RADAR Titan Flyby during S29/T28

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- Sequence: s29
- Rev: 042
- Observation Id: t28
- Target Body: Titan
- Data Take Number: 126
- PDT Config File: S29_ssup_psiv1_070131_pdt.cfg
- SMT File: s29_smt_070208.rpt
- PEF File: z0290c.pef

1 Introduction

This memo describes the Cassini RADAR activities for the 14th Titan flyby on which SAR data will be acquired. This SAR data collection occurs during the s29 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.

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 through most of 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 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

CIMS ID	Start	End	Duration	Comments
042TI_T28WARMUP001_RIDER	2007-100T14:56:25	2007-100T18:06:25	03:10:0.0	Warmup for T28 inbound radiometry. REU bits included.
042TI_T28INRAD001_PRIME	2007-100T18:06:25	2007-100T21:41:25	03:35:0.0	Inbound radiometry of unique terrain at mid latitudes, REU bits included
042TI_T28INSCAT001_PRIME	2007-100T21:41:25	2007-100T22:04:25	00:23:0.0	Mid latitude scatterometry of unique terrain coverage of Titan. REU bits included.
042TI_TI28INALT001_PRIME	2007-100T22:26:25	2007-100T22:40:25	00:14:0.0	Altimetry measurements on the inbound leg of the T28 flyby. REU bits included.
042TI_TI28ILSAR001_PRIME	2007-100T22:40:25	2007-100T22:49:25	00:09:0.0	Low resolution SAR imaging on the inbound leg of T28. REU bits included.
042TI_TI28HISAR001_PRIME	2007-100T22:49:25	2007-100T23:03:25	00:14:0.0	High resolution SAR imaging during the T28 closest approach period
042TI_TI28OLSAR001_PRIME	2007-100T23:03:25	2007-100T23:12:25	00:09:0.0	Low resolution SAR imaging on the outbound leg of T28. REU bits included.
042TI_TI28OTALT001_PRIME	2007-100T23:12:25	2007-100T23:25:25	00:13:0.0	Altimetry measurements on the outbound leg of the T28 flyby. REU bits included.

Table 1: t28 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-8:00:0.0	03:22:0.0	12.0	Warmup
b	standard_radiometer_inbound	-4:38:0.0	03:19:0.0	11.8	Inbound radiometry
c	standard_scatterometer_inbound	-1:19:0.0	00:04:0.0	7.2	Inbound scatterometry scan
d	standard_scatterometer_inbound	-1:15:0.0	00:23:0.0	41.4	Inbound scatterometry scan
e	standard_altimeter_inbound	-0:52:0.0	00:22:0.0	52.8	Inbound turn transition altimetry
f	standard_altimeter_inbound	-0:30:0.0	00:10:12.0	55.1	Inbound altimetry
g	standard_sar_hi	-0:19:48.0	00:00:48.0	2.4	Hi-SAR Turn transition, beam 3 only
h	standard_sar_low_inbound	-0:19:0.0	00:00:42.0	9.0	Inbound Low-SAR ping-pong
i	standard_sar_hi	-0:18:18.0	00:00:12.0	2.9	Inbound Hi-SAR ping-pong
j	standard_sar_low_inbound	-0:18:6.0	00:00:12.0	2.6	Inbound Low-SAR ping-pong
k	standard_sar_hi	-0:17:54.0	00:00:12.0	2.9	Inbound Hi-SAR ping-pong
l	standard_sar_low_inbound	-0:17:42.0	00:00:12.0	2.6	Inbound Low-SAR ping-pong
m	standard_sar_hi	-0:17:30.0	00:00:12.0	2.9	Inbound Hi-SAR ping-pong
n	standard_sar_low_inbound	-0:17:18.0	00:00:12.0	2.6	Inbound Low-SAR ping-pong
o	standard_sar_hi	-0:17:6.0	00:00:12.0	2.9	Inbound Hi-SAR ping-pong
p	standard_sar_low_inbound	-0:16:54.0	00:00:12.0	2.6	Inbound Low-SAR ping-pong
q	standard_sar_hi	-0:16:42.0	00:00:12.0	2.9	Inbound Hi-SAR ping-pong
r	standard_sar_low_outbound	-0:16:30.0	00:00:12.0	2.6	Inbound Low-SAR ping-pong
s	standard_sar_hi	-0:16:18.0	00:32:18.0	457.4	Hi-SAR main swath
t	standard_sar_low_outbound	00:16:0.0	00:01:0.0	12.8	Outbound Low-SAR
u	standard_sar_hi	00:17:0.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
v	standard_sar_low_outbound	00:17:12.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
w	standard_sar_hi	00:17:24.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
x	standard_sar_low_outbound	00:17:36.0	00:00:12.0	2.6	Outbound Low-SAR ping-pong
y	standard_sar_hi	00:17:48.0	00:00:12.0	2.9	Outbound Hi-SAR ping-pong
z	standard_sar_low_outbound	00:18:0.0	00:00:30.0	6.5	Outbound Low-SAR turn transition
lbrace	standard_sar_hi	00:18:30.0	00:01:12.0	3.6	Hi-SAR turn transition to altimetry, B3 only
vbar	standard_altimeter_outbound	00:19:42.0	00:10:18.0	55.6	Outbound altimetry
Total				768.6	

