RADAR Titan Flyby during S19/T12

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March 7, 2006

- Sequence: s19
- Rev: 022
- Observation Id: t12
- Target Body: Titan
- Data Take Number: 78
- PDT Config File: S19_ssup_ssg_060109_pdt.cfg
- SMT File: s19_2006_01_03.rpt
- PEF File: z0190c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the sixth Titan flyby on which RADAR data will be acquired. This data collection occurs during the s19 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidlines for preparing the RADAR IEB.

Like T4, this RADAR data collection includes only radiometry and scatterometry. RADAR will not operate at the closest approach time, therefore no altimeter or SAR data can be collected. The radiometry scans will include compressed scatterometry for the second time. Before the two outbound radiometry/compressed scatterometry scans, there will be a small scatterometry segment that follows an iso-doppler SAR-style profile with a constant incidence angle of 20 degrees. This segment will provide data that can be processed into higher-resolution scatterometry coverage. All of these scans are executed on momentum wheel control.

2 CIMS and Division Summary

Each RADAR observation is represented to the project by a set of requests in the Cassini Information Management System (CIMS). The CIMS database contains requests for pointing control, time, and data volume. The CIMS requests show a high-level view of the sequence design. Table 1 shows the CIMS request summary for this observation. Although the CIMS requests show Low-SAR intervals, in reality the radar will be operated in Hi-SAR mode throughout this flyby.

The CIMS requests form the basis of a pointing design built using the project pointing design tool (PDT). The details of the pointing design are shown by the PDT plots on the corresponding tour sequence web page. (See https://cassini.jpl.nasa.gov/radar.) The RADAR pointing sequence is ultimately combined with pointing sequences from other instruments to make a large merged c-kernel. C-kernels are files containing spacecraft attitude data.

CIMS ID	Start	End	Duration	Comments
022OT_WARM4TI12001_RIDER	2006-077T22:50:57	2006-078T01:24:57	02:34:0.0	Warmup for RADAR observation of Titan.
022TI_T12OUTRAD001_PRIME	2006-078T01:24:57	2006-078T05:35:57	04:11:0.0	Radiometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations.

Table 1: t12 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-1:15:0.0	02:39:0.0	2.4	Warmup
b	scatterometer_compressed	01:24:0.0	00:11:0.0	4.6	Slewing on target, 5-beams
c	standard_scatterometer_outbound	01:35:0.0	00:15:0.0	46.8	Hi-Res Scat, 8-2
d	scatterometer_compressed	01:50:0.0	00:15:30.0	139.5	Hi-Res Scat, 8-8
e	standard_scatterometer_outbound	02:05:30.0	01:42:30.0	19.1	Outbound Compressed Scat/Rad scan
f	scatterometer_compressed	03:48:0.0	00:12:0.0	0.0	Outbound Inbetween Scat/Rad scans
g		04:00:0.0	01:30:0.0	34.0	Outbound Compressed Scat/Rad scan
Total				246.4	

Table 2: Division summary. Data volumes (Mbits) are estimated from maximum data rate and division duration.

Div	Alt (km)	Slant range (km)	B3 Size (target dia)	B3 Dop. Spread (Hz)
a	22921	off target	0.03	off target
b	25861	off target	0.04	off target
c	29464	29531	0.04	419
d	34387	34532	0.05	381
e	39482	39662	0.05	354
f	73263	73645	0.10	302
g	77226	off target	0.10	off target

Table 3: Division geometry summary. Values are computed at the start of each division. B3 Doppler spread is for two-way 3-dB pattern. B3 size is the one-way 3-dB beamwidth

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-480.0	-75.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	84.0	yes	
time_step (s)	2700.0	2700.0	no	Used by radiometer only modes - saves commands
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	6 - Radiometer Only Mode
noise_bit_setting	don't care	4.0	no	
dutycycle	don't care	0.38	no	
prf (Hz)	don't care	1000	no	
tro	don't care	0	no	
number_of_pulses	don't care	8	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	0.250	0.248	yes	Kbps - actual data rate may be less
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: t12 div_a Warmup block

A RADAR tool called RADAR Mapping and Sequencing Software (RMSS) reads the merged c-kernel along with other navigation data files, and uses these data to produce a set of instructions for the RADAR observation. The RADAR instructions are called an Instrument Execution Block (IEB). The IEB is produced by running RMSS with a radar config file that controls the process of generating IEB instructions for different segments of time. These segments of time are called divisions with a particular behavior defined by a set of division keywords in the config file. Table 2 shows a summary of the divisions used in this observation. Table 3 shows a summary of some key geometry values for each division. Subsequent sections will show and discuss the keyword selections made for each division. Each division table shows a set of nominal parameters that are determined by the operating mode (eg., distant scatterometry, SAR low-res inbound). The actual division parameters from the config file are also shown, and any meaningful mismatches are flagged.

