RADAR Titan Flyby during S26/T21

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- Sequence: s26
- Rev: 035
- Observation Id: t21
- Target Body: Titan
- Data Take Number: 108
- PDT Config File: S26_ssup_psiv1_060927_pdt.cfg
- SMT File: s26_smt_060922.rpt
- PEF File: z0260c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the 11th Titan flyby on which SAR data will be acquired. This SAR data collection occurs during the s26 sequence of the Saturn Tour. This flyby starts with INMS ride-along SAR where radar acquires imaging data up to close approach while INMS keeps the -x spacecraft axis pointed into the ram direction. After closest approach, the outbound half is all radar with a pushbroom profile used on the outbound SAR segment. 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.

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.

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

CIMS ID	Start	End	Duration	Comments
035OT_WARM4T21001_RIDER	2006-346T08:52:25	2006-346T11:30:25	02:38:0.0	Warmup for T21 SAR ride along with INMS of Titan.
035TI_T21RASAR001_INMS	2006-346T11:30:25	2006-346T11:37:25	00:07:0.0	Ride along SAR of Titan with INMS.
035TI_T21OTHSAR001_PRIME	2006-346T11:37:25	2006-346T11:44:25	00:07:0.0	High resolution SAR imaging of Titan during closest approach period
035TI_T21OTLSAR001_PRIME	2006-346T11:44:25	2006-346T11:52:25	00:08:0.0	Low resolution SAR imaging during the post-closest approach time period
035TI_T21OUTALT001_PRIME	2006-346T11:52:25	2006-346T12:07:25	00:15:0.0	Altimetry during the outbound trajectory of T21
035TI_T21OTSCAT001_PRIME	2006-346T12:31:25	2006-346T13:12:46	00:41:21.0	Scatterometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations
035TI_T21OUTRAD001_PRIME	2006-346T13:12:46	2006-346T15:37:25	02:24:39.0	Radiometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations.

Table 1: t21 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-8:20:0.0	03:19:0.0	3.0	Warmup
b	standard_radiometer_inbound	-5:01:0.0	03:39:0.0	13.0	Inbound radiometry
c	standard_radiometer_inbound	-1:22:0.0	01:16:30.0	4.6	Inbound radiometry
d	standard_sar_hi	-0:05:30.0	00:01:30.0	21.4	Hi-SAR Turn transition
e	standard_sar_hi	-0:04:0.0	00:08:0.0	114.2	Hi-SAR around c/a
f	standard_sar_hi	00:04:0.0	00:12:0.0	171.4	Hi-SAR
g	standard_sar_low_outbound	00:16:0.0	00:01:36.0	20.6	Outbound Low-SAR
h	standard_sar_hi	00:17:36.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
i	standard_sar_low_outbound	00:17:48.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
j	standard_sar_hi	00:18:0.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
k	standard_sar_low_outbound	00:18:12.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
l	standard_sar_hi	00:18:24.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
m	standard_sar_low_outbound	00:18:36.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
n	standard_sar_hi	00:18:48.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
o	standard_sar_low_outbound	00:19:0.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
p	standard_sar_hi	00:19:12.0	00:00:12.0	2.9	Hi-SAR ping-pong
q	standard_sar_low_outbound	00:19:24.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
r	standard_sar_hi	00:19:36.0	00:00:12.0	2.9	Hi-SAR ping-pong
s	standard_sar_low_outbound	00:19:48.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
t	standard_sar_hi	00:20:0.0	00:02:0.0	28.6	Hi-SAR turn transition to altimetry, B3 only
u	standard_altimeter_outbound	00:22:0.0	00:07:34.0	14.1	Outbound altimetry
v	standard_altimeter_outbound	00:29:34.0	00:00:2.0	0.4	altimetry test 8-8
w	standard_altimeter_outbound	00:29:36.0	00:00:2.0	0.4	altimetry test 8-8, and reduced duty cycle
x	standard_altimeter_outbound	00:29:38.0	00:00:2.0	0.4	altimetry test 8-8, reduced duty cycle and bandwidth
y	standard_altimeter_outbound	00:29:40.0	00:22:20.0	41.5	Outbound altimetry including wheels transition
z	standard_scatterometer_outbound	00:52:0.0	00:30:0.0	59.4	Outbound scatterometer raster
lbrace	standard_scatterometer_outbound	01:22:0.0	00:13:0.0	25.7	Outbound scatterometer raster
vbar	standard_radiometer_outbound	01:35:0.0	03:45:0.0	13.4	Outbound radiometry scans
Total				564.6	

