CONSERT Operation Requests

Technical Note

CHANGE RECORDS

ISSUE	DATE	EVOLUTION	AUTHOR
1.0	5/12/2013	1st issue	P. Puget
1.1	09/05/2014	Update of CONSERT Restrictions, Constraints and Limitations (3)	

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1 Introduction

This technical note specifies the functioning of CONSERT and the associated constraints in term of orbits and relative orientations. It gives also some rough estimate of power consumption and data flow required.
For the SDL/FSS specifically the constraints developed in this note were included in RO-LAN-RD-1100.

2 CONSERT functioning

2.1 Overview

The purpose of the experiment is to determine the main dielectric properties from the propagation delay and, through modeling, to set constraints on the cometary composition (materials, porosity…) to detect large-size structures (several tens of meters) and stratification, to detect and characterize small-scale irregularities within the nucleus. A detailed analysis of the radio-waves which have passed through all or parts of the nucleus will put real constraints on the materials and on inhomogeneity and will help to identify blocks, gaps or voids.
CONSERT experiment consists in the rough tomography of the comet nucleus performed by the instrument (COmet Nucleus Sounding Experiment by Radiowave Transmission). It works as a time domain transponder between one module which will land on the comet surface (Lander) and another that will fly around the comet (Orbiter). The Figure 2-1 gives a schematic of the experiment. Basically, a 90 MHz sinusoidal waveform is phase modulated by a pseudorandom code or PSK (Phase Shift Keying) Coding. Such frequency, in the radio range, is expected to minimize the losses during the propagation inside the comet material and the generated pulse code maximizes the signal to noise ratio. In these experimental conditions great attempt is made on the good measurement of the mean dielectric properties and on the detection of large size embedded structures or small irregularities within the comet nucleus.

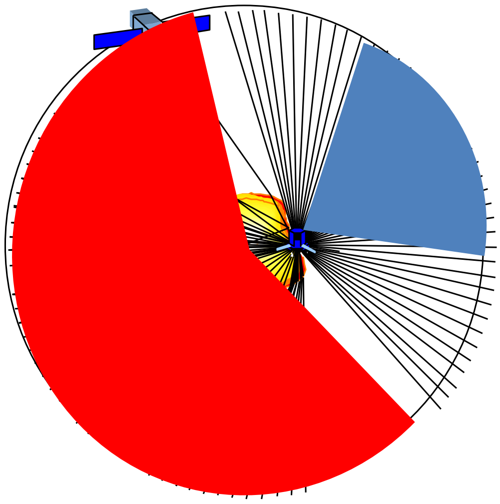

Figure 2-1 : CONSERT Operation throughout the Comet

2.2 CONSERT functioning

The basic measurement for Consert is the time delay directly linked to the length and the physical properties along the propagation path. That supposes the ability to measure time delay with a precision better than 0.1 µsec, which leads to very high constraints in terms of frequency stability ($\Delta f/f = 10^{-12}$) for both parts (as well as precise synchronization between clocks).
To summarize, the propagation from the orbiter to Philae synchronizes both time systems while the scientific measurement is in the propagation from Philae to the orbiter. These constraints on the clocks stability allow a relaxation to $\Delta f/f = 10^{-7}$ during a 10-hour period (actual stability is of 10^{-7} during 30 hours).
Several operational constraints for Consert scheduling are linked to this:

- Warming up the instrument, especially the clocks, needs some time to obtain the right functioning temperature allowing to match the stability required.
- **Tuning:** this phase, mandatory after the warming up, needs a direct signal between orbiter and lander allowing to match the frequency of both clocks and to synchronize both calendars.
- **Science sounding:** during this phase the signal between orbiter and lander needs to go through the comet nucleus. As each individual sounding gives only information integrated along the ray, the most efficient observation will need to cross as much as possible of the comet section. In addition observation at grazing angles allows obtaining information on the roughness at ground level.
- In addition what we call a **calibration** might be done in continuity after the science sounding; these measurements will allow a better adjustment of some parameters used for data analysis.

2.2.1 CONSERT Modes

Once powered ON Consert might be in three different modes, each one with specific power and data profiles.

- OFF: OCN and LCN are OFF no power no data

When CONSERT is ON it will be successively in the following modes:

- TUNNING warm up and tuning
- WAIT: OCN and LCN are ON but without any sounding, the power and TM data rate are reduced. This mode is used after tuning, waiting for the orbiter to arrive at grazing angle (10° above the horizon) to start sounding.
- SOUNDING: OCN and LCN are ON with soundings at a rate defined by the parameters (power and data rate may change depending on the selected parameter see § 2.2.3.

