RADAR Titan Flyby during S25/T20

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- Sequence: s25
- Rev: 031
- Observation Id: t20
- Target Body: Titan
- Data Take Number: 101
- PDT Config File: S25_ssup_psiv1_060829_pdt.cfg
- SMT File: s25_2006-08-24.rpt
- PEF File: z0250c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the tenth Titan flyby on which RADAR data will be acquired. This data collection occurs during the s25 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 T15, 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. After the two inbound radiometry scans, there will be a small scatterometry segment that sweeps about 10 beamwidths at an incidence angle around 35 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. The VIMS "snail" will be targeted for the first few minutes to get some low resolution radar imaging over the same area.

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
031OT_T20AWARM001_RIDER	2006-298T07:23:37	2006-298T10:23:37	03:00:0.0	Warmup for RADAR observation of Titan.
031TI_T20AINRAD101_PRIME	2006-298T10:23:37	2006-298T14:38:37	04:15:0.0	Radiometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations.
031TI_T20BINRAD201_PRIME	2006-298T10:23:37	2006-298T14:16:37	03:53:0.0	Radiometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations.
031TI_T20BISCAT201_PRIME	2006-298T14:38:37	2006-298T15:23:37	00:45:0.0	Scatterometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations
031TI_T20BINALT201_PRIME	2006-298T15:23:37	2006-298T15:38:37	00:15:0.0	Altimetry during the inbound trajectory of T20
031TI_T20BILSAR201_PRIME	2006-298T15:38:37	2006-298T15:46:37	00:08:0.0	Low resolution SAR imaging of Titan on the inbound trajectory
031TI_T20BHISAR201_PRIME	2006-298T15:46:37	2006-298T16:00:37	00:14:0.0	High Resolution SAR imaging of Titan's surface
031TI_T20BOLSAR201_PRIME	2006-298T16:00:37	2006-298T16:08:37	00:08:0.0	Low resolution SAR imaging of Titan on the outbound trajectory
031TI_T20BONALT201_PRIME	2006-298T16:08:37	2006-298T16:23:37	00:15:0.0	Altimetry during the outbound trajectory of T20
031TI_T20BOSCAT201_PRIME	2006-298T16:23:37	2006-298T17:16:37	00:53:0.0	Scatterometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations

Table 1: t20 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-8:25:0.0	03:00:0.0	2.7	Warmup
b	standard_radiometer_inbound	-5:25:0.0	01:53:0.0	1.7	Radiometer Scan 1
c	scatterometer_compressed	-3:32:0.0	01:46:0.0	19.7	Compressed Scatt/Rad scan 2
d	standard_scatterometer_inbound	-1:46:0.0	00:05:0.0	60.0	Distant SAR, buffer limited
e	standard_scatterometer_inbound	-1:41:0.0	00:05:0.0	60.0	Distant SAR, buffer limited
f	standard_scatterometer_inbound	-1:36:0.0	00:05:0.0	60.0	Distant SAR, buffer limited
g	standard_scatterometer_inbound	-1:31:0.0	00:06:0.0	72.0	Distant SAR, buffer limited
h	standard_scatterometer_inbound	-1:25:0.0	00:01:0.0	12.0	Distant SAR, buffer limited
i	standard_scatterometer_inbound	-1:24:0.0	00:07:0.0	84.0	Distant SAR, buffer limited
j	standard_altimeter_inbound	-1:17:0.0	00:02:0.0	4.8	Distant SAR, buffer limited
k	standard_radiometer_inbound	-1:15:0.0	00:01:0.0	0.1	Altimetry
Total				376.9	

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	166428	off target	0.21	off target
b	106406	off target	0.14	off target
c	68744	off target	0.09	off target
d	33419	off target	0.05	off target
e	31754	32204	0.04	213
f	30089	30476	0.04	230
g	28425	28844	0.04	248
h	26429	26901	0.04	272
i	26096	26339	0.04	276
j	23769	23769	0.03	308
k	23104	23104	0.03	319

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	-505.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-325.0	yes	
time_step (s)	2700.0	3600.0	yes	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: t20 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 2006-10-25T07:23:37.000 (-08:34:29.8). During the warmup, the IEB will be set for slow speed radiometer only data as shown in table 4.

