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A Dual-Frequency RF Front-End for Long Antenna-GPS Receiver Links

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BIOGRAPHIES

Frederic Chastellain received his MSc degree in 2002 from the Swiss Federal Institute of Technology in Lausanne (EPFL). Currently, he is a research assistant at the IMT where he is preparing his Ph.D. Thesis. His research interests are hardware design of radio frequency (RF) circuits for single-frequency and multi-frequency GNSS receivers.

Dr. Cyril Botteron is team leader at the IMT. He received his Ph.D. in Electrical Engineering from the University of Calgary, Canada. His current research interests comprise the development of radio frequency (RF) integrated circuits and statistical signal processing techniques with applications in digital and wireless communications, including global navigation satellite systems (GNSS) and ultra-wideband (UWB) communications.

Dr. Elham Firouzi is maitre assistant at the IMT. He received his Ph.D. in 1995. Currently, he is leading a project in the domain of GPS timing, which is realized in collaboration with local industry.

Dr. Pierre-Andre Farine is professor of electronics and signal processing at the IMT. He works in the field of low-power integrated products for portable devices, including wireless telecommunication and GNSS systems. He is Head of the electronics and signal processing laboratory (ESPLAB) at IMT. His R&D group works also for video and audio compression algorithms and signal processing. He received his Doctoral and MSc Degree from University of Neuchatel. He has been working 17 years for Swiss watch industries (Swatch Group), including developments for high-tech products, such as wrist-watch cellular phones and GPS watch prototypes.

Patrick Weber is chief of the R&D, at Oscilloquartz S.A. He is ETS engineer since 1981. After more than 10 years as development engineer in the company, he is now Head of the development department since 2000. He manages all the R&D projects: telecom including GPS, time and frequency as well as oscillators products and all the introduction of the required new technologies.

Dr Jean Pierre Aubry is C.E.O. (Chief Executive Officer) of Oscilloquartz S.A. He received his Ph D in Material Physics from University of Nancy, France, in 1979. Dr Aubry join Thomson Group in France in the Quartz and Oscillator division in 1979, where he was technical manager up to 1996. Dr Aubry joined Oscilloquartz SA Switzerland in 1996 as technical manager for the frequency sources division, and he was elected as CEO in 1998. He is author or co author of number of technical papers and patents in the field of time and frequency devices, piezoelectric material, high frequency devices, low G sensitivity oscillators and clocks for telecommunication applications. Dr Aubry was involved in the design of BVA resonators and high stability oscillators, to bring the first commercial oscillator in the $10^{-}14$ range of Allan variance.

ABSTRACT

While the Global Positioning System (GPS) is best known for its positioning applications, another way to use GPS is as a time reference for telecommunication networks synchronization. However, as every new communication standard is more demanding, the precision of the current single-frequency GPS based network synchronization solutions is about not to be sufficient anymore. The dominant source of error in current state-of-the-art receivers based on the L1 C/A code is due to the variations of the propagation delay through the ionosphere. Fortunately, a new GPS civilian signal, L2CS, is about to be released. Combined with the existing L1 signal, it will allow to cancel most of the ionosphere induced error and therefore offer better timing signals as compared to classical GPS receivers. In this paper, a dual-frequency front-end for long antenna-GPS receiver links is presented.

INTRODUCTION

The use of the GPS time in conjunction with a quartz or rubidium oscillator is an excellent solution for timing application: the oscillators have a very good short (to medium) term stability and accuracy but their performance degrade at long term. Fortunately, the time reference provided by the GPS complements the oscillators performance quite well: it is accurate at long term but the pseudorandom noise codes (PRN) used to spread the message data makes it unusable at short term. As a consequence, the long term stability of the GPS time, when combined with the short term stability of oscillators, relaxes the requirements of the oscillator as compared to other free-running oscillators such as cesium or hydrogen maser. The consequence is a much lower cost, area and weight at a high level of performances when used with a stable and accurate oscillator, such as an OCXO [1]. Such systems are called GPS disciplined oscillators (GPSDO).

With the apparition of several new civilian signals in the years to come, there's no doubt that the next "big thing" in Global Navigation Satellite Systems (GNSS) is the use of multiple frequencies to improve the performances of the next generation of receivers. For timing applications, this is also a great opportunity. The main factor limiting the precision of today's GPSDO is the delay introduced by the ionosphere. Though, when two signals with different carriers are available, the ionospheric error can be corrected. The ionosphere-free pseudorange measurement ρ^* is given in [2] as :

$$\rho^* = \frac{f_{L1}^2}{(f_{L2}^2 - f_{L2}^2)}\rho_{L1} - \frac{f_{L2}^2}{(f_{L2}^2 - f_{L2}^2)}\rho_{L2} \qquad (1)$$

where ρ_{L1} and ρ_{L2} are the pseudorange measurements at the L1 and L2 frequency, respectively.

