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New GNSS Signals: Receiver Design Challenges

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ABSTRACT

In the coming years, many more satellite positioning signals will become available to civilian users. In addition to the L2 and L5 signals of GPS is the array of different signals that will be broadcast by Galileo. A Galileo receiver will be required to be fully compatible with GPS, so the receiver will need to be sophisticated enough to receive and process all of these signals simultaneously. In this paper, we examine the implications for the receiver designer: how the antenna design becomes significantly more difficult, how the frequency plan must be very carefully thought out, how the correlator "channels" will be more elaborate. It may, however, be possible to simplify the design somewhat if advantages presented by the use of software radio, software-defined radio, and reconfigurable techniques are fully exploited

KEYWORDS: Software radio, GNSS receiver, Galileo, GPS.

1. INTRODUCTION

1.1 Satellite Signals

Commercial satellite navigation receivers have until recently largely been restricted to using the GPS signal at L1 (carrier 1575.42MHz, chipping rate 1.023Mcps) [1]. Soon GPS will provide a similar signal on L2 (carrier 1227.6 MHz) [1, 2] and a new signal on L5 (carrier 1176.45 MHz, chipping rate 10.23Mcps) [3, 4, 5].

The Glonass system has also been available to commercial users, but has proved less popular. Glonass channels were sometimes added to GPS receivers, but Glonass-only receivers are extremely rare. Its spectrum is different – a single code frequency 0.511Mcps spreads a series of carriers at 1602.0+0.5625n MHz, n = 1..12 [6].

Galileo will have several signals available to commercial users. Open services (OS) are available on E5 (1164-1215MHz) and E2-L1-E1, known for convenience as L1 (1559-1592Mz). Commercial services (CS), for which a fee is required but are not restricted to security services, are available on E6 (1215-1300MHz) and L1. At the time of writing, the above frequency allocations were the latest to have been formally released [7, 8], although it is known that they will change because of agreements between the Galileo and GPS teams [9, 10]. The OS L1 signal bandwidth, for instance, has been reduced by a factor of 2 so that it has a 1.023MHz chipping rate, and a binary offset code of 1.023MHz, a so-called BOC(1,1) code.

The locations of the GNSS signals in the spectrum are indicated in Figure 1.