For SDL/FSS, after a first session of sounding instrument is in “PAUSE” waiting for, a quite long period, the next one, allowing to minimize energy and/or data volume, or matching some interferences constraints.

The transitions tuning -> wait->science sounding are the normal functioning mode for Consert.
Transitions science sounding -> wait -> science sounding are quite specific using non standard TCs and should be used only in specific cases (typically needed for SDL - FSS phases).

2.2.2 Scheduling CONSERT

The PHILAE lander shall be awake with CDMS clock resynchronized on “orbiter time” before starting operation on LCN

CONSERT operations require OCN and LCN turn on with accuracy better than 10s.
This synchronization can be achieved by two ways:

- Orbiter schedules for both, orbiter and lander, commands being sent with RF link for immediate execution by PHILAE (Direct Commanding Mode TBC…).
- Absolute time tag commands at lander level that will separate scheduling on both platforms.

At lander level turn on can be achieved by AMST or by Secondary Time Line (STL) execution.

The scheduling of CONSERT activities is non-trivial, because both the CONSERT Lander and Orbiter Turn-On must be synchronized with a maximum delta time of 10 seconds. Moreover, as no combined ROSETTA or PHILAE events exist to trigger activities (unless RF communication), the synchronization should be scheduled based on absolute time, driven by the synchronized Orbiter and Lander clocks, OOBT and LOBT, respectively. For the measurement fine adjustment between the master clocks of OCN and LCN should be done prior to any science measurement, which is done by a “tuning” sequence at the beginning of the observation procedure. This tuning phase is nominally scheduled 6 minutes (minimum value) after the ON of both modules (OCN and LCN), during this phase orbiter and lander should be in direct view with some restriction in term of relative orientation depending on the distance between both parts. Obviously, the CONSERT science measurement requires the Orbiter to disappear beyond the Lander horizon; hence no further Lander communication will be possible anymore. The science measurement should be carried on until orbiter arrives 10° above the horizon of the lander to allow a better calibration of measurements.

2.2.3 Configuration Parameters

The CONSERT activities depend on the specific orbit and geometry and must be adapted accordingly for optimal science outcome. The following CONSERT parameters will/could be changed:

Parameter:	Description:	Mission Table	Energy	Data
DELTATIC	Time between 2 consecutive soundings Each sounding is reported in a short telemetry (4 reports per TM packet)	VCNGA040	The larger the value of DELTATIC, the more energy each sounding cycle requires due to prolonged stand-by.	Telemetry is emitted for each Deltatic step On OCN: 1 HK + 1SCI (if sounding) On LCN : 1 SCI
NBSOUND	Total number of soundings to cover entire measurement.	VCNGA050	Scales with number of soundings as the measurement duration changes.	Scales with number of soundings.
TUNETIC	The standby duration prior to the start of tuning (fixed parameter = 6 minutes)	VCNGA020	n.a	n.a.
STARTTIC	The standby duration prior to the start of sounding	VCNGA030	Longer STARTTIC values increase the standby power consumption	Telemetry is emitted for each Deltatic step
FIOV	Every FIOV soundings, a complete signal is reported in an additional Telemetry for security/calibration (4 TM packets per report)	VLNDA091	n.a.	The lower the FIOV value, the higher the data production.

Table 2-1: CONSERT Configuration Parameters

Typically the total measurement duration is given by the orbit geometry. The time step and number of soundings are adapted to cover this timespan. For more information on the power and data budget, please refer to section.

2.2.4 CONSERT Interferences

The green color corresponds to the instruments CONSERT can operate together with. The orange to those that generate some perturbation but could be acceptable, if not to many instruments of this type operates together. The red color corresponds to instruments that can't operate together with CONSERT.

	YES	Perhaps	NO
ALICE	x		
COSIMA	x		
GIADA		x	
MIDAS	x		
MIRO	x		
OSIRIS		x	
RPC/MAG		x	
RPC/MIP			x
RPC/LAP		x	
RPC/IES		x	
RPC/ICA	x		
ROSINA		x	
RSI		x	
VIRTIS (1)			x
SREM	x		

1. No operation even during the descent

Table 2-2 : CONSERT Orbiter interferences

LANDER

APX	x		
CIVA	x		
ROLLIS	x		
ROMAP		x	
SESAME (1)			x
SD2			x
COSAC			x no tests were done
PTOLEMY			x no tests were done
MUPUS			x

1. SDL chronogram is designed to allow joint operations during the SDL phase.

Table 2-3 : CONSERT Lander interferences

For complete information on interferences refer to document Consert Interferences tests report RO-OCN-TN-3832

3 CONSERT Restrictions, Constraints and Limitations

3.1 Turn ON

Successful synchronization and tuning of the two CONSERT units is a mandatory activity in order to obtain scientifically useful data. The synchronization is the turn on of LCN and OCN with an accuracy better than 10 seconds. The tuning (1 minute duration) is when both instruments adjust their frequencies and calendars.

