RADAR Titan Flyby during S22/T16

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- Sequence: s22
- Rev: 026
- Observation Id: t16
- Target Body: Titan
- Data Take Number: 87
- PDT Config File: S22_ssup_psiv1_060516_pdt.cfg
- SMT File: s22_2006_06_06.rpt
- PEF File: z0220d.pef

1 Introduction

This memo describes the Cassini RADAR activities for the 6th Titan flyby on which SAR data will be acquired. This SAR data collection occurs during the s22 sequence of the Saturn Tour. This flyby pushbrooms both ends of the SAR pointing profile to acquire more image coverage area. This is a partial radar pass with inbound radiometry, scatterometry, altimetry, closest approach SAR, and ending with outbound altimetry. 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
026OT_WARM4TI16001_RIDER	2006-202T16:25:27	2006-202T19:05:27	02:40:0.0	Warmup for RADAR observation of Titan.
026TI_T16RADIOM001_PRIME	2006-202T19:05:27	2006-202T22:42:27	03:37:0.0	Radiometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations.
026TI_T16INSCAT001_PRIME	2006-202T22:42:27	2006-202T23:33:27	00:51:0.0	Scatterometry of Titan. -Z scanned over Titan. Y axis controlled for different polarizations
026TI_T16INALT001_PRIME	2006-202T23:55:27	2006-203T00:10:27	00:15:0.0	Collect altimetry data while maintaining nadir pointing.
026TI_T16INLRES001_PRIME	2006-203T00:10:27	2006-203T00:18:27	00:08:0.0	Low Resolution Synthetic Aperture RADAR (SAR) Imaging.
026TI_T16HISAR001_PRIME	2006-203T00:18:27	2006-203T00:32:27	00:14:0.0	High Resolution Synthetic Aperture RADAR (SAR) Imaging.
026TI_T16OTLRES001_PRIME	2006-203T00:32:27	2006-203T00:40:27	00:08:0.0	Low Resolution Synthetic Aperture RADAR (SAR) Imaging.
026TI_T16OTALT001_PRIME	2006-203T00:40:27	2006-203T00:55:27	00:15:0.0	Collect altimetry data while maintaining nadir pointing.

Table 1: t16 CIMS Request Sequence

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-7:58:0.0	02:38:0.0	9.4	Warmup
b	standard_radiometer_inbound	-5:20:0.0	03:41:0.0	13.2	Inbound radiometry
c	standard_scatterometer_inbound	-1:39:0.0	00:24:0.0	50.4	Inbound scatterometer scan
d	standard_scatterometer_inbound	-1:15:0.0	00:23:0.0	45.5	Inbound scatterometer scan
e	standard_altimeter_inbound	-0:52:0.0	00:22:0.0	46.2	Inbound altimetry (turn transition)
f	standard_altimeter_inbound	-0:30:0.0	00:10:0.0	33.0	Inbound altimetry
g	standard_sar_hi	-0:20:0.0	00:01:30.0	21.6	Hi-SAR Turn transition, B3 only
h	standard_sar_low_inbound	-0:18:30.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
i	standard_sar_hi	-0:18:25.0	00:00:5.0	1.1	Inbound Hi-SAR ping-pong
j	standard_sar_low_inbound	-0:18:20.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
k	standard_sar_hi	-0:18:15.0	00:00:5.0	1.1	Inbound Hi-SAR ping-pong
l	standard_sar_low_inbound	-0:18:10.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
m	standard_sar_hi	-0:18:5.0	00:00:5.0	1.1	Inbound Hi-SAR ping-pong
n	standard_sar_low_inbound	-0:18:0.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
o	standard_sar_hi	-0:17:55.0	00:00:5.0	1.1	Inbound Hi-SAR ping-pong
p	standard_sar_low_inbound	-0:17:50.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
q	standard_sar_hi	-0:17:45.0	00:00:5.0	1.1	Inbound Hi-SAR ping-pong
r	standard_sar_low_inbound	-0:17:40.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
s	standard_sar_hi	-0:17:35.0	00:00:5.0	1.1	Inbound Hi-SAR ping-pong
t	standard_sar_low_inbound	-0:17:30.0	00:00:5.0	1.1	Inbound Low-SAR ping-pong
u	standard_sar_hi	-0:17:25.0	00:34:25.0	495.6	Hi-SAR
v	standard_sar_low_inbound	00:17:0.0	00:01:0.0	12.9	Outbound Low-SAR
w	standard_sar_hi	00:18:0.0	00:01:30.0	21.6	Outbound Hi-SAR, turn transition, B3 only
x	standard_altimeter_outbound	00:19:30.0	00:10:30.0	34.6	Outbound Altimetry
Total				797.9	

