Abstract—GPS carrier phase single and double difference characteristics are studied. Residual errors obtained from experimental results using independent commercial receivers for two antennas are analyzed. The potential of double differences for vehicle attitude estimation using a multiple antenna configuration with independent receivers is demonstrated. Receiver data synchronization is also given special attention.

Keywords—GPS, Attitude Estimation, Double Difference, Carrier Phase.

I. INTRODUCTION

Although the Global Positioning System (GPS) was originally developed for navigation purposes, it has also shown to be an important source of information for vehicle attitude determination. Using the subcentimetric carrier phase precision of GPS, the relative position of multiple antennas placed on a vehicle or platform can be determined with enough precision to estimate the attitude angles of such vehicle with an error of 0.1 degree (Parkinson and Spilker, 1996). With carrier phase double differences, it is possible to achieve such results using a standard commercial receiver for each antenna and some additional signal processing.

II. SIGNAL MODEL

A. Carrier Phase Observations

The carrier phase observation (variables observed directly) model of the signal sent by a satellite $j$, received by an antenna $\alpha$ at time $t$ is given by

$$
\phi_{\alpha}^{j}(t) = \rho_{\alpha}^{j}(t) - \lambda N_{\alpha}^{j} - c(dT_{\alpha} + \Delta T_{\alpha}) + \phi_{initial}^{j} + c.d_{\text{ion}}^{j} - c.d_{\text{trop}}^{j} + \varepsilon(\phi)
$$

where $\phi_{\alpha}^{j}(t)$ is the carrier phase variation measurement between antenna $\alpha$ and satellite $j$ (in meters) at time $t$ (starting from the receiver’s satellite acquisition instant); $\phi_{initial}^{j}$ is the carrier phase at the moment of transmission from satellite $j$; $\lambda$ is the wavelength for the L1 GPS frequency (0.1904 meters); $N_{\alpha}^{j}$ is the integer carrier phase cycle ambiguity between antenna $\alpha$ and satellite $j$; $\varepsilon(\phi)$ is the carrier phase measurement error due to receiver noise and multipath (up to 5 cm); $\rho_{\alpha}^{j}(t)$ is the geometric range (distance) from antenna $\alpha$ to satellite $j$ at time $t$; $dt^{j}$ is the satellite $j$ clock error; $dT_{\alpha}$ is the receiver $\alpha$ error; $d_{\text{ion}}^{j}$ is the ionospheric signal delay for satellite $j$; $d_{\text{trop}}^{j}$ is the tropospheric signal delay for satellite $j$ and finally $c$ is the propagation speed of electromagnetic waves in space (Kaplan, 1996). Figure 1 helps to visualize the model presented in (1).

B. Differential Observations

Single difference observations are constructed to cancel common effects shared by signals travelling from a satellite through different paths. A carrier phase single difference observation for two antennas $\alpha$ and $\beta$ with respect to satellite $j$ is formed subtracting two carrier phase observations like (1). The single difference is

$$
\Delta \phi_{\beta\alpha}^{j}(t) = \Delta \rho_{\beta\alpha}^{j}(t) - \lambda \Delta N_{\beta\alpha}^{j} - c \Delta T_{\beta\alpha} - \Delta c.d_{\text{ion}}^{j} - \Delta c.d_{\text{trop}}^{j} + \varepsilon(\Delta \phi_{\beta\alpha}^{j})
$$

where $\Delta$ represents the difference between receivers. In (2) the satellite clock error term is cancelled after