



# 自動控制於機電系統中之應用

- Design and Develop of High-Dynamics, Multiple-Antenna GPS Receivers
- An Optimal Design of Thermal-Actuated and Piezoresistive-Sensed CMOS-MEMS Resonant Sensors
- Quad Hybrid Engine Levitating Platform
- Development of Missile Mid-Course and Terminal Guidance for Constrained Impact Angle

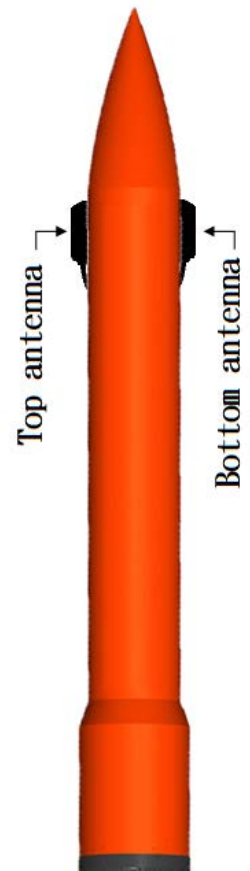


# **Design and Develop of High-Dynamics, Multiple-Antennas GPS Receivers**

# Background



- Commercial GPSR limitations
  - From US government regulations: altitude < 18km, speed < 515 m/s, accelerations < 4G
  - Signal unlock when the vehicle is rotating.
- Rocket launch vehicle applications
  - Altitude > 300 km, speed > 1000 m/s, acceleration < 15G
  - Rocket tumbling and/ or rotating could block the line-of-sight of the satellites.
- Our approaches
  - High dynamics GPSR design
  - Multiple antennas for omni-directional signal receiving.
  - Multiple antennas for the attitude determination.
  - Multiple antennas for the system redundancy.
- GPSR implementation



# Basic Principles of GPS Positioning



- Ideally, the information of the **3 sets of satellites' locations and distances to the GPS receiver** can determine the 3D location of the GPSR. ( $r = c(T_u - T_s)$ )

$$r_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2}$$

$T_s$ : the time signal is transmitted by the satellite

$$r_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2}$$

$T_u$ : the time signal is received by the GPSR

$$r_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2}$$

$c$ : light speed

- In reality, it is difficult to synchronize the clocks on the GPSR and atomic clocks on satellites, one need **4 satellites' information**.

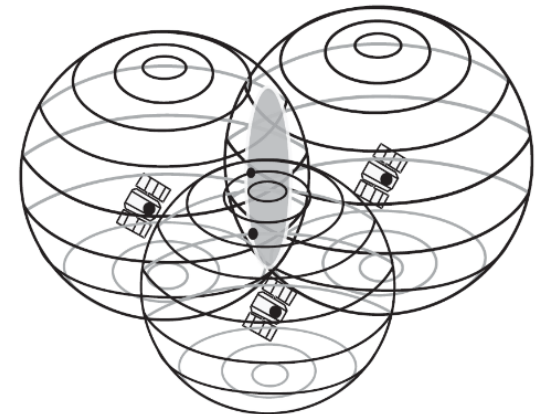
$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + ct_u$$