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	157408	off target	0.20	off target
b	104587	off target	0.13	off target
c	31000	32190	0.04	280
d	23033	23651	0.03	359
e	15426	15426	0.02	506
f	8257	8257	0.01	838
g	5131	5131	0.01	1178
h	4681	4802	0.01	1251
i	4657	4776	0.01	1255
j	4632	4750	0.01	1259
k	4607	4724	0.01	1264
l	4582	4698	0.01	1268
m	4558	4672	0.01	1272
n	4533	4646	0.01	1277
o	4509	4620	0.01	1281
p	4484	4594	0.01	1286
q	4459	4568	0.01	1290
r	4435	4542	0.01	1295
s	4410	4517	0.01	1299
t	4386	4491	0.01	1304
u	4361	4465	0.01	1308
v	4240	4336	0.01	1332
w	4533	4646	0.01	1277
x	4981	4981	0.01	1201

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	-478.0	yes	IEB Trigger time is usually later than this
end_time (min)	-300.0	-320.0	yes	
time_step (s)	2700.0	5400.0	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	0.992	yes	Kbps - actual data rate may be less
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: t16 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 2006-07-21T16:25:27.000 (-07:59:58.8). During the warmup, the IEB will be set to collect 1-second radiometer data on beam 3 as shown in table 4. Div A covers the turn to Titan and may provide data on the beam spillover sidelobes. This pass begins with two inbound radiometer scans using the usual one-second radiometer only bursts. No compressed scatterometry data is collected here due to data volume and instruction count constraints.

4 Div's C,D: Scatterometry Scan

The IEB instructions for the identical scatterometry divisions are generated by RMSS under the control of the set of config parameters shown in table 5. Although not shown in table 5, 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

