Enceladus Scatterometry Rev 088

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- Sequence: s44
- Rev: 088
- Observation Id: en_088_1
- Target Body: Enceladus

1 Introduction

This memo describes one of the Cassini RADAR activities for the s44 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
088OT_WARMUP4EN001_RIDER	2008-283T09:30:00	2008-283T10:30:43	01:00:43.0	Warmup for scatterometry and simultaneous radiometry of icy satellite.
088EN_SCATTRAD001_PRIME	2008-283T10:30:43	2008-283T14:06:43	03:36:0.0	Point -Z axis at target and execute raster scan(s) centered on target. Obtain simultaneous scatterometry and radiometry.

Table 1: en_088_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	00:00:0.0	01:06:0.0	3.9	Warmup
b	distant_scatterometer	01:06:0.0	00:00:30.0	0.6	Scatt division to force power up
c	distant_radiometer	01:06:30.0	00:05:30.0	0.3	Radiometer on Saturn
d	scat_compressed	01:12:0.0	00:09:48.0	2.5	On-Saturn scatt compressed 9 dB calibration
e	distant_scatterometer	01:21:48.0	00:01:12.0	13.3	Scatterometer target-Saturn with tone
f	distant_radiometer	01:23:0.0	00:04:0.0	0.2	Radiometer turning to Rings
g	distant_scatterometer	01:27:0.0	00:01:30.0	15.9	Scatterometer target-Rings with tone
h	distant_scatterometer	01:28:30.0	00:01:30.0	15.9	Scatterometer target-Rings with tone
i	distant_radiometer	01:30:0.0	02:05:0.0	7.4	Radiometer raster scan of Enceladus
j	scat_compressed	03:35:0.0	00:07:0.0	1.8	On-Enceladus scatt compressed 9 dB calibration
k	distant_scatterometer	03:42:0.0	00:20:0.0	252.0	Scatterometer target-center (Enceladus) with tone
l	distant_scatterometer	04:02:0.0	00:08:0.0	100.8	Scatterometer target-center (Enceladus) with tone
m	distant_radiometer	04:10:0.0	00:10:0.0	0.6	Radiometry turning off target
n	scat_compressed	04:20:0.0	00:10:0.0	2.6	off-target scatt compressed 9 dB calibration
o	distant_radiometer	04:30:0.0	00:05:0.0	0.3	Closing Radiometry
Total				418.3	

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	428977	off target	5.57	off target
b	403364	off target	5.23	off target
c	403151	off target	5.23	off target
d	400783	off target	5.20	off target
e	396471	off target	5.14	off target
f	395934	off target	5.14	off target
g	394132	off target	5.11	off target
h	393451	off target	5.11	off target
i	392767	off target	5.10	off target
j	324518	324518	4.21	717
k	319996	319996	4.15	726
l	306649	306649	3.98	753
m	301131	301131	3.91	763
n	294090	off target	3.82	off target
o	286888	off target	3.72	off target

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	0.0	no	
end_time (min)	varies	66.0	no	
time_step (s)	varies	1200.0	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_088_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 Receive Only Engineering Test Measurements

Div's D, J, and N (see table 5) provides scatt mode, 9 dB attenuator receive only data off and on Saturn and Enceladus for calibration of the scatterometer tone integration data. All of the receive only data is 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.

4 Special Saturn and Rings Scatterometry

The geometry in this observation allows for the first attempt by the radar to measure backscatter from Saturn and the Rings. A successful detection here could help to constrain or motivate future attempts at even closer ranges if the 2nd extended mission provides such opportunities. To accomodate three separate targets, RMSS will be run three times with different targets specified in the config file. In one run, Div E supplies parameters for a short integration of Saturn (see table 6). The observation is basically the same as the tone integrations performed on icy satellites. The doppler spread within the beam is quite large at about 12 KHz, and pulse parameters that could accomodate such a high PRF would cause an unacceptable loss of echo energy due to instrument timing constraints. Therefore doppler resolution will not be possible, but a beam integrated albedo can still be computed if a signal is detected. Most of the data volume is reserved for Enceladus which is the primary target, so the chances of detecting a signal from Saturn are small.