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	163816	off target	0.21	off target
b	97898	off target	0.13	off target
c	25299	off target	0.03	off target
d	1469	1988	0.01	2272
e	1255	1541	0.00	2399
f	1255	1362	0.00	2399
g	3967	4047	0.01	1409
h	4428	4535	0.01	1316
i	4487	4597	0.01	1306
j	4546	4659	0.01	1295
k	4604	4720	0.01	1285
l	4663	4782	0.01	1274
m	4722	4844	0.01	1264
n	4782	4906	0.01	1254
o	4841	4967	0.01	1244
p	4901	5028	0.01	1234
q	4960	5090	0.01	1225
r	5020	5150	0.01	1215
s	5080	5211	0.01	1206
t	5140	5272	0.01	1196
u	5747	5747	0.01	1110
v	8113	8113	0.01	868
w	8124	8124	0.01	868
x	8135	8135	0.01	867
y	8145	8145	0.01	866
z	15397	15397	0.02	528
lbrace	25299	26494	0.03	357
vbar	29604	30958	0.04	318

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	-500.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-301.0	yes	
time_step (s)	2700.0	3600.0	yes	Used by radiometer only modes - saves commands
bem	00100	11111	yes	
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: t21 Div a Warmup block

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 Radiometry

The radar warmup rider begins at 2006-12-12T08:52:25.000 (-02:49:5.8). During the warmup, the IEB will be set to collect 4-second radiometer data on all 5 beams as shown in table 4. Div's B and C cover the turn to Titan with 1-second radiometry and may provide data on the beam spillover sidelobes at the very end. Data will not be collected until after -7 minutes when the command to switch to a radar compatible telemetry mode is issued. There is a 64 second uncertainty as to where this command will execute, so the beams may be already on target when this happens.

4 Div's D-T: SAR Imaging

Div D covers the transition to INMS ride-along from -5.5 min to -4 min where the incidence angle is high. Prior experience with the T17 and T18 INMS ride-along observations showed that high incidence angle ride-along SAR still has good science quality. Div E covers the 8 minutes centered on closest approach. Hi-SAR is used throughout to obtain the best resolution possible. A pushbroom profile is used on the outbound side to extend the imaging swath. At +16 minutes, range and azimuth resolution and SNR favor Low-SAR and the instrument switches to this mode in

Name	Nominal	b	c	Mismatch	Comments
mode	radiometer	radiometer	radiometer	no	
start_time (min)	-300.0	-301.0	-82.0	yes	
end_time (min)	-120.0	-82.0	-5.5	yes	
time_step (s)	2700.0	3600.0	3600.0	yes	Used by radiometer only modes
bem	00100	00100	00100	no	
baq	don't care	5	5	no	
csr	6	6	6	no	
noise_bit_setting	don't care	4.0	4.0	no	
dutycycle	don't care	0.38	0.38	no	
prf (Hz)	don't care	1000	1000	no	
tro	don't care	0	0	no	
number_of_pulses	don't care	8	8	no	
n_bursts_in_flight	don't care	1	1	no	
percent_of_BW	don't care	100.0	100.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	1.000	0.992	0.992	yes	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 5: t21 Div bc standard_radiometer_inbound block

div G. Div's H-S then ping-pong back and forth every 12 seconds between Hi-SAR and Low-SAR with overlapping pixels. This provides a small increase in image quality since the two modes provide rectangular pixels with the short side in different directions. Targetting of the outbound pushbroom profile ends at +20 minutes. SAR-Hi mode is used during the backsweep to nadir in div T. This extra coverage may provide some stereo opportunities. Table 6 shows the standard Hi-SAR divisions, table 7 shows two representative Low/Hi-SAR ping pong divisions, and table 8 shows the B3 only Hi-SAR division at the end. The left look option is selected here to produce a swath that crosses more prior swaths and altimeter tracks.