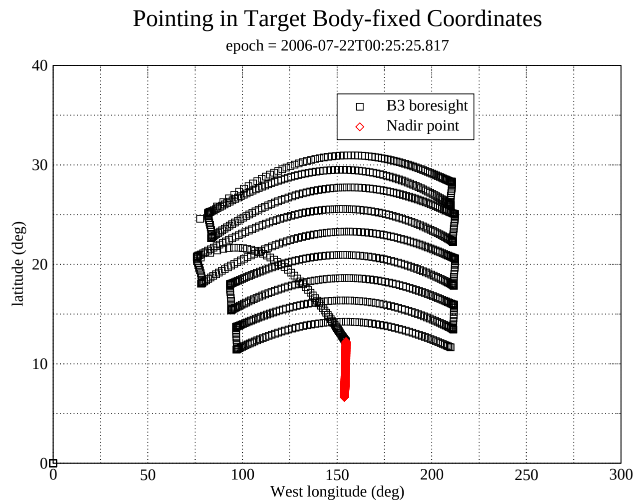

Figure 1: Scatterometry scan in target body-fixed coordinates

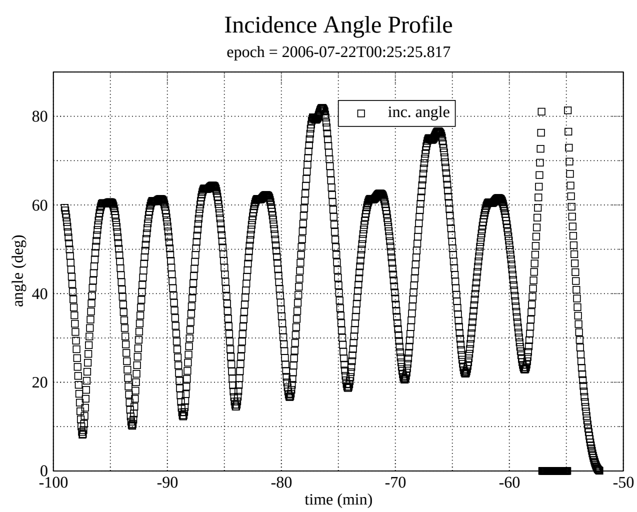

Figure 2: Incidence angle variation during scatterometry scan

Name	Nominal	c	d	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	-99.0	-75.0	no	
end_time (min)	varies	-75.0	-52.0	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	8	0	0	yes	0 - No auto-gain, fixed attenuator set to avoid clipping
noise_bit_setting	4.0	4.0	4.0	no	9 dB attenuator
dutycycle	0.60	0.70	0.70	yes	
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	35.000	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 5: t16 div_cd standard_scatterometer_inbound block

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 T16, all of the scan lines remain above 20 degrees incidence, so the 9 dB attenuator setting is used throughout.

5 Div's E,F,X: Altimetry

Following the scatterometer scan, the spacecraft performs a transition from momentum wheel to thruster attitude control. 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. Nonetheless, the opportunity to extend the altimetry track is exploited here with a data rate of 35 Kbps (see Div E). Following this, the nominal inbound altimetry track (Div F) begins and the data rate is increased to 55 Kbps to improve the quality of the altimetry data and use available data volume left over from SAR imaging. The outbound altimetry segment (Div X) also runs at 55 Kbps. The parameters used by the three altimeter segments are shown in table 6.

Name	Nominal	e	f	x	Mismatch	Comments
mode	altimeter	altimeter	altimeter	altimeter	no	
start_time (min)	-30.0	-52.0	-30.0	19.5	yes	
end_time (min)	-19.0	-30.0	-20.0	30.0	yes	
time_step (s)	don't care	8.0	6.0	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	2.0	4.2	4.2	2.5	yes	
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	35.000	55.000	55.000	yes	leaving as much data for SAR as possible
interleave_flag	on	on	on	on	no	
interleave_duration (min)	varies	10.0	9.0	6.8	no	

Table 6: t16 div_efx standard_altimeter_inbound block

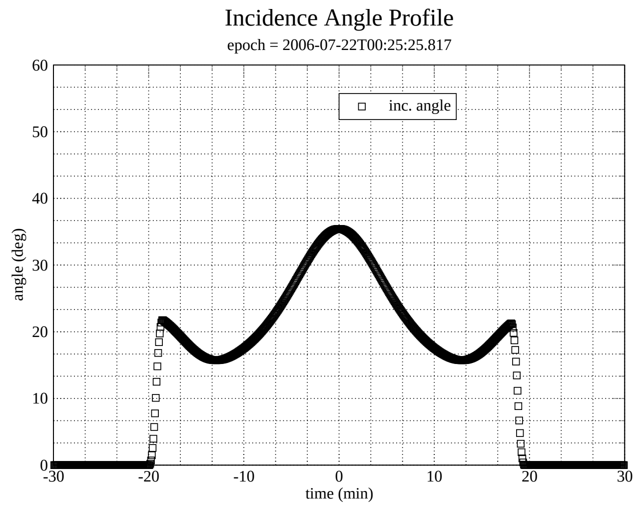

Figure 3: B3 boresight incidence angle during the time around c/a.

6 Div's G-W: SAR Imaging

After the altimetry track, there is a 1.5 minute turn transition to the SAR pointing profile during which SAR data is collected in Hi-SAR mode to maximize range resolution and in beam 3 only to maximize the number of looks while the beam is moving rapidly (Div G). This also occurs on the outbound side during the turn to altimetry to pick up imaging during the sweep back to nadir pointing (Div X). A pushbroom profile is used on both inbound and outbound sides to extend the imaging swath. The profile is targetted from -18.5 minutes through +18 minutes. From -18.5 minutes to -17.4 minutes, Div's H-T switch the radar mode back and forth between Low-SAR and Hi-SAR every 5 seconds. During this time, the two SAR modes provide a different balance between range (cross-track) and doppler (along-track) resolution. In Hi-SAR, cross-track resolution is better than along-track resolution. In Low-SAR, along-track resolution is better than cross-track resolution (see Fig. 5). Switching back and forth will let us try out a special kind of processing to enhance resolution. This is a low-risk experiment because the standard SAR processing will still work without modification. This same experiment was tried on T13, but the data was lost, so it is repeated here. Div U covers most of the SAR swath from -17.1 min to +17 min with Hi-SAR. At +17 minutes, Low-SAR is favored and the instrument switches to this mode for the last minute of SAR swath imaging. Targetting of the outbound pushbroom profile ends at +18 minutes. SAR-Hi mode is used during the backsweep to nadir. This extra coverage may provide some stereo opportunities. Table 7 shows the two B3 only Hi-SAR divisions, table 8 shows two representative Low/Hi-SAR ping pong divisions, and table 9 shows the Hi-SAR division that covers the bulk of the swath.