$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + ct_u$$

$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + ct_u$$

$$\rho_4 = \sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + ct_u$$

$t_u$ : clock error

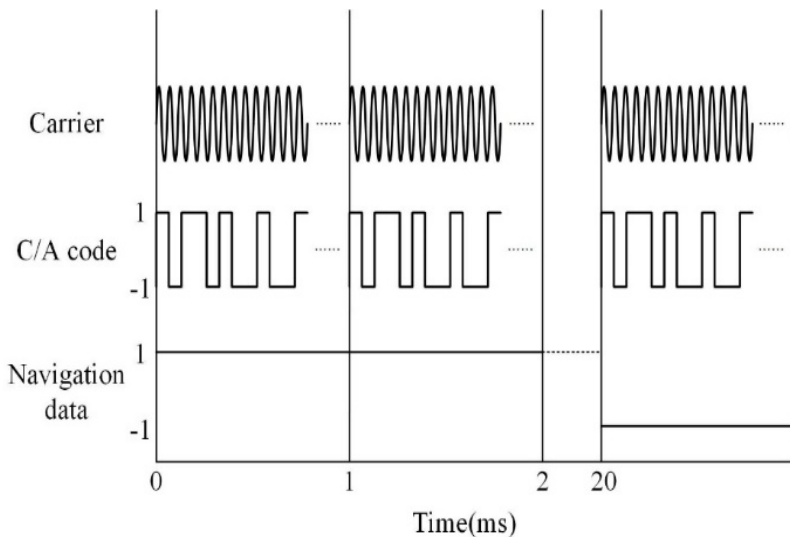


# GPS Signals

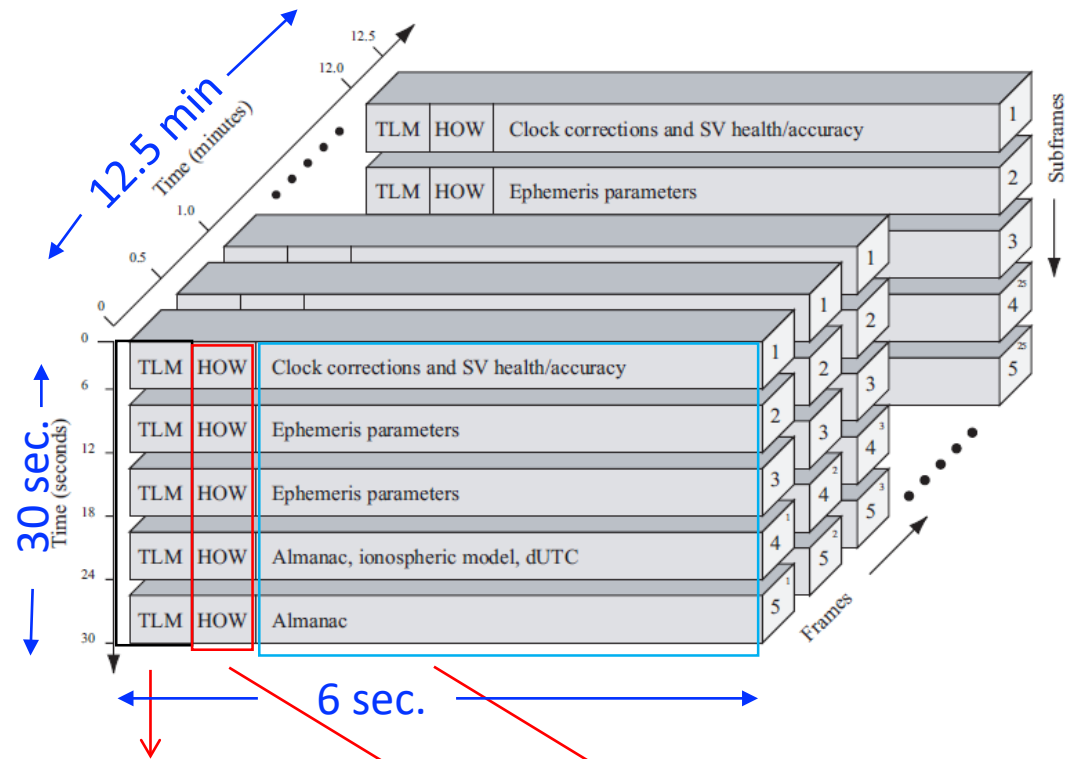


- GPS L1 signal composition**

Carrier (1575.42MHz)  
C/A Code (1.023MHz)  
Navigation Data (50Hz)



- GPSR navigation data**

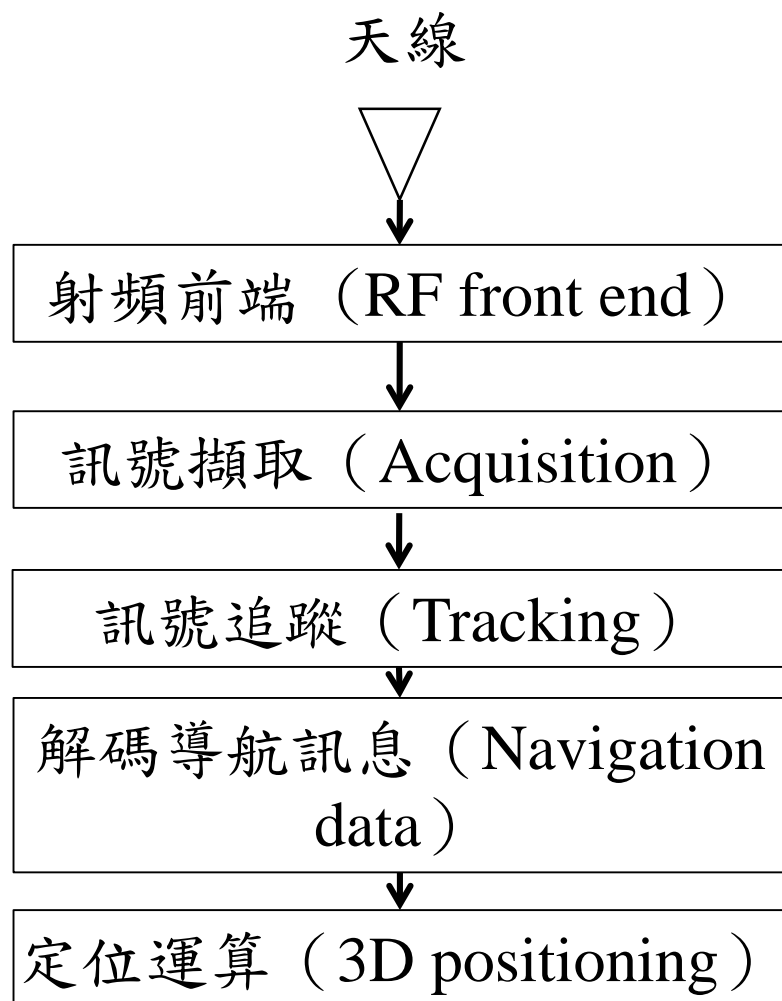


- GPSR receiving signal**

$$s(t) = \sqrt{P_{rcv}} C(t - \tau) D(t - \tau) \cos(2\pi(f_{IF} + f_D)t + \theta)$$