4.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 1) are optimized for maximum usuable imaging coverage. The Ta profiles were produced for a 950 km flyby which is the most common SAR flyby altitude. The T3 profiles were optimized for a 1500 km flyby. The T21 flyby will be at 1000 km altitude, and the lower altitude profile used at Ta will be used again here. The optimized profile maximizes usable cross-track width while avoiding gaps in the imaging swath. Unlike some previous SAR imaging passes, this pass will not include any PRF hopping which has not proven necessary.

4.2 SAR Resolution Performance

For all of the SAR divisions the effective resolution can be calculated from the following equations,

$$\delta R_g = \frac{c}{2 B_r \sin\theta_i}, \tag{1}$$

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

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

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-4.0	yes	
end_time (min)	6.0	4.0	yes	
time_step (s)	don't care	10.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	11111	no	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	3.0	3.0	no	
dutycycle	0.70	0.70	no	
prf (Hz)	don't care	0	no	RMSS follows profile
tro	don't care	0	no	
number_of_pulses	don't care	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	98.0	yes	
auto_rad	off	off	no	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	238.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 6: t21 Div e standard_sar_hi block

Name	Nominal	h	i	Mismatch	Comments
mode	sarh	sarh	sarl	yes	
start_time (min)	-6.0	17.6	17.8	yes	
end_time (min)	6.0	17.8	18.0	yes	
time_step (s)	don't care	6.0	6.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	11111	11111	no	
baq	0	0	0	no	0 - 8 to 2
csr	8	0	0	yes	8 - auto gain
noise_bit_setting	3.0	3.4	2.9	yes	
dutycycle	0.70	0.70	0.70	no	
prf (Hz)	don't care	0	0	no	RMSS follows profile
tro	don't care	0	0	no	
number_of_pulses	don't care	0	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	off	off	off	no	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	238.000	215.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	off	yes	
interleave_duration (min)	varies	10.0	10.0	no	

Table 7: t21 Div hi standard_sar_hi block

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	20.0	yes	
end_time (min)	6.0	22.0	yes	
time_step (s)	don't care	6.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	00100	yes	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	3.0	3.0	no	
dutycycle	0.70	0.70	no	
prf (Hz)	don't care	0	no	RMSS follows profile
tro	don't care	0	no	
number_of_pulses	don't care	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	off	off	no	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	238.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	12.0	no	

Table 8: t21 Div t standard_sar_hi block

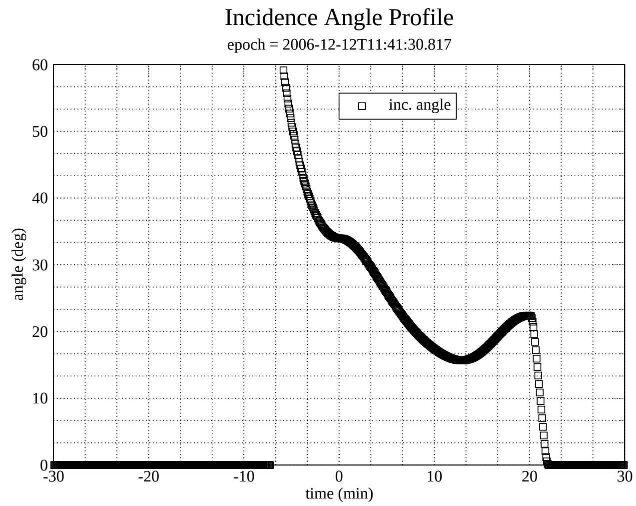

Figure 1: B3 boresight incidence angle during the time around c/a.