Among the new US and European civilian signals, L2CS (1227.6MHz) will be the first available signal and it was therefore chosen for our application. L2CS, is a time division multiplexed (TDM) code alternating between a 515kHz medium code (CM) and a 515kHz long code (CL) [3]. As a consequence, the L2CS code occupies a bandwidth similar to that of the L1 C/A code. It is received with a power of -127dBm, which is 3dB lower than the L1 C/A code (see Fig.1).

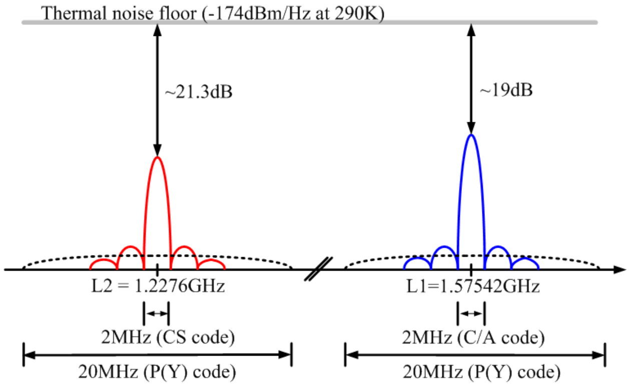

Fig. 1 Spectrum of the GPS L1 and L2 band.

The pulse per second (PPS) accuracy of current GPSDO is 50ns to UTC and stability is better than 100ns [4] when the system is carefully calibrated. The ionosphere error can range from a few nanoseconds to hundreds of nanoseconds [5]. For years, there has been efforts to circumvent this error. Most consumer receivers use the model of the ionosphere delay contained in the broadcasted navigation message but its effectiveness is limited to approximately 50% [6]. Dual-frequency receivers (DFR) already exist, which make use of L2 P(Y) signal to correct the ionospheric errors. L2CS will enable full civilian DFR with lower complexity and higher precision.

The DFR unit will provide improved accuracy, better timing residual noise (maximum time interval error (MTIE) less than 5ns) compared to the 50ns residual available now on low cost industrial devices, or better frequency transfer accuracy (lower than 10^{-13}) under normal conditions of reception. It will provide accurate timing with less than 4 satellites in common view, combining the timing accuracy extracted from a dual-frequency operation and the hold-over characteristic of the local oscillator of the static receiver.

Beside PPS accuracy, there's another challenge when designing a GPS receiver for timing application. Indeed, it is mandatory for any GNSS, in order to work properly, to have a clear view of the sky. Unfortunately, it is often not the case in timing applications because the receiver is located in hostile environments such as urban canyons or even deep canyons. Worse, the antenna has a fixed position and therefore if no satellite is found after the receiver has been initialized, there's a great probability that the situation won't improve with time. As a consequence, the antenna is most of the time placed on the roof of the building in order to have the best available view of the sky, while the GPS receiver is placed close to the basement-located telecommunication equipment. This leads to antenna-GPS receiver links which can be several hundreds of meters long (see Fig.2)!

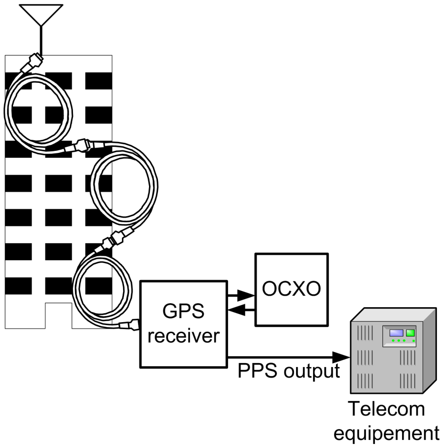

Fig. 2 Illustration of a situation where the antenna-GPS receiver link can be several hundreds of meters long

The problems met when designing a dual-frequency front-end (DFFE) added to those present at the transport level impose a very limiting set of constraints on the design of the RF front-end.

The paper is organized as follow. The first section presents the current solutions to the aforementioned problems. The second section presents the solution proposed. The third section presents the simulation results, realization and measurement setups. The fourth section concludes the paper.

CURRENT SOLUTIONS

Current multi-frequency front-ends

With as much as six new signals to be available in the years to come, there's quite some activity in the design of multi-frequency RF front-ends today. Indeed, if the Galileo L1 signal is compatible with current GPS L1 front-ends, most of the other new signals, such as GPS L2C, GPS L5 or Galileo E5, have different carrier frequencies and will therefore require the development of new multi-frequency architectures.