need to estimate  $\tau, f_D, \theta$  to obtain navigation data

# GPSR Signal Processing



goal

Down-sampling

Rough estimation of Doppler frequency and CA code

Precise estimation of Doppler frequency and CA code

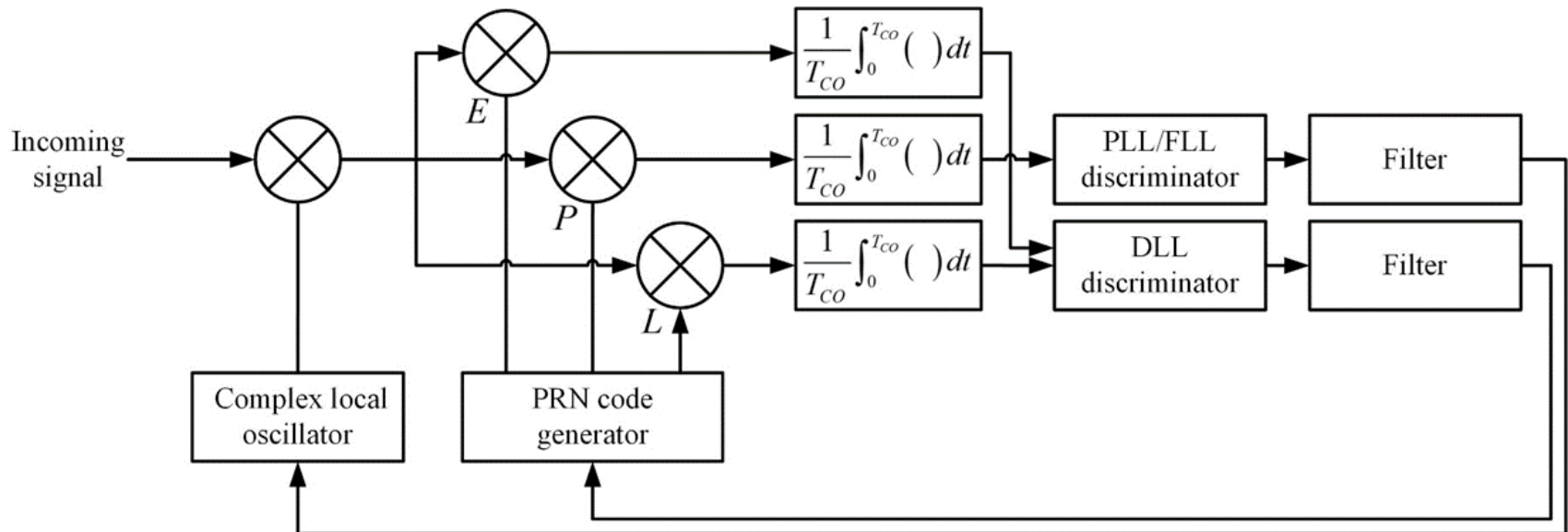
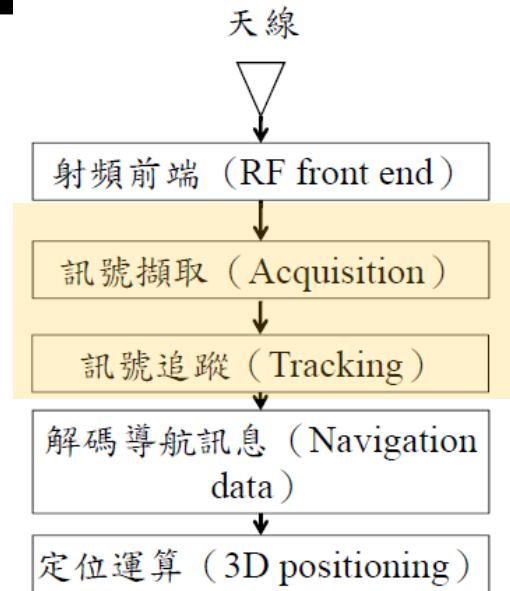
Retrieving satellite ephemeris

3D positioning

# GPS Signal Tracking



- **DLL tracking loop** for the CA code alignment
- **FLL/ PLL tracking loop** to get the Doppler frequency shift and phase shift
  - Filter design for the **high-dynamics**
  - “atan” for the discriminator (lock at 0 or 180 degree)



# High Dynamics Tracking Loop Design

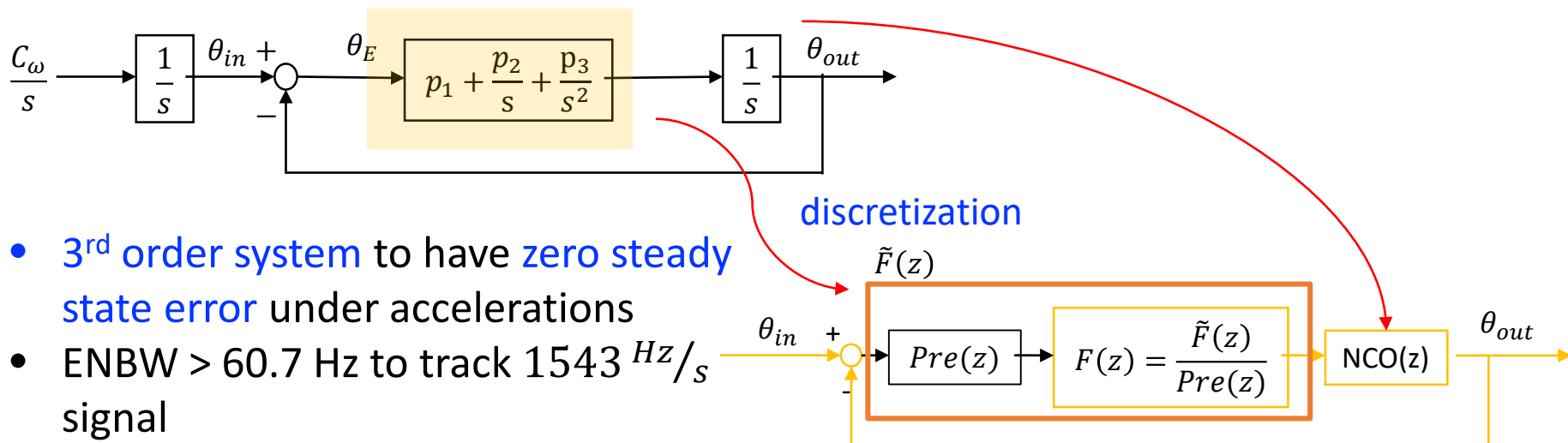


- **Design constraints**

- Nonlinear behavior of the PLL
- Discriminator work for  $-\pi/2 \sim \pi/2$
- Trade-off between bandwidth and noise attenuation
- Worst case time delay  $0.5 \times \text{sampling time}$

- **Design specifications**

- Max. acceleration 30G, max. velocity 1500 m/s



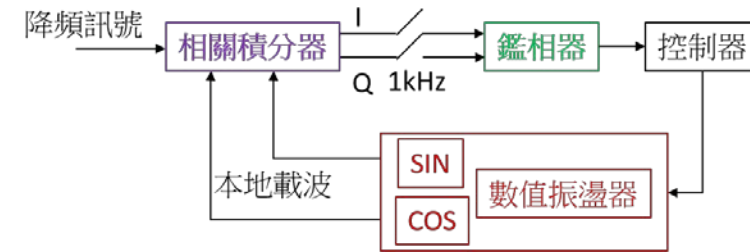
- 3<sup>rd</sup> order system to have zero steady state error under accelerations
- ENBW > 60.7 Hz to track  $1543 \text{ Hz/s}$  signal

