# The Cassini Radar Investigation

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## Abstract

The Cassini/Huygens Mission is a nineteen-year multinational project to design, construct and execute an investigation of the Saturn system, with emphasis on its largest moon, Titan. Titan's atmosphere is nearly opaque at optical wavelengths, so a Ku-band radar imaging system was required to map its surface. In this paper we describe the radar instrument, discuss some of the challenges to its design, and review its operating modes. We briefly summarize the surprises that the radar instrument has revealed while investigating Titan.

## 1 The Cassini Mission

### 1.1 Introduction

The Cassini–Huygens mission to Saturn and Titan is designed to carry out in-depth exploration of the Saturn system. Cassini–Huygens' conception and design began in 1988, and its interplanetary journey launched in 1997 and entered Saturn orbit in 2004. After releasing the Huygens probe into Titan's atmosphere, the Cassini Orbiter began its remote observations. A payload of twelve science investigations continue to make in-situ measurements or observe the many targets of interest. The various instruments are listed in **Table 1**.

Cassini's nominal mission ended in 2008, but an extended mission of 2 years duration has been approved and will start immediately afterward.

**Table 1.** Cassini Orbiter Investigation Complement

| |
|---|
| Plasma Spectrometer |
| Cosmic Dust Analyzer |
| Magnetometer |
| Ion and Neutral Mass Spectrometer |
| Magnetospheric Imaging Instrument |
| Radio and Plasma Wave Science |
| Radar (RADAR) |
| Composite Infrared Spectrometer |
| Imaging Science Subsystem (ISS) |
| Radio Science Instrument (RSS) |
| Ultraviolet Imaging Spectrograph |
| Visible and Infrared Mapping Spectrometer (VIMS) |

### 1.2 Mission Description

Designed to explore the Saturn system and all its elements, the Orbiter made 44 close flybys of Titan during its nominal mission, at distances as close as 1200 km from the surface. Most of the investigations listed in Table 1 have interests in Titan or in its immediate proximity, so observation time is shared among them. Because the spacecraft's main (or "high-gain") antenna is used both to communicate with Earth and for RSS and RADAR observations, the resulting data are stored onboard in two solid-state recorders for later downlink. Since observations of other targets begin immediately after the downlink, total data volume for each Titan pass is also a restriction, limited either by the recorder capacity or the downlink data volume.

### 1.2 Science Objectives

The overriding objectives of the radar investigation [1] are determination of the physical state, topography, and composition of the Titan surface; and the measurement of global temperatures and general circulation on Titan. Radar data are also used to contribute to discovery of the internal structure of Titan (through measurement of its spin axis and rate), and to help constrain scenarios of formation and evolution of Titan and its atmosphere. As possible, radar also observes the icy satellites, Saturn's rings, and Saturn itself, consistent with the priorities of other instruments.

Radar data and its interpretations will eventually assist in the understanding of the entire Saturn system, for example through the determination of Titan's tidal interactions. Correlative studies by radar and other instruments are also of high value: for example, the VIMS spectral data, when superposed onto the higher-resolution synthetic-aperture radar (SAR) data has already aided in determination of global surface units.

Another objective of the experiment is to conduct radiometric and scatterometric observation of icy satellites during untargeted flybys at distances of less than about 100,000 km. Operations at closer ranges, when the satellite disk can be covered by a sufficient number of footprints, present an opportunity to identify "hot spots" if there is cryovolcanic activity as is conceivable at least for Enceladus. Microwave flux due to the thermal emission by the rings particles and to scattering by the same particles of the emission from the deep atmosphere of Saturn will be sensed in the radiometer mode. Microwave emission from the ring particles uniquely probes through the mass of the particles—the 2-cm wavelength penetration depth is of the order of 1 m. Thus, the RADAR radiometer presents the best way to measure the ice-to-dust ratio of the particles, as a function of radial distance from Saturn.

