Theoretical Analysis of Overlay GNSS Receiver Effects

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ABSTRACT

Having given a short overview of GNSS signals and state-of-the-art multi-band front-end architectures, this paper presents a novel contribution to efficient multi-band GNSS reception. A general overlay based front-end architecture is introduced that enables the joint reception of two signals broadcast in separate frequency bands, sharing just one common baseband stage. The consequences of this overlay are analyzed for both signal and noise components. Signal overlay is shown to have a negligible impact on signal quality. It is shown that the noise floor superposition results in non-negligible degradations. However, it is also demonstrated that these degradations can be minimized by judiciously setting the relative gain between the two signal paths. As an illustration, the analytical optimal path-control expression to combine overlaid signals in an ionospheric-free pseudorange is derived for both Cramér-Rao Lower Bound and practical code tracking parameters. Finally, some practical overlay receiver and path control aspects are discussed.

Keywords: Cramér-Rao Bounds, Global Navigation Satellite System (GNSS), Global Positioning System, Multiple Access Interference, Satellite Navigation Systems

INTRODUCTION

Global navigation satellite system (GNSS) receivers greatly benefit from the modernization of existing GNSS constellations such as GPS and GLONASS as well as from the launch of new ones such as Galileo and COMPASS. First, the combining of these constellations can significantly improve the navigation solution availability in urban canyons and heavily shadowed areas. Second, increased satellite availability translates into higher measurement redundancy and improved reliability. Additionally, the excellent inherent noise and multipath mitigation capacity of the new and modernized wide-band signals notably improves accuracy in both measurement and position domains.

Single-frequency users can receive GNSS signals and services but there are several advantages to multi-frequency processing: The frequency diversity offers an additional protection against jamming and interference since, if one frequency band is corrupted, the receiver is still able to provide a navigation solution
relying on another frequency band. Moreover a faster reception of the navigation messages is often possible since the same information is transmitted on several bands (e.g., the Galileo I/NAV message broadcast on both E1B and E5B) using page swapping (European Union, 2010). Finally, multi-frequency can be used to form ionosphere-free pseudorange measurements that can remove the first-order ionospheric bias and therefore provide a higher positioning accuracy.

The challenges of multi-band reception are a much higher required bandwidth, higher sampling rates, often several reception chains, a higher digital bandwidth (the raw sample rate from the front-end output to the baseband signal processing) and more self-generated interferences (e.g., when several frequency synthesizers for different local oscillator frequencies are needed). This all leads to a noticeable increase in receiver complexity, size, and power consumption, especially for the radio frequency (RF) front-end.

Currently the most common method is that each additional frequency band is received using an extra RF front-end reception chain. This makes their implementation straightforward but is not necessarily efficient.

Traditional GNSS front-ends but also current mass-market GNSS receivers typically feature a low intermediate frequency (low-IF) architecture with an RF-bandwidth of approx. 2 to 4 MHz and a low-resolution analog-to-digital converter (ADC) of 1 to 3 bit (STMicroelectronics, 2008; Maxim, 2008). This is sufficient for the legacy GPS L1 C/A or the narrow-band Galileo E1 BOC(1,1) signals but not for most of the new GNSS signals, especially if their full potential in terms of accuracy and multipath resistance is to be reached. For these, considerably larger bandwidths are necessary (e.g., at least 14 to 16 MHz and 20 MHz for the GPS/Galileo L1/E1 MBOC(6,1,1/11) and L5/E5A BPSK(10) signals, respectively) which leads to higher sampling rate requirements. Wider RF-filters also make the front-end more susceptible to jamming and unintentional interferers. Therefore, a higher ADC resolution is required to offer a superior dynamic range and to enable digital mitigation algorithms.

The straightforward approach is to widen the bandwidth and to use higher sampling rates for each desired GNSS-signal while keeping the original low-IF architecture where the intermediate frequency is within the range of the radio frequency bandwidth. These solutions can already be found as integrated circuits and can easily be tuned to the required GNSS signal band (Wistuba et al., 2011; Chen et al., 2010).

However, for the wide-band BOC signals such as the Galileo E5 AltBOC(15,10) or the Galileo PRS signals E1A BOCC(15,2.5) and E6A BOCC(10,5), a zero-IF architecture can be very advantageous since the inherent zero-IF problems, namely DC-offset and flicker noise, are not so relevant to the DC-free BOC signals. If needed a Hilbert transformation can be implemented in the digital signal processing to select the lower or upper band of the complex signal received. Moreover, quasi zero-IF architectures can be used to enable simultaneous reception of the L1/E1 GPS/Galileo signals and the GLONASS G1 frequency division multiple access (FDMA) signals by placing the local oscillator between both signal bands.

The continuously improving ADC performance makes direct RF-sampling or sub-sampling front-ends feasible even for the L-band GNSS signals (Psiaki, Powell, Hee Jung, & Kintner, 2005). The desired signals are filtered and down-converted using intentional aliasing in the analog to digital conversion. However, this type of architecture still suffers from several limitations such as a high power consumption in the front-end and the following digital baseband signal processing, stringent ADC sampling jitter requirements, potential instability due to the high amplification needed on one frequency range, or susceptibility to interference. Therefore, the sub-sampling architecture is currently not the best choice for a multi-band GNSS front-end receiver. However, since it closely matches the software defined radio (SDR) philosophy, it is expected to gain importance in the coming years.
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