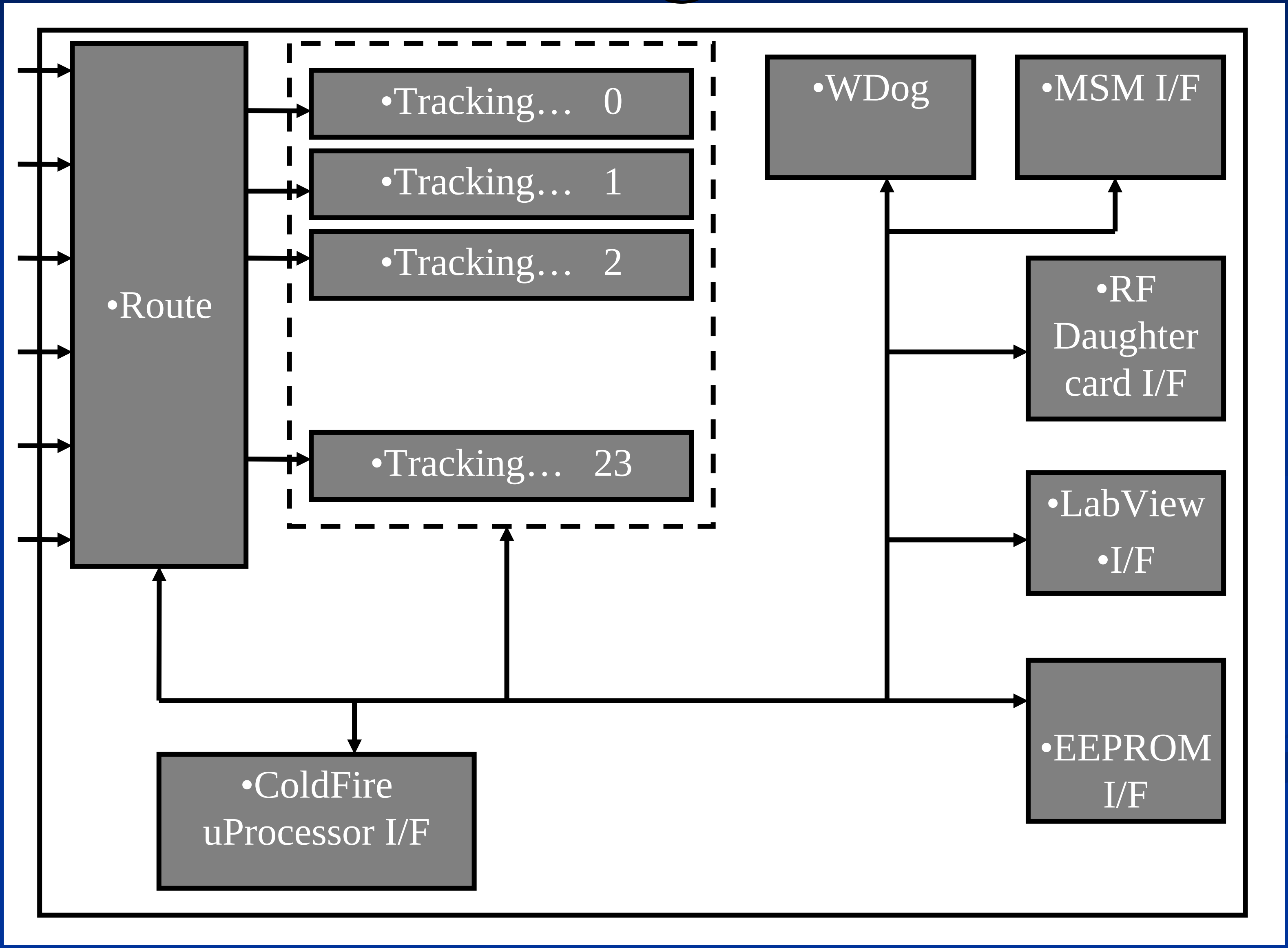


Design Flow

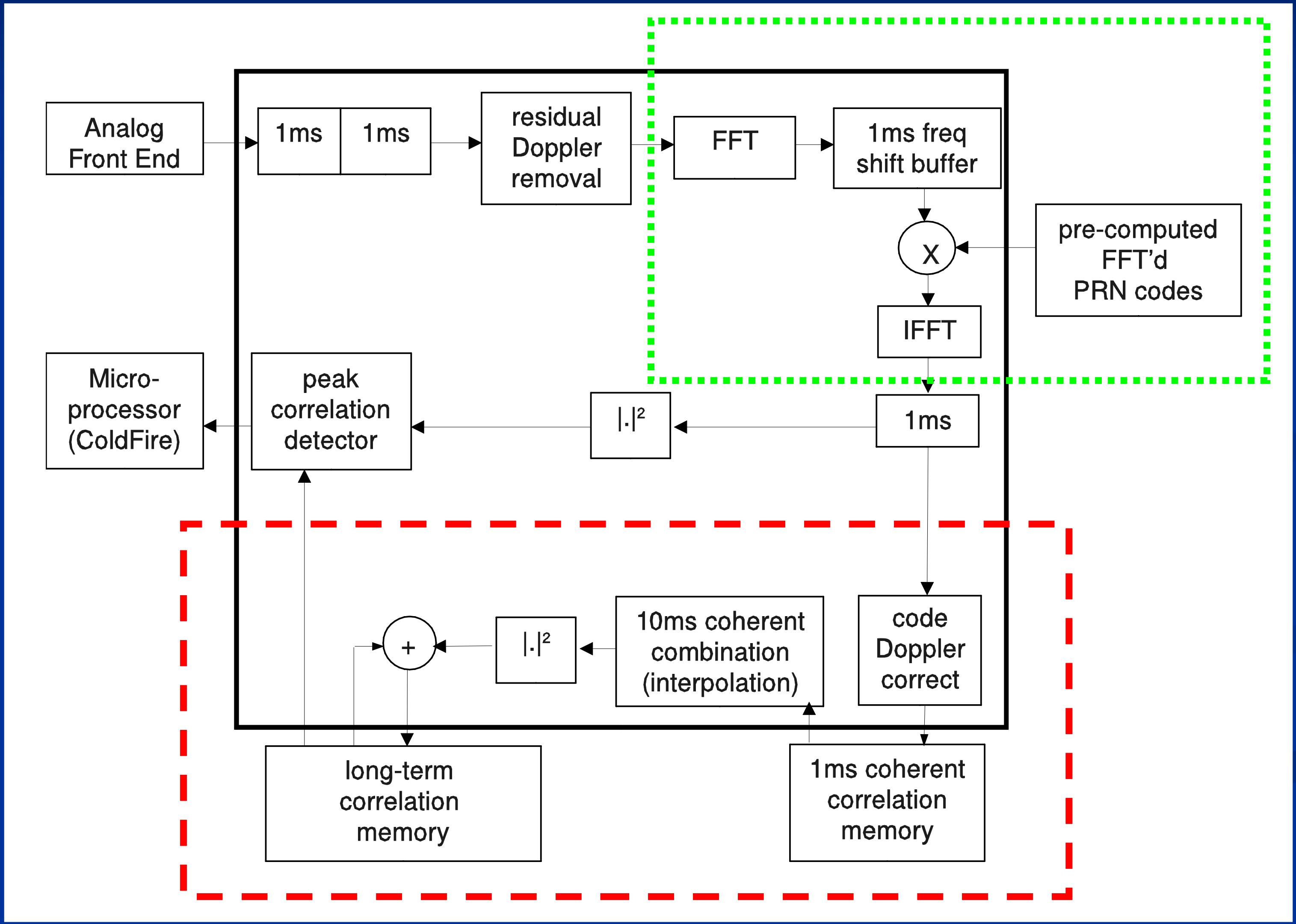
- Can use up to 8 ADCs
- Tracking passes data to Acquisition
- Acquisition searches for satellite and reports location
- Processor controls all parameters.



Tracking FPGA



Acquisition Steps



FPGA Statistics

FPGA	Utilization	Speed Margin
Tracking	80%	8 %
Acquisition	80%	8 %
FFT	55%	19 %

Status

- Hubble SM4 Oct 2008 Space Shuttle
  - Relative Navigation Sensor (RNS) experiment
- Magnetospheric Multiscale Mission (MMS) 2014
  - GPS + crosslink transceiver
- Global Precipitation Measurement
- Orion
  - Fast position during reentry

Skip Reentry Benefit