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BELA receiver performance modeling over the BepiColombo mission lifetime

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ABSTRACT

Performance modeling of the BepiColombo laser altimeter (BELA) receiver has been performed in the context of return pulse detection probability and measurement accuracies. Models have been extended beyond earlier work [Gunderson, K., Thomas, N., Rohner, M., 2006. A laser altimeter performance model and its application to BELA. IEEE Transactions on Geoscience and Remote Sensing 44, 3308–3319] to explore the receiver response to time-varying orbital conditions and potential instrument component degradations over the mission lifetime. New signal processing derivations are presented, and the set of measurement accuracy predictions has been broadened to include albedo and return pulse width in addition to range accuracy. Two detector gain optimization derivations are also described and applied as guides towards the identification of a preferred performance enhancing strategy.

1. Introduction

The BepiColombo Laser Altimeter (BELA) is a laser ranging experiment to be flown aboard the Mercury Planetary Orbiter (MPO) element of the BepiColombo mission. BELA's primary objective is to support the derivation of global topographical maps of the hermean surface. BELA accomplishes this by providing measurements of round trip travel times of short laser pulses between the spacecraft (S/C) and the planetary surface. Those travel times translate readily into distance measurements. When combined with knowledge of the S/C position and laser transmitter optical axis vectors with respect to the planetary center of gravity (CG), the range measurements enable the derivation of a vector from the CG to the laser illumination footprint. Characterizations of the laser return pulse strengths and shapes will support secondary objectives of photometric measurements of the surface at the laser wavelength and surface roughness measurements within the laser footprint.

BELA is a classical laser altimeter experiment following the approach taken by the Mars Orbiter Laser Altimeter (MOLA) team (Zuber et al., 1992). An Nd:YAG laser is used to produce a 50 mJ pulse at 1064 nm with a width of 5–8 ns in duration. The light passes through a beam expander to produce a 60 μrad footprint on the surface of the planet. The light reflected from the surface is collected by a receiver composed of a 20 cm diameter beryllium reflecting telescope and a back-end reimaging optic which focuses the return pulse onto an infrared-enhanced silicon avalanche photodiode (APD). The signal from the APD is digitized at 80 MHz sampling frequency and passed to a rangefinder module which detects the return pulse digitally in a field programmable gate array. The entire system is controlled by an electronics unit which houses the power supply and the onboard computer. Fig. 1 shows a current (post-preliminary design review) CAD/CAM model of the instrument.

The scientific goals and a more detailed description of the experiment architecture of BELA are described in Thomas et al. (2007). The signal processing model that was used to evaluate the ability of the selected architecture to meet the scientific goals is described in Gunderson et al. (2006). These works will be referred to as Paper I and Paper II, respectively, throughout the remainder of this text.

An important conclusion of Paper II was that the most critical figure of merit that should be used to discriminate between potential instrument configurations is the return pulse detection probability (or PFD, the probability of false detections) rather than the range accuracy: as long as random noise fluctuations in the receiver chain do not obscure the true laser return pulse signal, range measurement accuracy requirements can be met. However, Paper II evaluated only a single set of instrument parameter values at one hermean orbital position when in fact the BELA receiver's ability to properly extract true laser return pulse signals is sensitive to a variety of parameters that are expected to vary considerably over the BepiColombo mission lifetime. These include, for example, instrument component degradations, solar background contamination levels, and S/C orbital drift. To examine the impact that these variations are expected to exert upon the instrument performance, time evolution has been incorporated into the models described in Paper II. Accuracy predictions for albedo and pulse width measurements also have been derived to support feasibility studies of secondary scientific investigations.