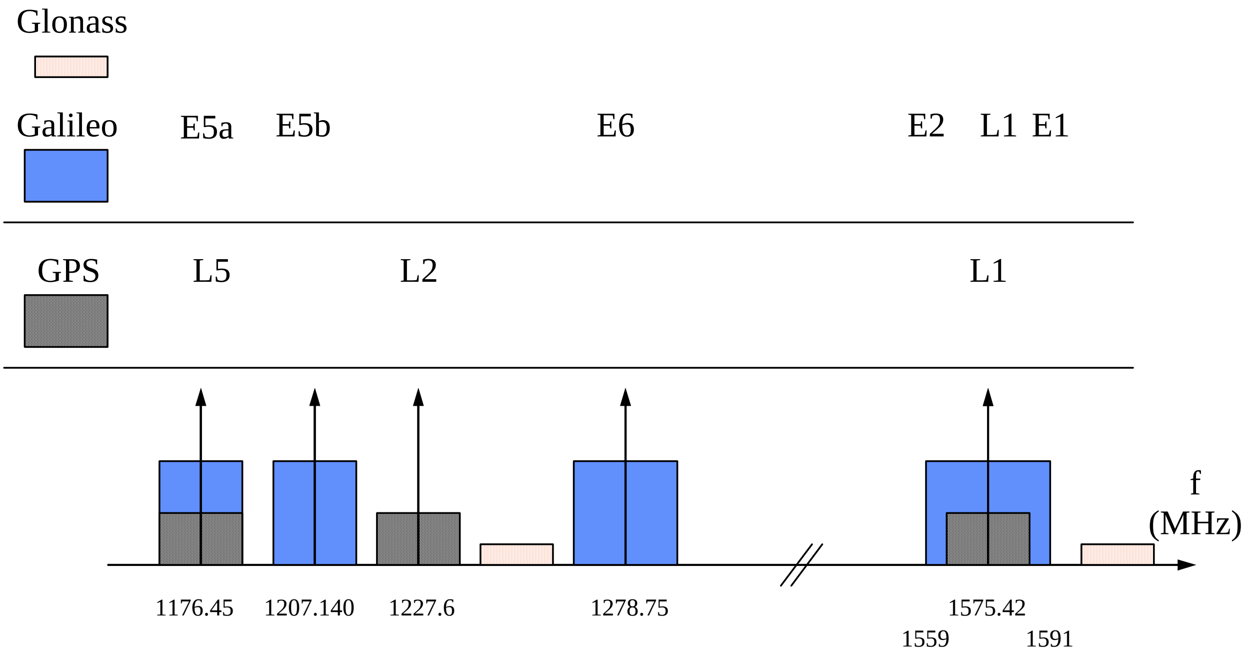

Figure 1. Spectral Locations of GNSS Signals

Combinations of these signals were selected that are likely to be common within a “GNSS” receiver. The Glonass system has not for some time been complete and has an uncertain future, so it was not included in the considerations. The GPS L5 signal is intended primarily for aviation users, so Example 1 is the most expensive receiver processing GPS L1, L2, L5 and Galileo OS and CS, using L1, E5 and E6. Example 2 uses only the free-to-air GPS L1 and L2 and Galileo OS, on L1 and E5. Example 3 uses L1 and E5 (ignoring L2) and example 4 uses L1 and L2 (i.e. the GPS bands that are “currently” available, and incorporating the Galileo L1). An even cheaper arrangement would be simply to continue with “L1 only” and incorporate the new Galileo signal. This will definitely be an attractive option for many receiver manufacturers but does not provide the sort of “challenge” we are examining here.

The frequencies required for the four examples are shown in **Error! Reference source not found.**. It can be seen that because the frequency bands are contiguous, in all cases, only two bands are required. Example 1, for instance, must receive in the range 1164-1300MHz and 1573-1577MHz.

Band	E5 (L5)	L2	E6	L1
fmin	1164	1217	1260	1573
fmax	1214	1238	1300	1577
Ex. 1	X	X	X	X
Ex. 2	X	X		X
Ex. 3	X			X
Ex. 4		X		X

Table 1 Frequency bands for example receiver designs

1.2 Receiver Configurations

There are many different receiver design types that can be considered. The two main categories that we differentiate here are the IF receiver, where the RF signal is downconverted to an IF and then sampled, and the software defined radio (SDR) using direct digitisation, or *bandpass sampling*. Some authors claim that there is no real difference in performance between these two methods [11] while others say that bandpass sampling cannot help but alias in to the baseband a large amount of noise [12,13]. These two configurations are shown in Figure 2 for two frequency bands.

