Enceladus Scatterometry Rev 120

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- Sequence: s54
- Rev: 120
- Observation Id: en_120_1
- Target Body: Enceladus

1 Introduction

This memo describes one of the Cassini RADAR activities for the s54 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidelines for preparing the RADAR IEB. A 3-hour warmup occurs first using the parameters shown in table 4.

2 CIMS and Division Summary

CIMS ID	Start	End	Duration	Comments
120OT_WARMUP4EN001_RIDER	2009-305T22:14:00	2009-306T01:13:58	02:59:58.0	Warmup for scatterometry and simultaneous radiometry of icy satellite.
120EN_SCATTRAD001_PRIME	2009-306T01:13:58	2009-306T06:41:58	05:28:0.0	Point -Z axis at target and execute raster scan(s) centered on target. Obtain simultaneous scatterometry and radiometry.

Table 1: en_120_1 CIMS Request Sequence

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.

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

Division	Name	Start	Duration	Data Vol	Comments
a	distant_warmup	-9:30:0.0	03:20:0.0	11.9	Warmup
b	distant_radiometer	-6:10:0.0	00:06:0.0	0.4	Radiometer quick-steps
c	distant_radiometer	-6:04:0.0	01:54:0.0	6.8	Radiometer raster scans
d	distant_radiometer	-4:10:0.0	00:25:0.0	1.5	Radiometer placeholder for off-saturn engr tests
e	distant_radiometer	-3:45:0.0	00:55:0.0	3.3	Radiometer placeholder for on-saturn engr tests
f	distant_scatterometer	-2:50:0.0	00:10:48.0	45.4	Scatterometer rcv only off-Enceladus 9 dB cal
g	distant_radiometer	-2:39:12.0	00:00:6.0	0.0	Radiometer division to force power up on next Scatt
h	distant_scatterometer	-2:39:6.0	00:00:6.0	0.7	Scatterometer rcv only on-Enceladus 9 dB cal
i	distant_scatterometer	-2:39:0.0	00:04:0.0	48.0	Scatterometer target-center (Enceladus) with tone
j	distant_scatterometer	-2:35:0.0	00:05:0.0	60.0	Scatterometer target-center (Enceladus) with chirp
k	distant_scatterometer	-2:30:0.0	00:05:0.0	37.5	Scatterometer rcv only on-Enceladus 9 dB cal
l	distant_radiometer	-2:25:0.0	00:25:0.0	1.5	Radiometer filler
m	scatterometer_imaging	-2:00:0.0	00:27:0.0	162.0	Scatterometer imaging
n	scatterometer_imaging	-1:33:0.0	00:29:0.0	174.0	Scatterometer imaging
Total				552.9	

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	205627	off target	2.67	off target
b	169068	off target	2.20	off target
c	167178	off target	2.17	off target
d	121772	off target	1.58	off target
e	109826	off target	1.43	off target
f	82323	off target	1.07	off target
g	76847	76847	1.00	1213
h	76796	76796	1.00	1212
i	76745	76745	1.00	1212
j	74718	74718	0.97	1194
k	72186	72186	0.94	1171
l	69657	69660	0.91	1147
m	57098	57121	0.74	1015
n	43762	43785	0.57	842

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)	varies	-570.0	no	
end_time (min)	varies	-370.0	no	
time_step (s)	varies	5400.0	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	0.248	0.992	yes	Kbps - set for slowest burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: en_120_1 Div a distant_warmup block

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. 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 Overview

This observation is primarily a high altitude SAR imaging observation of Enceladus. It provides the only SAR imaging data for Enceladus until the E16 observation scheduled for Nov 2011 during the second extended mission. The observation begins with an engineering test targeting Saturn. Then the radar central beam is turned to Enceladus for a standard inbound Radiometry raster scan at high range (166,000 km), followed by disk integrated tone and chirp observations just like prior distant icy satellite observations. Following these segments, the spacecraft turns to offset the beam to a suitable imaging area and the radar collects high altitude scatterometer imaging data down to an altitude of about 30,000 km.

4 Receive Only Engineering Test Measurements

Div's D and E provide place holders for the off-Saturn and on-Saturn engineering tests. These tests are inserted into the IEB separately using the spreadsheet interface. They consist of receive only data collections in each of the four bandwidth modes and using various typical attenuator settings for each mode. These receive only data collected while pointing at Saturn and at cold space (two known reference sources) can then be processed into gain and noise temperature data for the instrument and later used to adjust calibration settings if needed. These data are collected in compressed mode to get more integration time. The PRF and number of pulses are chosen to fill the science data buffer. These parameters give the best performance possible from the compressed mode.