Up to that day two types of multi-frequency front-end (MFFE) architectures have been published:

The in-parallel single-frequency front-end solution replicates a single-frequency front-end for each added frequency (see Fig. 3). Usually the design is based on a front-end which has been demonstrated and it is therefore a secure way to proceed. However, the problems of harmonics and spurious present in such a design multiply with the number of mixers and frequency synthesizers present in a GPS front-end. Besides complexity, this solution is also expensive since it multiplies the front-end cost by the number of signals to be downconverted!

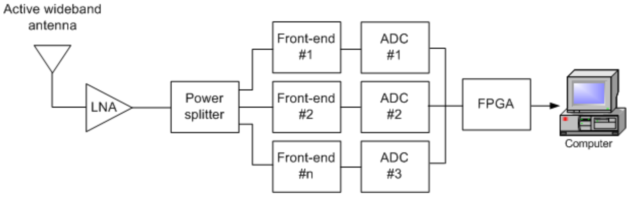

Fig. 3 MFFE based on the in-parallel single-frequency front-end principle.

The direct-RF sampling uses aliasing to down-convert the different signals present at the antenna (see Fig. 4). Indeed, if the sampling frequency f_s is chosen carefully, all the bands can be downconverted simultaneously to reasonable IF frequencies and no overlapping occurs. In [7], an L1 C/A and L2 P(Y) direct-RF sampling front-end has been implemented. In the case where no overlapping between the two signals is allowed, the minimal f_s is 99.23MHz. As a consequence, 30 seconds of data represent approximately 3G samples of data which is quiet a large amount of disk storage!

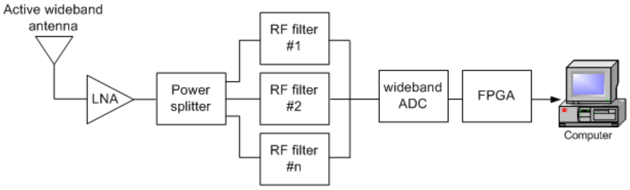

Fig. 4 Multi-frequency front-end based on the aliasing principle.

Current solutions to the long antenna-GPS receiver link

Most timing receivers are placed in hostile environments where they experiment shadowing and multi-paths due to the surrounding buildings (see Fig. 6). For these reasons, the antenna is usually placed on the roof of the building where the clearest view of the sky is available. On the other hand, the GPS receiver is preferred close to the telecommunication equipment which is usually located in the basement. For these reasons, the antenna - GPS receiver link is quite long, between 20m and 400m meters. The transport mean used is usually a low cost coaxial cable such as RG213. In Fig.5, the measured losses for a 60m RG213 and a 60m LMR400 cables are represented for frequencies between 300kHz and 2.5GHz. The losses of the RG213 model used for simulation are also represented. As we can see, the RG213 and its model are matched up to 500MHz. At higher frequency, the losses of the model become more important than that of the actual cable. The losses of the different cables at the front-end key frequencies have been summarized in Table 1.

Frequency (MHz)	RG213 meas. (dB)	RG213 model (dB)	LMR400 meas. (dB)
175.0	-5.0	-3.3	-4.6
1227.6	-14.6	-9.0	-16.6
1575.42	-17.0	-10.2	-20.0

Table 1 Losses at system specific frequency

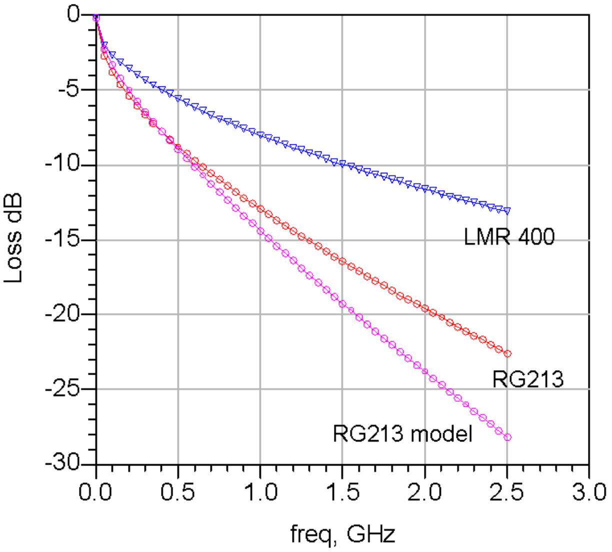

Fig. 5 Losses versus frequency for a 60m RG213, a 60m LMR400 and a 60m RG213 model

For a standard active antenna with a gain of 30dB, the performance of the receiver degrades severely for links longer than 50m. Line amplifiers and higher performance cable are avoided since they only slightly improve the maximal link length at a much higher cost. There are currently three solutions adopted in order to realize long antenna-GPS links:

- Down-up converter (DUC): since losses over a copper cable decrease with frequency, this solution downconverts the signal to an intermediate frequency (IF). Then the IF signal propagates through the cable and is upconverted to its original RF frequency before it enters the basement located RF front-end. The DUC has the advantage that it is transparent for the front-end and therefore can be used with any GPS front-end chipset.