# 2 The Cassini Radar Instrument

## 2.1 Design Challenges

Most planetary missions place unusual constraints on engineering design, whether in instrument design or in support subsystems like power or thermal control. For the radar, some of the most pressing constraints were driven by the requirement that a variety of targets must be observed by many, if not most, of the other instruments. The limited number of Titan encounters, for example, led to the need for a wide SAR swath; power, volume and mass constraints forced the 4-m diameter antenna to be shared with the telecommunications and radio science subsystems and thus to support three frequencies (S, Ka and Ku bands; the Saturn tour required a very limited time near Titan for each encounter; restrictions on communications time led to a very limited data volume per Titan pass; and of course, a spacecraft not in orbit around the principal target produced severe complications in both instrument design and operations. The Magellan (Venus) radar had some of the same design difficulties, but it was the lone instrument on a spacecraft in orbit around the target while Cassini includes twelve instruments and passes Titan in a swift, hyperbolic trajectory.

## 2.2 Instrument Timing

The anticipated uncertainties in the spacecraft ephemeris and attitude predictions led to a "burst timing" design for signal transmission and reception. In this timing approach, as shown in the lower portion of **Figure 1**, the radar transmits a series of pulses for a given time period and is then switched to receive the return echo burst. After reception, the radar switches to the radiometer mode to collect the surface reflections. With such an approach, the uncertainty in timing due to ephemeris and pointing errors is accommodated by adjusting the burst period and data window rather than the pulse-to-pulse timing as in the case of the conventional interleaved-pulse approach. The chosen approach is expected to be more effective in utilizing the allocated data rate and volume, as well as in lowering the probability of data loss. The upper portion of Figure 1 illustrates the sequence of bursts as each antenna beam is used. For each beam the bursts overlap to give the multiple looks necessary for SAR in order that the speckle noise be reduced. A flyby with a closest approach altitude is used as an example in the following discussion but during actual operations the predicted profile will be used to set all the RADAR parameters for each pass.

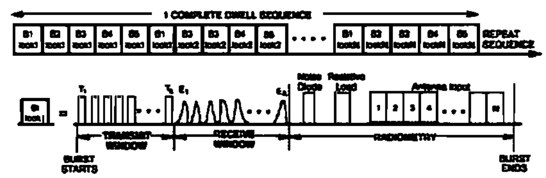


**Figure 1.** Non-interleaved multi-beam pulse burst timing

## 2.3 Operating Modes

### 2.3.1 SAR Imaging

During SAR imaging, the spacecraft rolls to either the left- or right-side of the suborbital track according to the pre-determined sequence, and five antenna beams are utilized, one at a time, to obtain the maximum possible cross-track swath. The azimuth image resolution is accomplished by unfocussed SAR processing of the echo burst The azimuth resolution is between 350 and 720 m throughout the imaging period of each flyby.

### 2.3.2 Altimeter

The altimeter mode is used to generate relative elevation profiles along the Cassini spacecraft nadir track. Operating at spacecraft altitudes between 4,000 km and 15,000 km, this mode utilizes the central antenna beam (Beam 3) for transmission and reception of chirp pulse signals at a system bandwidth of 4.25 MHz. The altimetric measurements along the ground track have horizontal resolution (pulse-limited radar footprints) ranging between 24 and 27 km and vertical resolution of about 50 m.

### 2.3.3 Scatterometer

The functional concept of the scatterometer mode is similar to that of the altimeter except for one major difference—the scatterometer bandwidth is but 106 kHz, to give sufficient signal-to-noise ratio at long ranges. The scatterometer mode operates at altitudes between 9,000 km and 25,000 km, as the spacecraft executes specified scanning maneuvers. Both backscatter and noise-only measurements are collected so that the surface backscatter coefficient can be estimated. Depending on the range distance and angle of incidence, this mode can detect backscatter as low as -35 dB.

