Antenna and Multipath Calibration System for High-accuracy Geophysical Application of GPS

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High-accuracy GPS Applications & AMCS

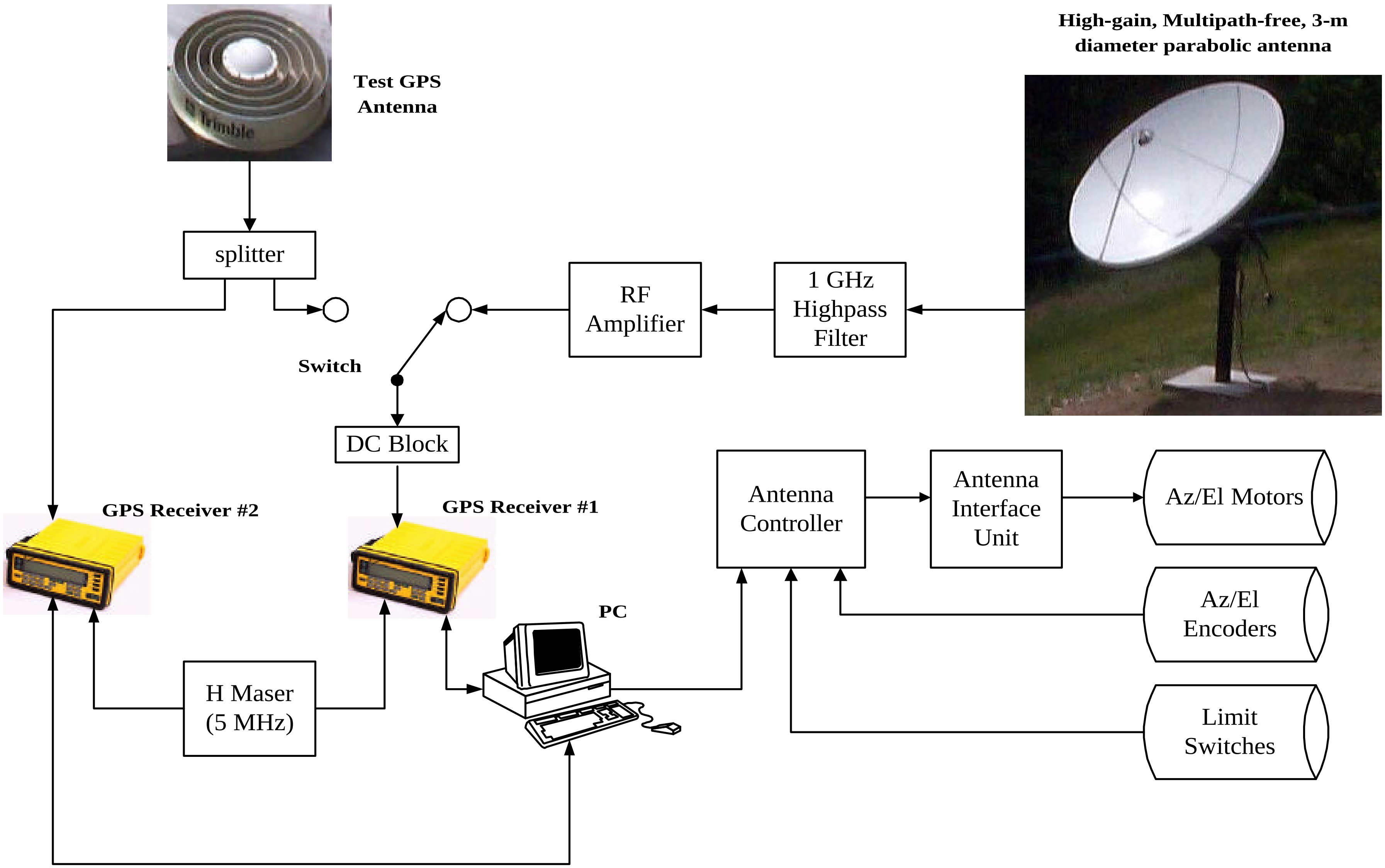
- Applications of GPS in studies of global sea level change and glacial isostatic adjustment (GIA) require <u>a very high accuracy (1 mm/year)</u> in determining the site velocity, especially its vertical component

- However, site-specific errors such as signal scattering and multipath remain problematic