- Optical links: their main disadvantage is the high noise figure (NF) of the electrical-optical (EO) transmitter and optical-electrical (OE) receiver. However, with current low-noise amplifiers, the NF of the complete optical link can be as low as 3dB. They also have several other advantages: lower losses allow km links, unsensitivity to electromagnetic radiations during propagation, easier installation due to the thinner and more flexible fiber. Their drawback is their price.
- Window receivers: from a cost point of view they are the most promising solution: indeed if the antenna can be placed at the window of an office or even indoor, the cabling costs are suppressed (see Fig. 6). For a single-frequency receiver, the indoor context doesn't have great impact on the timing performance. Indeed, the standard deviation of the PPS offset error is increased from 0.1ns to 1.8ns when going from clear sky conditions to indoor condition [8]. This degradation is not considered to have a major impact as compared to the the ionosphere error. However, when the ionospheric error is corrected, this error can't be neglected anymore.

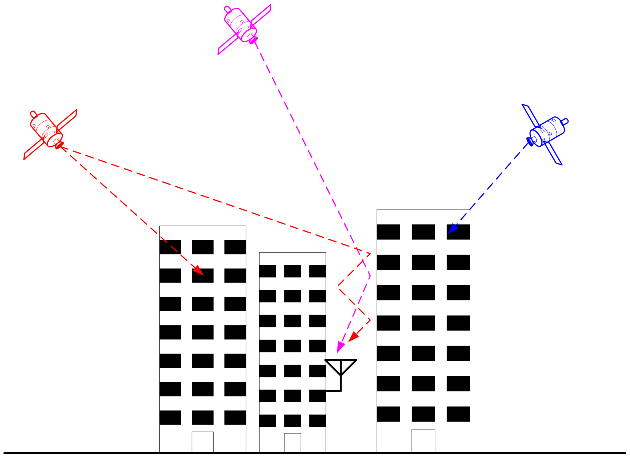

Fig. 6 Multipath and shadowing problems of window receivers in urban canyon environment.

Our decision was to use the optical solution as an option for links longer than 400m, a link length where the optical solution becomes economically attractive. The window receiver option has been quickly rejected due to the impact of weak signals on the PPS offset error. As a consequence, our choice was to use a coaxial link for standard links up to 400m. To solve the attenuation problem, we have used a similar principle as the DUC.

A DUAL-FREQUENCY FRONT-END FOR LONG ANTENNA-GPS RECEIVER LINKS

The shifted-LO dual-frequency front-end

In [9], an L1/L2CS CMOS GPS receiver has been published which uses a first LO at $(L1+L2)/2 = 1401.54MHz$. This solves the image frequency problem since L1 and L2C are image of each other and the interference mask in the GPS bands is very low. Unfortunately, after the first mixing stage, L1 and L2CS are superposed and can't be differenciated/separeted anymore. This architecture must therefore be preceded by a switchable band selection filter when only one signal at a time is selected. For simultaneous acquisition/tracking of L1 and L2CS, the front-end must be duplicated.

Another solution has been presented in [10], where the LO is shifted from 1401.51MHz. In most wireless standards this wouldn't be possible since strong interferers may be present in the frequency spectrum surrounding the band of interest. However, for GPS, we can take advantage of the fact that the GPS inband interference mask is much lower than in other bands and that the GPS civil bands only occupy 2MHz of the 20MHz allocated to the military bands. As a consequence, the LO frequency can be shifted while keeping the images in the GPS bands. Therefore the images are limited to thermal noise and the image rejection requirements are relaxed. In [11], a similar principle has been used within the GPS L1 band for a low-IF architecture.

The shifted-LO dual-frequency front-end modified for long antenna - GPS receiver links

We now merge the DFFE with the long coaxial cable link. As explained in the precedent paragraph, downconversion to an IF is used to lower the losses over the coaxial cable. The complete front-end cannot be deported to the roof since it must interact with the DSP section of the GPS receiver and steer the OCXO. As a consequence, the RF front-end is split into two modules which, for clarity, will be called the RF module and the IF module (see Fig. 7). The cables are named after the frequency range of the signals they propagate: the cable between the antenna and the RF module will be called the RF cable and the cable between the RF module and the IF module will be called the IF cable.