4 Div B: Compressed Scatterometry and Radiometry Scans

There are two radiometry scans in this observation. The first is just radiometry, while the second also includes compressed scatterometry. The limiting factor here is data volume. The compressed scatterometry obtained during the radiometry scans follows the same constraints and considerations confronted in the T7 design. The on-board summation (compressed scatterometry) keeps the data rate down to about 5 Kbps.

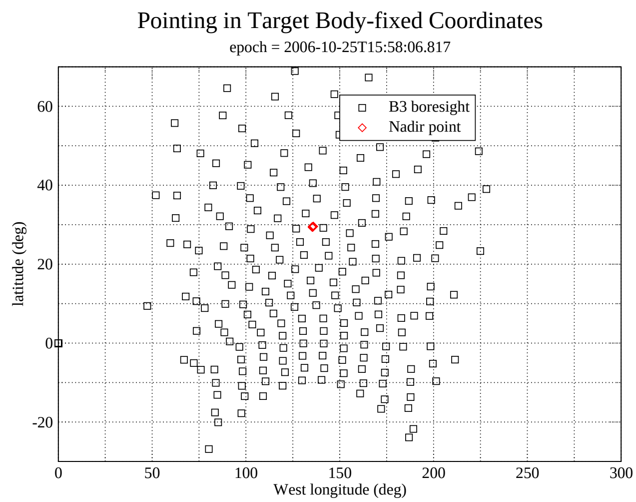

Figure 1: Scans in target body-fixed coordinates

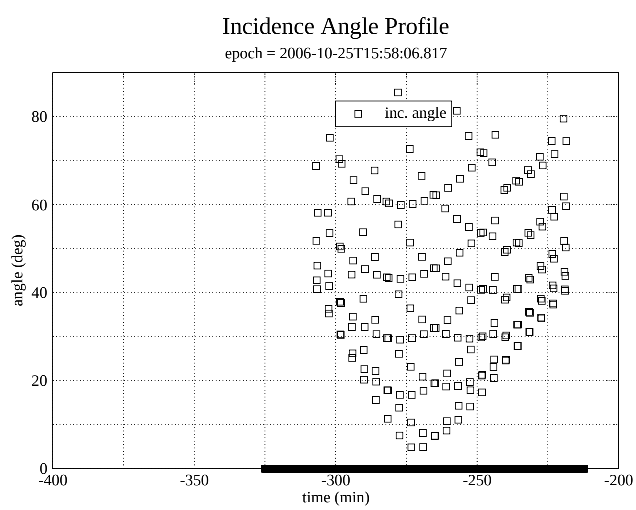

Figure 2: Incidence angle variation during scan

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-300.0	-325.0	yes	
end_time (min)	-120.0	-212.0	yes	
time_step (s)	2700.0	3600.0	yes	Used by radiometer only modes
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	
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	1.000	0.248	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: t20 Div b standard_radiometer_inbound block

5 Div's D-I: High Altitude Imaging

From -106 min to -84 minutes, the pointing design slews beam 3 about 10 beamwidths around the normal iso-doppler attitude for an incidence angle of 35 degrees. This design allows for a high altitude imaging segment with performance characteristics inbetween segments B and C of the high altitude imaging presentation made at the T13 science team meeting (see high altitude imaging memo and presentation on radar web page under CRST meetings).

Div's D-H covers the imaging time with scatterometer divisions that push against the 7% duty cycle limit, the 32 Kbyte size of the science data buffer, the round trip time limitation, and the number of pulses that the ESS can put out. To allow the best possible azimuth resolution, the duty cycle is reduced to allow a longer pulse train while still remaining below the 7% duty cycle limit. This trades SNR for resolution which is the same as was done on T19, but different from the T15 design where SNR was maximized. The T20 imaging segment is quite a bit higher than the T19 segment with ranges from 32,000 km down to 25,000 km, so the azimuth resolution will be worse due to reduced doppler spread in the beam footprint. Resolution in this segment will be about 2.5 km by 8 km at the beginning, and then improving to about 2.5 km by 3 km by the end. Four divisions are used to adjust the PRF to keep range and doppler ambiguities balanced and out of the beam footprint during the observation time. To allow enough pulses to fill the science data buffer and maximize the resolution, the pulse duty cycle needed to be reduced to about 0.18 which will reduce thermal SNR in the image.

