# A Reconfigurable Multi-band GNSS Receiver Front-end for Space Applications: System Level Considerations

A. Noroozi, C.J.M. Verhoeven, G.L.E. Monna, E.K.A. Gill

***Abstract*—Global navigation satellite system (GNSS) signals are used for different applications. They were originally designed for finding navigation solutions. However, the signal provides a wealth of information that can be used for various scientific applications. Therefore, flexible receiver architectures should support multiple user requirements. In this paper we propose a reconfigurable GNSS receiver for space applications which provides the flexibility to the user to operate it in the best configuration as required.**

***Index Terms*—GNSS, GPS, Galileo, direct conversion receiver, reconfigurability**

## I. INTRODUCTION

As a solution to positioning on Earth, different GNSS systems have been developed during the past years. Some of them like American Global positioning system (GPS) and Russian GLONASS are operational and some like European Galileo is expected to be operational soon. As it will be discussed later in this paper, it would be very useful to have a receiver which is capable of tracking as much satellites as possible and from different navigation systems at the same time.

Traditionally GNSS receivers in space applications are providing little flexibility in selecting frequency bands and adapting to changes in the accuracy requirements. There have been some efforts, mainly in terrestrial applications, to have a dual-band receiver in a single chip but they are basically complicated approaches [1], [2] and [3].

Among GNSS systems GPS and Galileo navigation systems are most similar to each other. Their frequency bands overlay in a wide range of frequency and both use code division multiplex access (CDMA) coding. This enables the same analog front-end to work for both systems. Focus of this work will be on these two systems. Fig. 1 shows the frequency bands and signal shape of GPS and Galileo signals.

Aim of this work is to design a reconfigurable GNSS receiver front-end in a single chip with no external components and suitable for space applications. Contribution of this new front-end architecture to the complete receiver is that both analog front-end and digital back-end would be fully reconfigurable and controllable by the On-Board Computer (OBC) of a satellite for example.

## II. GNSS RECEIVER APPLICATIONS

Applications of GNSS receivers can be divided in two major categories, navigation-based application and scientific-based applications. TABLE I shows a list of these applications. In navigation applications the GNSS signal code and carrier are used to find position, time and velocity (PVT) solution. In scientific applications other characteristics of GNSS signal are used to derive scientific quantities, even though the GNSS signals are basically designed for navigation purposes. Some of these characteristics are sources of error in navigation solutions. For example the different delays caused by ionosphere on signals with different frequencies can be used for ionospheric modeling while it is causing error in positioning.

Some scientific applications for GNSS signals in space are Earth gravity model improvement, high resolution ionospheric imaging, atmospheric limb sounding (density, pressure,

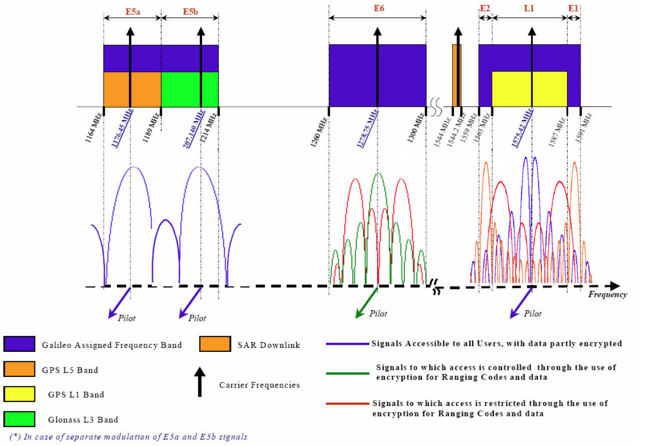

Fig. 1. GNSS signal structure (based on the report of the Galileo signal task force of European Commission)

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temperature and water vapor distribution) and reflectometry (altimetry and scatterometry).

Different applications seek different requirements in term of accuracy. Accuracy requirement for different missions varies from couple of meter in e.g. autonomous formation flying [4] to millimeters in e.g. Earth gravity modeling [5]. It is important that the overall system performance converges to an optimum state based on a compromise between the user requirements in one hand and available resources such as available power and number of satellite in view from different GNSS systems on the other hand.