- For the purpose of characterizing site-specific GPS phase measurement errors, we have developed an **Antenna and Multipath Calibration System** (**AMCS**)

- The AMCS consists of
  - High-gain, multipath-free, 3-m diameter parabolic antenna
  - GPS Antenna to be calibrated
  - Two Trimble GPS receivers

AMCS Diagram



Modes of Operation

– ZBL (**Z**ero-**B**ase**L**ine) Mode

- Both receivers collect data from the test antenna
- ZBL-mode data is processed to estimate the receiver clock offset and the phase offset of each satellite, which will be used in AMCS-mode data processing as constants

– AMCS Mode

- **Static**
  - The parabolic antenna is stationary, pointing toward a certain direction, and the target GPS satellite drifts in and out of the antenna beam
  - The target satellite passes through the center of the antenna beam
- **Tracking**
  - The parabolic antenna tracks the target GPS satellite and its direction is updated at each observation epoch, usually at every 10 seconds
  - The pointing accuracy is ~0.1 degree in the elevation direction and ~0.5 degree in the azimuth direction

Mathematical Models

- The model for ZBL-mode phase

$$\Delta f^{k}(t) = \dot{r}(t)\Delta T + \Delta f_{0}^{k}$$

Δf^{k} : ZBL - mode phase for the kth satellite

$\dot{r}$: Range - rate between th e antenna and the satellite

ΔT : Clock offset, assumed constant over the entire analysis

Δf_{0}^{k} : Constant offset, one per satellite

- The model for AMCS-mode phase

$$\Delta j^{K}(t) = \dot{r}(t)\Delta\hat{T} + \Delta\hat{f}_{1,0}^{K} + lN + \hat{s}\cdot\vec{b} + C\cos e$$

Δj^{K} : AMCS - mode phase for the Kth satellite

$\Delta\hat{T}$: Clock offset from ZBL - mode analysis

$\Delta f_{1,0}^{K}$: Constant phase offset from ZBL - mode analysis

l : Wavelength

N : Integer cycle ambiguity

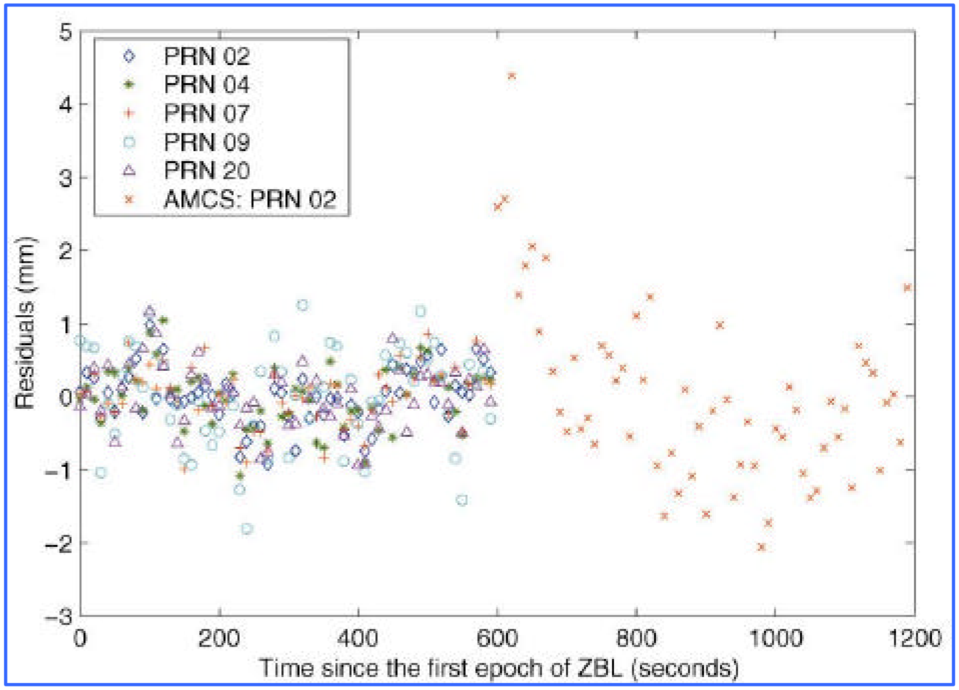
$\hat{s}$: Satellite topocentr ic unit vecto r

$\vec{b}$: Baseline vector (between t wo antennas)