After the side-looking sweep, the spacecraft turns to point beam 3 at a special target of interest called Tortolla for about 4 minutes. A lower incidence angle of about 25 degrees changes the balance between range and azimuth resolution to 3 km by 2.5 km. Pulse parameters here allow a higher pulse duty cycle of 0.34 which will help SNR.

5.1 PRF and Incidence Angle Choices

RMSS does not support all of the SAR options in scatterometer mode, so this high-res scatterometer profile uses a constant incidence angle and a fixed PRF in each division. The PRF value is varied from 500 Hz 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 D-I varies from about 170 Hz to about 470 Hz as range varies from 32,000 km to 25,000 km. At the same time the PRF

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-106.0	no	
end_time (min)	varies	-101.0	no	
time_step (s)	don't care	4.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	0	yes	5 - 8 bits straight
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.18	yes	
prf (Hz)	1200	500	yes	
tro	6	6	no	
number_of_pulses	8	56	yes	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	200.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 6: t20 Div d standard_scatterometer_inbound block

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,

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

and

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

where R_{max} varies across this segment, θ_{bw} is 6 mrad for beam 3, and θ_i is 35 or 25 degrees.

5.2 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

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-84.0	no	
end_time (min)	varies	-77.0	no	
time_step (s)	don't care	4.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	0	yes	5 - 8 bits straight
csr	0	0	no	0 - fixed attenuator
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.35	yes	
prf (Hz)	1200	1000	yes	
tro	6	6	no	
number_of_pulses	8	96	yes	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	200.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 7: t20 Div i standard_scatterometer_inbound block

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. Fig. 3 shows the results from these equations for divisions D-I. The calculations are performed for the boresight of beam 3 which is the center of the swath.

5.3 SNR and Looks

Noise performance will be better in this segment than it was in the T12 high altitude imaging because of the lower altitude range. In scatterometer mode the noise equivalent σ_0 for beam 3 will be better than -5 dB. The number of looks will varies but will generally be higher than 100. 8-2 BAQ is used to get more looks out of available data volume.

6 Revision History

1. Oct 24, 2006: Initial release

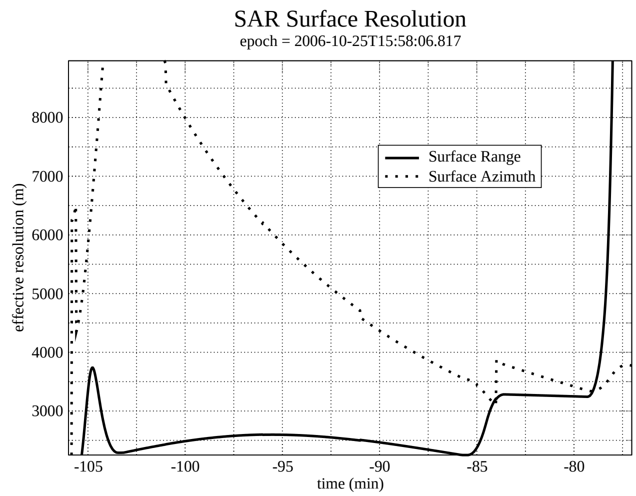

Figure 3: Div's D-I: Projected range and azimuth resolution. These values are computed from the IEB parameters.