3.2 Pointing Constraints for tuning

The tuning must occur with direct visibility between the Lander and Orbiter and is subjected to a set of constraints. The geometrical constraints for tuning visibility vary with OCN/LCN distance (orbit radius) and are defined as illustrated in Figure 2-1 : CONSERT Operation throughout the Comet (in blue sector).

For SDL/FSS these constraints are not applicable, as the tuning will be done before the separation (RO-LAN-RD-1100)

The parameters that change as a function of orbit radius are α, β and θ.

The angle β defines a cone around the Lander +Z axis within which the Orbiter must be located and remain during the tuning of the CONSERT Orbiter and Lander units.

The angle θ defines a cone around the Orbiter +Z axis within which the Lander must be located and remain during the synchronization of the CONSERT Orbiter and Lander units.

Theta depends on the attitude of the orbiter while beta defines constraints on the orbiter position.

The values for β and θ scale with Lander – Orbiter distance in a non-algebraic relationship and the specific values as a function of orbit radius must be simulated.

Lander – Orbiter Distance [km]	β_max [deg]	θ_max [deg]
0-15	40	40
15-20	25	25
>25	20	20

Table 3-1 : Beta and Theta with respect to Lander – Orbiter Distance

These limits **must** be adhered otherwise the CONSERT synchronization will fail and the measurement will be useless.

Once the tuning is completed, these angles are not relevant anymore and the only geometrical constraint for sounding is the angle alpha, as defined in Figure 3-1: CONSERT α_{max} versus Orbit Altitude.

The angle α describes the angle between the vector from the Orbiter to the Lander and the Orbiter +Z axis. This angle constrains the degree of allowable off-pointing of the Orbiter attitude. The maximum angle (Nadir off-pointing), α_{max} [deg], is described by the following function

$$\alpha_{\max} = 39 - \tan^{-1}\left(\frac{R_{comet}}{R_{orbit} - R_{comet}}\right)$$

The maximum value of α as a function of orbit radius is illustrated in Figure 3-1: CONSERT α_{max} versus Orbit Altitude