6.1 PRF and Incidence Angle Profiles

The PRF profile and incidence angle profile (Fig. 3) 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 T16 flyby will be at 950 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.

6.2 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	g	w	Mismatch	Comments
mode	sarh	sarh	sarh	no	
start_time (min)	-6.0	-20.0	18.0	yes	
end_time (min)	6.0	-18.5	19.5	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	2.0	3.0	3.0	yes	
dutycycle	0.73	0.70	0.70	yes	
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	240.000	240.000	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 7: t16 div_gw standard_sar_hi block

Name	Nominal	h	i	Mismatch	Comments
mode	sarl	sarl	sarh	yes	
start_time (min)	-19.0	-18.5	-18.4	yes	
end_time (min)	-6.0	-18.4	-18.3	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	2.0	3.3	3.7	yes	
dutycycle	0.73	0.70	0.70	yes	
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	225.000	210.000	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 8: t16 div_hi standard_sar_low_inbound block

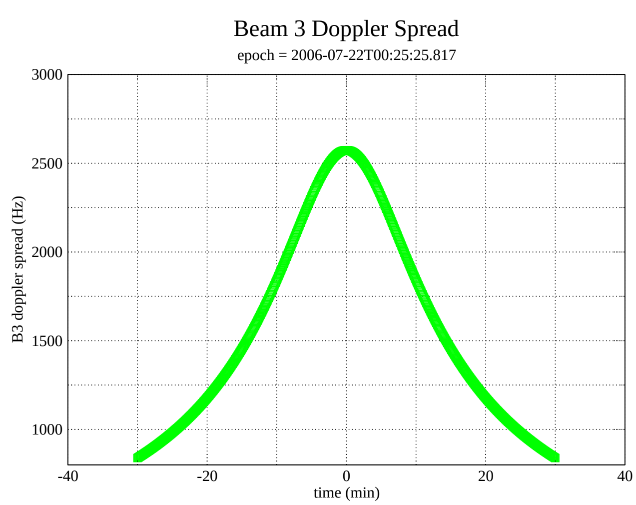

Figure 4: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the two-way 3 dB beam pattern.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-17.4	yes	
end_time (min)	6.0	17.0	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	11111	no	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	2.0	3.7	yes	
dutycycle	0.73	0.70	yes	
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	240.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	off	yes	
interleave_duration (min)	varies	10.0	no	

Table 9: t16 div_u standard_sar_hi block

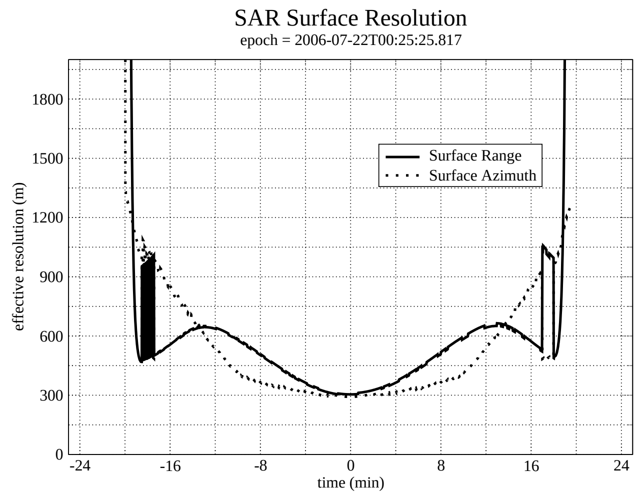

Figure 5: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

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

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 5 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.

7 Revision History

1. Jun 13, 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