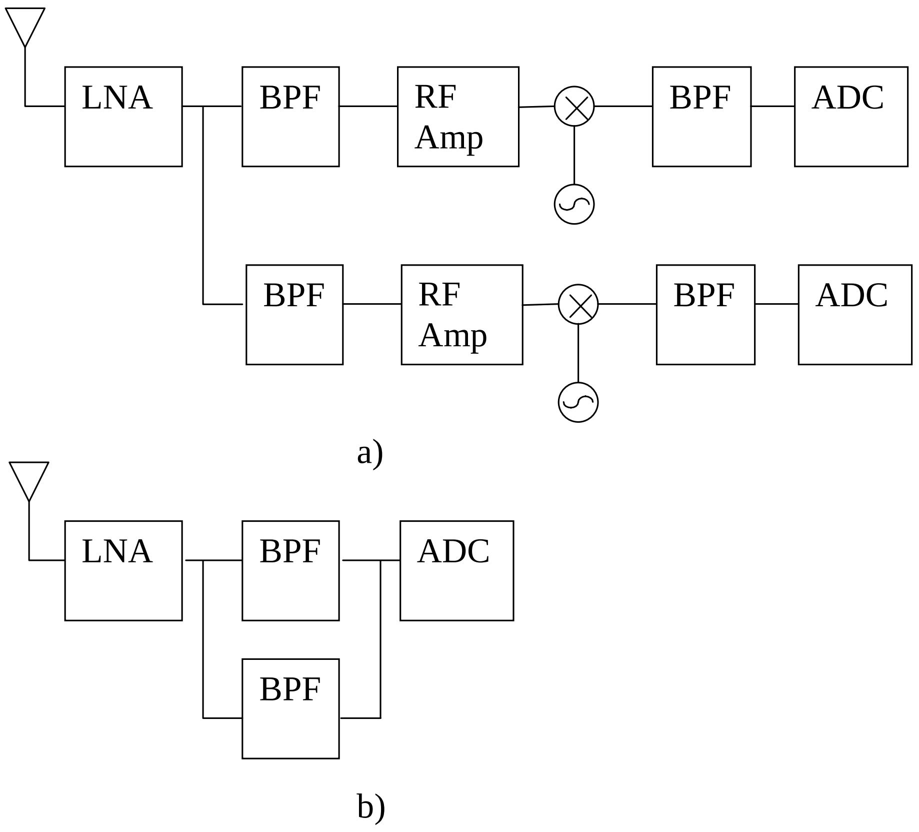

Figure 2. Possible radio receiver configurations for a multi-frequency receiver: a) IF sampling, b) software radio concept, using bandpass sampling

2. RF FRONT END

2.1 Antenna Design

In both the IF and bandpass sampling cases, there is a requirement that the RF antenna is capable of receiving with reasonable gain from all the frequencies identified in **Error! Reference source not found.**. This represents a relatively difficult task. Studies have shown [14] that for several frequency bands, patch antennas tend to be difficult to design and are somewhat bandlimited, while a conical spiral gives best results. The problem is that for commercial receivers, the antenna needs to be cheap, and the search for a dual-frequency patch has turned up some stacked patches [15, 16], which are more expensive to produce, and some single-layer slotted patches [17, 18]. One triple-frequency GPS design is a quite large 4.7 inch square [19]. So it is fair to say that an inexpensive multi-frequency antenna design is still some way off.

2.2 Bandpass Filter Design

Design of the front-end bandpass filters in the IF sampling case is relatively straightforward, requiring only relatively standard image and noise rejection. The only requirement that differs greatly from a normal GPS design is that when several bands are combined into one, the filter required is broader than for GPS L1 or L2 design. Example 1 has the widest requirement, with a band of 136MHz between 1164-1300MHz.

The bandpass sampling case is different, however. In that case, out-of-band rejection must be very good because out-of-band noise is aliased into the baseband. The SNR in the baseband sampled case is [13]:

$$\mathrm{SNR}_s = \frac{S}{N_p + (n-1)N_0} \tag{1}$$

where S is the signal power density, N_p is the in-band noise power density, N_0 is the out-of-band noise power density, and n is a sub-sampling ratio ($n = 1$ for lowpass sampling). The maximum value of n is [13]:

$$n_{\max} = \left\lfloor \frac{f_{\max}}{B} \right\rfloor \tag{2}$$

which for the L1 GPS is 1576/2 = 788, i.e. the out-of-band aliased noise must be attenuated by 29dB, simply to have the same effect in (1) as the in-band noise, diminishing SNR by 3dB. Out-of-band noise must therefore be attenuated more than this to make it insignificant. More importantly, it is highly likely that out-of-band transmitted signals are stronger than the noise and hence must be attenuated such that they contribute less interference than the in-band noise. Note, however, that the above example (GPS L1) is the worst case that we could discuss. For most of the cases we are dealing with, B will be much larger, and fewer bands are aliased into baseband.

3. SIGNAL PROCESSING

3.1 Task Allocation

Figure 1 shows where the divide exists between analogue and digital processing of the received signals, but does not identify which digital processes are performed in hardware and which in software. For low-cost receivers, it still appears that the all-software approach (SWR) is not appropriate [25], due to the cost of the processors required. However, it is sensible to perform signal tracking in hardware because it fully utilises that hardware. Compare that with the acquisition function which is used intermittently and so it has been suggested it may better be performed in software [25]. In a broader SDR approach, however, it would be possible to reallocate the acquisition hardware to another task, or turn it off altogether.

3.2 Software Radio

Software receivers have been designed for the GPS L1 signal [11, 21, 22] and for the L5 signal [23]. Dual band receivers have also been designed, for L1 GPS and Glonass [24], and for GPS L1 and L3 [20].

