THE EFFECT OF ATMOSPHERE TURBULENCE
ON
GPS OPEN LOOP TRACKING

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Abstract

High altitude field tests have established experimental knowledge on the influence of atmosphere/ionosphere turbulence on receiver performance in tropical regions. The ionosphere and the moist atmosphere turbulence measurements have been studied for spectral signal structure characteristics based on observations originating from measurements at the top of Haleakala, Hawaii, in the fall of 2004.

We have studied the spectral properties of the signals as received by the high-precision GPS instrument in both phase-locked mode (PL) and open-loop mode (OL) and compared the obtained data to simulated results. The OL mode provides a sample rate of 1000 Hz, which enables investigation of spectral signatures that are normally not seen in GPS data. The use of directive antennas pointed towards the horizon enables signal recording down to the lowest layers of the atmosphere.

We have analyzed the signal dynamics and spectral content of low-elevation measurements in OL tracking mode. We find that the high-frequency part of the signal is dominated by thermal noise, while the lower frequency part are dominated by clock-noise, which for the receiver rubidium clock falls off as the inverse of the frequency squared. In order to study atmospheric low-elevation turbulence by spectral analysis, we investigated spectral fluctuations above the noise characteristics of the clock caused by the turbulent atmosphere.

The instrument setup consists of separate L1 and L2 antennas placed right next to each other and oriented with the main gain lobe toward the horizon. The signals are fed into a prototype version of the satellite GRAS receiver. The instrument software is modified for ground-based signal Doppler conditions. An ultra-stable rubidium frequency reference is used to control the receiver clock for precise timing of the measurements. Signals are tracked in both PL and OL mode at the same time in separate channels in the receiver. Especially during multi-path conditions, traditional PL tracking receivers may loose signal lock and hence fail to track the signal. The OL data sampling rate of 1000 Hz is much more suited for capturing the bulk atmospheric Doppler on the signal, enabling detection and investigation of noise, multi-path and other signal error sources.

In order to assess the receiver performance we estimate the spectral components of the signal during the measurement in order to derive the corresponding bending angle profile. The derived bending angle profiles are compared with bending angle profiles calculated using simulating software and refractivity data derived from other sources of meteorological data.

The main atmospheric modulation of GPS signals in low-elevation measurements is attenuation and frequency shift due to ray bending, whereas the presence of turbulence is causing a spectral broadening of the signal. Displaying the power spectrum as function of frequency difference from the main signal peak reveals the characteristic domains of the spectrum. Up to 10 Hz the spectrum is approximately sloping as the inverse of the frequency squared. While for higher frequencies, in the range 10 - 500 Hz, the spectrum flattens. The latter part of the spectrum originates from thermal noise, while the first sloping part is characteristic for the rubidium frequency references used in both the GPS transmitter and the receiver. The background signal frequency drift can be removed by subtracting a least squares fit parabola to the phase when constructing the spectrum. The turbulence of the atmosphere causes detectable spectral broadening of the signal. Analysis of the trend of the mean slope in the spectra for different frequency domains showed an increased slope as function of the elevation of the received signal above the horizon. This is linked to turbulence and eddies in the beam direction, since lower elevation angles indicate increased spectral mean slope. Additionally it follows the general picture of atmospheric turbulence, where scale lengths are longer in the horizontal direction than in the vertical.