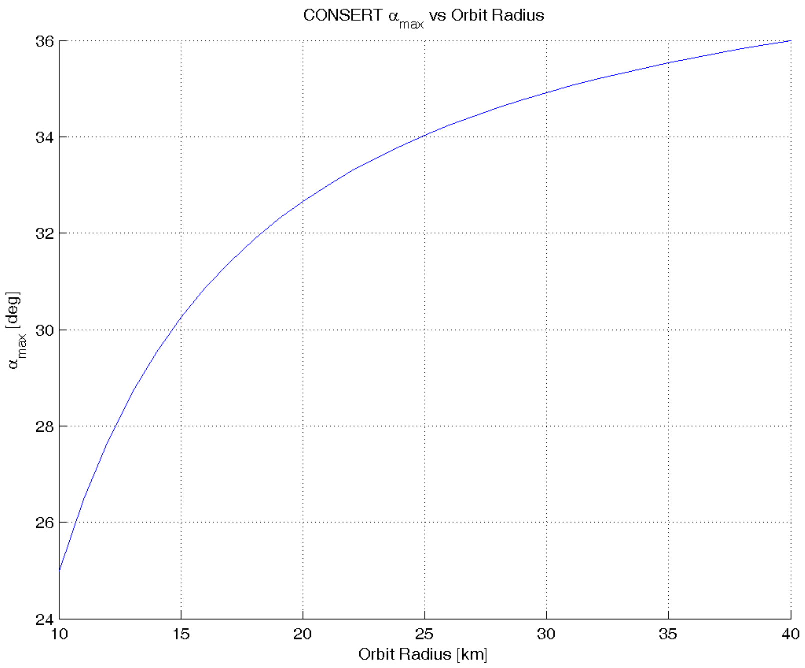

Figure 3-1: CONSERT α_{max} versus Orbit Altitude

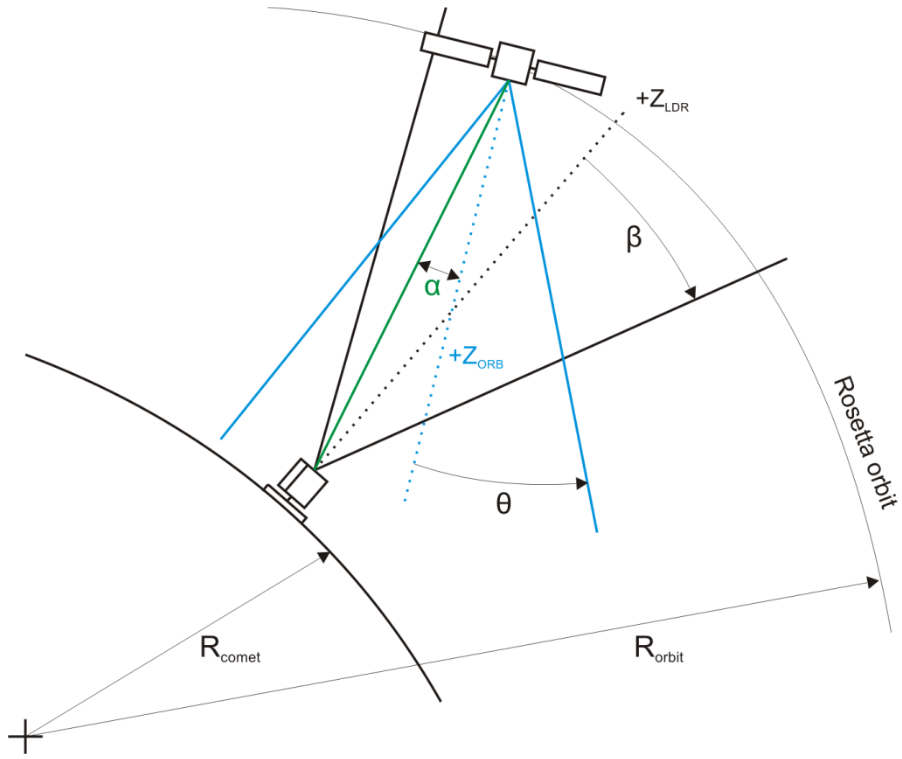

Figure 3-2 : CONSERT Visibility constraints

Figure 3-2 illustrates the CONSERT orbit geometry and the conditions for occultation and visibility. The Rosetta Orbiter can be considered as approx. fixed in space, due to its relatively slow motion, and the rotation is provided by the comet rotation. Occultation occurs once the Orbiter disappears beyond the horizon, which in the illustration is approximated in a simplified manner by the horizontal at the landing site. The angle between the orbit half section and the visibility/occultation is approximated by the angle η [deg]:

$$\eta = \sin^{-1}\left(\frac{R_{comet}}{R_{orbit}}\right)$$

In reality this angle will be larger due to the actual comet surface and horizon features.

The rotation is provided by the comet, thus the rotation period, P, is approx. 12.72hr. The parameters P1 and P2 are the duration of the Orbiter – Lander visibility in the respective range.

$$P1 = \left(\frac{2 \cdot \beta}{360}\right) \cdot P$$

$$P2 = \left(\frac{180 - 2 \cdot \beta - 2 \cdot \eta}{2 \cdot 360}\right) \cdot P$$

These two formulas define how the duration of P1 and P2 varies with changing the orbit radius for an assumed comet radius of 2km.

3.3 Pointing Constraints for science measurements

Consert sounding mode must begin before the end of the direct Lander-Orbiter visibility, typically when the orbiter is +10° above the Philae local horizon. In practice, Consert sounding mode must start before this 10° elevation in order to take in account uncertainties on orbitography and timing

Preferably the CONSERT Orbiter and Lander units have direct visibility prior to terminating the measurement to allow for calibration at the end of the measurement, to increase the confidence in the scientific data: see Figure 2-1 (red sector). The calibration is desirable, not mandatory. For calibration, Orbiter elevation has to be higher than 10° above the horizon taking into account orbitography and timing margins, as illustrated in Figure 3-3: CONSERT Occultation and Visibility