Div's F, H, and K provide additional receive only data for the scatterometer mode and the 9 dB attenuator setting when viewing Enceladus and cold space. They provde calibration data for the Enceladus observation.

5 Div's I,J: Enceladus Distant Scatterometry

Figures 1 and 2 show the pointing design for the scatterometry stare from the merged ckernel. The angular size of the target is about 4.3 mrad during this division. The beam 3 beamwidth is 6 mrad. The division parameters for the tone target integration are shown in table 5.

5.1 Distant Scatterometer Performance

The detection performance is shown in figures 3, 4, and 5. The maximum doppler spread in Div j is 1194 Hz which comes from rotation and spacecraft motion. In this division, the PRF needs to be higher than the doppler spread to support potential range-doppler processing, and is set by division parameter to 1300 Hz. With this PRF, the range ambiguity spacing is 115 km while Enceladus is 249 km in radius. The range-spread of the beam depends on where it is pointed. For target centered pointing the cosine law can be applied to solve the geometry. At 74718 km range, the range-spread is 151 km. These numbers show that ambiguities will limit the usable parts of the beam to some degree.

Figure 5 shows that range processing is marginal due to low SNR. The PRF is still set to 1300 to cover the doppler spread and cleanly show the doppler spectrum. Disk integrated results from the tone division should be very stable.

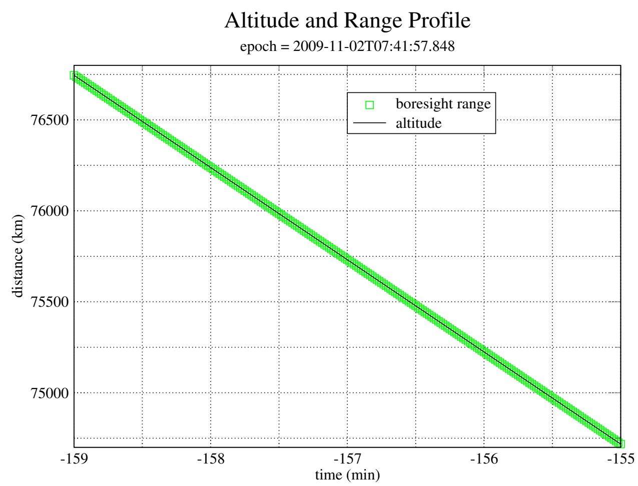

Figure 1: Div I: Altitude and range to the boresight point

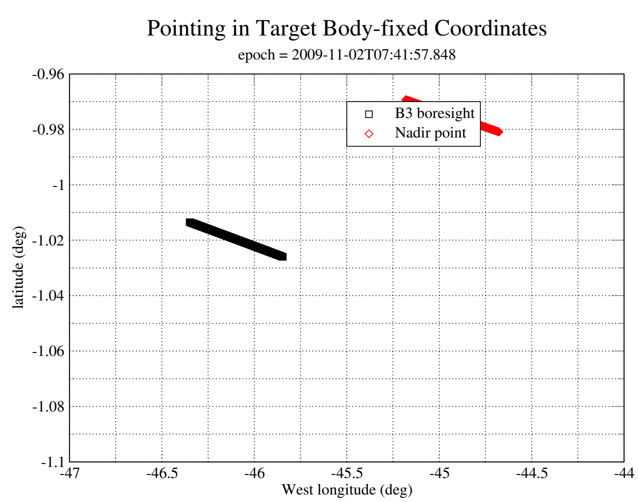

Figure 2: Div I: Stare in target body-fixed coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-159.0	no	
end_time (min)	varies	-155.0	no	
time_step (s)	don't care	6.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	
csr	0	0	no	0 - normal operation with fixed attenuator set to match Phoebe for easier cross-calibration
noise_bit_setting	4.0	4.0	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	no	
prf (Hz)	varies	2232	no	Set to cover doppler spread and allow CSF*PRI = integer
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	90	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	2	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	0.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	200.000	200.000	no	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: en_120_1 Div i distant_scatterometer block

