DORIS SYSTEM GROUND SEGMENT MODELS

(Issue 1.1)

CONTENTS

1. PURPOSE

This document lists the modelling parameters for DORIS ground equipments (for all generation beacons) used for DORIS measurements ground processing.

2. APPLICATION DOMAIN

This document applies to every operational DORIS/satellite projects and in particular to ground segments which process the data from these projects.

3. DESCRIPTION OF MEASUREMENT TYPES

There are two types of measurements:

- Doppler measurements (Figure 1) which are implemented for each measurement on a beacon,
- Pseudo-range measurements (described in Modelling of DORIS Instruments) which are used to determine and control ground/onboard synchronisation.

NB: Time-tagging on beacons other than master beacons has no effect on final performance which only depends on the restored onboard ground/time correspondence.

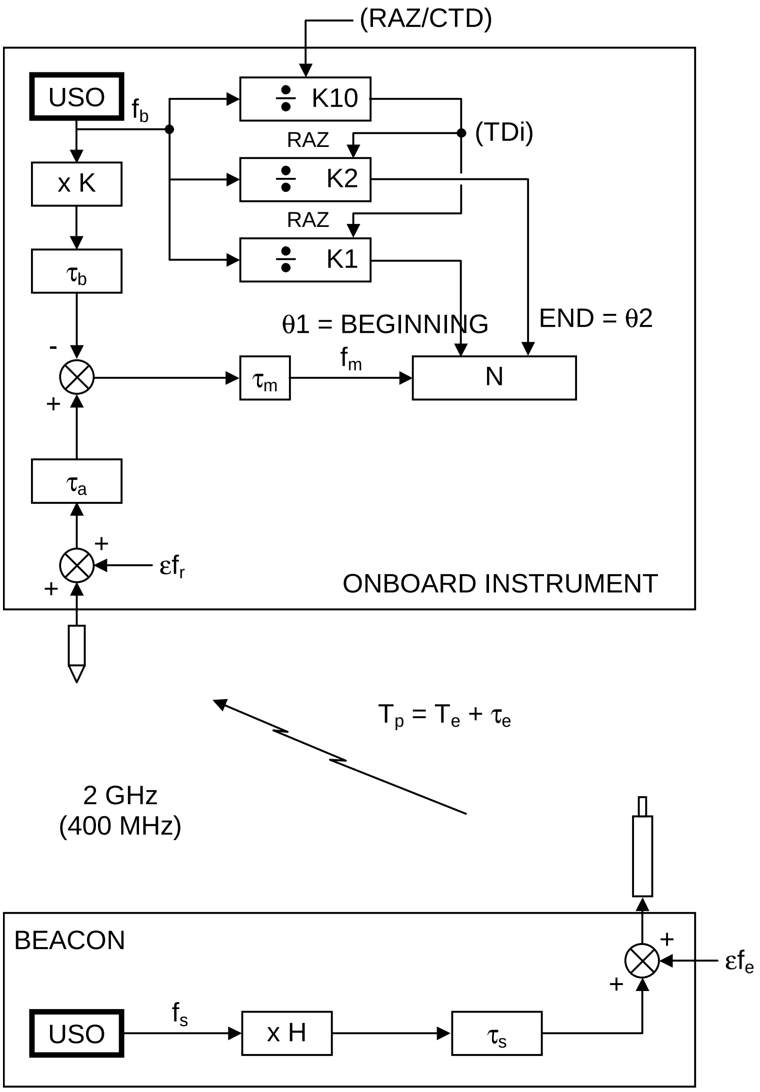

Figure 1: 2 GHz Doppler counting chain
(400 MHz Doppler counting chain)

4. CONVENTIONS

Notations are defined below and indexed as follows:

- Index 0: nominal values; indexes completed if necessary by 400 MHz for the 400 MHz channel and 2 GHz for the 2 GHz channel when the values are different.