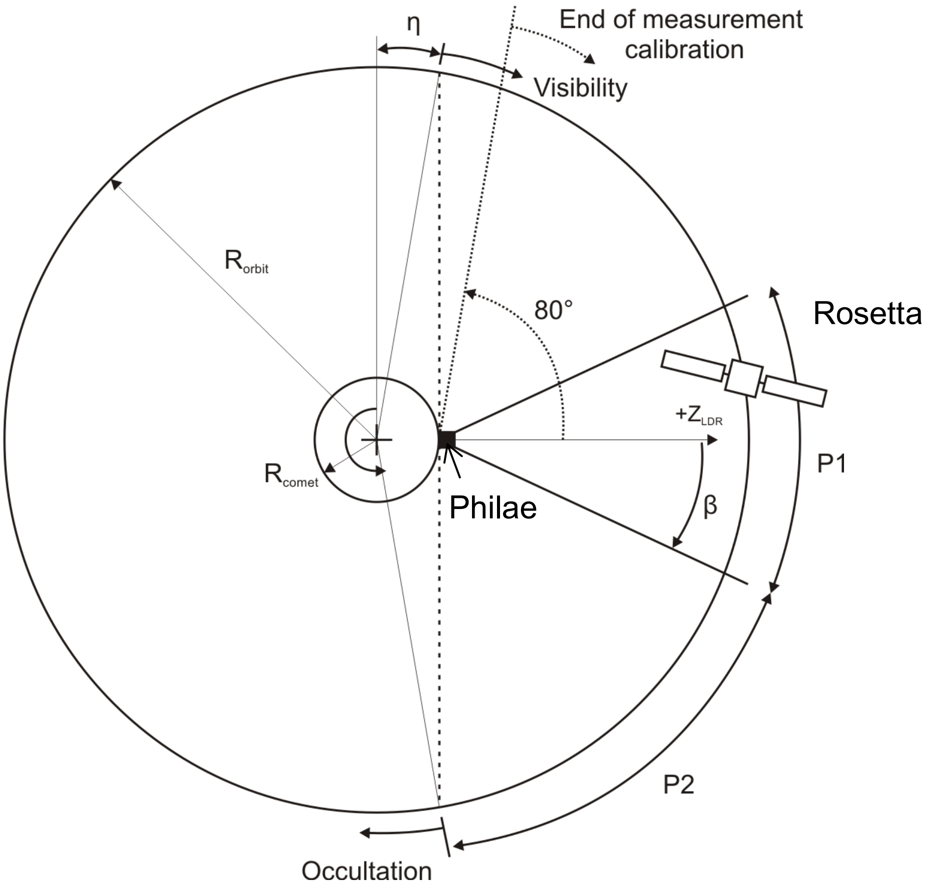

Figure 3-3: CONSERT Occultation and Visibility

These formulas assume the spherical comet. In the real case one should take into account the local horizon and $+Z_{LDR}$ axe.

3.3.1 Orbit Constraints

The Rosetta orbit must guarantee an occultation period to ensure a valid CONSERT measurement. More specific orbit constraints are listed below.

#	Parameter	Constraint	Comment
General			
1	R_{orbit}	<30km	As low as possible
Synchronization / Tuning			
2	Beta angle	$\beta < \beta\_max$	As low as possible
3	Theta angle	$\theta < \theta\_max$	As low as possible
Sounding			
4	Footprint velocity*	< 1m/s	For orbit radii above 10km this constraint is always adhered
5	Max. chord length max(S)	>1.5*Rcomet	Maximum chord as large as possible. R_{comet} is the mean comet radius. The factor 1.5 is TBC when the first shape is available (Mid-August 2014) and the rotation axis and the axis ratios are known
6	Occultation time for which #5 is fulfilled	>1.5 hours	As large as possible
7	αmax	$< 39 - \tan^{-1}\left(\frac{R_{comet}}{R_{orbit} - R_{comet}}\right)$	Nadir off pointing This constraint should be fulfilled when 5 and 6 are fulfilled. Outside of this period it is desirable to fulfill this condition as long as possible.

Table 3-2 : CONSERT Orbit Geometry Constraints

These values will be updated after the FSS.

**) The footprint velocity is the velocity of the Orbit Surface Section point (Ps on* Figure 3-4*) during the rotation.*

The Surface-Section track and Ground Track (R_{GT}) vectors are illustrated in Figure 3-4 Ground Track and Surface Section

- The Ground Track represents the projection of the Rosetta orbit on the comet surface with respect to the comet's centre (preferably centre of form but centre of mass is possible).
- The Surface Section represents the track of the intersection of the line connecting the Orbiter and Lander and the comet surface.
- The chord S represents the length of the Lander to surface segment of the line connecting the Orbiter and Lander.

The distance from the Lander to these projections varies over the entire projection. If the maximum value of R_{GT} equals the comet radius it means that the Orbiter is flying a great circle over landing site. In this case the Ground Track and Surface Section are identical.

