Distant Titan Scatterometry/Radiometry in S05, Rev A

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- Sequence: s05
- Rev: 00A
- Observation Id: ti_00a_1
- Target Body: Titan

1 Introduction

This memo describes one of the Cassini RADAR activities for the s05 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.

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. 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

The radar warmup rider begins at 2004-10-24T23:56:00.000 (-03:00:0.0) and lasts for the standard 03:00:0.0. During the warmup, the IEB will be set for slow speed radiometer only data as shown in table 4.

CIMS ID	Start	End	Duration	Comments
00AOT_WARMUP001_RIDER	2004-298T23:56:00	2004-299T02:56:00	03:00:0.0	Warmup for calibration and science data collection.
00ATI_SOUTH7CAL001_PRIME	2004-299T02:56:00	2004-299T04:16:00	01:20:0.0	Obtain distant Titan radiometer science and calibration data. One of a set that provides coverage of Titan southern latitude variation along with some obtainable associated longitude variation.
00ATI_SOUTHSCAT001_PRIME	2004-299T04:26:00	2004-299T06:06:00	01:40:0.0	Obtain distant Titan scatterometry science and calibration data. One of a set that provides coverage of Titan southern latitude variation along with some obtainable associated longitude variation.

Table 1: ti_00a_1 CIMS Request Sequence

4 Div B: Radiometry Scan

Figures 1 and 2 show the pointing design for the radiometry scan from the merged ckernel. The boresight is pointed most of the time off target, hence the lat-lon plot shows only a few discrete points. The scans use 1/4 beamwidth spacing to allow for some super-resolution processing of the radiometer data. The angular size of the target is about 6.7 mrad during this division. The beam 3 beamwidth is 6 mrad. The IEB for this division is controlled by a block of keywords as shown in Table 5

Near the end of division B, there is a 10 minute period (01:20 - 01:30) during which the telemetry mode will change from 8A to 5A for an ISS observation. During these 10 minutes, ISS controls the pointing, and RADAR is restricted to 1 s burst periods or longer, and a maximum data rate of 7.6 Kbps. The radiometer burst period is slightly less than 1 s during this time and we expect to drop 5 or 6 packets (bursts). This will not affect the RADAR science collection. Starting at 1:30, the telemetry mode changes back to 8A for the upcoming scatterometer operations.

5 Div's C,E: Scatterometer Noise-only Integrations

Two noise only integrations will be collected in scatterometer mode to aid in cross-calibrating the scatterometer with the radiometer, and to help understand the effects of the scatterometer bandpass filter on calibration of the scatterometer data. The first in division C is a two minute off-target data collection with the transmitter disabled by selecting the Antenna calibration source. See table 6 for the specific parameters. The only difference between this collection and a distant scatterometer integration is the disabling of the transmitter. The off-target integration is intended to provide a cold sky measurement using the scatterometer bandpass. Pointing plots were checked to verify that no targets (eg., Sun, Saturn) were in the beam 3 main lobe during the division C time interval. The second integration in division E is an on-target data collection with the transmitter again disabled. The on-target collection provides a Titan radiometric measurement using the scatterometer bandpass.

Division	Name	Start	Duration	Data Vol	Comments
a	distant_warmup	-3:00:0.0	03:00:0.0	2.7	Warmup
b	distant_radiometer	00:00:0.0	01:38:0.0	5.9	Radiometer scan
c	distant_scatterometer	01:38:0.0	00:02:0.0	24.0	Scatterometer off-target 2 minute noise accumulation
d	distant_radiometer	01:40:0.0	00:15:0.0	0.9	Radiometer inbetween Scatt noise accumulations
e	distant_scatterometer	01:55:0.0	00:02:0.0	24.0	Scatterometer on-target 2 minute noise accumulation
f	distant_radiometer	01:57:0.0	00:13:48.0	0.8	Radiometer inbetween Scatt noise accumulation and normal Scatt target integration
g	distant_scatterometer	02:10:48.0	00:36:12.0	434.4	Scatterometer on-target stare
h	distant_radiometer	02:47:0.0	00:23:0.0	1.4	Radiometer during final turn
Total				494.1	

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	861241	off target	1.08	off target
b	790019	off target	0.99	off target
c	751684	off target	0.95	off target
d	750905	off target	0.94	off target
e	745066	745066	0.94	1719
f	744288	744288	0.94	1718
g	738923	738923	0.93	1707
h	724880	724880	0.91	1678

Table 3: Division geometry summary. Values are computed at the start of each division. B3 Doppler spread is for one-way 3-dB pattern.