## III. RECONFIGURABLE OPERATION SCENARIOS

Ideally a GNSS receiver should receive all available GNSS signals at all time but in GNSS applications there are some cases where it is not required to have all the frequency bands at the same.

In applications like gravity modeling the more GNSS bands are processed more accurate results will be achieved which means maximum GNSS signals should be available. In cases like finding the ambiguity in signal tracking it is more convenient to have three frequency bands but after resolving the ambiguity it is not necessary to have triple frequency as it has not much effect in signal quality. In this case, the third frequency band can be turned off and the system switches to dual-band mode.

Another application which benefits from reconfigurability is baseline calculation between two satellites. In this application differential GNSS signal is used and the effect of ionospheric delay can be cancelled with single band when the satellites are near each other since the GNSS signal is passing through the same ionosphere portion. But in the same mission when the distance between two satellites is increased, the received GNSS signal by each satellite is passing through different ionosphere portions and to cancel its effect two bands are required.

TABLE I
GNSS RECEIVER APPLICATIONS IN SPACE

| NAVIGATION-BASED | SCIENTIFIC-BASED |
|---|---|
| Precise orbit determination (POD) | Earth gravity model improvement |
| Attitude solution | High resolution ionospheric imaging |
| Timing solution | Atmospheric limb sounding |
| Clock stability estimation | Reflectometry |
| Data time stamping | |
| On-board autonomy | |

Another issue which is more related to the hardware and operations is the cases when the satellite is facing reduction in available power. Examples are missions without battery and only relying on solar cells, e.g. Delfi-C3, or when the satellite enters eclipse with not fully charged battery. In these example cases based on the mission definition, there is a possibility that data transmission should not be interrupted to ground while the GNSS data can be of lower quality (interrupted operating scheme). In such cases it is possible to reduce the GNSS signal quality to make more power available to other parts of the system, e.g. transmitter in this case, and after resolution of power problem switch back to the normal operation scheme.

## IV. PROPOSED ARCHITECTURE

In this work to achieve the reconfigurability and simplicity in the design, an architecture based on direct conversion concept is proposed. The direct conversion architecture is the simplest receiver architecture with minimum number of components. In this architecture, the received signal is directly translated to baseband where most of the amplification is performed. Using this architecture as the basis of design makes it possible to have a multi-band receiver by placing the complete receiver chain for each band in parallel. Fig. 2 shows a triple band receiver (GPS L1/L2C/L5 and Galileo E1/E5).

In this configuration three signal paths are placed in parallel and from signal flow point of view they have no influence on