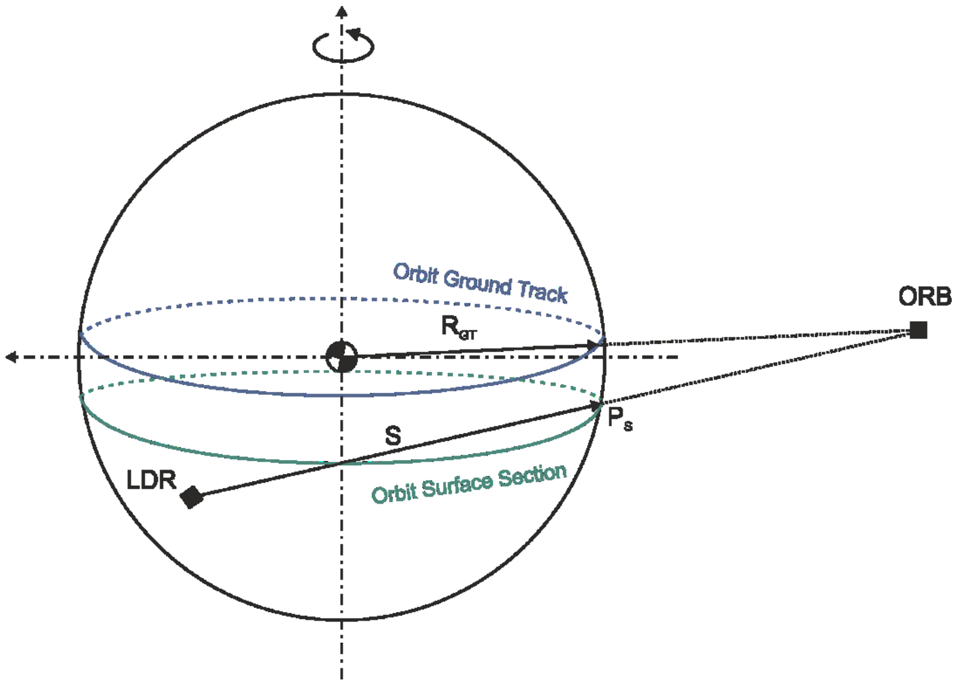

Figure 3-4 Ground Track and Surface Section

4 CONSERT Budget

4.1 Power Budget

4.1.1 Orbiter Power Budget

Experiment phase	Orbiter Power Usage	Typical Duration
Init	4.5 W tbc	60 s
Wait mission table	2.9 W	60 s
Wait tuning	2.9 W	200 s
Tuning	6.2 W	60 s
Wait Sounding	2.9 W	60 s
Sounding	3.4 W Peak 10.9 W	duration 2 to 20 hours, comet type dependent
End Sounding	2.9 W	Wait for switch-off

Table 4-1 : Orbiter Phase power budget summary @-20°c (Worst Case)

4.1.2 Lander Power Budget

Figure 4-1: CONSERT Power Profile shows the power profile as a function of the configuration parameters. The total power budget for a CONSERT measurement is a function of their specific value.