### 2.2.4 Radiometer

While operating in the radiometry mode, at a bandwidth of 135 MHz, the instrument measures the 13.8-GHz emissivity of Titan and targets of opportunity. This mode can be used alone or in conjunction with others. During each burst, after the active portion of the cycle is completed, the radiometer first switches to a noise diode as input, and then to a resistive load in the Front End Electronics. Each of these calibration sources are sampled once per burst, and the integration times are set to yield between 2,000 and 3,500 counts in a 12-bit (4095) counter. After the two calibration measurements are made, multiple (up to 255) measurements are made through the antenna port. These multiple 12-bit values are summed to give one 20-bit value per burst. Thus, during each burst three radiometer data-points are recorded. Before and/or after each radiometer only data-taking the antenna is turned to "cold-space" for an absolute calibration of the antenna-input relative to the internal calibration sources.

## 3 Science Results

At this writing, more than 20% of the surface of Titan has been covered by SAR, and nearly 100% by radiometry. Because they have the highest ground spatial resolution of all the instruments, the SAR data are yielding most of the surface feature identifications. In fact, almost every surface modification process known on the Earth has been seen. [2, 3] Aeolian modification is evidenced by equatorial sand dunes that are likely made of either granular water ice or some organic compound (**Figure 2**); evidence for modification by volcanism is present in many of the dark plains at mid-latitudes (**Figure 3**); many ranges of quasi-linear topographic features (hills or mountains) are indicative of some form of tectonic activity; and many examples of river-like channels exist, some many hundreds of kilometers long. Perhaps the most spectacular SAR images are those of more than one hundred lakes, some large enough to be called seas, in the north polar area (**Figure 4**). Some of these lakes are the darkest of any areas imaged, consistent with a low-loss hydrocarbon liquid. Adding to the strength of this hypothesis are lighter features within the dark lakes, mostly at the perimeter. Some of these resemble estuaries or swamps on Earth. A few impact craters have been seen, one as large as 400 km, but the crater density is lower than expected, indicating some method of resurfacing is at work. Space and resolution limit any reasonable representation of the SAR dataset in this abstract, but more will be shown in the presentation.