The rings of Saturn pose a more challenging target because they are not a cohesive body like Saturn and the icy satellites. To provide a suitable target for RMSS to track range and doppler with, we modified the SPICE kernel file that specifies planetary constants (pck file) to make Saturn look more like the rings. Specifically, the equatorial radii were set to 144643 km which is the outer radius of the rings, while the polar radius was set to 100 m. The resulting triaxial ellipsoid provides a surface at close to the correct range for the time interval when the beam 3 boresight traverses the rings. The relative doppler, however, will not be correct except at one point where the ring model rotation rate matches the ring particle orbital velocity. To get approximately correct doppler shifts, the rotation rate was set to match the inner ring edge orbital velocity in one run, and to the outer ring edge orbital velocity in another run of RMSS. These end point values for doppler were then linearly interpolated across the rings and manually inserted into the IEB. The relevant parameter being modifed was the chirp start frequency. Fortunately, this parameter does not affect the timing of radar instructions, so this manual change was relatively easy to implement. Div's G and H are the same and provide the parameters needed to target the RINGS (see table 7). As with Saturn, the doppler spread within the beam was too high to accomodate with pulse timing parameters without losing a large fraction of the echo energy. Again, the PRF was set to a lower value (1302 Hz) to allow for efficient collection of energy at the expense of being able to resolve the doppler spread. At closer ranges, SNR will be less restrictive and then it will be possible to use a higher PRF. The rings integration is more likely to yield a signal detection because the rings are composed of many icy particles that are large compared to the radar wavelength (2 cm). Limited integration time might still make this a difficult detection depending on how strong the ring backscatter actually is.

Name	Nominal	Actual	Mismatch	Comments
mode	scat_compressed	scat_compressed	yes	
start_time (min)	varies	72.0	no	
end_time (min)	varies	81.8	no	
time_step (s)	don't care	30.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	3	3	no	3 - PRI summation
csr	1	1	no	1 - receive only antenna measurement
noise_bit_setting	4.0	4.0	no	9 dB setting used by all low SNR scatterometry
dutycycle	don't care	0.38	no	
prf (Hz)	1200	1200	no	
tro	don't care	6	no	automatically set to 6
number_of_pulses	150	150	no	Set with the PRF to fill the science data buffer - Only 2 PRI's worth of data are downlinked.
n_bursts_in_flight	1	1	no	
percent_of_BW	don't care	0.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	4.300	4.300	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: en_088_1 Div d scat_compressed block

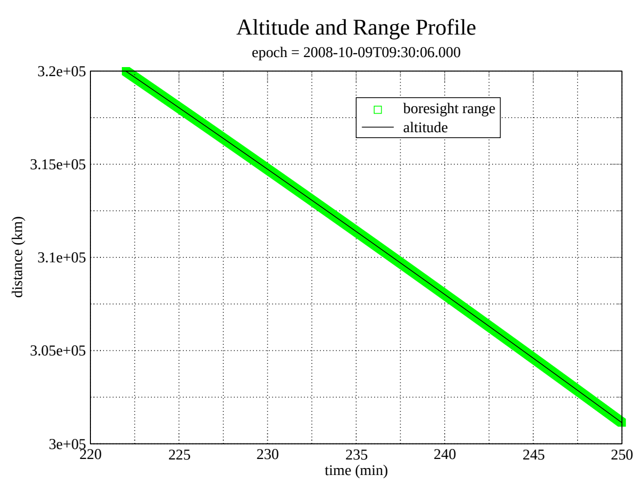

Figure 1: Div K,L: Altitude and range to the boresight point

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	81.8	no	
end_time (min)	varies	83.0	no	
time_step (s)	don't care	30.0	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	7800	no	Can not cover doppler spread, set to allow CSF*PRI = integer multiple
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	210	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	8	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	185.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 6: en_088_1 Div e distant_scatterometer block

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	87.0	no	
end_time (min)	varies	88.5	no	
time_step (s)	don't care	5.0	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	0.65	yes	
prf (Hz)	varies	1302	no	Can not cover doppler spread, set to allow CSF*PRI = integer multiple
tro	6	6	no	6 - allows for some noise only data in time domain
number_of_pulses	varies	96	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	3	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	177.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 7: en_088_1 Div g distant_scatterometer block

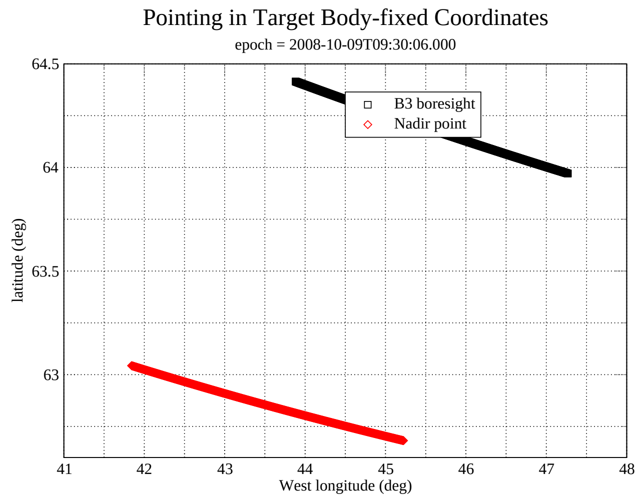

Figure 2: Div K,L: Stare in target body-fixed coordinates

5 Div's K,L: Enceladus 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 1.2 mrad during this division. The beam 3 beamwidth is 6 mrad. The division parameters for the tone target integration are shown in table 8.