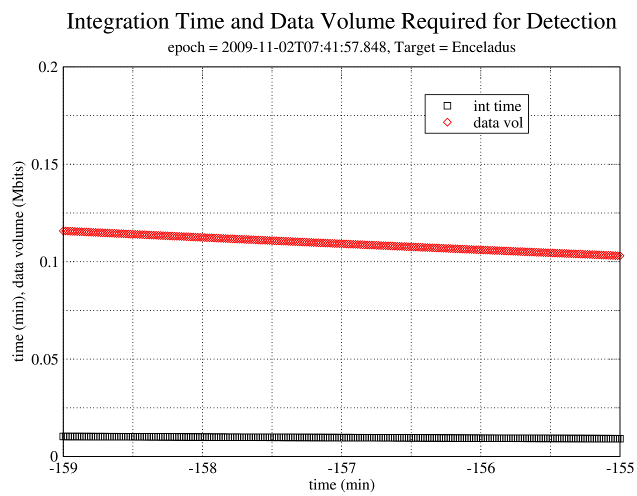

Figure 3: Scatterometry Div's I: Detection integration time required for a single point detection using optimal chirp bandwidth

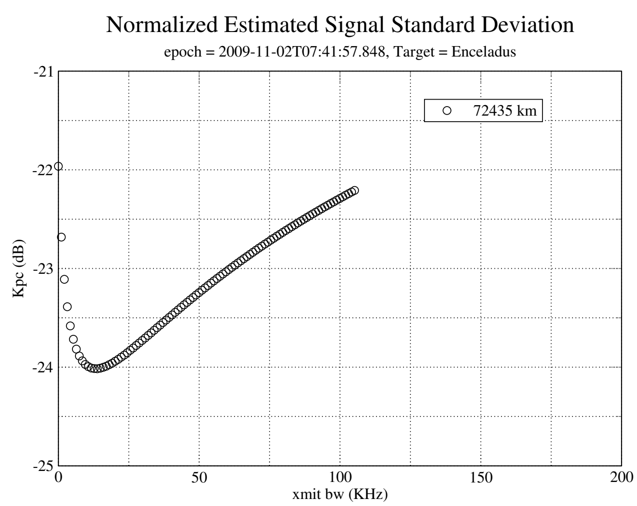

Figure 4: Div J: Normalized estimated signal standard deviation for a disk integrated observation using optimal chirp bandwidth and assuming all the bursts occur at minimum range, and 15 minutes away from minimum range.

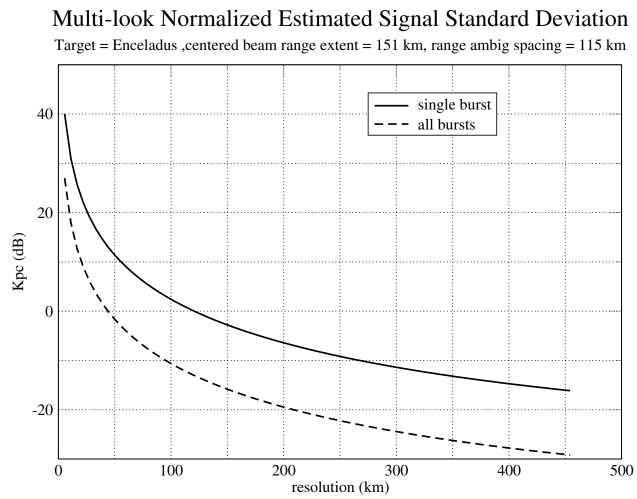

Figure 5: Div J: Normalized estimated signal standard deviation for a range/doppler cell as a function of resolution. Range/doppler resolution elements are both set equal to the specified resolution. Results are shown for a single burst, and for all the bursts in this division. Calculations are performed using the geometry at the start of the division. The presence of ambiguities are not shown.

6 High Altitude Scatterometer Imaging

After the distant scatterometry, division l puts the radar into radiometer mode to save data volume and wait for the range to decrease enough to permit useful SAR imaging using the scatterometer mode to maximize SNR and keep range/doppler pixels reasonably square. This mode of data collection is similar to the high altitude scatterometer imaging conducted on Titan at similar ranges (20,000 - 35,0000 km). The spacecraft turns to offset the beam from centered pointing to provide an ambiguity free area in the Southern hemisphere. Figure 6 show the beam 3-dB footprint overlaid on the target. Both the nadir point and the limb are in the footprint. Their presence in the footprint will complicate processing, but a central area of the beam should still provide an ambiguity free image.