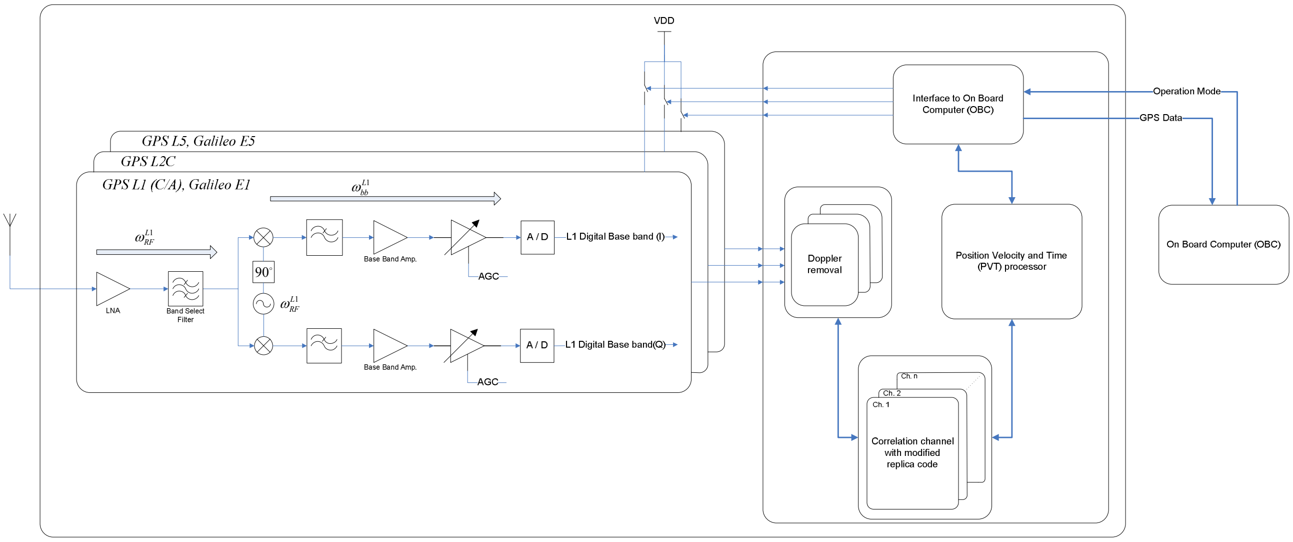

Fig. 2. Proposed reconfigurable multi-band GNSS receiver architecture

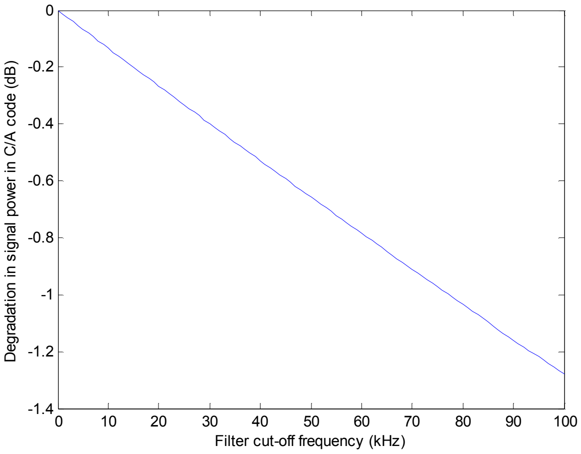

Fig. 3. Power degradation in C/A code because of high-pass filtering

each other. To be able to achieve reconfigurability each path is connected to power supply by a switch which can turn on or off the signal path based on the required configuration. The on-board computer (OBC) of the satellite, for example, determines the mode of operation. Based on this mode of operation the receiver will change its configuration in analog and digital sub-systems. The analog paths can be turned on or off and the digital algorithms can change respectively.

This architecture provides more flexibility in resource allocation and relaxes the performance of digital back-end than other receiver architectures. Based on the momentarily requirements, digital processor can decide to use different operation scenarios. Inside the digital back-end, there is a possibility of allocating different numbers of channels to different bands based on the tracking loop algorithm detail of which is out of scope of this work.

## V. SIMULATION RESULTS

Simulation results show that this configuration is suitable for both GPS and Galileo signals. One of the major issues in using direct conversion is the DC offset generated because of self-mixing effect. It should be taken into account that a high-pass filter might be required after the mixer to suppress the DC offset. It may cause a problem when GPS signal is concerned. GPS signal as its power spectrum is shown before is a rectangular binary phase shift keying (BPSK-R) signal which has its maximum power at its center frequency. Galileo signal on the other hand is a binary offset carrier (BOC) signal, for example BOC (1, 1) for Galileo E1. This signal structure makes its power spectrum to have its maximums at an offset frequency of 1.023 MHz from its center frequency. When these signals are down converted to base band, the power peak lies on zero frequency in case of GPS while it lies on an offset of 1.023 MHz in case for E1. So having a high-pass filter has very small effect on Galileo signal while it causes some power loss for GPS signal which causes degradation in signal to noise ratio (SNR). This was one of the reasons that made this architecture not very popular in the past for this particular application.

To see the effect of the high-pass filter on SNR the power of C/A code signal is calculated from integrating its power spectral density from DC to 10 MHz. The power reduction due to filtering is achieved by integrating of multiplication of power transfer of the filter with the power spectral density of the signal in the same frequency range. The power reduction will be the ratio of these two values.