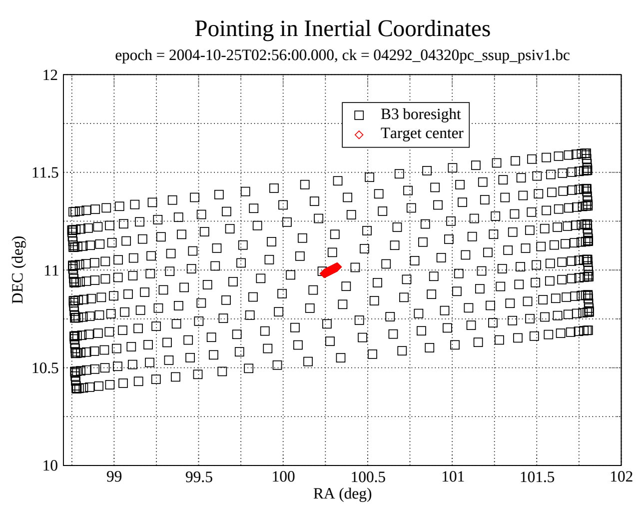

Figure 1: Inbound scan in inertial coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	varies	-180.0	no	
end_time (min)	varies	0.0	no	
time_step (s)	varies	1800.0	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	no	
dutycycle	don't care	0.38	no	
prf (KHz)	don't care	1.00	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	0.250	no	Kbps - set for slowest burst period
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: ti_00a_1 div_a distant_warmup block

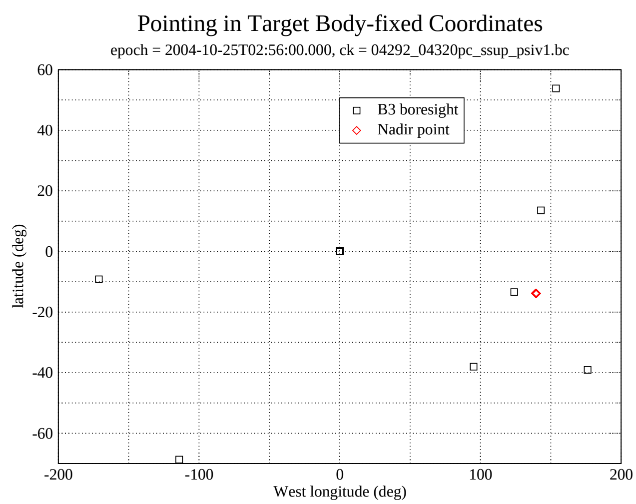

Figure 2: Inbound scan in target body-fixed coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	varies	0.0	no	
end_time (min)	varies	98.0	no	
time_step (s)	varies	1800.0	no	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	no	
dutycycle	don't care	0.38	no	
prf (KHz)	don't care	1.00	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	starting value for auto-rad
max_data_rate	1.000	1.000	no	1 Kbps - 1 s burst period which is adequate for slow radiometer scans
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: ti_00a_1 div_b distant_radiometer block

The radiometric sensitivity of the receiver is given by,

$$\Delta T = \frac{T_{\rm sys}}{\sqrt{tB}}, \quad (1)$$

where $T_{\rm sys} = T_r + T_a$ is the system temperature (the sum of the receiver noise temperature and the antenna temperature), t is the integration time (the length of the echo window for one burst), and B is the measurement bandwidth (the width of the selected bandpass - 117 KHz for scatterometer mode). For this pair of observations, about 50 Mbits will be set aside for this cross-calibration study. This will still leave 250 Mbits for the primary detection which should be enough (see figure 3).

Dividing the data volume in samples by the sample rate (250 KHz) gives an integration time of 12 s for each integration. Assuming a system temperature of 1000 K gives a ΔT of 0.8 K which is about 1% of Titan's apparent radiometric temperature.

6 Div G: Scatterometer Performance

Following the radiometer raster scan and the noise only integrations, the spacecraft will have beam 3 pointed at the center of Titan for a distant scatterometer integration. The range to the target 36 hours prior to the Ta closest approach is about 750,000 km. The extreme range more than counter balances the fact that the disk is a little larger than the beam main lobe. The detection performance is shown in figures 3 and 4. The performance is similar to the inbound Phoebe observation, and the IEB strategy will be similar as shown in table 7.