The RF module is placed close to the antenna and it proceeds to the downconversion of the L1 and L2CS signals to an IF around 175MHz. The signals are than transmitted through a common coaxial cable to the IF module. The IF module is placed close to the telecommunication equipment and performs the downconversion to baseband (BB) and AD conversion of the signals. The cable losses when using an IF of 170MHz are lowered to 8dB/100m.

Two problems remain: the image noise and the gain control:

In a dual frequency GPS receiver were both signals are images one of each other, each signal sees unfiltered noise at its image frequency (Fig.8(b)(2)). The SNR at the output of the RF mixer is therefore 3dB lower than at its input

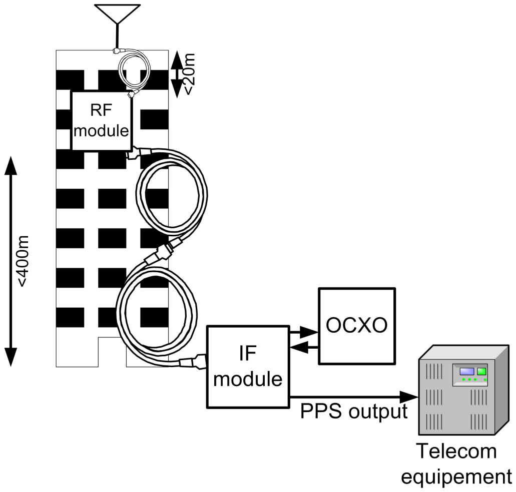

Fig. 7 The RF and IF module principle to reduce attenuation over the long coaxial cable

(Fig.8(b)(3)). In our case, L1 and L2CS are not exactly image of each other and therefore if the LO shift is sufficient, the images are rejected by the filters (Fig.8(c)(2)). If the RF cable is long, the L1 SNR is even further degraded. Indeed, due to its higher carrier frequency, L1 experiments a higher attenuation than L2CS (Fig.8(d)(2)). As a consequence, L1 is more attenuated than the noise at its image which leads to higher than 3dB SNR degradation (Fig.8(d)(3)). For L2CS, the SNR improves since it is less attenuated than its image noise. This is true for any gain/loss difference introduced between L1 and L2CS prior to the mixer. As a consequence, the total gain experienced by L1 and L2CS between the antenna and the input of the RF mixer may often not be equal.

Since power consumption is not a constraint for timing products, we have created a dedicated "path" for L1 and L2CS while still keeping a common frequency synthesizer, as shown in Fig.9. The signals coming from the antenna is splitted and each signal is filtered and downconverted individually by its own filter and mixer. This solution has the advantage of the parallel single-frequency solution since each signal has its own optimized path. However, instead of replicating the frequency synthesizer for each frequency, it uses a common LO which limits number of potential harmonics and other intermodulation products. Also, if supplementary components are required for the two paths, this architecture relaxes the performances of the RF filters (and therefore their price), probably the most expensive components of the front-end.

The front-end should have quite a large dynamic gain in order to deal with the different link lengths. The GPS signals are CDMA-like signals with a negative SNR. As a consequence, the variable gain amplifier is not directly controlled by the GPS signals but by the noise power dominating the signal. The whole gain planning is therefore defined by the noise power present at the antenna and by the noise power P_{FSR} required at the ADC input to use its full scale range (FSR). For the chosen ADC, P_{FSR} is -1.6dBm and the noise power density at the antenna is integrated over 8MHz, leading to a noise power of -105dBm at the antenna. Assuming a 5dB system NF, the required system gain is

$$G_{system} = -1.6 + 5 - (-105) = 98.4dB \tag{2}$$

The temperature used to compute the noise power density is 290K. Noise power variations due to temperature changes and components gains variations are considered sufficiently small to be absorbed by the variable gain amplifier (VGA) without modifying the performances of the front-end.

If the noise power can be approximated as constant, important dynamic gain is still required due to the variable length of the RF and IF cables (0-20m and 0-400m respectively), which represent an attenuation between 0 and 40dB. The VGA used in this work has a controllable gain between 0 and 80dB which is sufficient to work with the different links configurations but doesn't leave sufficient margin in the case interferers need to be rejected. As a consequence, the amplifier preceding the quadrature mixers has been implemented with three gain modes. For simplicity, the switchable gain amplifier and the quadrature IF mixer will be grouped under the denomination "IQ demodulator". The IQ demodulator performances are summarized in Table 2.

Mode	Gain (dB)	IIP3 (dBm)	NF (dB)
Low gain	-6.5	+23.6	31.0
Med. gain	12.0	+3.6	14.5
High gain	31.0	-14.0	11

Table 2 Three gain settings for the amplifier preceding the quadrature mixers.

Three links types have been defined: short(50m), typical(200m) and long(400m). The VGA gain required in the different configurations is given in Table 3. For more clarity, the table has been stripped down to the elements with gain depending on the link length. As we can see, the VGA is kept in the middle part of its gain range for the short, typical and long links.