# Loop Filter Design



相關積分器

Incoming signal frequency:  $\omega_{in}$ , phase:  $\phi_{in}$ ;  
local generated signal  $\omega_{out}$ ,  $\phi_{out}$



$$I = \int_0^T \cos(\omega_{in}t + \phi_{in}) \cos(-\omega_{out}t - \phi_{out}) dt$$

$$\cong \left( \frac{1}{\omega_{in}T - \omega_{out}T} \right) \cos\left(\frac{\omega_{in} - \omega_{out}}{2}T + \phi_{in} - \phi_{out}\right) \sin\left(\frac{\omega_{in} - \omega_{out}}{2}T\right)$$

$$Q = \int_0^T \cos(\omega_{in}t + \phi_{in}) \sin(-\omega_{out}t - \phi_{out}) dt$$

$$\cong \left( \frac{1}{\omega_{in} - \omega_{out}} \right) \sin\left(\frac{\omega_{in} - \omega_{out}}{2}T + \phi_{in} - \phi_{out}\right) \sin\left(\frac{\omega_{in} - \omega_{out}}{2}T\right)$$

鑑相器

$$\tan^{-1}(Q/I) = \frac{\omega_{in} - \omega_{out}}{2}T + \phi_{in} - \phi_{out} = \theta_{in} - \theta_{out}, \text{ if } \theta_{in}$$

$$= \frac{\omega_{in}}{2}T + \phi_{in}, \theta_{out} = \frac{\omega_{out}}{2}T + \phi_{out}$$

鎖相迴路實際架構圖

振盪器

$$\phi_{out,i} = \phi_{out,i-1} + \omega_{out,i-1}T \rightarrow NCO(z) = \frac{\phi_{out,i}}{\omega_{out,i}} = \frac{Tz^{-1}}{1 - z^{-1}}$$

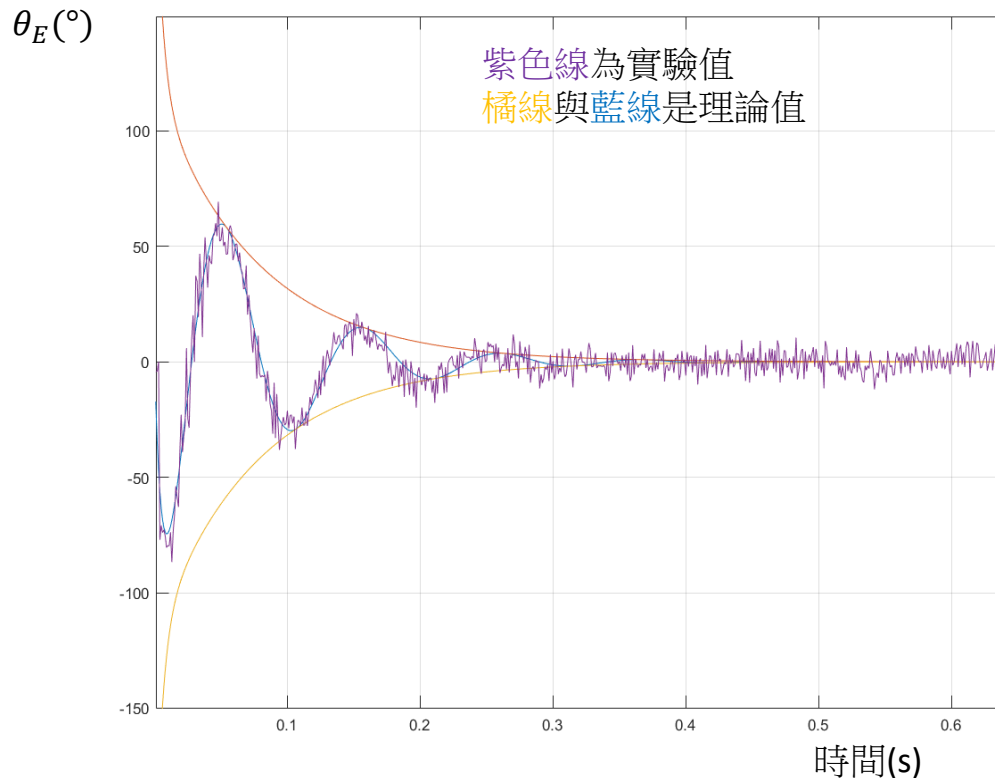
$$\theta_{out,i+1} = \frac{\omega_{out,i}}{2}T + \phi_{out,i} \rightarrow \frac{\theta_{out,i}}{\omega_{out,i}} = NCO(z) \times \frac{(1 + z^{-1})}{2}$$

# Tracking Loop Design



- Experimental data

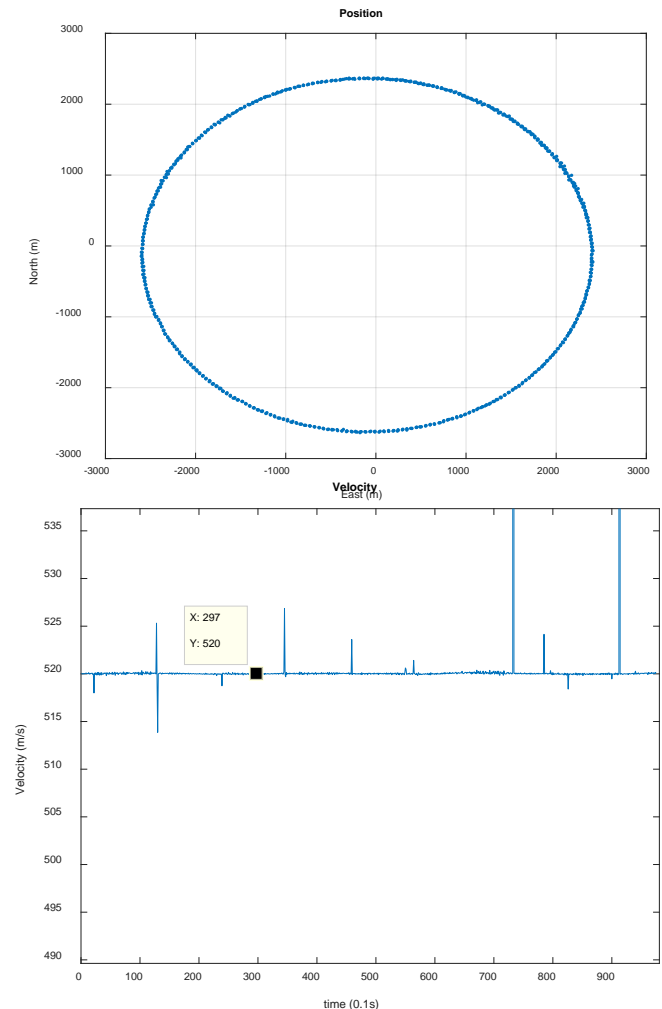
Loop filter performance using Real GPS signals



Experimental results are compatible with design.

