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Tracking performance and average error analysis of GPS discriminators in multipath

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ABSTRACT

Signal multipath in GPS leads to undesirable tracking errors and inaccurate ranging information. The extent of the tracking error in compromising the receiver performance depends on the multipath amplitude, delay, and phase relative to the direct path. The coherent discriminator and the noncoherent early-minus-late power discriminator offer different tracking accuracy and sensitivity to multipath parameters. In this paper, we develop analyses of the effect of multipath carrier phase offset on GPS tracking error bounds as well as statistical average error values. Although the two receiver discriminators share the same performance bounds, they differ in their response to the multipath within these bounds. The analytical expressions for this response provide the framework to assess the average performance of the two discriminators over the multipath phase distribution and other important propagation channel variables.

1. Introduction

The multipath problem in geolocation can cause severe degradation of the performance of GPS receivers [1–4]. In reality, a GPS receiver must replicate the coarse acquisition (C/A) code that is transmitted with the carrier frequency $L1 = 154 \times 10.23$ MHz by the satellite vehicles (SV) and thereafter acquired by the receiver. The receiver must then shift the phase of the replica code until it fully correlates with the SV C/A code. This operation is executed by the receiver delay lock loop (DLL). The DLL reaches the maximum correlation between the incoming SV code and the local replica code during the tracking phase by using an early–late discriminator. However, multipath attributed to reflections of the GPS signal from ice, water, building structure, or glass surface compromises the DLL discriminator function, producing tracking errors [5–7]. Therefore, it becomes important to evaluate the GPS receiver performance as a function of multipath amplitude, phase, and time delay.

Both coherent and noncoherent discriminators can be applied in the GPS receivers. Various studies on multipath effects for the DLL discriminators have been performed [8–11]. This paper provides detailed analytical treatment of the GPS multipath effect on both the coherent discriminator and the noncoherent early-minus-late power discriminator. It compares the average as well as the worst tracking error performance of the two discriminators under one dominant multipath. Specifically, the role of carrier phase offset due to multipath propagation is demonstrated and its contribution to the tracking error is examined. This paper analyses the receiver performance for direct line-of-sight case. The corresponding analytical error expressions for obstructed line-of-sight propagation environments follow similar derivation

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steps, although, in the final form, they assume different structures and behaviors. Computer simulations of the impact of a dominant multipath on the discriminator tracking performance are provided. It is assumed that there is an infinite front-end precorrelation bandwidth, the early and late correlations are performed within the same navigation symbol, and no symbol transitions are encountered over the correlation interval. It is shown that in direct line-of-sight case, the noncoherent discriminator offers a better performance than the coherent discriminator; however, in obstructed line-of-sight case, the result turns out to be the opposite.

The paper considers stand-alone receivers and does not deal with assisted GPS [12–14]. It focuses on GPS receivers, although the developed analysis may be examined and expanded to other satellite systems, navigation code structures, and properties [15]. Section 2 of this paper provides an overview of DLL in-phase and quadrature outputs in multipath. Closed form expressions of the tracking error as a function of multipath parameters using the coherent and the early-minus-late power (noncoherent) discriminators, are provided in Sections 3 and 4, respectively. A performance comparison of the two discriminators in multipath based on averaged error values in multipath is provided in Section 5. The conclusion is given in Section 6.

2. DLL in multipath

The GPS DLL tracks the GPS signals and provides the corresponding time delays. It is implemented by a simple cross-correlation process. At the receiver, the DLL cross-correlates the received GPS navigation data, which is modulated onto the C/A code, with a copy of the C/A code. In the absence of noise, interference, multipath, and Doppler shift, the received GPS signal after downconversion and phase tracking is given by

$$s_{\mathrm{db}}(t) = Ag(t-\gamma)\exp[\mathrm{j}(\phi-\hat{\phi})] \tag{1}$$

where A is the signal amplitude, $g(t)$ the ± 1 valued C/A code, γ the time delay of the original signal, ϕ the carrier phase, and $\hat{\phi}$ the estimated carrier phase. The code replica, generated by the receiver, is therefore

$$s_{\mathrm{r}}(t) = g(t-\hat{\gamma}) \tag{2}$$

In the above equation, $\hat{\gamma}$ is the estimated time delay. Thus, the correlator output becomes

$$\overline{s_{\mathrm{db}}(t)s_{\mathrm{r}}(t)} = A\ \exp[\mathrm{j}(\phi-\hat{\phi})]\overline{g(t-\gamma)g(t-\hat{\gamma})} = A\ \exp[\mathrm{j}(\phi-\hat{\phi})]R(\hat{\gamma}-\gamma) \tag{3}$$

where $\overline{\{\cdot\}}$ is the expected value operator and $R(\tau)=R(\hat{\gamma}-\gamma)$ is the autocorrelation function of the C/A code. Typically, the C/A code generator produces three copies of the code at different shifting positions, early, punctual, and late, but with equal spacing. The DLL, thereby, executes the multiply-and-accumulate operation between the reference C/A code and the in-phase and quadrature baseband components of GPS signal. This is achieved by using three correlators, as depicted in Fig. 1, yielding three in-phase components I_{E}, I_{P}, I_{L} and three quadrature components Q_{E}, Q_{P}, Q_{L}, which are given by [16]

$$I_{\mathrm{E}} = \frac{A}{\sqrt{2}}\cos(\zeta)R(\tau+d/2), \quad I_{\mathrm{P}} = \frac{A}{\sqrt{2}}\cos(\zeta)R(\tau), \quad I_{\mathrm{L}} = \frac{A}{\sqrt{2}}\cos(\zeta)R(\tau-d/2)$$

$$Q_{\mathrm{E}} = \frac{A}{\sqrt{2}}\sin(\zeta)R(\tau+d/2), \quad Q_{\mathrm{P}} = \frac{A}{\sqrt{2}}\sin(\zeta)R(\tau), \quad Q_{\mathrm{L}} = \frac{A}{\sqrt{2}}\sin(\zeta)R(\tau-d/2) \tag{4}$$

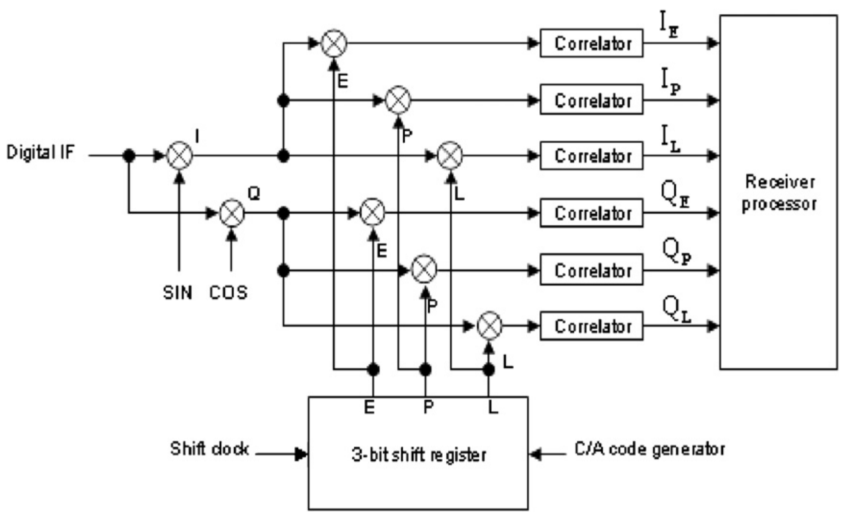

Fig. 1. GPS DLL cross-correlation process.