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	166040	off target	0.21	off target
b	95319	off target	0.12	off target
c	25701	off target	0.04	off target
d	24305	25415	0.03	342
e	16300	16300	0.02	497
f	8749	8749	0.01	840
g	5386	5386	0.01	1199
h	5132	5184	0.01	1239
i	4911	5014	0.01	1276
j	4848	4946	0.01	1287
k	4786	4879	0.01	1298
l	4723	4813	0.01	1309
m	4661	4749	0.01	1320
n	4599	4686	0.01	1332
o	4537	4622	0.01	1344
p	4475	4557	0.01	1355
q	4413	4493	0.01	1367
r	4352	4428	0.01	1380
s	4291	4362	0.01	1392
t	4199	4263	0.01	1411
u	4506	4585	0.01	1349
v	4568	4650	0.01	1338
w	4630	4715	0.01	1326
x	4692	4781	0.01	1315
y	4754	4847	0.01	1303
z	4817	4913	0.01	1292
lbrace	4974	5050	0.01	1265
vbar	5354	5354	0.01	1204

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	-480.0	no	IEB Trigger time is usually later than this
end_time (min)	-300.0	-278.0	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	0.248	0.992	yes	Kbps - actual data rate may be less
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: t28 Div a Warmup block

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 Special Features of this Pass

This is a partial radar pass which ends with outbound altimetry. The SAR profile is pushbroomed on both ends. The SAR swath was shifted three degrees lower in incidence angle to make it line up more evenly with the T30 inbound nadir track. This will allow for conicident SAR and altimetry data. The T28 SAR swath also overlaps extensively with the T25 SAR swath in the north polar area providing same side stereo data. A short segment of this overlap will also include T30 altimetry.

4 Warmup and Radiometry

The radar warmup rider begins at 2007-04-10T14:56:25.000 (-08:01:34.8). During the warmup, the IEB will be set to collect 4-second radiometer data on all 5 beams as shown in table 4. Div B covers the inbound radiometry scans with 1-second radiometry.

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-300.0	-278.0	yes	
end_time (min)	-120.0	-79.0	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	0.992	0.992	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: t28 Div b standard_radiometer_inbound block

5 Div's C,D: Scatterometry Raster Scan

The inbound segment has a regular scatterometry raster scan (not hi-altitude imaging). The inbound scan is all at incidence angles above 10 degrees and uses the 9 dB attenuator throughout. At the end of the scatterometry raster, the spacecraft turns to nadir pointing. Div's C and D are shown in table 6

Scatterometer mode operations use a transmit-receive window offset (TRO) of 6 which 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.