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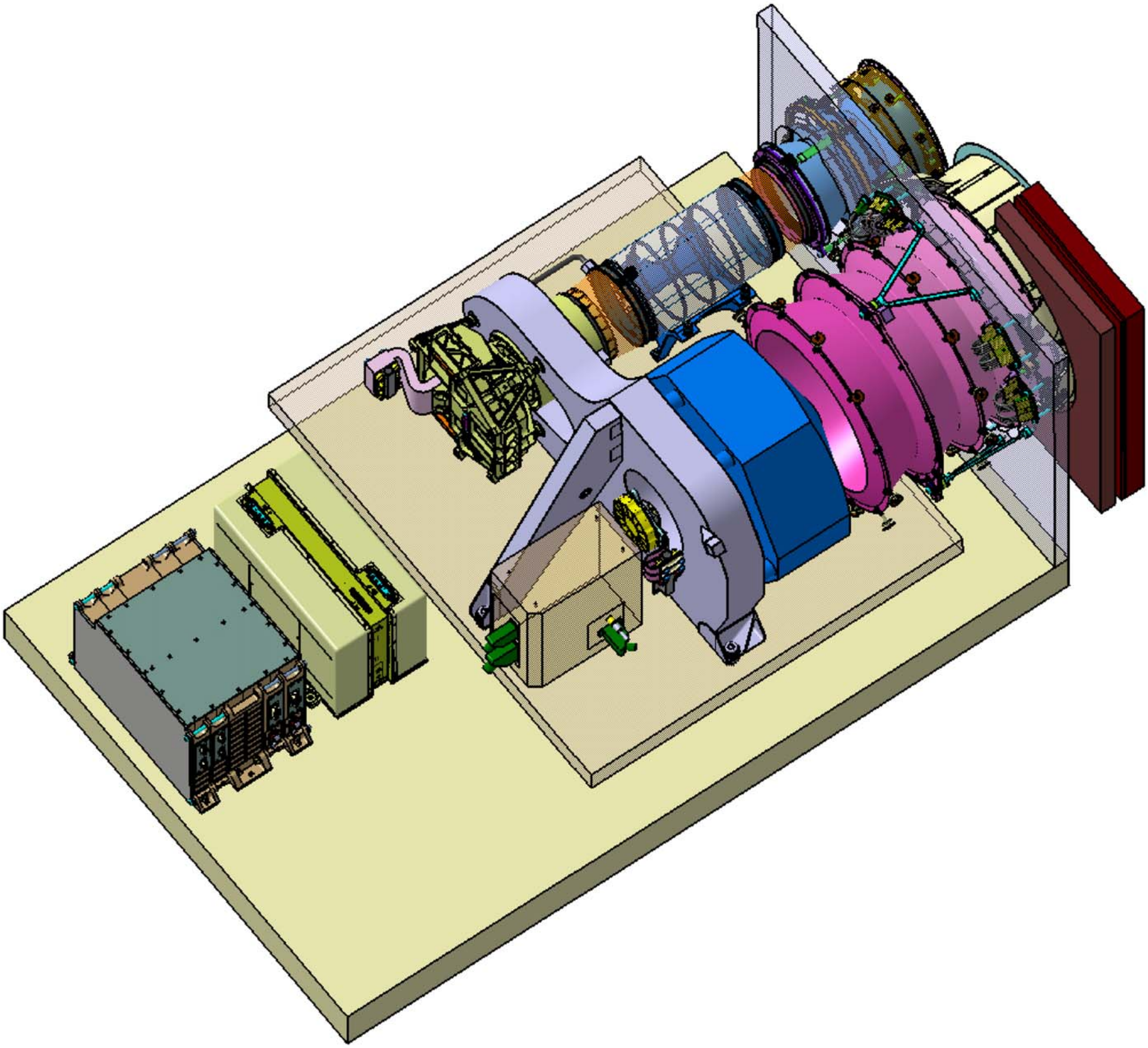

Fig. 1. CAD/CAM model of the BELA instrument. The transmitter can be seen in the upper half of the drawing, and the receiver is at the bottom.

Additional attention has been given to optimizations of the APD's gain value. Although an APD can help weak signals to overcome background noise via charge multiplication in the silicon substrate, amplification uncertainties associated with excessive gain values can degrade system behavior. Two strategies are explored to balance this tradeoff: one analytically maximizes signal to noise ratios (SNRs), and the other numerically minimizes PFD.

2. Lifetime variability

The time-varying parameters can be categorized as either component degradations within the BELA instrument or the evolution of orbital configurations. Both are presumed to vary linearly over time from beginning-of-life (BOL), defined as the time of S/C injection into orbit around Mercury, to end-of-life (EOL), which is reached one Earth year later. Selection of BOL and EOL values might seem a bit arbitrary considering that the mission operational lifetime is one Earth year after a multi-year cruise phase from Earth to Mercury, and the presumption of a smooth, linear component degradation is not necessarily physical, but the forthcoming analysis under those presumptions still provides insights into performance sensitivities and risks.

2.1. Orbital geometry

The S/C orbit around Mercury is presumed to be perfectly polar and elliptical with minimum and maximum altitudes of 400 and 1500 km, respectively. The argument of periherm, ω, is defined as the latitude over which the S/C reaches its minimum altitude. Ideally, ω would be 0°, as was presumed in the test cases in Paper II. However, a non-zero J_2 perturbation of Mercury's surface figure (equatorial bulge) will cause ω to drift southward from ω_{BOL} to ω_{EOL}. This drift is illustrated in Fig. 2. Because the true value of J_2 is uncertain, the amount of drift in ω is also uncertain, but is likely to be less than 40° over one Earth year for realistic values of J_2. To