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Radar sounding of Jovian icy moons : a simulation approach to active and passive sounding scenarios

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Abstract

We present an approach aimed at comprehensively simulating passive and active radar acquisitions from orbit in the noisy radio environment of the Jovian system. By comparing how a given representative target area on the icy moons appears in both cases, we expect to be able to extract valuable informations with regard both to the feasibility and value of passive sounding. Examples of simulations of Europa-like terrains are shown and discussed.

1. Introduction

Europa, Ganymede and Callisto, the three Jovian icy moons, are targets of two upcoming planetary science missions, both having a radar sounder included in their payload: ESA's Jupiter Icy Moons explorer (JUICE), carrying the RIME instrument, and NASA's Europa Clipper, carrying the REASON instrument. RIME operates at a central frequency of 9 MHz with a bandwidth of 1 or 2.8 MHz, while REASON is a dual-frequency instrument, with a mode at 9 MHz with a bandwidth of 1 MHz and another at 60 MHz a bandwidth of 10 MHz.

The Jovian radio environment in the HF band is very challenging. At frequencies below 40 MHz, it is characterised sporadic cyclotron emissions about five orders of magnitudes more intense than the galactic background [1]. The duration of those emissions can vary from hours to milliseconds. This limits the possibility to have standard active radio acquisitions, which in presence of this noise would have a very low SNR. However, recent research has suggested that those Jovian emissions could be used to perform passive sounding [2]. This may enhance the scientific value of the instrument, enabling data acquisitions in presence of Jovian noise. In [3], passive and active sounding are compared through their respective signal-to-noise (SNR) and signal-to-clutter (SCR).

In [3] the surface roughness is considered through a spreading factor in the SCR equation, but the roughness-induced loss of coherence was neglected. In [4], the influence of the ionosphere on the phase, amplitude, and harmonic content of considered signal was thoroughly examined. However, no comparative study of radar acquisitions in active and passive mode that takes all those effects into account simultaneously has yet been carried out.

In this paper, we propose to generalise to passive sounding scenarios the 3D scattering simulation method presented in [5] for active sounding. For a given target area, the proposed method can thus provide simulated data for (i) active sounding with no noise to provide context, (ii) active sounding with Jovian noise, and (iii) passive sounding. This will allow to compare the simulated radargrams obtained with active and passive sounding and to bring further insight into identifying conditions where passive sounding can provide additional scientific value to active sounding. Preliminary simulations obtained with band-limited white noise confirm that passive sounding is possible, and is able to reveal surface and subsurface echoes otherwise invisible in active sounding in presence of Jupiter radio noise, but at the price of increased clutter.

2. Proposed simulation technique

The simulation method relies on the Stratton-Chu formula and on the linear phase approximation. It is able to compute radar echoes coming from target areas with an arbitrary number of rough geological layers [5]. The simulated data thus contains both the surface and the subsurface response. The noise is modelled as a plane wave, with a constant wavevector that depends on the relative position of Jupiter and the sounder. The noise considered in both passive and active simulations can be generated using a random number generator, or can come from samples of the actual Jovian noise. In either case, the noise amplitude and polarisation at each moon can be derived from [1]. The propagation through ionosphere can be modelled after the formulas presented in [4].

In the case of passive sounding with a long burst, where an acquisition contains both incident and reflected noise signals, range-compression is done through an autocorrelation of the signal. The resulting function contains two symmetric copies the echoes reflected from the target area, along with a central peak corresponding to the incoming wave. In the case of a short burst, a cross-correlation between the recorded incident signal and its non-overlapping reflections is performed, similarly to the active sounding case.

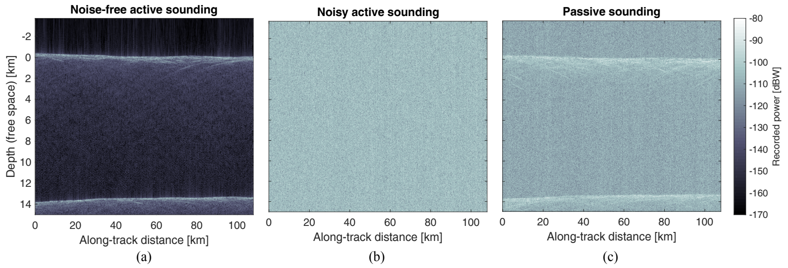

Figure 1: Example of simulations of RIME observing an Europa-like two-layer target area in presence of strong Jovian emissions: (a) active sounding with zero noise, (b) active sounding, (c) passive sounding.

3. Experimental results

Simulations were conducted with RIME as the considered instrument.

The central frequency of the radar was thus set $f = 9$ MHz, its bandwidth $B = 2.8$ MHz, and its sampling frequency at $f_s = 12$ MHz. The platform altitude was set at $h = 400$ km. The Jovian emissions were assumed to come from the anti-nadir direction.

The considered DEM was procedurally-generated and is composed of two layers: the space-ice interface (*i.e.*, the surface), and an interface modelling an hypothetical ice-ocean boundary. The surface was obtained with a fractional Brownian motion (fBm) process characterised by a Hurst's coefficient $H = 0.6$ and an RMS height of 210 m. The second layer ("ice-ocean interface"), also generated with a fBm process using $H = 0.8$, has an RMS height of 80 m, and is placed at a depth of 8 km. The interlayer dielectric properties are set according to the Europan ice and ocean described in [6]: $\epsilon_1 = 2.95$, $\tan\delta_1 = 2 \cdot 10^{-4}$ for the space below the surface and $\epsilon_2 = 80$ for the space below the second layer (*i.e.* the water ocean).

The noise we considered in these simulation is a band-limited white noise with a spectrum ranging from 7 MHz to 11 MHz. The noise amplitude was calculated from the Europan flux density of 10^{-14} $\mathrm{Wm^{-2}Hz^{-1}}$[1]. No ionosphere was modelled in this preliminary test.

Results are shown in fig. 1. Comparing the noise-free (1-a) and noisy active sounding results (1-b) , we observe that the echoes are completely overshadowed by the noise. When the same scene is observed with passive sounding (fig. 1-c), echoes from the surface and subsurface become apparent. However, this comes at a price of enhanced clutter echoes compared to noise-free active sounding. The surface we used in the example was relatively smooth, thus we expect clutter to overtake the subsurface echo when the surface is too rough. These observations obtained with the proposed simulator resemble those of [3].

4. Conclusion

The Jovian icy moons are the targets of two major planetary science missions carrying radar sounder instruments. However the active radio environment of Jupiter makes radar sounding a challenging objective. Preliminary results obtained with a purpose-made multilayer coherent simulator using band-limited white noise over a procedurally-generated DEM indicate that, in low-clutter environments, passive sounding is able to detect deep subsurface layers in situations where active sounding echoes are overtaken by Jupiter's noise.

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