6 Div's E,F,|: Altimetry

The parameters used by the main altimeter segments are shown in table 7. Division E covers the usual bonus altimetry during the wheel transition time. Division F and | covers the regular altimetry down to 5000 km altitude for the inbound and outbound segments respectively. The pulse parameters for these divisions are all the same. The main difference is the data rate. During the wheel transition time, the beam footprint moves slowly so a slower data rate is used here. During the regular altimetry segment, 30 Kbps is normally also used. In this data take there is enough data volume to increase this rate to 90 Kbps and provide better sampling during the lower altitude portion.

7 Div's G-{: SAR Imaging

Div's G and { cover the turn transitions with beam 3 only imaging. The data rate has been reduced to 50 Kbps to conserve data volume. This should still provide enough looks during the turn transition because only one beam is used. The SAR swath is pushbroomed at both ends. Div's H-R and U-Z ping-pong back and forth every 12 seconds

Name	Nominal	c	d	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-79.0	-75.0	no	
end_time (min)	varies	-75.0	-52.0	no	
time_step (s)	don't care	12.0	12.0	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	4.0	4.0	no	9 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	30.000	30.000	no	
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 6: t28 Div cd standard_scatterometer_inbound block

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. Div S covers the 32 minutes centered on closest approach. Hi-SAR is used throughout to obtain the best resolution possible. At +16 minutes, range and azimuth resolution and SNR favor Low-SAR and the instrument switches to this mode in div T. Targetting of the outbound pushbroom profile ends at +18 minutes. Table 8 shows the standard Hi-SAR divisions, table 9 shows two representative Low/Hi-SAR ping pong divisions, and table 10 shows the B3 only Hi-SAR divisions at the ends. The left look option is selected here to produce a swath that will overlap extensively with the planned T25 swath (also left look) and with the T30 inbound altimeter track. These three observations together will provide stereo SAR coverage overlapping an altimeter track in the north polar region where lakes are likely.

7.1 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 T25 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.

7.2 SAR Resolution Performance

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

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

Name	Nominal	e	f	vbar	Mismatch	Comments
mode	altimeter	altimeter	altimeter	altimeter	no	
start_time (min)	-30.0	-52.0	-30.0	19.7	yes	
end_time (min)	-19.0	-30.0	-19.8	30.0	yes	
time_step (s)	don't care	10.0	10.0	10.0	no	Set by valid time calculation
bem	00100	00100	00100	00100	no	
baq	7	7	7	7	no	7 - 8 to 4
csr	8	8	8	8	no	8 - auto gain
noise_bit_setting	2.3	2.3	2.3	2.3	no	
dutycycle	0.73	0.73	0.73	0.73	no	
prf (Hz)	5000	5000	5000	5000	no	
tro	don't care	-6	-6	-6	no	auto set to -6 except interleaved bursts where +6 is used
number_of_pulses	21	21	21	21	no	
n_bursts_in_flight	1	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	100.0	no	
auto_rad	on	on	on	on	no	
rip (ms)	34.0	34.0	34.0	34.0	no	
max_data_rate	30.000	40.000	90.000	90.000	yes	
interleave_flag	on	on	on	on	no	
interleave_duration (min)	varies	8.0	8.0	8.0	no	

