Icarus 270 (2016) 248–259

Contents lists available at ScienceDirect

Icarus

journal homepage: www.journals.elsevier.com/icarus

Observations of the surface of Titan by the Radar Altimeters on the Huygens Probe

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ARTICLE INFO

Article history:
Received 14 December 2014
Revised 21 October 2015
Accepted 1 November 2015
Available online 1 December 2015

Keywords:
Titan
Instrumentation
Radar observations

ABSTRACT

Results from the radar altimeters on board the Huygens probe are reported, noting the content of data archived on the NASA Planetary Data System and its ESA counterpart. These instruments provide unique high-resolution information on the topography and electrical properties of the Titan surface over a ~15 km track across a boundary between a bright highland and the dark dissected alluvial terrain on which the probe landed. The highland appears ~100 m higher than the dark terrain. The dark terrain has a fairly high nadir radar backscatter, consistent with terrestrial lakebeds and alluvial surfaces, and shows small (5–10 m) elevation fluctuations. Possible signatures of surface or volume scattering in the backscatter amplitude and intermediate frequency spectrum are discussed. A previously-undocumented characteristic of the Automatic Gain Control (AGC) on the flight altimeter is noted.

1. Introduction

The Radar Altimeters on the Huygens Probe measured the distance to the surface of Titan during its descent through the atmosphere. Originally foreseen purely as an engineering subsystem for the real time provision of instantaneous altitude data in order to trigger near-surface measurements by the camera and other instruments, it was soon realized that several scientifically useful parameters could be derived from the radar surface return. Indeed, in principle the probe radar altimeter offers some of the highest-spatial-resolution radar data on Titan's surface, owing to its operation at ranges ~20 to ~500 times closer than the Cassini orbiter's instrument. Previous space probes have carried radar altimeters which have also yielded planetary surface information, for example a topography profile indicated during the entry and descent of Viking (Withers et al., 2002) and the lunar radar reflectivity estimated from the altimeter on Surveyor 1 (Parkes, 1966; Brown, 1967). Such measurements are of particular interest on worlds with thick atmospheres where the surface is obscured from remote optical observation – e.g. the radar altimeter on Venera 8 was used to estimate a terrain profile and ground reflectivity (Bashmashnikov et al., 1976).

Three principal datasets were recorded by the Huygens altimeter. First is the instantaneous altitude determined in the instrument itself used for on-board sequencing. Second, an internal parameter, the voltage of the Automatic Gain Control (AGC) was recorded: this is in effect a measure of echo signal strength and thus, indirectly, of the reflectivity of the Titan surface beneath the probe. These two quantities were recorded as housekeeping telemetry by the Huygens probe Command and Data Management Unit (CDMU) system. Third, the radar Intermediate Frequency (IF) signal within the altimeter was sampled by the Huygens Atmospheric Structure Instrument's Permittivity and Wave Analyzer (HASI/PWA) where both hardware processing and digital signal processing has been performed. This processing (e.g. Fig. 9 of Grard et al., 2006) allows the measured altitude to be calculated to a higher precision, post flight, than possible by the radar unit itself via its real time interface to the probe and allows recovery of other information.

Although a brief review of the altimeter operation was described a 'lessons learned' paper (Trautner et al., 2006) and in the industrial flight operation report (Couzin, 2006) and some cursory plots of the radar altimeter data have been presented with minimal commentary in a few papers (e.g. Fig. 8 of Fulchignoni et al., 2005; Fig. 8

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http://dx.doi.org/10.1016/j.icarus.2015.11.007
0019-1035/

of Grard et al., 2006), a systematic close study of the data have not been published until now, in part because certain nonideal aspects of the altimeter demanded on-ground calibration measurements, and in part because observations of Titan's surface by the Cassini orbiter in 2005/2006 were too sparse to properly interpret the Huygens altimeter results in context. This paper examines the altimeter data with the benefit of a decade of Cassini observations, and documents the data in the archive: we refer to the NASA Planetary Data System (PDS) records, but note that the data are mirrored on the ESA Planetary Science Archive (PSA).

2. Huygens radar altimeter operation

The Radar Altimeter system consists of two separate and independent units (Radar Altimeter Units A and B – also referred to in some documentation as 'Proximity Sensor' A and B), described in some detail in Hughes (1994). The probe command and data handling systems, including the altimeters, were fully redundant. Each system uses independent 15 cm by 15 cm slotted wave-guide antennas, one to receive and one to transmit – using separate antennas (Fig. 1) for transmit and receive functions simplifies the electronics design. The operating frequencies are 15.4 GHz and 15.8 GHz, which correspond to wavelengths of about 2 cm – close to that of the 13.6 GHz Ku band multimode RADAR instrument on the Cassini orbiter (Elachi et al., 2005). The two altimeters operate with linearly polarized signals, and are mounted such that the signals are nearly orthogonal in polarization (Fig. 2). The antennas are planar slot radiator arrays providing an antenna gain of 25 dB with a symmetrical full beam width of 7.9° (e.g. Clausen et al., 2002).