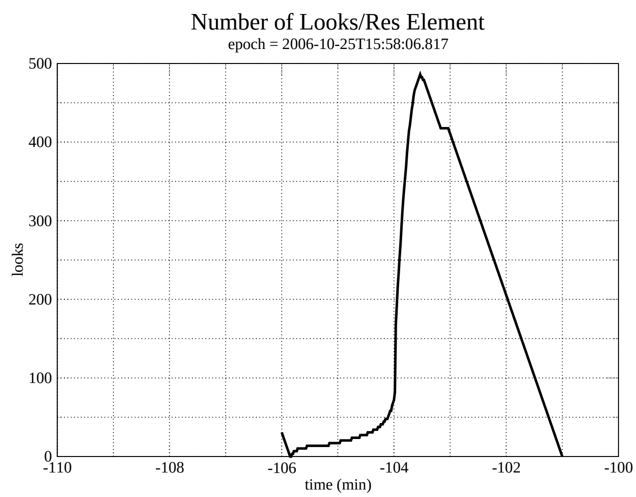

Figure 4: Div D: Number of looks. These values are computed from the IEB parameters.

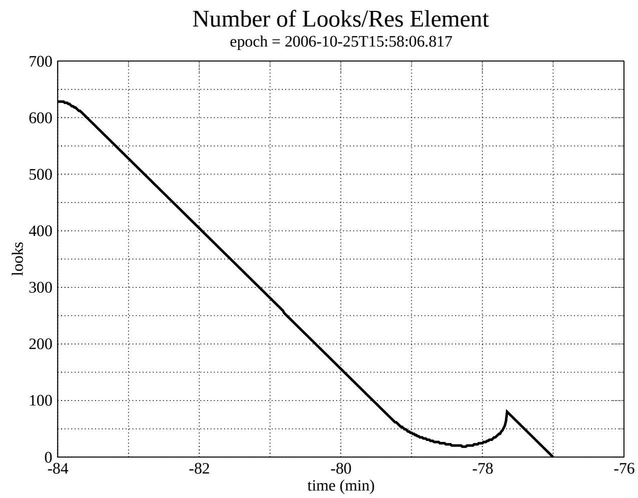

Figure 5: Div I: Number of looks. These values are computed from the IEB parameters.

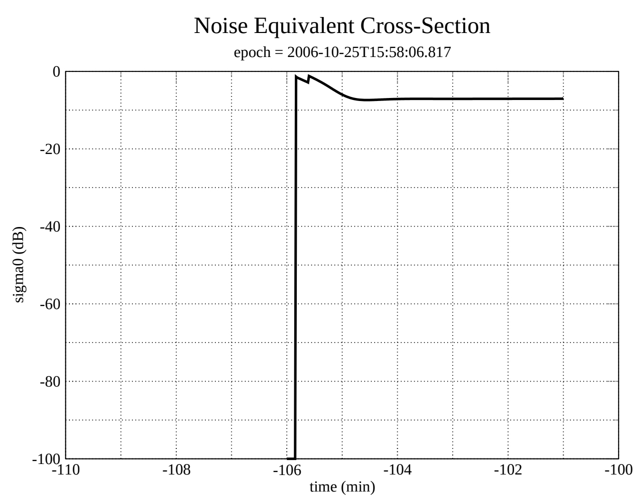

Figure 6: Div D: Noise equivalent σ_0. These values are computed from the IEB parameters.

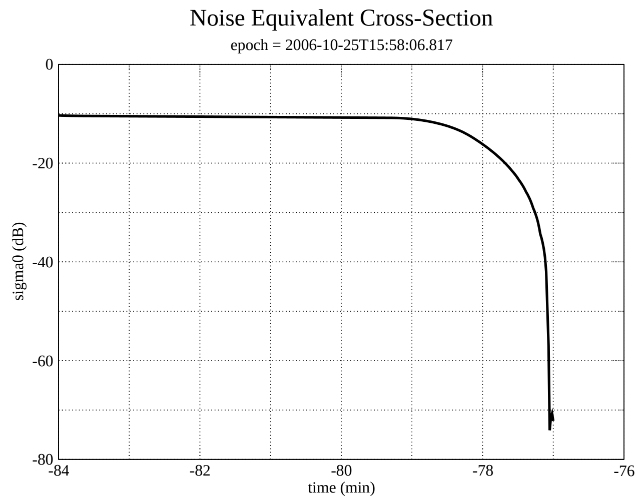

Figure 7: Div I: Noise equivalent σ_0. These values are computed from the IEB parameters.

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