Simulation results show that using first order high-pass filter with corner frequencies of 1 kHz to 100 kHz would result in 0 dB to 1.3 dB SNR degradation in the GPS C/A code signal as shown in Fig. 3. The C/A code is of most concern and is the bottleneck in direct conversion architecture. Because of its low bandwidth, higher corner frequencies in the high-pass filter will degrade the signal more rapidly than other GNSS signals. There have been several approaches to solve this problem. This can be prevented in hardware by designing a filter with lowest possible corner frequency or designing a mixer with high port isolation which may eliminate the need for filtering. Another approach to solve this problem is to modify the code replica such as if it is passed through the same high-pass filter [6]. Simulation shows that in this way the similarity of the

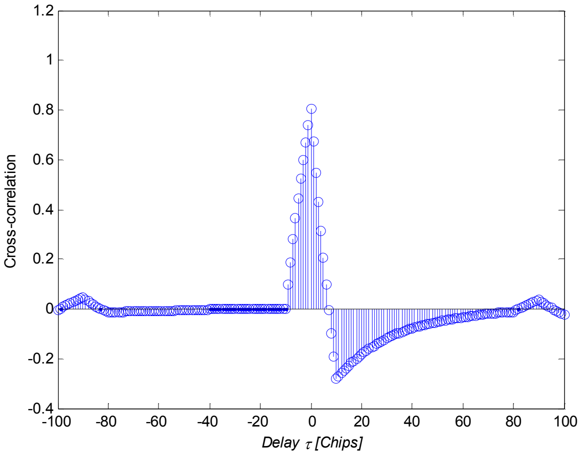

Fig. 4. Cross-correlation of C/A code passed through high-pass filter with C/A code replica with filter corner frequency of 70 kHz

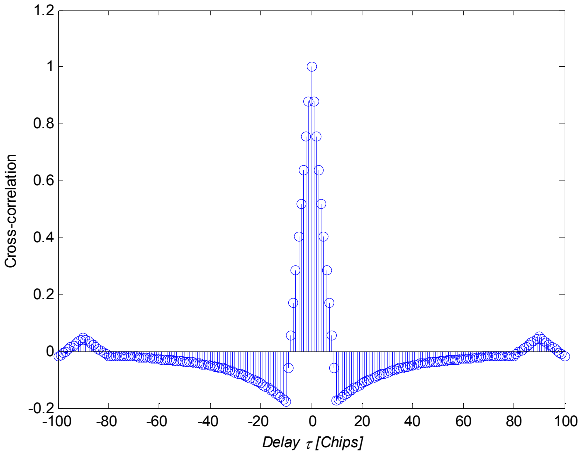

Fig. 5. Cross-correlation of C/A code passed through high-pass filter with C/A code replica with filter corner frequency of 70 kHz

replica and the received code is restored and the correlation output is more symmetrical and its peak is increased. Simulation result is given for first order high pass filter with corner frequency of 70 kHz in Fig. 4 and Fig. 5.

Flicker noise becomes important in the receiver chain after down conversion by the mixer. Passive CMOS mixers introduce almost no Flicker noise but they attenuate the signal. By using passive mixers and distributing the gain in other stages, it is possible to reduce the effect of Flicker noise.

Another issue which becomes important in direct conversion architecture is second-order distortion. There are different approaches to reduce the effect of even-order harmonics in a direct conversion receiver. Fully differential circuits will reduce the even-order nonlinearity by the expense of increased power. Another approach as given in [7] is to use even-order harmonic reduction loop.

I/Q mismatch which is caused by component mismatches will produce errors in amplitude of down converted signal. It becomes important if the carrier phase of GNSS signal is of interest as it is directly proportional to the ratio of I and Q amplitudes. This can be overcome by using layout design techniques in the IC to achieve the best matching between components.

And finally this receiver is intended to be used for space applications and must be immune against harsh space environment conditions such as radiation, high temperature change rate, vacuum and vibration. The effect of radiation on commercial CMOS technologies in space can be reduced by using specific layout design techniques.

## VI. CONCLUSION

In this paper a high level system consideration of designing a GNSS receiver for space applications is discussed. The main focus was on different applications of GNSS receiver and their requirements. Nowadays GNSS signals fulfill many more functions than pure navigation. Thus the GNSS receiver should fulfill application requirements among which flexibility in operation and accuracy are the most important issues. At the end based on the requirement, a reconfigurable GNSS receiver architecture is proposed and briefly the challenges in the design with possible solutions are introduced.

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