Link length	RF cable loss (dB)	IF cable loss (dB)	IQ gain (dB)	Req. VGA gain (dB)
Short (5m/50m)	-1.7	-3.9	-6.5	48.5
Typical (10m/200m)	-3.5	-15.4	12.0	43.3
Long (20m/400m)	-7.0	-31.0	31.0	44.8

Table 3 Losses and VGA required gain overview in the short, typical and long link scenarios.

LO choice

As a consequence of the modifications brought to the front-end, the conditions on the choice of the first LO are relaxed. First, since the signals are splitted before being filtered, there's no more image noise problem. Also, the attenuation in the IF cable prevents the second LO to perturb the RF

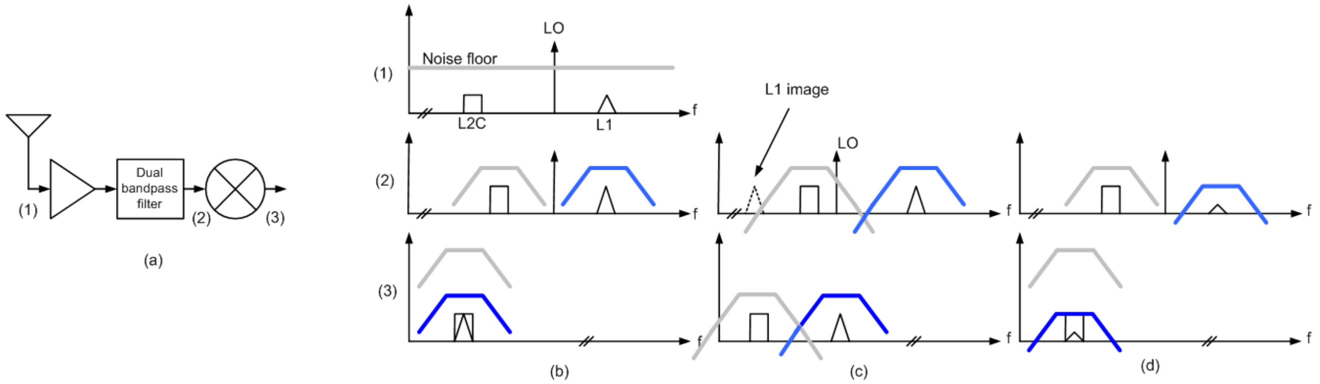

Fig. 8 Problem of the noise at the image frequency (a) a simplified representation of the components involved in the image noise problem, (b) L1 and L2CS are image one of each other (the first LO is 1401.51MHz), (c) the LO is shifted from 1401.51MHz, (d)the two bands do not experiment the same gain/loss prior to the mixer.