The high altitude imaging segments are designed to optimize range-doppler ambiguities, resolution, number of looks and noise-equivalent cross-section. These segments 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 as was done in T19. Resolution in these segments will be in the 2 km range. For more technical details on range and doppler ambiguities, refer to the discussion in the T19 sequence design memo.

6.1 SAR-style Scatterometer Resolution Performance

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

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

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

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 body, and θ_v is the angle between the velocity vector and the look direction. Figure 7 shows the results from these equations for the scatterometer imaging time. The calculations are performed for the boresight of beam 3 which is the center of the swath.

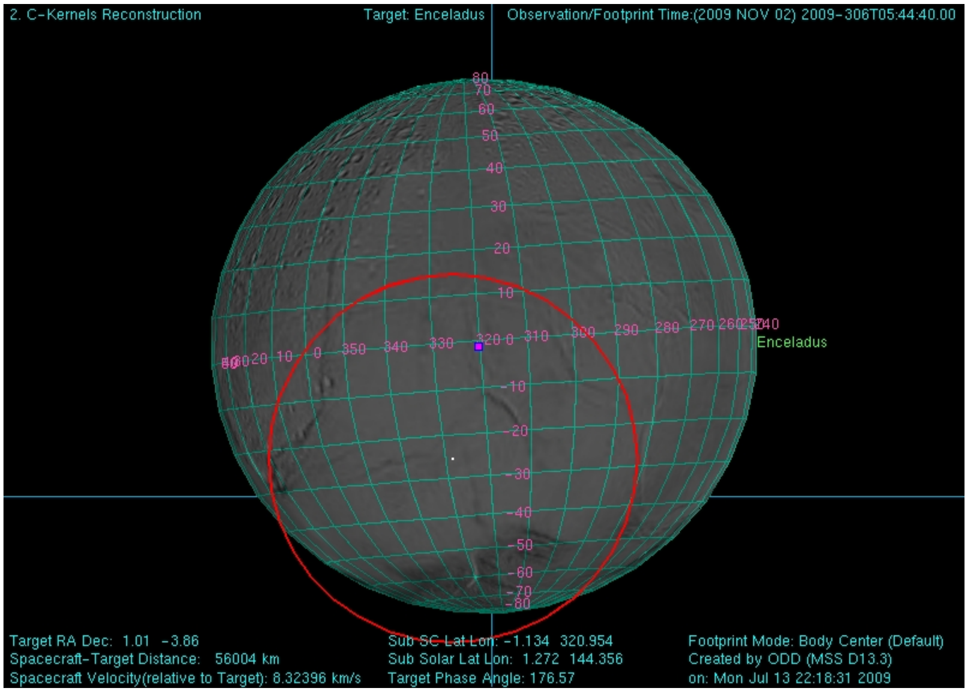

Figure 6: Div N: Beam 3 footprint on Enceladus at the end of the scatterometer imaging period. Shows the illuminated area. Ambiguities, including the nadir ambiguity will reduce usable area in processed image.

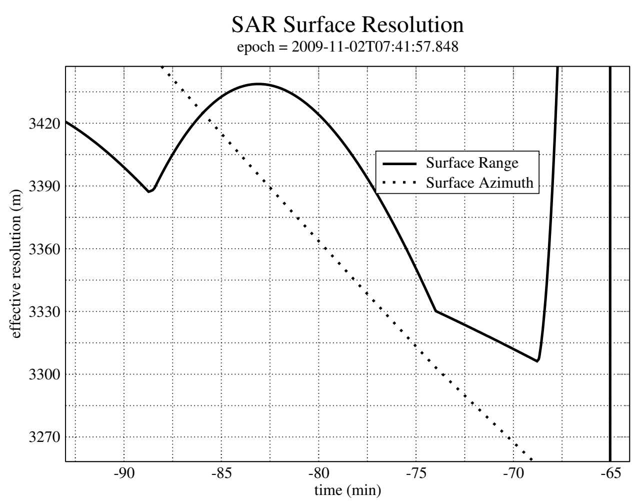

Figure 7: Scatterometer imaging projected range and azimuth resolution. These values are computed from the IEB parameters.

7 Revision History

1. Dec 08, 2010: Initial Release

8 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