NOTATIONS

f_s	ground USO frequency (fs0 = nominal frequency)
τ_s	ground beacon and antenna electronic delays
f_e	emitted frequency (antenna output)
εf_e	noise on emitted frequency
T_p	propagation time between phase centres
T_e	geometric propagation time
τ_e	propagation errors (iono, tropo, antenna patterns)
f_r, εf_r	frequency received and noise on f_r (antenna input)
τ_a	electronic delay on onboard MVR and antenna input
f_b	onboard USO frequency (f_{b0} = nominal frequency)
τ_b	frequency delay for onboard reference (K x f_b)
τ_m	delay on bit frequency
f_m	Doppler counting frequency (f_{m0} with null Doppler)
$\theta 1$	delay in opening the counting window/TD_i
$\theta 2$	delay in closing the counting window/TD_i
K1, K2	pulse count for f_b used to generate $\theta 1$ and $\theta 2$
K10	division value of f_b used to make the TD_i
RAZ, CTD	TD_i resynchronisation
N	number of f_m cycles (fraction counting the vernier values at the beginning and end) between $TD_i + \theta 1$ and $TD_i + \theta 2$
K4	value of divider used as a clock for time-tagging the TD_i
K	multiplier of f_b giving onboard reference frequency
K5	divider value acting as clock for time-tagging T_3
H	multiplying coefficient for the beacon USO frequency
TD_i	10 s time pulse for onboard sequencing
T10	10 s TAI integer time pulses
t10	10 s TAC integer time pulses
ε_{TF}	TAC – TAI difference
τ_{Si}	delay between Beacon Si and TAB
TAB	Beacon Atomic Clock Time
K3	count f_s used to generate the time-tagging bit
τ_{s3}	ground beacon and antenna electronics delay affecting the time-tagging bit
τ_{m3}	onboard MVR and antenna electronics delay affecting the time-tagging bit
T3	onboard time-tagged event (arrival of time-tagging bit at counter input)
IT3	‘Time-tagging’ = number of cycles of frequency f_b/K5 between TD_i and T3
IDATE	‘TD_i onboard time’ = count of f_b/K4 between the RAZ and the given TD_i (IDATE2 represents the least significant bits of IDATE)
T_{p3}, T_{e3}, τ_{e3}	ditto T_p, T_e, τ_e but for the time-tagging bit

NB: T10, t10, Si, T3, TD_i, RAZ and CTD are **events** which can be tagged in TAI or onboard time or some other time scale.

Example: TAI (T3) or TOUS (T3).

5. MODELS

Depending on the case, delays are represented either by a time or by a phase difference for the given frequency.

5.1 BEACONS

5.1.1 GROUND BEACON FREQUENCY (FS)

f_s is identical for both channels. The orbit calculation determines an estimate of f_s per passage. On first generation orbit determination beacons, one can model f_s (T°bal) or f_s (IOUS); with T°bal: beacon temperature and IOUS: data USO current given in the TM :

- f_s (T°bal) = TBD
- f_s (IOUS) = TBD

$f_{s0} = 5$ MHz

For the BMs: $f_s = f_{s0}$

$H_{2GHz} = 407{,}25$ and $H_{400MHz} = 80{,}25$

$\varepsilon f_e = 0$ (no model)

5.1.2 BEACON TIMES ADJUSTEMENT

ε_{TF}: known *a posteriori*.

This parameter is monitored weekly for each of the master beacons (cf. GECO Report).

τ_{si} = measured on-site during installation. This parameter is also monitored by the GECO which updates it if the installation is modified.

Emission moment of time-tagging bit:

- K3 = $13.9.10^6$ for the master beacons.
- K3 = $26.9.10^6$ for the other beacons.

NB: Delay introduced by the K3 count (written D3).

Nominal values:

$D3_0 = 2.78$ s for the master beacons

$D3_0 = 5.38$ s for other beacons

τ_{s3} = no model $\Rightarrow \tau_{s3} = 0$ for both channels.

τ_{e3}: ditto $\tau_{e\ 400\ MHz}$ for the part due to the antenna phase patterns.