C : Constant determined by surveys

$\mathring{a}$: Satellite elevation angle

AMCS-mode Operation: Static



• An example plot of the L1 phase residuals

• The left hand side (the first 10 minutes) is for the ZBL-mode residuals of five satellites

• The right hand side (the next 10 minutes) is for the AMCS-mode residuals of PRN 2

- RMS (Root-Mean Square) Error
  - ZBL-mode: 0.4-0.6 mm
  - AMCS-mode: 1-3 mm

- ZBL-mode residuals
  - Systematic trends are visible
  - Some of the variations appear to be satellite independent, so are not variations of *ÄT*
  - Some of the variations are satellite dependent
  - The variations are similar from one day to the next

- AMCS-mode residuals
  - Highly systematic variations
    - Parabolic antenna pointing offset errors
    - Survey errors in measuring the relative geometry of the two antennas
    - Parabolic beam pattern errors
    - Low SNR (Signal-to-Noise Ratio) in the AMCS-mode data collection

Effect of an Error in the AMCS Baseline Geometry

- (ÄN,ÄE,ÄV) = Errors in the north, east, and vertical components of the baseline
- Effect on the AMCS phase
  - *è*: azimuth, *å*: elevation

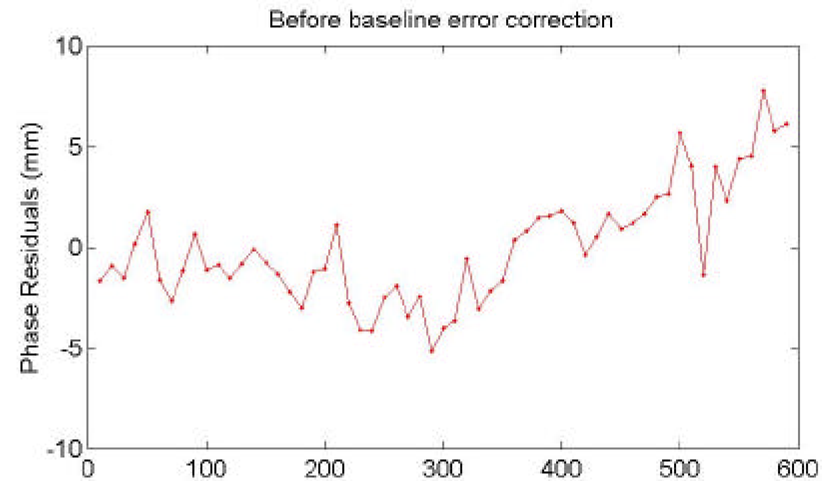
$$\Delta f = \Delta N \cos q \cos e + \Delta E \sin q \cos e + \Delta V \sin e$$

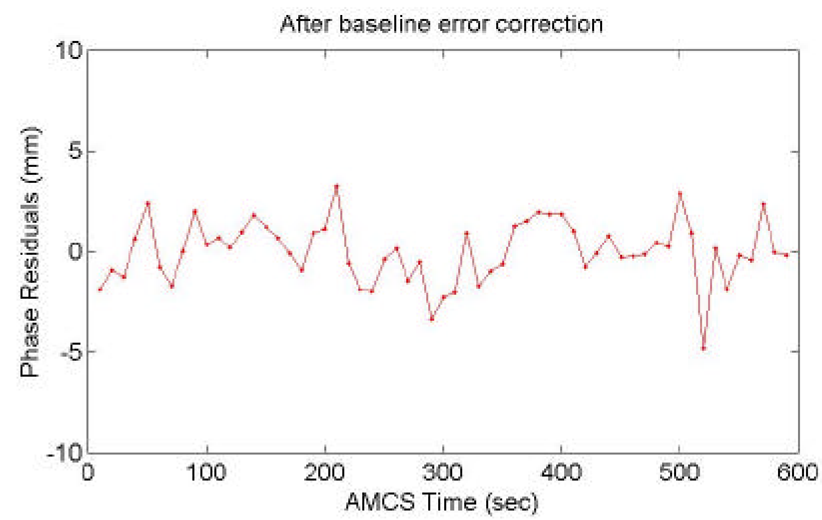
- For static AMCS-mode analysis, the range of azimuth and elevation is quite small
- Expanding the above equation about $å=å_0$ and $è=è_0$ to the first order in $Äå= å-å_0$ and $Äè=è-è_0$

$$\begin{aligned}\Delta f &\cong \Delta N(\cos q_0 - \Delta q \sin q_0)(\cos e_0 - \Delta e \sin e_0)\\ &\quad + \Delta E(\sin q_0 + \Delta q \cos q_0)(\cos e_0 - \Delta e \sin e_0)\\ &\quad + \Delta V(\sin e_0 + \Delta e \cos e_0)\\ &= c_0 + c_1 \Delta q + c_2 \Delta e\end{aligned}$$