3 Warmup and Overview

The radar warmup rider begins at 2006-03-18T22:50:57.000 (-01:14:58.8). During the warmup, the IEB will be set for slow speed radiometer only data as shown in table 4. Division B cycles all 5 beams as the spacecraft slews onto Titan to collect information about spill-over sidelobes. The instrument operates in compressed scatterometer mode during this time to collect off-target receive only data in the scatterometer bandpass and in radiometer mode. These data provide a calibration reference point. The compressed mode keeps the data volume down while still collecting a large amount of integration time.

Name	Nominal	Actual	Mismatch	Comments
mode	scat_compressed	scatterometer	yes	
start_time (min)	varies	84.0	no	
end_time (min)	varies	95.0	no	
time_step (s)	don't care	5400.0	no	Set by valid time calculation
bem	00100	11111	yes	
baq	3	3	no	3 - PRI summation
csr	1	1	no	1 - receive only antenna measurement
noise_bit_setting	4.0	4.0	no	9 dB setting used by all low SNR scatterometry
dutycycle	0.70	0.70	no	
prf (Hz)	1200	1202	yes	
tro	don't care	6	no	automatically set to 6
number_of_pulses	150	150	no	Set with the PRF to fill the science data buffer - Only 2 PRI's worth of data are downlinked.
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	0.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	8.000	4.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: t12 div_b scatterometer_compressed block

Name	Nominal	c	d	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	95.0	110.0	no	
end_time (min)	varies	110.0	125.5	no	
time_step (s)	don't care	4.0	4.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	5	0	5	yes	5 - 8 bits straight
csr	8	0	0	yes	8 - auto gain
noise_bit_setting	4.0	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.70	0.70	yes	
prf (Hz)	1200	1000	1000	yes	
tro	6	6	6	no	
number_of_pulses	8	70	70	yes	
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	30.000	52.000	150.000	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 6: t12 div_cd standard_scatterometer_outbound block

4 Div's C,D: High Resolution Scatterometry

Divisions C and D (see table 6) shows the parameters for a scatterometry segment to be collected before the outbound compressed scatterometry and radiometry scans begin. In this segment, the radar will acquire data just as it does for SAR imaging, but in a lower bandwidth mode. The pointing profile is a DLAP profile similar to those used for SAR, but targetted from a much higher range. Scatterometer mode is used becuase the the high range (see Fig. 2) requires a smaller bandwidth to boost SNR. Using beam 3 only also boosts SNR and increases the number of looks.

4.1 PRF and Incidence Angle Profiles

RMSS does not support all of the SAR options in scatterometer mode, so this high-res scatterometer profile uses a constant incidence angle (see Fig. 1) and PRF. The PRF value is set to 1 KHz to adequately space the range and doppler ambiguities. Doppler ambiguities occur at intervals equal to the PRF, so the PRF needs to be set higher than the doppler spread within the beam footprint. The doppler spread during divisions C and D varies from about 420 Hz down to about 350 Hz as range varies from 30000 km to 40000 km. At the same time the PRF needs to be low enough to keep the range ambiguities outside of the beam footprint. Assuming a locally flat surface, range ambiguities have an angular spacing of,

$$\alpha = \frac{c}{2Rf_p \tan\theta_i}, \tag{1}$$

where α is the angular spread from the spacecraft position, c is the speed of light, θ_i is the incidence angle, R is the range to the surface, and f_p is the PRF. If we set the angular spread equal to the beamwidth θ_{bw}, then f_p should lie between the two limits,

$$f_p(max) = \frac{c}{2R_{\text{max}}\theta_{\text{bw}} \tan\theta_i} = 1717Hz, \tag{2}$$