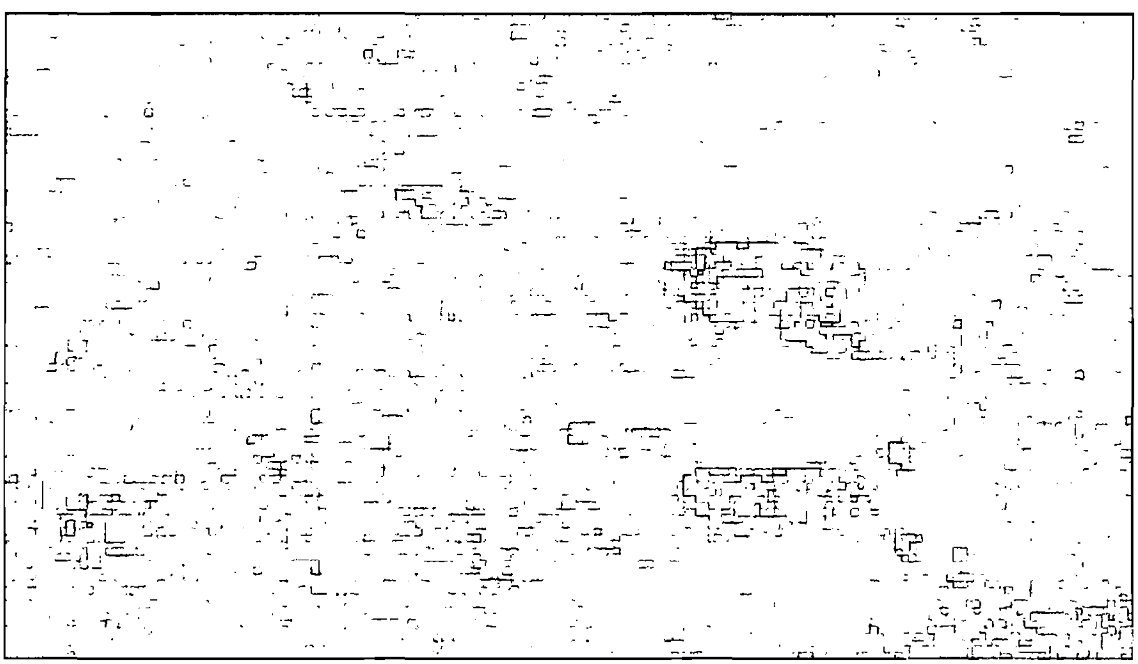

**Figure 2.** These long, dark ridges extend for hundreds of kilometers in Titan's equatorial regions. Indirect measurements indicate that they are a few hundred meters in height and 1–2 km apart (JPL PIA03567).

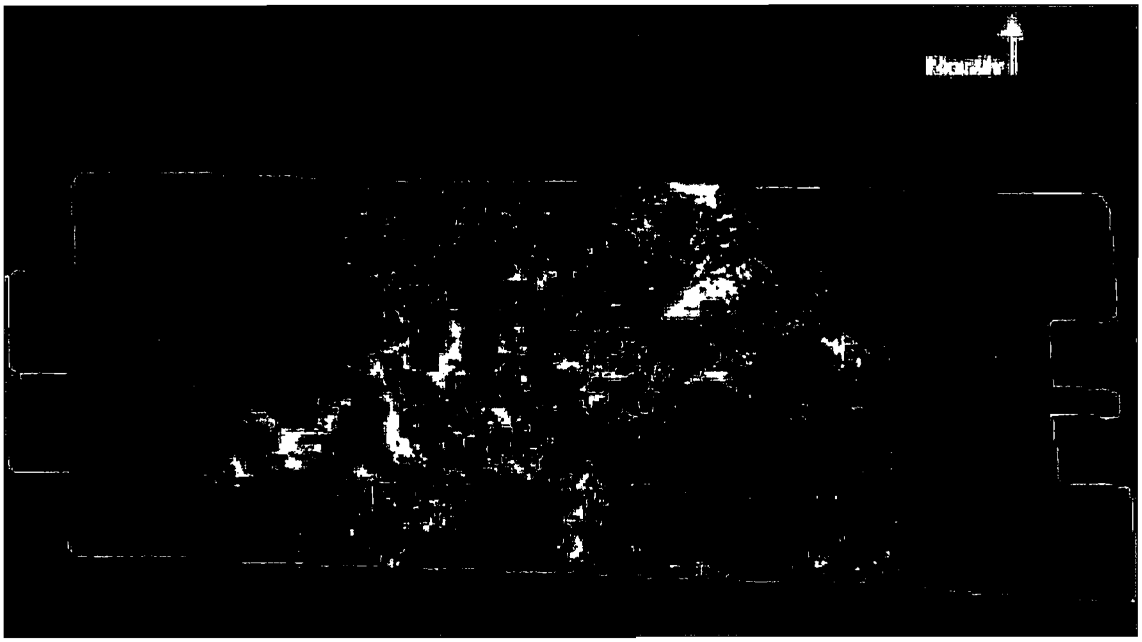

**Figure 3.** The central feature in this figure is interpreted as a volcanic construct, with flows extending to the right. Volcanics, or more properly cryovolcanics, extend over much of the mid-latitudes on Titan (JPL PIA06988).