A tone transmission will be used because the signal is too weak to allow for any range compression processing. The PRF will be set higher than the disk bandwidth to allow for doppler processing without any folding of the signal onto itself from the comb pattern generated by the pulsed nature of the signal. The resolution of the signal as a function of doppler will be limited due to the weak signal. This is not a big issue for this observation because its primary purpose

Name	Nominal	c	e	Mismatch	Comments
mode	scatterometer	scatterometer	scatterometer	no	
start_time (min)	varies	98.0	115.0	no	
end_time (min)	varies	100.0	117.0	no	
time_step (s)	don't care	16.0	16.0	no	Used when BIF > 1, otherwise set by valid time calculation
bem	00100	00100	00100	no	
baq	5	5	5	no	
csr	0	1	1	yes	1 - Antenna calibration, transmitter disabled, fixed attenuator set to match Phoebe for easier cross-calibration
noise_bit_setting	4	4	4	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	0.70	no	
prf (KHz)	varies	2.00	2.00	no	Set to cover target doppler bandwidth
number_of_pulses	varies	100	100	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	10	10	no	Used to increase PRF and data rate at long range
percent_of_BW	0.0	0.0	0.0	no	
auto_rad	on	on	on	no	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	200.000	200.000	200.000	no	Kbps - determines burst period
interleave_flag	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	no	

Table 6: ti_00a_1 div_ce distant_scatterometer block

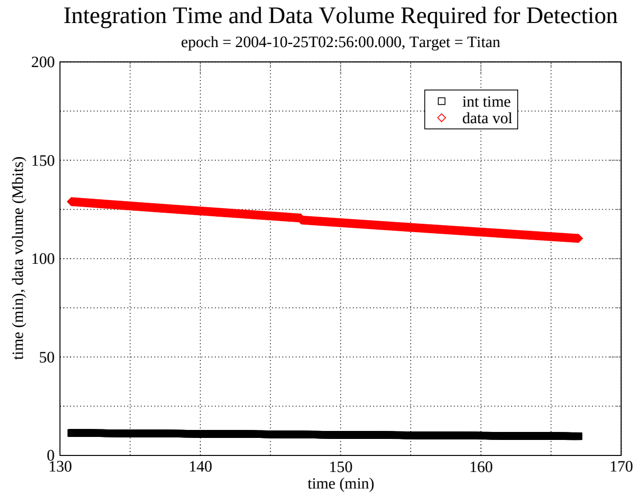

Figure 3: Inbound scatterometry Div G: Detection integration time required for a single point detection using optimal chirp bandwidth

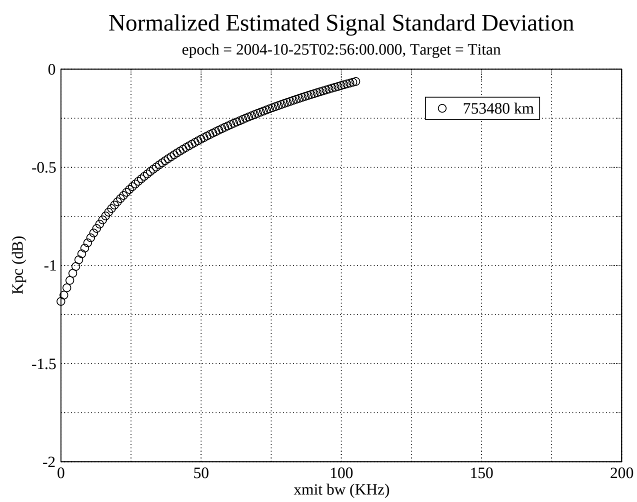

Figure 4: Inbound observation Div C: Normalized estimated signal standard deviation for a disk integrated observation assuming all the bursts occur at minimum range, and 15 minutes away from minimum range.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	130.8	no	
end_time (min)	varies	167.0	no	
time_step (s)	don't care	16.0	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	4	no	Scat signal set higher than ALT/SAR
dutycycle	0.70	0.70	no	
prf (KHz)	varies	2.00	no	Set to cover target doppler bandwidth
number_of_pulses	varies	100	no	depends on PRF choice (can have more shorter pulses)
n_bursts_in_flight	varies	10	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 7: ti_00a_1 div_g distant_scatterometer block