and

$$f_p(min) = \text{max doppler spread} = 420Hz, \tag{3}$$

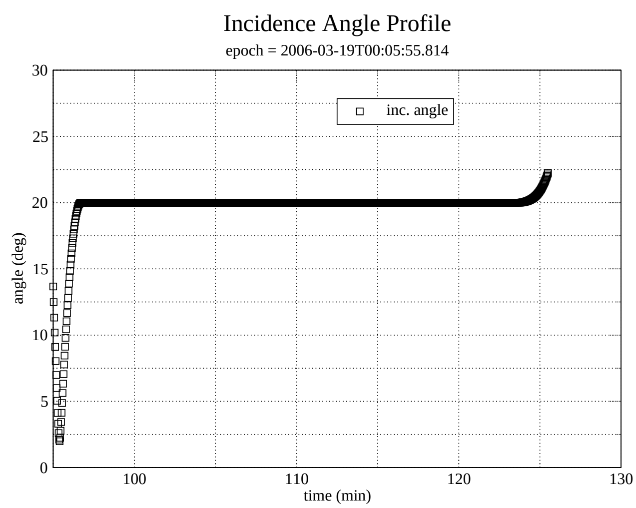

Figure 1: B3 boresight incidence angle during the time of div's C,D.

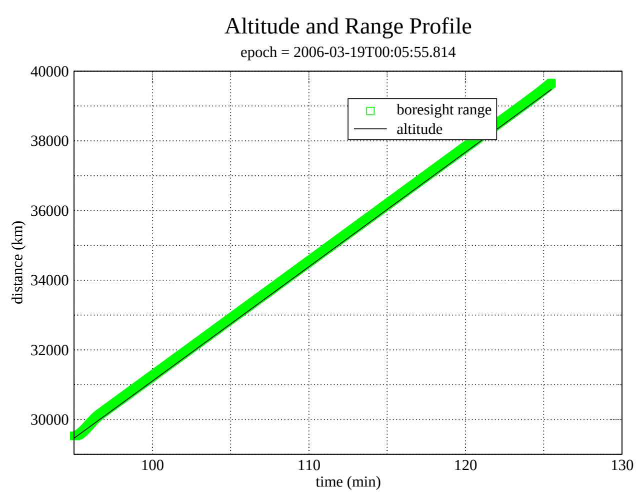

Figure 2: Altitude and range to the B3 boresight point during div's C,D

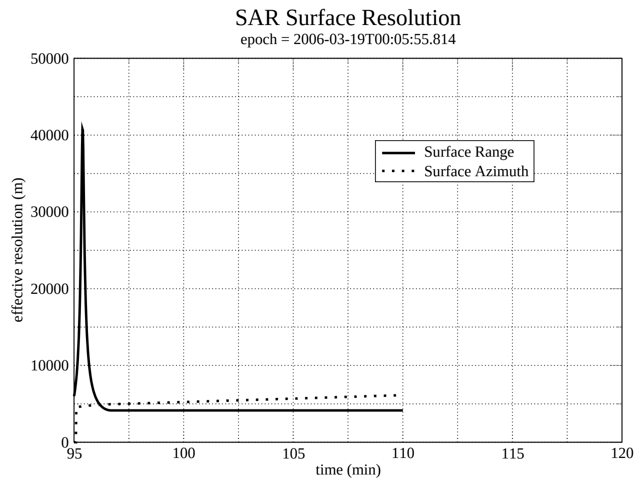

Figure 3: Div C: Projected range and azimuth resolution. These values are computed from the IEB parameters.

where R_{max} is 40000 km, θ_{bw} is 6 mrad for beam 3, and θ_i is designed to be 20 degrees. For divisions C and D, the PRF is set in the middle at 1000 Hz to balance the spacing of the range and azimuth ambiguities.

4.2 SAR-style Scatterometer Resolution Performance

Since SAR processing will be applied to this segment, the effective resolution can be calculated from the same equations,

$$\delta R_g = \frac{c}{2B_r \sin\theta_i}, \tag{4}$$

$$\delta x = \frac{\lambda R}{2\tau_{rw} v \sin\theta_v}, \tag{5}$$

where δR_g is the projected range resolution on the surface, c is the speed of light, B_r is the transmitted chirp bandwidth, θ_i is the incidence angle, δx is the azimuth resolution on the surface, λ is the transmitted wavelength, R is the slant range, τ_{rw} is the length of the receive window, v is the magnitude of the spacecraft velocity relative to the target body, and θ_v is the angle between the velocity vector and the look direction. Figure 4 shows the results from these equations for divisions C and D. The calculations are performed for the boresight of beam 3 which is the center of the swath.