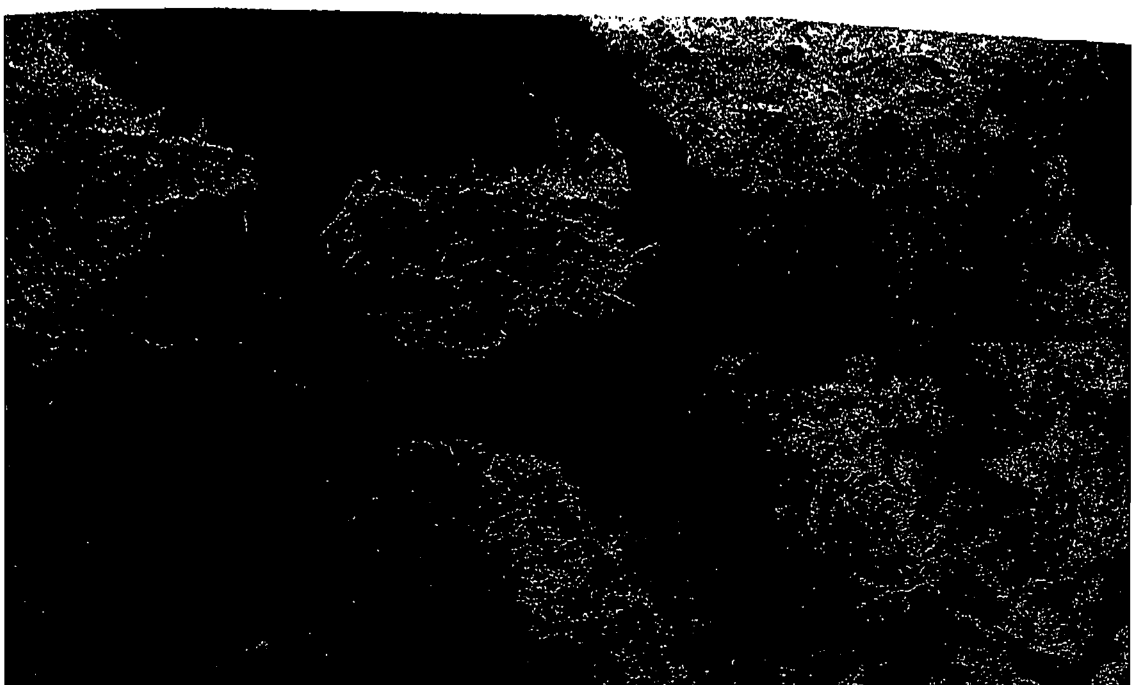

**Figure 4.** One of the many lakes seen in Titan's north polar regions. The liquid in the lakes is likely to be a combination of ethane and methane. Note the lighter areas within the lake, which may represent shallower liquid (JPL PIA09180).

Altimeter data have been supplemented with other techniques for deriving topography, including radar stereogrammetry and a novel technique called SAR-Topo that uses antenna gain pattern matching at the beam boundaries. Results show that at global scale Titan is topographically very flat, although in some area s as much as a few kilometers of relief exist. Radiometry has revealed local variations of a few K and a similar equator-to-pole variation of similar magnitude. Scatterometry data analysis is proceeding, and will eventually provide information on surface electrical properties.

An important indirect result from the SAR data is produced by attempting to overlay repeat coverage taken several months apart. The precision of the pixel placement on the surface is such that apparent misregistrations of features in repeat coverage can be taken as an indication of errors in the assumed spin axis spin rate, and higher time derivatives of these values. These in turn can be used to validate or rule out various models of Titan's interior. Early indications at this writing indicate that Titan may well have an interior (subsurface) ammonia-water ocean that effectively decouples its core from its outer shell.

This work was performed by the Jet Propulsion Laboratory, under a contract with NASA. The Cassini/ Huygens Project is a joint effort of NASA, the European Space Agency, and the Italian Space Agency.

## References

[1] Elachi, C., et al.: RADAR: *The Cassini Titan Radar Mapper*, Space Sci. Rev. 117, pp. 71 - 110 2005

[2] Elachi, C., et al., Cassini radar views the surface of Titan, Science 308, pp. 970 - 974, 2005

[3] Titan Radar Mapper observations from Cassini's T3 fly-by, Nature 441, pp. 709 - 713, 2006