More tests are on the way

Loop filter performance using  
GPS emulator, speed 515 m/s



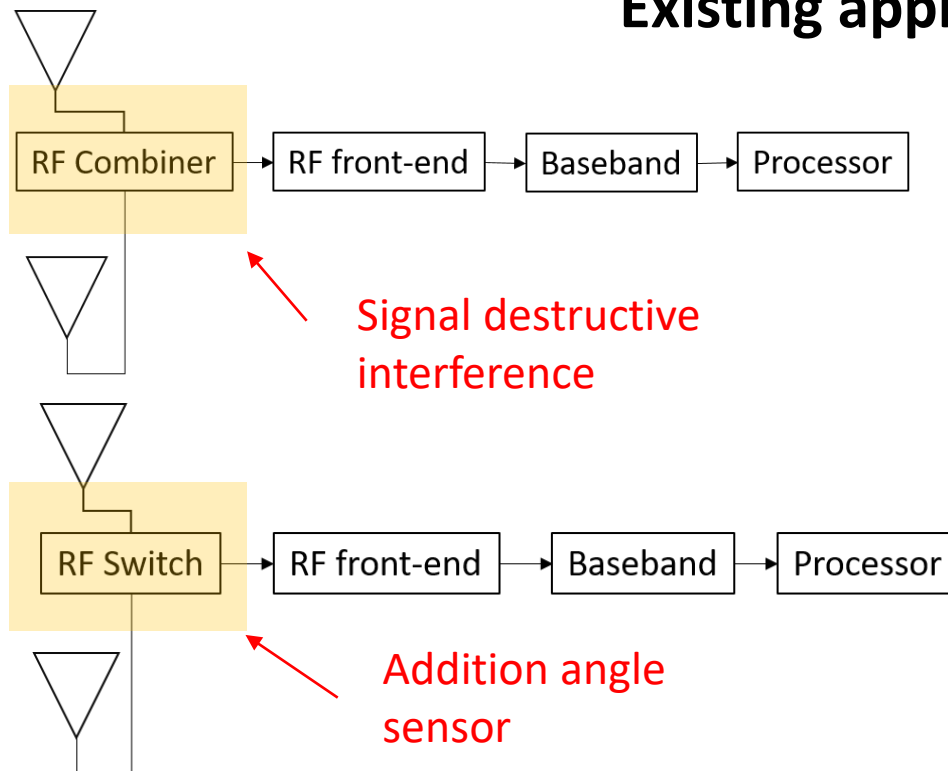
# Dual-antenna GPS receiver (I)



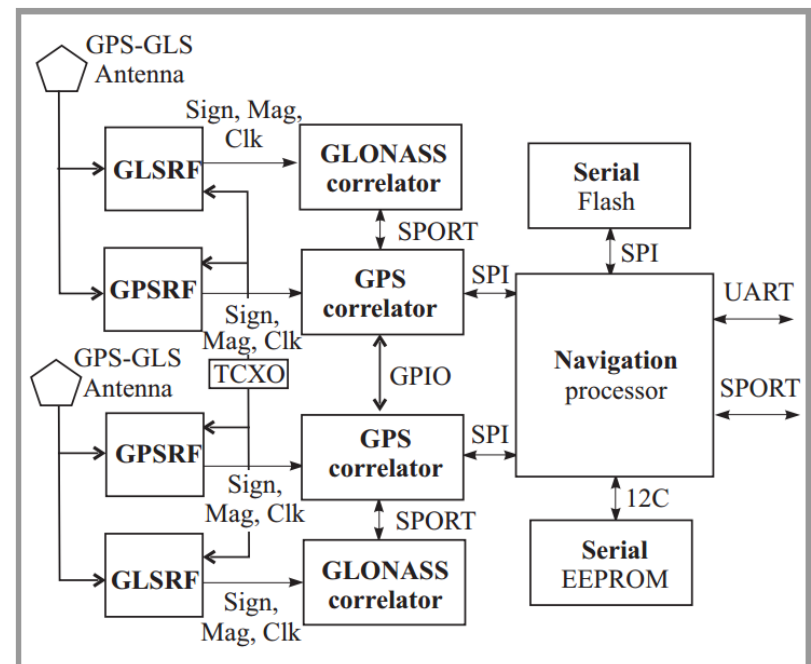
- **Challenges for the conventional GPSR in rotating**

- Satellite line-of-sight could be blocked by the GPSR carrier.
- If **losing track of satellite signal for 20ms**, it needs to **least 6 seconds** to find the **Preamble** to ensure the data phase, and **at least 18 seconds** to do the positioning.