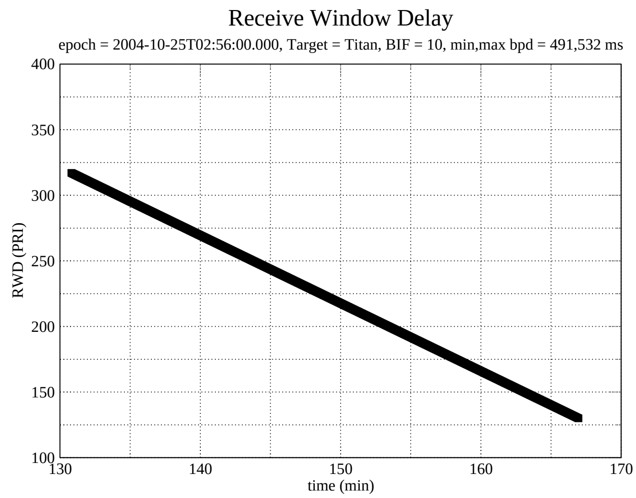

Figure 5: Div G: Inbound scatterometer receive window delay. Subtitle shows the minimum and maximum burst periods that are in principle compatible with the division selected number of bursts in flight.

is to provide a disk integrated backscatter value for calibration against Earth based radar measurements of Titan. Any doppler spectrum data will be an extra bonus. This observation will also include an upgraded RMSS calculation that will make the chirp start frequency an integer multiple of the PRF. This is done to keep the echo peak from being split in the frequency domain by the comb pattern due to the pulsed nature of the signal. System parameters for division G:

- P_t = 46 W
- T_{sys} = 800 K
- $G_{antenna}$ = 50.7 dB
- frequency = 13.78 GHz
- beamwidth = 0.35 deg
- PRF = 2000 Hz
- pulse width = 350.0 us
- burst period = 530.0 ms
- bursts in flight = 10
- burst duty cycle = 0.07

The range is large enough that multiple bursts in flight will be needed. Figure 5 shows the receive window delay (RWD) that will be needed for the current pulse parameters shown in table 7. The range of burst periods that are compatible with the number of bursts in flight (giving RWD $\in [0, 1023]$) is also shown. RMSS actually imposes a more strict limit on RWD to accomodate timing constraints in the instrument. Although not shown in table 7, 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. The positive TRO value also guarantees noise-only data in each burst which eliminates the need to insert special noise-only bursts.

Name	Nominal	d	f	h	Mismatch	Comments
mode	radiometer	radiometer	radiometer	radiometer	no	
start_time (min)	varies	100.0	117.0	167.0	no	
end_time (min)	varies	115.0	130.8	190.0	no	
time_step (s)	varies	300.0	600.0	600.0	no	Used by radiometer only modes
bem	00100	00100	00100	00100	no	
baq	don't care	5	5	5	no	
csr	6	6	6	6	no	
noise_bit_setting	don't care	4	4	4	no	
dutycycle	don't care	0.38	0.38	0.38	no	
prf (KHz)	don't care	1.00	1.00	1.00	no	
number_of_pulses	don't care	8	8	8	no	
n_bursts_in_flight	don't care	1	1	1	no	
percent_of_BW	don't care	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	starting value for auto-rad
max_data_rate	1.000	1.000	1.000	1.000	no	1 Kbps - 1 s burst period which is adequate for slow radiometer scans
interleave_flag	off	off	off	off	no	
interleave_duration (min)	don't care	10.0	10.0	10.0	no	

Table 8: ti_00a_1 div_dfh distant_radiometer block

7 Div's D,F,H: Radiometer Inbetween Scatterometer Operations

During the times inbetween the scatterometer noise only integrations and the scatterometer target integration, and at the end of this observation, the instrument will be put in radiometer only mode with parameters shown in table 8. These divisions are essentially the same as the radiometer settings for the raster scan. The only differences are the start and stop times and the time interval used to generate a few instructions for each radiometer segment.

8 Revision History

1. Aug 20, 2004: Initial release
2. Sep 21, 2004: Added description of telemetry mode changes between radiometer and scatterometer operation

9 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