Projected range varies with incidence angle. Since the incidence angle is held constant, the range resolution stays constant even though the beam footprint gets larger as range increases. Azimuth resolution is a function of the synthetic aperture size which is determined by the length of the receive window in each burst. At the high range of this observation, the energy storage system (ESS) limits the number of transmitted pulses to 70 for a PRF of 1 KHz. This limits the size of the sythetic aperture to a fixed size. As the spacecraft moves away from Titan, the squint angle increases and the doppler spread within the beam decreases. This leads to deteriorating azimuth resolution since the fixed doppler resolution is applied to less and less doppler spread.

4.3 SNR and Looks

The most problematic factor for this segment is the low SNR expected because of the high range. The noise equivalent σ_0 for beam 3 is about -25 dB at the end of a nominal SAR swath (4000 km range). In this division the range is 7.5 - 10 times larger which would mean 35 - 40 dB of SNR reduction if the same resolution were maintained. However, the resolution will be reduced from about 1 km in range and azimuth at the end of a nominal SAR swath to about 5 km in range and azimuth. This brings back 14 dB of SNR because the pixels have 25 times more area. Using the scatterometer mode instead of the Low-Res SAR mode reduces the noise bandwidth by a factor of 4 which adds another 6 dB. Adding these changes results in a noise equivalent σ_0 of -10 dB to -5 dB during this division. This is a little bit worse than the nominal performance of the outer beams at the end of a SAR swath where the noise equivalent

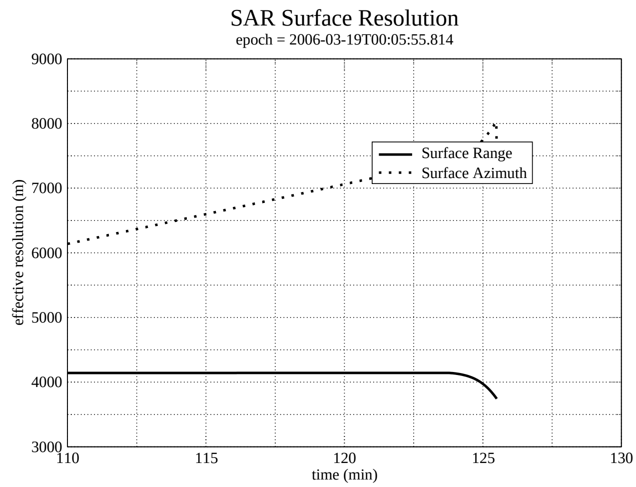

Figure 4: Div D: Projected range and azimuth resolution. These values are computed from the IEB parameters.

σ_0 is about -11 dB at 4000 km range. However, the deficit in SNR will be compensated to some extent by a greatly increased number of looks. The average speed of the beam footprint is about 0.075 km/s while the average along track extent is about 210 km. Thus, the beam will move less than a beamwidth along track and all of the bursts count as looks. Div C has a burst period of 0.7 s, while division D has a burst period of about 0.9 s. Using 0.8 s, there will be about 2250 looks on average for each pixel. This may be excessive, and future attempts at imaging from this altitude should attempt to move the beam faster than the natural motion of the spacecraft.

In the first part of the high-res scatterometry segment, there is enough round trip time to take advantage of 8-2 block adaptive quantization (BAQ) to increase the number of looks until the burst duty cycle hits the 7% limit. Using the 8-2 BAQ for the first 15 minutes frees up enough data volume to push the 8 bit straight collection in the second 15 minutes up close to the 7% burst duty cycle limit. Making this internal tradeoff maximizes the signal energy in the image swath at the expense of some increased quantization noise in the 8-2 BAQ segment. The imaging performance of these two segments will be compared to assess the future use of 8-2 BAQ on these types of high range data collections.

5 Div's E,F,G: Compressed Scatterometry and Radiometry Scans

The compressed scatterometry obtained during the radiometry scans follows the same constraints and considerations confronted in the T7 design. To avoid reducing the radiometer integration time, two bursts in flight are used in the outer scan. Here, the high range increases the round trip time to the point that a one-second burst period does not leave enough radiometer integration time. Two bursts in flight with a burst period of about 0.5 s allows the active mode data collection to work while still maintaining a resonable duty cycle (around 50%) for the radiometer integration. The on-board summation (compressed scatterometry) keeps the data rate down to about 5 Kbps.

