THE PARIS IN-ORBIT DEMONSTRATOR

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1. ABSTRACT

Mesoscale ocean altimetry remains being a challenging area for satellite observations, and yet of great interest for oceanographers trying to validate and drive their ocean circulation models with real measurements. Conventional nadir looking radar altimeters can make observations only along the satellite ground track and many of them are needed to sample the sea surface at the required spatial and temporal resolutions [1]. Ad hoc constellations of a few of such nadir looking altimeters [2] are being exploited to increase the spatial and temporal sampling of the ocean. There have even been proposals to embark many radar altimeters on large constellations of commercial communication satellites, as was considered for the next generation of Iridium's space segment. In parallel, several concepts have been put forward to extend altimetry to the side of the satellite track including (a) bi-static radar within a constellation of cooperative radar altimeters [3], (b) radar interferometry from a single satellite [4][5][6], and (c) bi-static radar using GNSS reflected signals [7]. This paper deals with the latter concept which will be referred to as Passive Reflectometry and Interferometry System or PARIS.

PARIS is a very wide swath altimeter, capable of reaching 1000 km swath or even more, depending on orbital altitude, as it picks up ocean-reflected (and direct) signals from several GNSS satellites, up to 12 tracks when Galileo will be available.
Due to the global coverage and the multi-static nature of this technique, a low-Earth-orbiting PARIS instrument would allow high spatial-temporal sampling of the Earth surface. For these reasons PARIS has been identified as a very promising complementary technique with respect to conventional radar altimeters in order to address mesoscale altimetry detection.

However, the PARIS technique presents few issues which shall be carefully analyzed in the instrument design when the full mesoscale altimetry mission in considered. An ideal design of the PARIS altimeter shall maximize the mesoscale height accuracy while preserving instrument mass, size, power consumption and cost.
As well known, generally speaking, the PARIS altimeter height estimation is affected by random zero average height error (commonly referred to as the height precision) and by additional random and deterministic errors that affect the total absolute measurement error or accuracy. Therefore both precision and accuracy terms shall be carefully addressed in the altimeter design in order to maximize the performance, i.e. the total absolute height error.

On one hand, the height precision, apart the speckle noise, is mainly determined by system parameters such as transmitted power and bandwidth, TX and RX antennae gain, receiver thermal-noise figure, coherent integration time and geometry.
On the other hand, the height accuracy is also affected by propagation effects such as the ionospheric and tropospheric delay and by electromagnetic scattering effects, such as electromagnetic bias and skewness bias. In particular, the ionospheric delay is the major cause of absolute ranging error at L-band for it can reach tens of meters. The ionospheric delay, being a frequency dispersive effect, is typically corrected in conventional altimetry by combining measurements performed at two widely separated frequencies. This error term, if not properly corrected for, could have a major effect on the final altimeter height precision.

The present paper describes a PARIS altimeter specially conceived to fully exploit the GNSS signals (to maximize the height precision) and to provide multi-frequency observations (to correct for the ionospheric delay) in order to fully meet mesoscale ocean altimetry requirements of 5cm over 100Km.
The proposed PARIS altimeter is a new type of instrument which combines radar and radiometer techniques, including interferometry. As described throughout the paper this combination enables optimal use of the spectrum of the GNSS signals for precise ranging, accurate correction of the ionospheric delay and fine amplitude and delay calibration.

The proposed PARIS altimeter configuration is indeed based on the so called interferometric processing which is able to maximize both height precision and accuracy.
The interferometric processing is based on the adoption of direct cross-correlation between the received up-looking direct and down-looking reflected navigation signals. This configuration allows processing also restricted access GNSS signals, maximizing the height precision of the instrument since the full power spectral density of the TX GNSS signal is exploited for range estimation. However, with respect to the conventional PARIS configuration, which performs the cross-correlation with on-board generated replica of open access codes, the interferometric configuration would experience a degradation of signal-to-noise ratio at the correlation output, and, hence, a degradation of height precision. The performance degradation due to the presence of thermal noise in both inputs of the cross-correlation is analyzed in the paper, and it is shown that can be arbitrarily reduced by appropriate sizing of the up-looking antenna.
In addition, the adoption of the interferometric processing implies the availability of high precision measurements for all the transmitted frequencies and for all the GNSS systems. This characteristic distinguishes the interferometric processing from the conventional GNSS altimetry adopting open access codes.
Indeed, a conventional PARIS altimeter exploiting open access GPS navigation signals would not be able to correct the ionospheric delay down to centimeter level accuracy. This is simply due to the narrow bandwidth of open access navigation signals at GPS L1 and L2 which limits the achievable range precision at these bands to a few decimeters, far above the centimeter precision requested for mesoscale altimetry. Thus this noisy measurement would severely affect the absolute accuracy when combined with the high precision measurement of the wide band L5 signal, as typically performed to estimated the ionopheric delay.

This paper presents in detail the proposed instrument configuration, the adopted delay and amplitude calibration strategy, the instrument sizing and the corresponding performance. A comparison at system level with a conventional PARIS altimeter is also addressed.
Furthermore an in-orbit demonstration mission carrying a reduced-size PARIS altimeter on a small satellite platform that would prove the expected altimetric accuracy suited for mesoscale ocean science is proposed.

2. REFERENCES

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