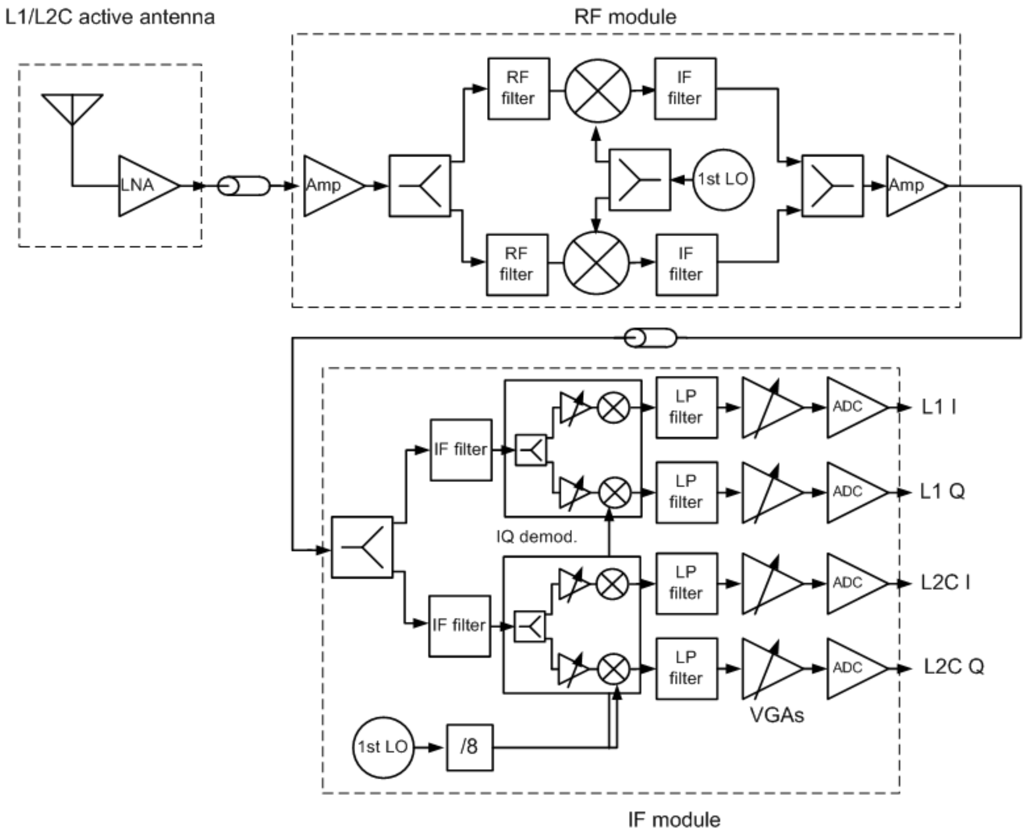

Fig. 9 Simplified representation of the dual-frequency front-end modified for transport.

module. With a first LO of 1405.5MHz, the L1 and L2CS IF are 169.92MHz and 177.9MHz respectively. The 2nd LO is 175.6875MHz resulting in L1 and L2CS baseband frequencies at 2.2125MHz and 5.7675MHz respectively.

SIMULATION RESULTS, REALIZATION AND MEASUREMENT SETUP

Simulation results

The front-end has been simulated with Agilent's Advanced Design System (ADS). Most models used for simulation are ADS system models. Several simulation engines such as the Harmonic Balance (HB), Envelope or S-parameter have been used to check the performances of the front-end in its different configurations. Simulation is very convenient for this type of system since it allows to perform various sweeps such as that of the RF and IF cables lengths.

Fig.10 shows the gain budget for the three different link configurations. As expected, the different cable losses between the short, typical and long configurations are compensated by the three gain setting of the IQ demodulator, which relaxes the VGA dynamic.

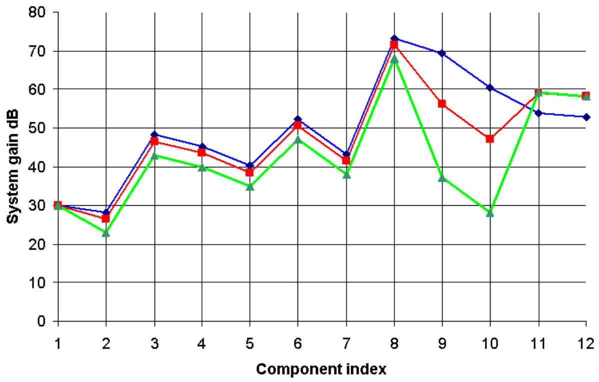

Fig. 10 System gain at the output of the indexed components for the short (blue), typical (red) and long (green) links. The indexed components are: 1: active antenna, 2: RF cable, 3: RF amplifier, 4: power splitter, 5: RF filter, 6: RF mixer, 7: IF filter 1, 8: IF amplifier, 9: IF cable, 10: power splitter and IF filter 2, 11: IQ demodulator, 12: lowpass filter

Fig.11 shows the system NF in the three different IF cable ranges. For links from 0 to 100m, the low gain setting is used. For 100m to 250m, the medium gain setting is used and for 250m to 400m, the high gain setting is used. As we can see, with an active antenna with a gain of 30dB and a NF of 2.75dB, the system's NF is kept below 4dB for IF lengths up to 400m.

IP3 budget simulations have been ran to check the different components influence on the degradation of the system's IP3 and optimize the gain planning in consequence. Table.4 gives a cropped version of the simulation results for the short link configuration. As we can see, in the short link configuration, the component limiting the linearity is, despite its high IIP3, the IF amplifier.

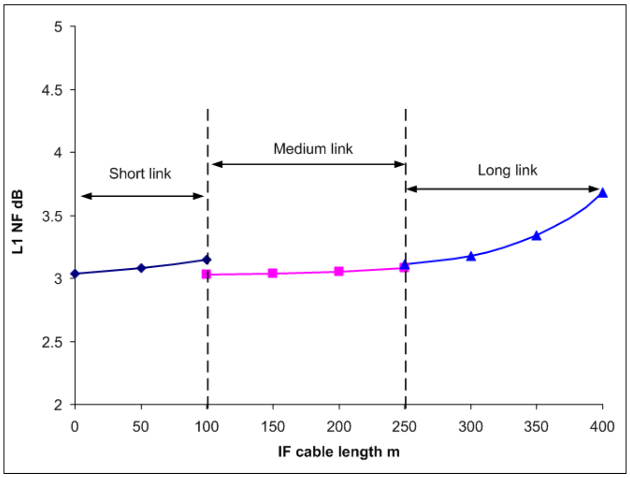

Fig. 11 Overview of the system's NF vs the IF cable length for the three gain settings