6 Revision History

1. Mar 7, 2006: Corrected beam motion and look count error for Div's C,D

2. Feb 8, 2006: Initial release

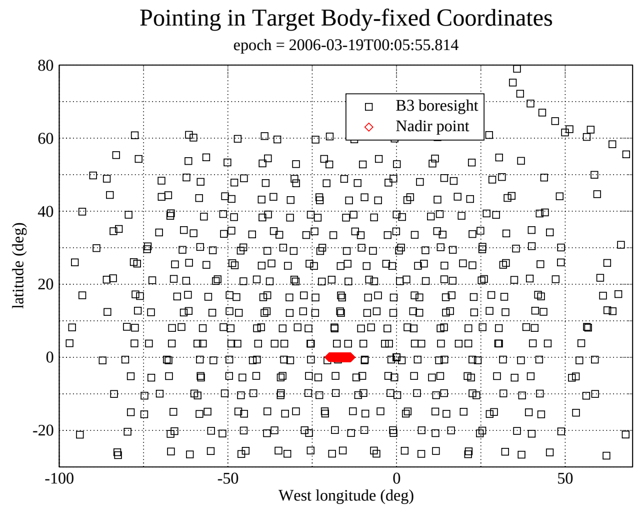

Figure 5: Outbound Scans in target body-fixed coordinates

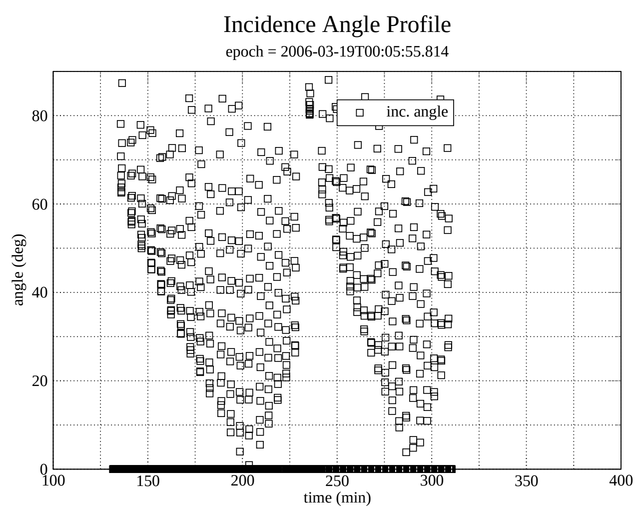

Figure 6: Outbound incidence angle variation during scan

Name	Nominal	e	g	Mismatch	Comments
mode	scatterometer	scat_compressed	scat_compressed	yes	
start_time (min)	varies	125.5	240.0	no	
end_time (min)	varies	228.0	330.0	no	
time_step (s)	don't care	4.0	4.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	5	3	3	yes	5 - 8 bits straight
csr	8	0	0	yes	8 - auto gain
noise_bit_setting	4.0	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.70	0.70	yes	
prf (Hz)	1200	2000	2000	yes	
tro	6	6	6	no	
number_of_pulses	8	150	90	yes	
n_bursts_in_flight	1	1	2	yes	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	30.000	3.100	6.300	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 7: t12 div_eg standard_scatterometer_outbound block

7 Acronym List

AL	Acronym List
ALT	Altimeter - one of the radar operating modes
BAQ	Block Adaptive Quantizer
CIMS	Cassini Information Management System - a database of observations
Ckernel	NAIF kernel file containing attitude data
DLAP	Desired Look Angle Profile - spacecraft pointing profile designed for optimal SAR performance
ESS	Energy Storage System - capacitor bank used by RADAR to store transmit energy
IEB	Instrument Execution Block - instructions for the instrument
ISS	Imaging Science Subsystem
IVD	Inertial Vector Description - attitude vector data
IVP	Inertial Vector Propagator - spacecraft software, part of attitude control system
INMS	Inertial Neutral Mass Spectrometer - one of the instruments
NAIF	Navigation and Ancillary Information Facility
ORS	Optical Remote Sensing instruments
PDT	Pointing Design Tool
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
RMSS	Radar Mapping Sequencing Software - produces radar IEB's
SAR	Synthetic Aperture Radar - radar imaging mode
SNR	Signal to Noise Ratio
SOP	Science Operations Plan - detailed sequence design
SOPUD	Science Operations Plan Update - phase of sequencing when SOP is updated prior to actual sequencing
SSG	SubSequence Generation - spacecraft/instrument commands are produced
SPICE	Spacecraft, Instrument, C-kernel handling software - supplied by NAIF to use NAIF kernel files.
TRO	Transmit Receive Offset - round trip delay time in units of PRI