## Existing approaches



## 2 RF frontend + 2 Baseband processor



# Dual-antenna GPS receiver (I)

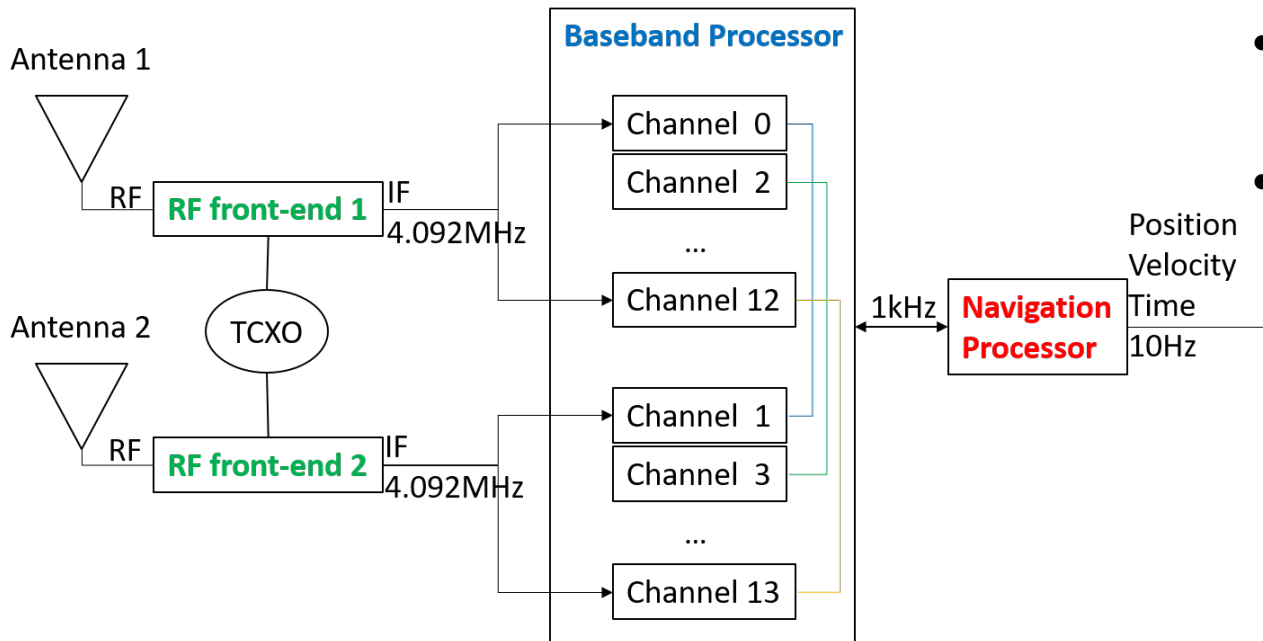


- **Proposed dual-antenna GPSR architecture**

- Two antennas, two **RF front-ends**, one **Baseband Processor**, and one **Navigation Processor**.
- RF frontends are synchronized to each other.
- Two channels are assigned to one satellite.

## Advantages

- No signal-destructive-problem
- Compact and cost effective design



# Dual-antenna GPS receiver (II)

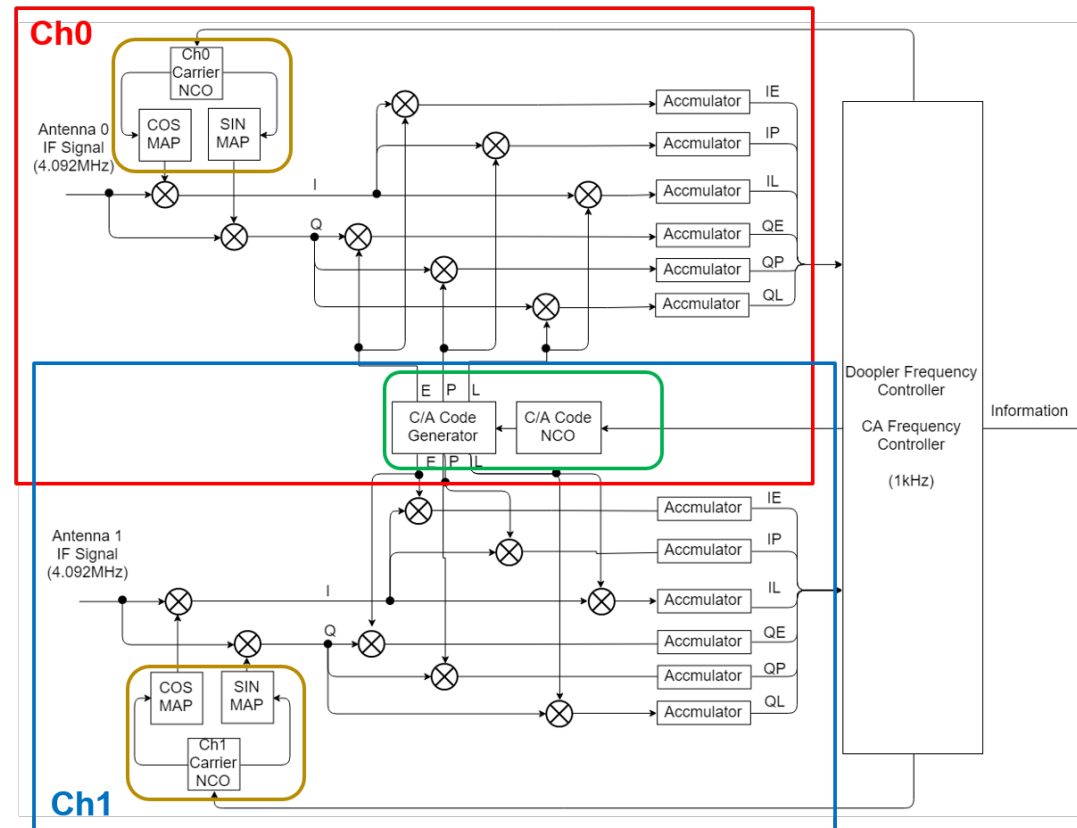


- Baseband Processor (**Ch0**, **Ch1** for example)
  - CA code wavelength 293m → 2 channel shares one DLL loop.
  - Carrier wavelength 19cm → Independent PLL/FLL loop for 2 channels

- Phase coordination for the signal decoding

- The channel which has bigger accumulation value and above threshold in the pair channel would be chosen for:

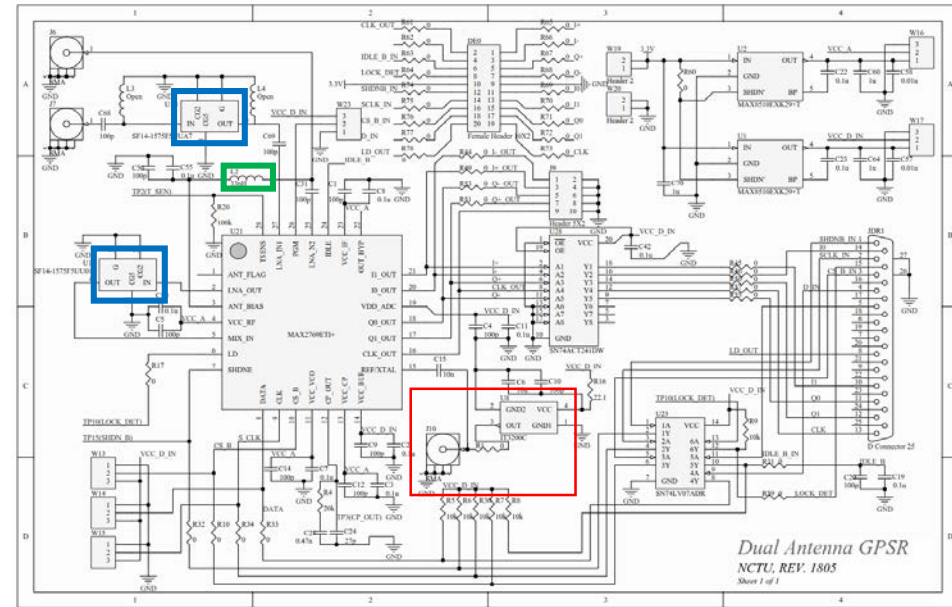
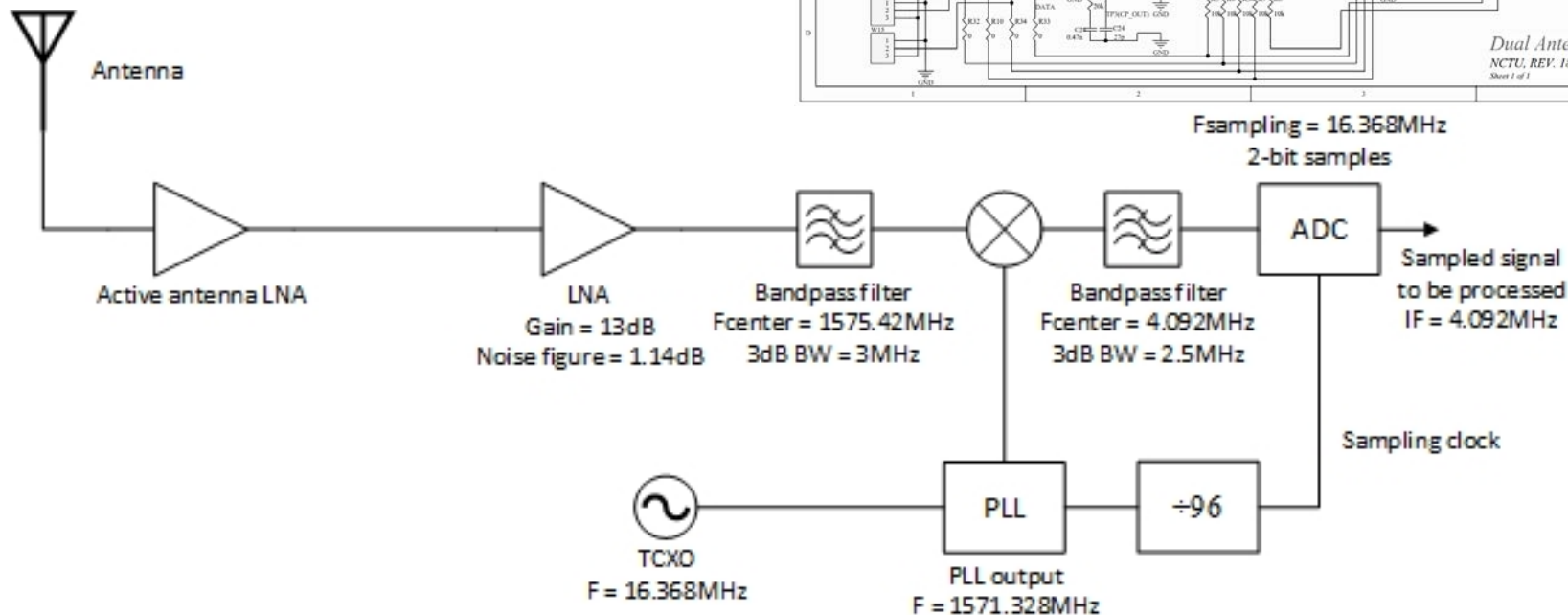
(1) retrieving the navigation data, (2) assign the phase information to the other channel.



# RF Frontend for Multiple Antennas



- RF frontend
  - Active antenna and bias circuit
  - Two SAW filters
  - Synchronization between other RF frontends



# GPSR Implementation (III)

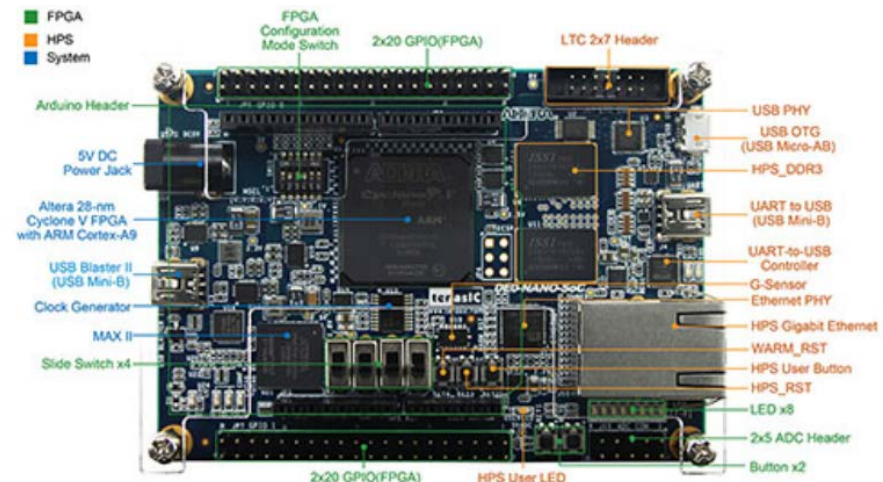
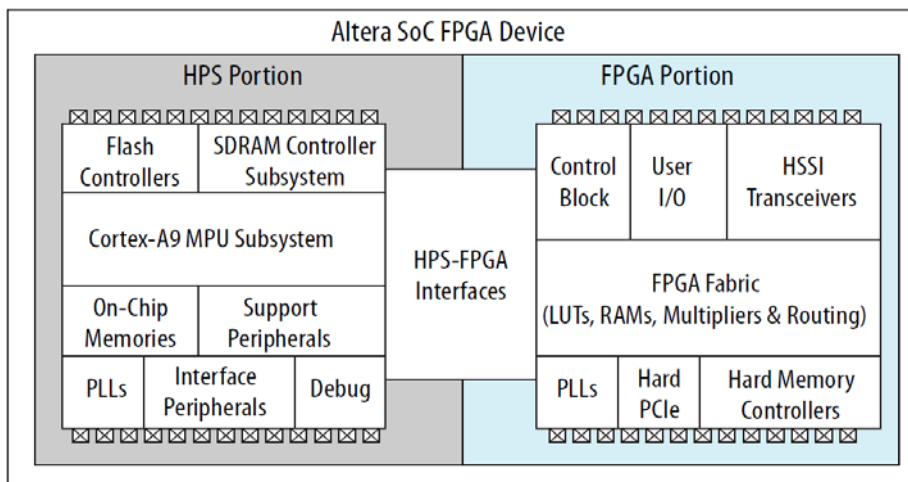