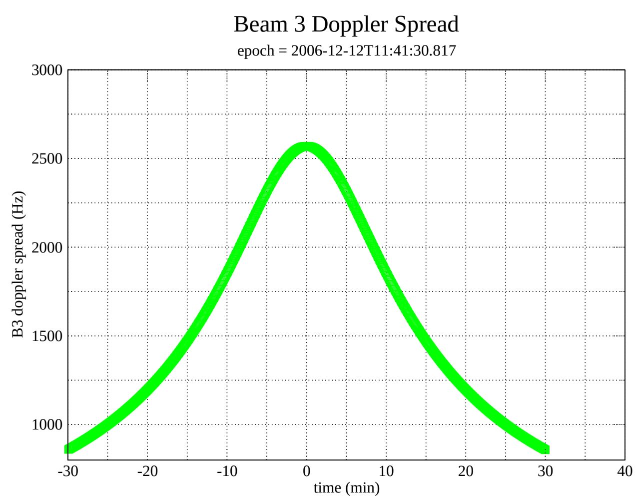

Figure 2: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

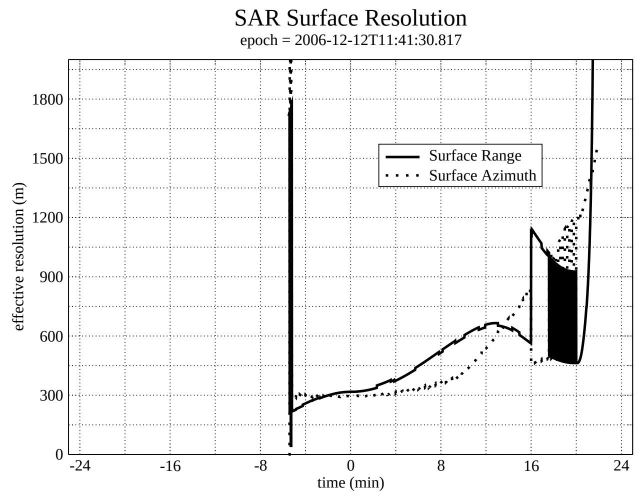

Figure 3: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

body, and θ_v is the angle between the velocity vector and the look direction. Figure 3 shows the results from these equations for the Ta flyby using the parameters from the IEB as generated by RMSS. The calculations are performed for the boresight of beam 3 which is the center of the swath.

Projected range increases with decreasing incidence angle, so the range resolution varies across the swath with better resolution at the outer edge. The SAR pointing profile decreases the incidence angle as time progresses and altitude increases, so there is progressive deterioration of range resolution away from closest approach. The projected range resolution rapidly deteriorates as the incidence angle decreases toward zero at the very beginning and end of the swath.

Azimuth resolution is a function of the synthetic aperture size which is determined by the length of the receive window in each burst (assuming the receive window is always filled with echos). Azimuth resolution deteriorates less quickly because the number of pulses and the length of the receive window are increased as altitude increases which mitigates the increasing doppler bandwidth of the beam patterns. The receive window length increases to fill the round trip time until the science data buffer is filled. At this point it is no longer possible to extend the receive window, and azimuth resolution starts to deteriorate more rapidly.

5 Div's U-Y: Altimetry

The spacecraft performs a transition from momentum wheel to thruster attitude control outside of the altimeter segment. During this time, the -Z axis (high gain antenna axis) is pointed at nadir, so we collect data in altimetry mode. The altitude here is higher than the nominal altimetry, so performance will suffer, and pointing performance is not guaranteed. Div's V,W,X perform some diagnostic checks to make sure there are no issues with the altimetry data. The parameters used by the main altimeter segments are shown in table 9. Note that the pulse duty cycle has been reduced from 70% to 50% to provide better echo separation.

6 Div's Z,{: Scatterometry Scan

The T21 outbound scatterometry scan covers a wide latitude range from about 25 N down to the south pole. It is coordinated with a scatterometry scan in T23 which will partially overlap and provde radiometry and scatteromtry data in an orthogonal polarization. These two scans together will allow a determination of the equator to pole temperature gradient. Very low incidence angle coverage is also provided to help with modelling of the surface response.

The IEB instructions for the scatterometry scan are generated by RMSS under the control of the set of config parameters shown in table 10. Scatterometer mode operations use a transmit-receive window offset (TRO) of 6 which

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	19.0	22.0	yes	
end_time (min)	30.0	29.6	yes	
time_step (s)	don't care	6.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	7	no	7 - 8 to 4
csr	8	8	no	8 - auto gain
noise_bit_setting	2.0	2.3	yes	
dutycycle	0.73	0.50	yes	
prf (Hz)	5000	5000	no	
tro	don't care	-6	no	auto set to -6 except interleaved bursts where +6 is used
number_of_pulses	21	21	no	
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	85.000	31.000	yes	
interleave_flag	on	on	no	
interleave_duration (min)	varies	10.0	no	