Like many compact airborne radar altimeters, they operate with a Frequency Modulated Continuous Wave (FMCW) method, implemented with a servo mode, i.e. the ramp rate is continuously adjusted to keep the signal in the center of the 200 kHz first Intermediate Frequency (IF) band. The RF bandwidth, corresponding to the sweep range, is 30 MHz. The IF bandwidth is 15 kHz and the RF output power is 100 mW. During the search for the surface signal, the ramp rate is continuously adjusted up and down, by a dedicated search control, until a signal is detected in the IF band by a Phase Locked Loop (PLL). After detection, the radar locks the PLL output to the ramp rate and the surface will be tracked by the system. The ramp rate signal (which has a triangular shape, sweeping up and down) is directly proportional to the altitude and the system is adjusted such that the period of this signal corresponds to 1 ms per 1 km altitude. The period of this ramp rate is determined inside the radar unit and the digital number is provided to the probe CDMU. To account for the very high dynamic range of the received signal an Automatic Gain Control (AGC) is included. The voltage of this control signal is also provided to the CDMU and included in the system housekeeping data. Analysis of this voltage gives information on the strength of the backscattered signal. Both pairs of antennas are identical, apart from the small tuning to match the different operating frequencies. The Full Width Half Power (FWHP) beam width is about 8°, so from an altitude of 40 km, a footprint of diameter 5.5 km is illuminated and range gate length (i.e. the equivalent pulse length) is 3 km. Thus, the system is generally 'beam limited', i.e. the beam diameter rather than the pulse length determines the actual foot print diameter.

At 40 km, the Fresnel zone diameter is only 39.5 m, and it always remains much less than the footprint diameter. Considering this together with the wavelength of 2 cm, it was expected that the surface return from the different regions within the footprint would sum up incoherently for most surfaces (although in fact the Fresnel zone dominates the return on Titan's exceptionally flat lakes – Wye et al., 2009; Zebker et al., 2014). Footprint diameter and range gate length decrease linearly with altitude while the Fresnel zone diameter decreases as the square root of the altitude.

The performance of the instrument under field conditions and the terrain information recoverable from it has been investigated in a number of tests of opportunity. These have included helicopter flight tests (Tucson, USA, 1997 and 1998) as well as several stratospheric balloon flights with parachute recovery (Leon, Spain 1997; Trapani, Sicily 2003; Teresina, Brazil, 2004). The Trapani flight was also used by several other Huygens sensors (Fulchignoni et al., 2004).

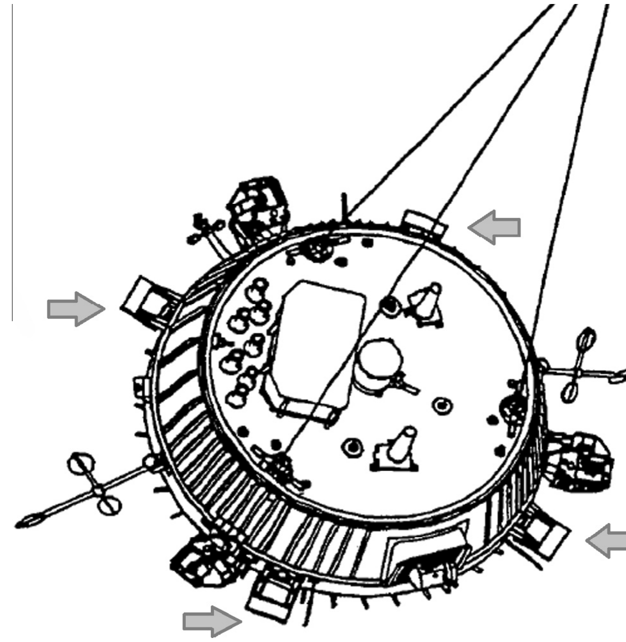

Fig. 2. Huygens probe in descent configuration. The four planar radar altimeter antennas can be seen (arrowed) around the periphery (one transmit and one receive antenna, for each radar unit A and B).

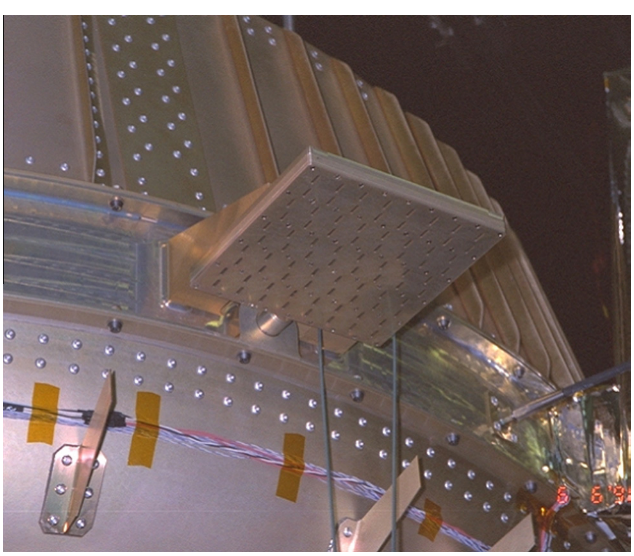

Fig. 1. Slotted wave-guide antenna mounted at the equator of the Huygens probe, seen from slightly below. Vanes intended to cause a slow spin of the probe during descent are at bottom left; taped cabling is also visible.

3. Flight data

Although the original requirement for altitude triggering was only for detection of the 10 km altitude mark, the altimeters were