Table 7: t28 Div efvbar standard_altimeter_inbound block

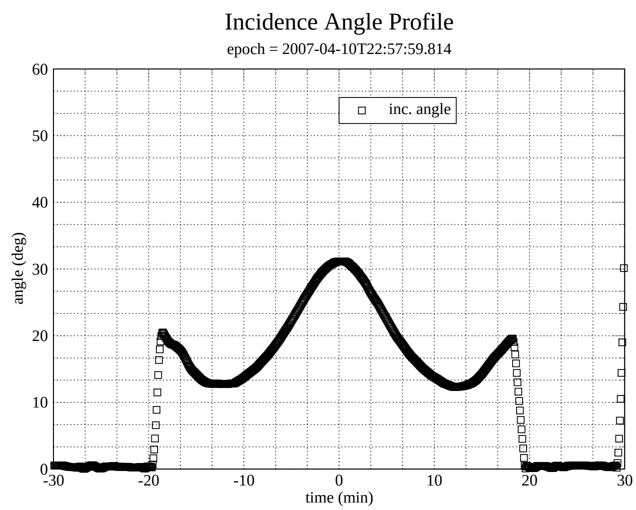

Figure 1: B3 boresight incidence angle during the time around c/a.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-16.3	yes	
end_time (min)	6.0	16.0	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	3.4	yes	
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	236.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 8: t28 Div s standard_sar_hi block

Name	Nominal	h	i	Mismatch	Comments
mode	sarl	sarl	sarh	yes	
start_time (min)	-19.0	-19.0	-18.3	yes	
end_time (min)	-6.0	-18.3	-18.1	yes	
time_step (s)	don't care	6.0	6.0	no	Set by valid time calculation
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	2.9	3.4	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	on	off	off	yes	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	255.000	215.000	238.000	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 9: t28 Div hi standard_sar_low_inbound block

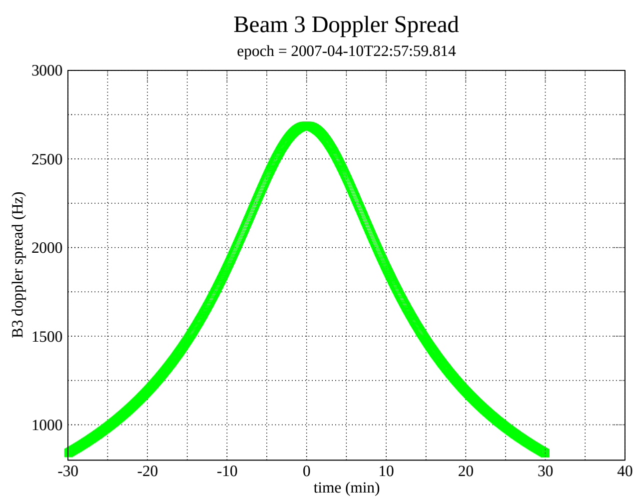

Figure 2: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

Name	Nominal	g	lbrace	Mismatch	Comments
mode	sarh	sarh	sarh	no	
start_time (min)	-6.0	-19.8	18.5	yes	
end_time (min)	6.0	-19.0	19.7	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	00100	00100	yes	
baq	0	0	0	no	0 - 8 to 2
csr	8	8	8	no	8 - auto gain
noise_bit_setting	3.0	3.4	3.4	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	50.000	50.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	off	yes	
interleave_duration (min)	varies	10.0	12.0	no	

Table 10: t28 Div glbrace standard_sar_hi block

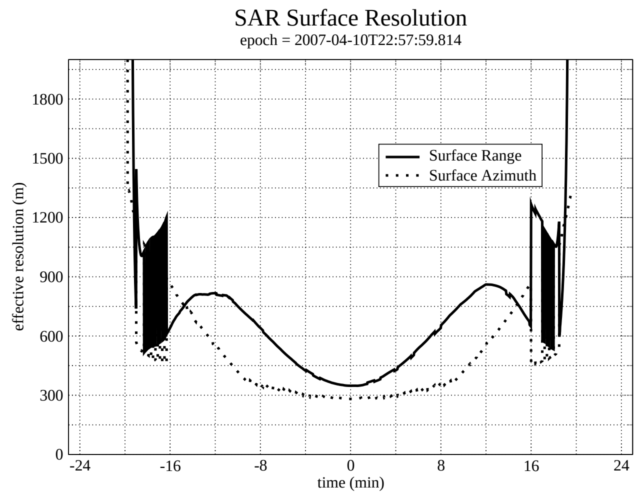

Figure 3: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

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

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 body, and θ_v is the angle between the velocity vector and the look direction. Figure 3 shows the results from these equations 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.

8 Revision History

1. Apr 3, 2007: Initial release

9 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