Table 9: t21 Div u standard_altimeter_outbound block

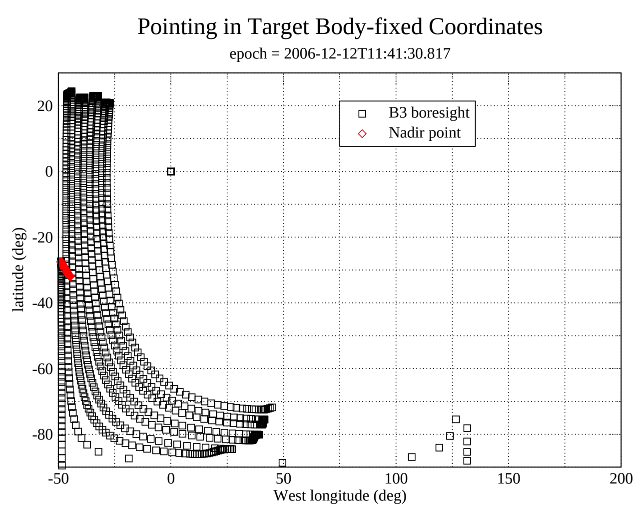

Figure 4: Scatterometry scan in target body-fixed coordinates

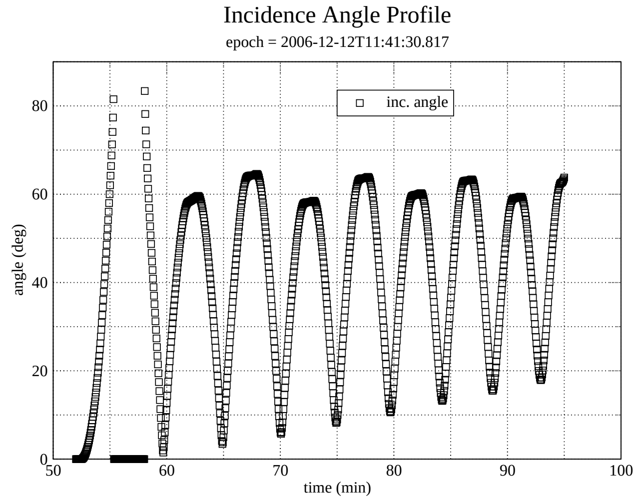

Figure 5: Incidence angle variation during scatterometry scan

Name	Nominal	z	lbrace	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	52.0	82.0	no	
end_time (min)	varies	82.0	95.0	no	
time_step (s)	don't care	6.0	6.0	no	Set by valid time calculation
bem	00100	00100	00100	no	
baq	5	5	5	no	5 - 8 bits straight
csr	0	0	0	no	0 - No auto-gain, fixed attenuator set to avoid clipping
noise_bit_setting	4.0	3.1	4.0	yes	15 dB attenuator
dutycycle	0.70	0.70	0.70	no	
prf (Hz)	1200	1200	1200	no	
tro	6	6	6	no	
number_of_pulses	8	8	8	no	
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	33.000	33.000	yes	leaving as much data for SAR as possible
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 10: t21 Div zlbrace standard_scatterometer_outbound block

makes the echo window 6 PRI's longer than the number of pulses transmitted. This is done to increase the valid time for an instruction by letting the pulse echos walk through the longer echo window before the range-gate needs to be updated. This is particularly important during Titan scatterometry raster scans where the number of instructions needed to track the varying range can exceed the number available if a smaller TRO value is used. The positive TRO value also guarantees noise-only data in each burst which eliminates the need to insert special noise-only bursts. The PRF of 1.2 KHz is high enough to cover the doppler spread within beam 3, so doppler sharpening could be performed.

During Ta, the scatterometry scans suffered from clipping during the center of the scan lines. The clipping occurred because RMSS placed all of the instruction boundaries near the outer edges of the scan where they were most needed to track the rapidly varying range. Thus, the auto-gain algorithm did not have an opportunity to see the higher signal levels near the center of the scan lines where the incidence angle dropped close to nadir pointing. To prevent this problem from recurring, auto-gain will not be used for scatteromtry raster scans. Instead, a fixed attenuator value will be used to keep the signal on-scale over the whole raster scan. Based on experience with T3, a 15 dB attenuator setting will be used for scan lines that go below 10 degrees incidence. For T21, the first half of the scan lines go below 10 degrees incidence and a 15 dB attenuator is used here. The remaining scan lines are above 10 degrees incidence so the 9 dB attenuator setting is used.

7 Revision History

1. Oct 19, 2006: Initial release

8 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