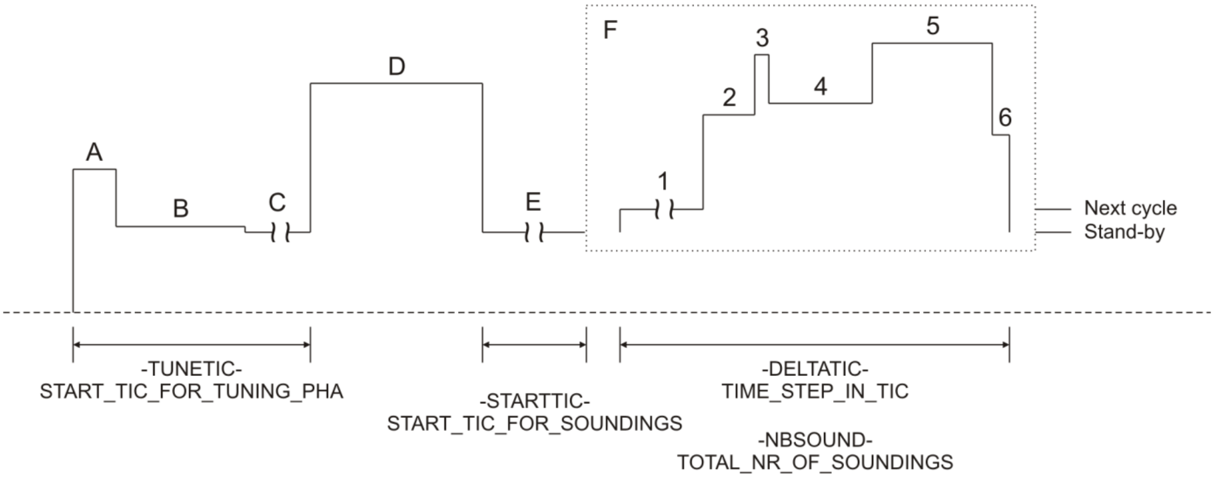

Figure 4-1: CONSERT Power Profile

The associated power requirement for the individual parts is listed below Table 4-2 : Lander phase power budget summary

A	Unit switch-on, Initialization and USO oven heating	15 sec	5 W	2.08E-02 Wh
B	Continue initialization and USO oven heating	45 sec	3 W	3.75E-02 Wh
C	Standby (waiting for tuning)	variable	2.8 W	n.a.
D	Tuning phase	60 sec	8 W	1.33E-01 Wh
E	Standby (waiting for sounding)	variable	2.8 W	n.a.
F	Sounding			
	F.1 Standby	variable	3.6 W	n.a.
	F.2 Waiting Rx	90 msec	6.9 W	1.73E-04 Wh
	F.3 Rx phase	25 msec	9 W	6.25E-05 Wh
	F.4 Processing	180 msec	7.3 W	3.65E-04 Wh
	F.5 Tx phase	210 msec	9.4 W	5.48E-04 Wh
	F.6 Reporting	30 msec	6.2 W	5.17E-05 Wh

Table 4-2 : Lander phase power budget summary @ -40°C worst case

This results in a total energy requirement governed by the equations listed below:

$$P_{TUNETIC} = (TUNETIC - 60) \cdot \left(\frac{2.8}{3600}\right) + 5.83 \cdot 10^{-2}$$

$$P_{STARTTIC} = \left(\frac{STARTTIC}{3600}\right) \cdot 2.8$$

$$P_{DELTATIC} = \left(\frac{DELTATIC - 0.535}{3600}\right) \cdot 3.6 + 1.20 \cdot 10^{-3}$$

$$P_{TOTAL} = P_{TUNETIC} + P_{STARTTIC} + NBSOUND \cdot P_{DELTATIC}$$

4.2 CONSERT Data Budget

This budget is estimated in 3 cases, knowing that the real timing, duration and sounding number will depend on the orbit configuration. The typical case corresponds to a bounded orbit (20 km) with tuning at the vertical of the lander (2.5 hours waiting) and science sounding starting at 10° above lander horizon and ending after a calibration 10° above horizon following a complete occultation (8 hours).

	Typical	Slow	Typical + FIOV 5
Number of sounding	12000	5800	12000
Deltatic	2.5 s	4.95 s	2.5 s
Orbit Duration	10.5 h	10.5 h	10.5 h
Orbiter			
HK (Kbytes)	320	160	320
Sci (Kbytes)	11900	5950	11900
Other (Kbytes)	< 10	< 10	< 10
Total (Kbytes)	12930	6 120	12930
Power Mean (W)	3.9	3.9	3.9
Power Max (W)	10.9	10.9	10.9
Total Power (Wh)	31	31	31
Lander *			
Sci Number	4800	2400	12200
Sci (Kbytes)	1300	650	3300
Power Mean (W)	4.8	4.8	4.8
Power Max (W)	9.4	9.4	9.4
Total Power (Wh)	39	39	39

Table 4-3 : straw man cases: parameters and budgets

(*) assuming FIOV = 25 and -40°c (power budget worst case)

5 Scheduling

The scheduling of CONSERT will depend on the phase of the mission. We will present these phases:

5.1 SDL-FSS scheduling

Turn-On and tuning before separation

Start sounding 20 min TBC after separation

Functioning parameters TBD compatible for SDL and FSS phases

Stop sounding before the beginning of touch-down window up to starting sounding for FSS (10° above horizon) that is done through the stop/go (patching procedure)

It is obvious that scheduling the start of the CONSERT measurement in absolute time within the guaranteed communication window will, in some cases, result in a CONSERT measurement commencing long (up to 2 hours) before occultation occurs.

For FSS the base line is ATTC and STL, however in case of difficulties of this solution the RF mode should be envisaged.

5.2 SDL alone scheduling

If SDL is not directly connected to FSS the SDL sequence will remain identical with a different set of parameters and a stop before the beginning of touch-down window.