When using lowpass sampling, the designer can happily choose any sampling frequency above the Nyquist rate. When using bandpass sampling, the Nyquist rate minimum still applies, i.e. the sampling frequency must exceed twice the signal bandwidth, or in the case of several bands, the sum of the bandwidths of the signals of interest. However, because bandpass sampling relies on aliasing, it effectively performs downconversion, which places restrictions on the sampling rates that are available [13]. This is because each downconverted signal band must not:

i) overlap dc,
ii) overlap the Nyquist rate, or
iii) overlap any other downconverted signal band

This means that unwanted aliasing can occur at sampling frequencies above the minimum required rate, and that selection of sampling frequency is a very important part of the design.

The dual band receivers that have used bandpass sampling have therefore not used the minimum sampling rate. The receiver designed for L1 GPS and Glonass was described in [24]. A sampling frequency of 24.205MHz was used successfully to separate the signals. Another dual frequency design, to receive L1 (carrier 1575.42MHz, chipping rate 1.023Mcps) and monitor L3 (carrier 1381.05MHz, chipping rate 10.23Mcps), required a sampling rate of 73.45 MHz [20].

It was also noted in [24] that, because GNSS signals are CDMA spread spectrum signals, it is in fact possible to downconvert bands “on top of each other”. In such a case, the noise floor comes up due to several sets of noise being aliased into the same spectral region, but as long as the cross correlation properties of the different systems’ codes allow it, signals can be extracted using the normal correlation techniques. If this signal overlap was allowed, the sampling frequency of the L1 GPS and Glonass receiver [24] could be dropped to 15.402MHz, with the aliased noise effectively lifting the noise floor by 3dB.

3.3 Correlation

Like the old GPS L1 signal, the new GPS signals use BPSK [1, 3] modulation. The codes are longer and the L5 codes are 10 times the rate, but in general, the hardware or software allocated to do the correlation would be quite similar for all the GPS signals. The Galileo signals are quite different, however. Manchester encoding of signals is used to produce signals which have low spectral characteristics around the carrier. These codes are known as binary-offset carrier (BOC) codes. By adding such a code to a BPSK signal, and setting powers appropriately, a six-phase signal can be produced, carrying three separate signals (as opposed to the two carried on I and Q channels in the GPS signals). This type of modulation is called tricode hexaphase [26] or interplex modulation.

Despreading a BOC signal is a more complicated process than for a BPSK signal. Importantly, the BOC signal has multiple peaks where the BPSK signals have only one, and therefore when tracking the receiver needs to ensure it is on the right peak. This can be done using a “bump-jump” method [27], a “BPSK-like” method [28] or a 12-14 tap method [29]. All of these techniques tend to be more complex than their GPS equivalents.

In practical terms this has many implications for receiver design. If a receiver has a number of “channels”, the GPS channels will be simpler than their Galileo counterparts. This means that a receiver that is being used as the Galileo constellation is being accumulated will have a lot of redundant hardware. Once the Galileo signals are available, however, they will give superior performance to the GPS signals and should be preferred. This leads to the almost inevitable conclusion that for a receiver design incorporating Galileo, reconfigurable hardware will give great benefits.

4. A NOTE ON POWER CONSUMPTION

The original L1 GPS signal has a much narrower bandwidth than most of the new signals and as such required far fewer operations to perform the basic requisite processing: acquisition, tracking etc. This type of processing can be expected to increase with the increased bandwidth (or sampling rates as already discussed), hence increasing the power consumption proportionally. Similarly, because the code lengths are longer, more effort is required to deal with the correlation function, especially when acquiring (although this effort is not proportional due to the “tiered” nature of the codes [25]). This increase in computational effort is militated slightly by the fact that for GPS L1, greater efforts are required in order to deal with multipath, weak signals, cross-correlations and other difficulties dealt with in the new signal designs. It is unlikely, however that these savings will outweigh that due to increased bandwidth and code length.

5. CONCLUSION

The new GNSS signals offer many opportunities which have been well discussed. For the receiver designer, however, there remain a number of challenges:

- Both the antenna and RF front end need to cope with multiple bands, which are wider than earlier GPS L1
- The different signals have different coding and modulation schemes which tend to push the design to be reconfigurable, or at least software-defined, in order to make best use of the channel processing

- This in turn means that there are tighter constraints on the RF filtering and the sampling rate must be carefully chosen.
- Attention needs to be paid to power consumption, because although the gains made by processing many new signals may be small and incremental to the user, they require much more processing due to increased bandwidths and sampling rates. This in turn will flatten the user's battery unless measures are taken to reduce power.

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