	System IIP3 dBm	Component IIP3 dBm	Pre-stage gain dB	Component contribution to system IIP3
Antenna	-57.0	10.0	-0.5	0.0
RF amp	-28.9	5	28.0	0.0
Mixer	-12.0	1.8	44.6	0.2
IF amp	-8.9	-6.9	48	4.0
IQ demod	5.4	23.6	57.6	0.0
VGA1	-1.0	29.0	51.5	0.0
VGA2	-1.0	-1.0	51.5	1.9

Table 4 IP3 budget for the short link configuration

Realization

A standard active antenna with a gain of 30dB and a NF of 3dB (similar to current single-frequency antenna) is used as a basis to design the RF module. This is sufficient a gain to "compensate" for the losses in an RG213 cable up to 20m. The first stage of the RF module is a 20dB wideband amplifier with a Nf of 3dB. Next, the signal is splitted into an L1 and and L2C path with a 3dB power splitter. Each path is filtered with a ceramic filter with a 4MHz 3dB bandwidth and an insertion loss (IL) of 5dB. The filtered signals are downconverted to their respective IF with a set of active mixers. Finally, the IF signals are filtered and added. Before the design is considered definitive, the IF filters are realized with (high-Q) lumped components for a greater flexibility of the design. These filters have 8MHz 3dB bandwidth and 8dB IL. The local oscillator is generated with a combination of a programmable PLL and a VCO. A standard OCXO is used as the reference for the PLL.

At the IF module input, the signal is splitted again, filtered with the same lumped filters as in the RF module and then fed to an IQ demodulator with a switchable gain. An 80dB VGA then amplifies the signals to a level sufficient to optimize the ADC full-scale range. An interface is implemented to digitally control the VGA gain from the FPGA. The FPGA sets the VGA gain so that the magnitude bit duty cycle is 30 %

and the sign bit duty cycle is 50 %. The LO of the IF module is locked to the steered OCXO. The ADCs provide 6 bits for each of L1/L2C I and Q path. The bits are fed to an FPGA which determines the magnitude and sign bits of each signal from the bits provided by the front-end. The sampling clock is derived from a divided by N version of the LO fed by the FPGA.

To reduce installation costs, the DC supply of the RF module and of the antenna must be supplied via the coaxial cable. The IF module supplies +8V via the IF cable. In the RF module, a +6V and a +5V power regulator are used to supply the amplifiers and mixers respectively. A third +5V power regulator is used to supply the active antenna.

Measurement setup

Acquisition and tracking measurements using L1 and L2CS could not be realized since no satellite broadcasts L2CS now. Also the signal processing section of the receiver is still under development. However, beside the standard NF, IP3 and gain measurements, Agilent's E4308 signal generator has been used to check the signal along the downconversion chain. This instrument has a GPS personality option, which allows to generate the signal of a single satellite at any carrier frequency between 9kHz and 6GHz. This allows primary testings of the front-end with the C/A code not only at L1 but also at L2. Other lower carrier frequencies can also be used to inject the signal at any particular stage of the front-end for ”debug” purposes. The signal generated doesn't contain any navigation data but two modes, RAW for bit error rate (BER) measurements and telemetry (TLM) for sensitivity tests. Additionally, an L1 GPS simulator can be combined with the E4438C to realize measurements with both signals present at the front-end input (see Fig.12).

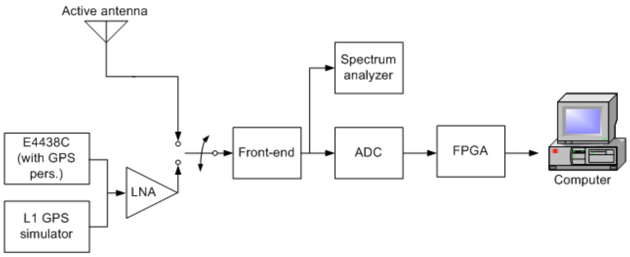

Fig. 12 Measurement setup to have L1 ad L2C simultaneously at the front-end input

A first set of measurements have been made using continuous wave (CW) signals at L1 and L2. The results have been observed with an Agilent's ESA4407B spectrum analyzer and are in good correlation with the simulation results.

CONCLUSIONS

A dual-frequency front-end for long antenna-GPS receiver links has been designed. It uses a common LO for both bands in order to reduce the number of potential harmonics and other intermodulation products. The front-end has been splitted into an RF module and an IF module. The RF module downconverts the signals to IF before they are propagated over the coaxial cable, which lowers the losses and allows longer links. A set of simulations has been performed to check the front-end performances in the different link configurations. It has then been realized and is currently being measured.

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