- Estimate three constants: <u>c1, c2, and c3</u>

- The average RMS residual after correction for the geometry error is ~1.2 mm, a reduction of a factor of ~2 from the AMCS-mode residuals.

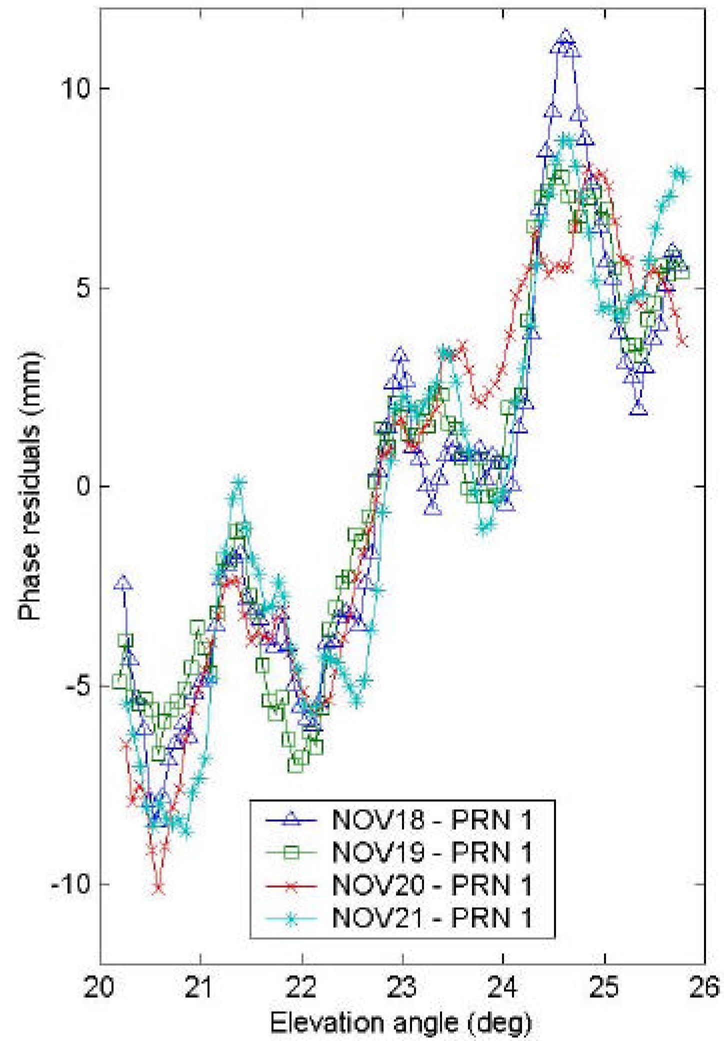




AMCS-Mode Operation: Tracking

- Tracking tests performed
  - 15-minute tracking data collection after 10-minute ZBL data collection
  - High, mid, and low elevation angles
  - Several different azimuth angles
  - RMS is up to several mm

- Results
  - Repeating patterns for the same satellite – Indication of multipath
  - Apparent multipath has high frequency
  - 4-6 mm amplitude variations for low elevation angles
  - 1-2 mm amplitude variations for high elevation angles
  - RMS is ~1 mm after subtraction of the modeled variations (using a very simple boxcar-filtering)



AMCS-Mode Operation: Tracking (Cont’d)

- Questions
  - Different patterns for slightly different azimuth angles (or GPS satellites)
  - Pointing accuracy of the parabolic antenna
  - Drifts in residuals – Caused by *DT* drift, baseline errors, or feed rotation?
- Current experiments underway
  - Installed another test GPS antenna
  - Compares the phase residual characteristics with the first antenna
- Future work
  - Test and calibrate pointing accuracy
  - Independent determination of the baseline vector
  - Analysis of antenna rotation tests plus feed rotation effect