- Implementation platform

## Altera ARM-Based SoC FPGA

1. 把ARM cortex A9處理器和FPGA整合在一塊晶片上，減少了系統的功率、成本還有板子大小
2. 連接處理器和FPGA的距離變小使得頻寬變大，彼此的傳輸速度變快
3. 依據需求的不同，可以選擇用軟體(HPS)或硬體(FPGA)來實現

Size : 68.59x96mm

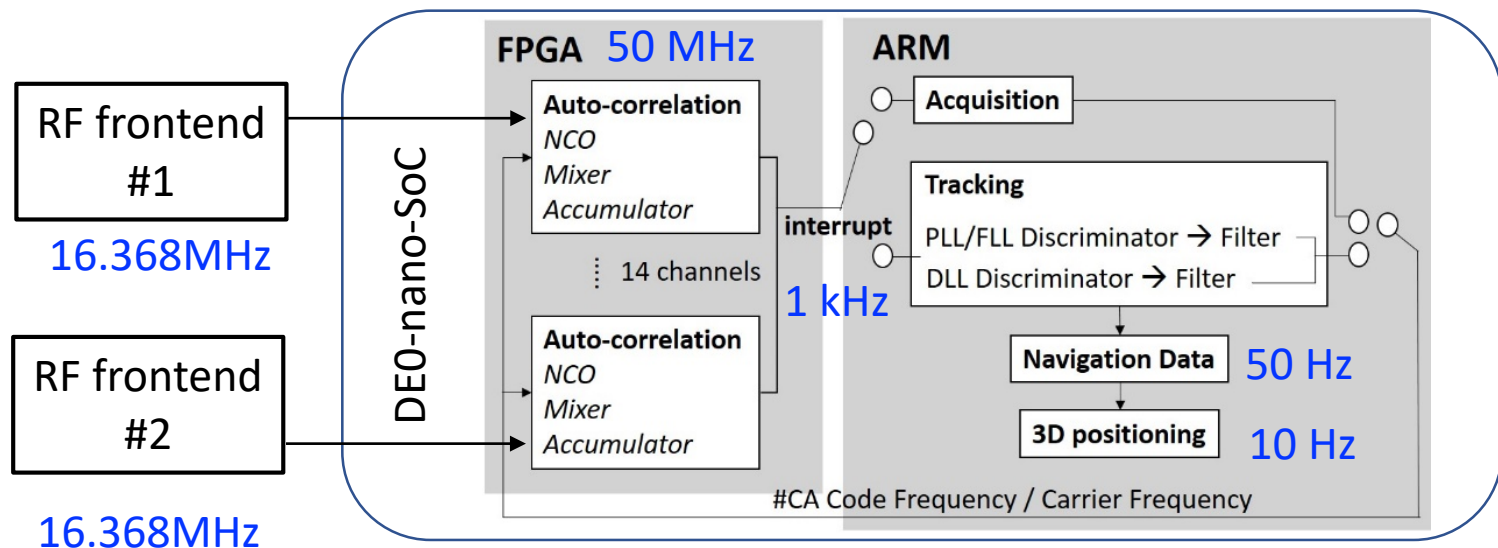
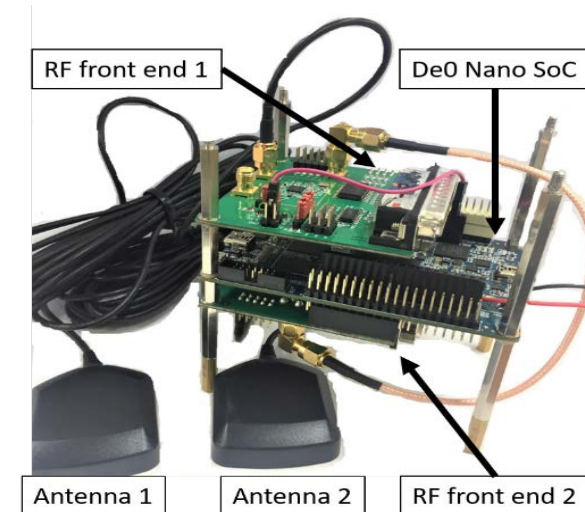


# Experiment (I)



## • Experimental Setup

- Antenna: U-blox active antenna.
- RF front-end: MAX2769 chip and homemade board.
- Platform: Terasic DE0-Nano-SoC → FPGA + ARM.
- Baseband processing → **FPGA (Verilog)**
- Controller, discriminator and navigation processing → **ARM (bare metal + multi-thread)**



# Experiment (II)



- **Experimental Result**

- GPSR can correctly output the position when the arm rotates at the speed of 7.5 rpm.
- But some channel fail at 22 rpm due to weak signal receiving.