5.3 FSS alone scheduling

If FSS is not programmed within the SDL operation, FSS will follow the same rules as LTS operation (see next point). That might be the case if the orbit after delivery doesn't allow acceptable measurement for CONSERT.

5.4 LTS scheduling

During LTS escort phase should be adapted depending on type of orbits (bounded/fly-by). In any case the main rules defined previously shall be applied:

- ON synchronized between OCN and LCN within 10 sec
- Tuning (roughly 6 min after ON) Lander and orbiter in visibility see §3.2 and Figure 3-2 : CONSERT Visibility constraints
- Wait until orbiter arrive 10° above the horizon of lander
- Science soundings up to 10° above the horizon after crossing all occultation
- OFF

The telecommands (TCs) to switch CONSERT ON and to initiate the synchronization must already be uploaded to the Lander timelines prior operations. This upload introduces additional constraints on geometry (TxRx RF link and CDMS time update) to be studied in detail.

5.5 Implementation of CONSERT Activities

5.5.1 Operational Process

For a given observation slot, the definition of the instrument setting, as listed in section Table 2-1: CONSERT Configuration Parameters, depends primarily on the landing site/area and to a lesser extent on the Rosetta trajectory. The five candidate landing sites will be selected approx. 60 days prior landing and the final landing site will be confirmed approx. 30 days prior landing. The CONSERT team will evaluate each landing site and derive the correct configuration of their parameters.

For a given set of landing sites positions a complete simulation and analysis process is 5 days long. In case of significant deviations of the final selected landing site, new simulations must be performed and the final values for the configurable parameters will be provided within **5 days**.

For a given orbitography assuming a previously defined landing position, the typical operation analysis is 1 day long. Once the final landing area is confirmed and the ESOC flight dynamics products are available approx. 15 days prior landing, CONSERT will provide SONC/LCC with the final values for the configurable parameters, via LIOR through the W3-SONC interface, within **1 day**.

In all the cases, these two durations could be significantly reduced in case of contingency, meaning a rougher analysis.

5.5.2 Stop & Start procedure

This procedure includes a « patch command » allowing to switch the OCN and LCN in a PAUSE mode during the touchdown window, that may allow also to postpone the restart of the Sounding Mode in order to minimize the energy and/or data budget.

Step [-]	**Time [hh:mm:ss]**	**Activity [-]**	**TC Setting [-]**	**Comments**
1.	00:00:00	OCN ON		*Via ATTC*
2.	00:00:05	LCN ON		*Synchronisation within first 10 seconds*
3.	00:02:00	OCN and LCN Mission Tables		*2min +-1min*
4.	Begin of TDW	Patch OCN	*End of TDW date to be patched (in CN time referential)*	
5.	Begin of TDW	¨Patch LC	*End of TDW date to be patched (in CN time referential)*	
6.	TBD	LCN DUMP before OFF		
7.	TBD	OCN DUMP before OFF		
8.	TBD	LCN OFF		
9.	TBD	OCN OFF		

Table 5-1 : CONSERT SDL-FSS   procedure with Stop&Start

Annex

Summary of Consert Objectives from "Ranking of the Scientific Objectives of the Philae Mission" (RO-LAN-LI-1001 Issue: 1.2. A 25/07/2011

	CON-SDL-001	CONSERT Gravimetry measurement during the descent phase
Must be	CON-SDL-002	CONSERT Surface and sub-surface dielectric constant and reflectivity measurements
	CON-FSS-001	CONSERT Constraining the nature of nucleus material by estimating the density, the type of refractory material, the dielectric permittivity
Must be	CON-FSS-002	CONSERT Assessment of the internal structure of the cometary nucleus and to constrain existence and nature of cometesimals, internal interfaces, homogeneity at different scales (>0.1m), typical scale of heterogeneities.
Must be	CON-FSS-003	CONSERT Determination of surface material properties by sounding the near surface stratification using grazing signal extinction; characterization of surface roughness on various scales for the whole surface
	CON-LTS-001	CONSERT Deriving a tridimensional view of the nature of nucleus material by density, class of refractory material, dielectric permeability
Must be	CON-LTS-002	CONSERT Determining a 3-dimensional view of the internal structure of the cometary nucleus to assess the existence and nature of cometesimals, internal interfaces, homogeneity at different scales (>0.1m), typical scale of heterogeneities.
	CON-LTS-003	CONSERT Determine surface material properties by sounding the near surface stratification using grazing signal extinction; characterization of surface roughness on various scales for the whole surface