5.1 Scatterometer Performance

The detection performance is shown in figures 3, 4, and 5. The maximum doppler spread in Div l is 763 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 919 Hz. With this PRF, the range ambiguity spacing is 163 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 306649 km range, the range-spread is 248 km.

Figure 5 shows that range processing is impossible due to low SNR. The PRF is still set to 919 to cover the doppler spread and cleanly show the doppler spectrum. Disk integrated results from the tone divisions will be less stable than earlier icy satellite integration becuase the target is much smaller than the beam. A nominal standard deviation of 0.1 in the albedo measurement would require about 500 Mbits (see Fig. 3), but only 424 Mbits in total are available. With available data volume, the standard deviation of the albedo measurement will be about 0.25. The data volume expended on the Saturn and Rings observations is too small to make a signficant difference here.

6 Revision History

1. Aug 13, 2008: Initial Release

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	242.0	no	
end_time (min)	varies	250.0	no	
time_step (s)	don't care	20.0	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	919	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	56	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	4	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	210.000	yes	Kbps - determines burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 8: en_088_1 Div l distant_scatterometer block

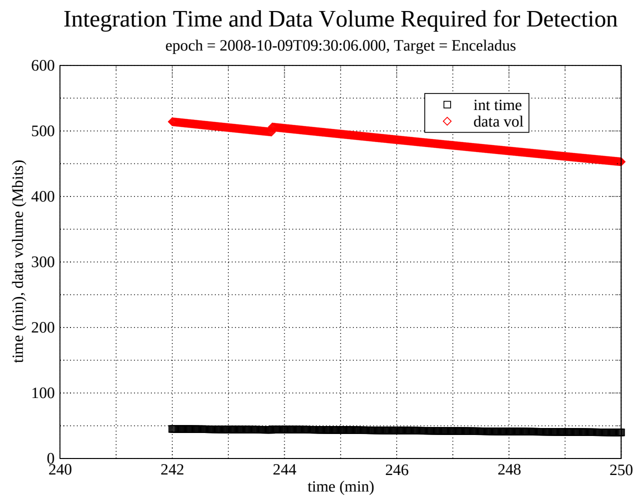

Figure 3: Scatterometry Div's L: Detection integration time required for a single point detection using optimal chirp bandwidth

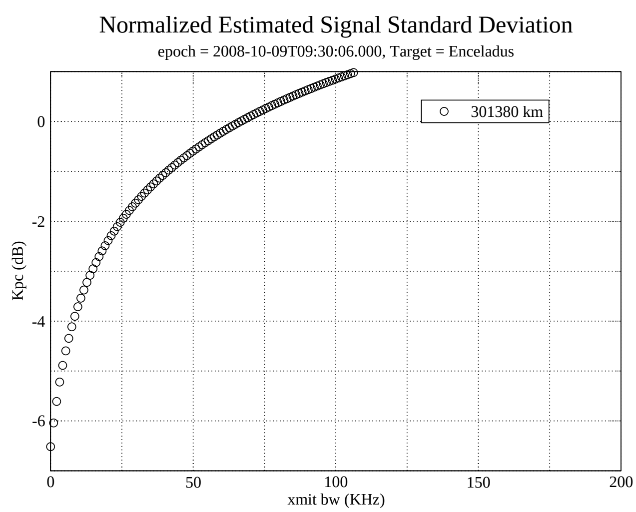

Figure 4: Div's L: Normalized estimated signal standard deviation for a disk integrated observation using optimal chirp bandwidth and assuming all the bursts occur at minimum range, and 15 minutes away from minimum range.

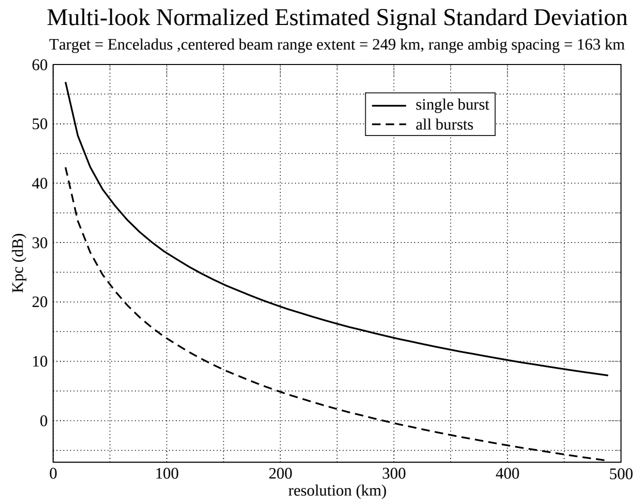

Figure 5: Div L: Normalized estimated signal standard deviation for a range/doppler cell as a function of resolution. Range/doppler resolution elements are both set equal to the specified resolution. Results are shown for a single burst, and for all the bursts in this division. Calculations are performed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

7 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