5.1.3 GROUND TRANSIT TIME

No model $\Rightarrow \tau_s = 0$

5.2 GROUND ANTENNAS

Z is the geocentric-centrifuge axis

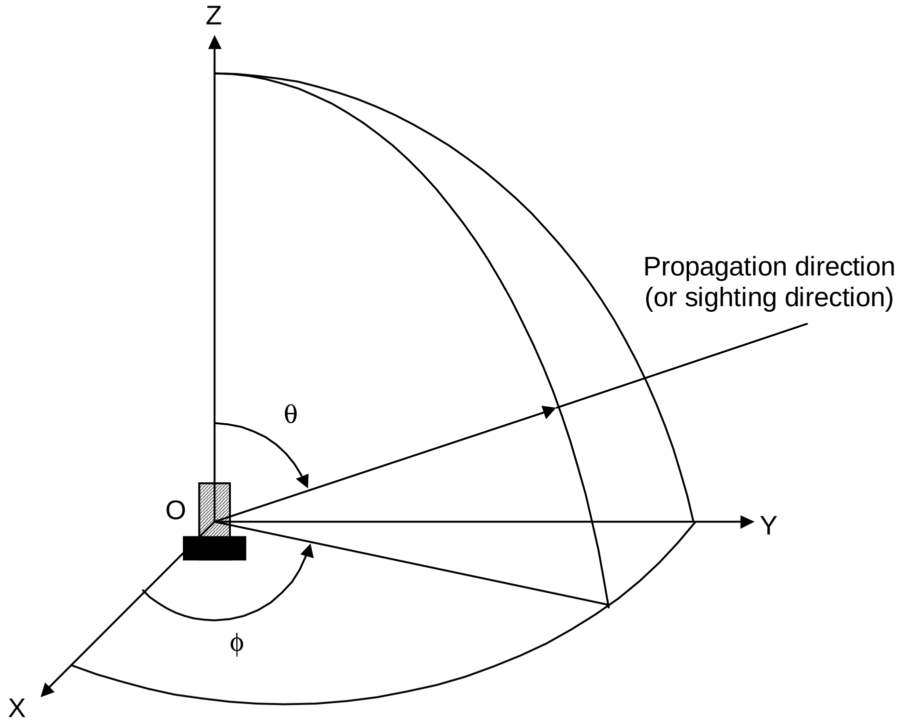

Figure 2: Antennas reference frame
(O = phase centre)

5.2.1 GEOMETRY OF GROUND ANTENNAS

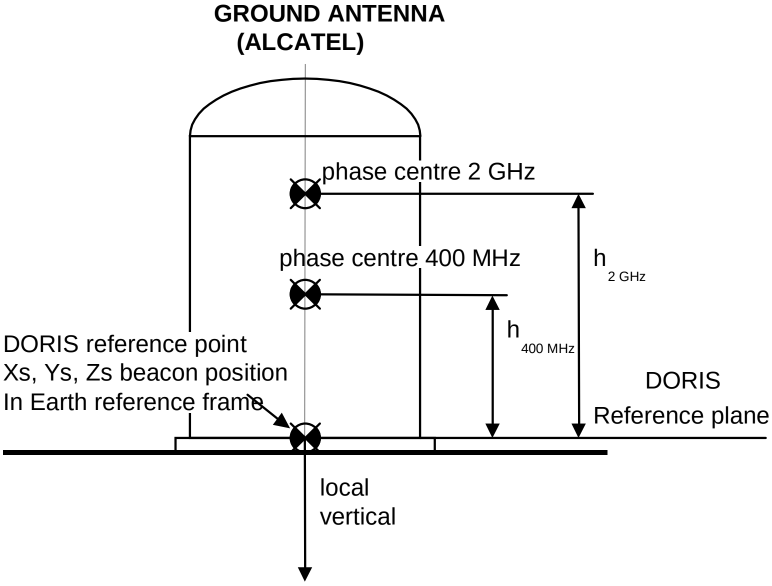

Figure 3

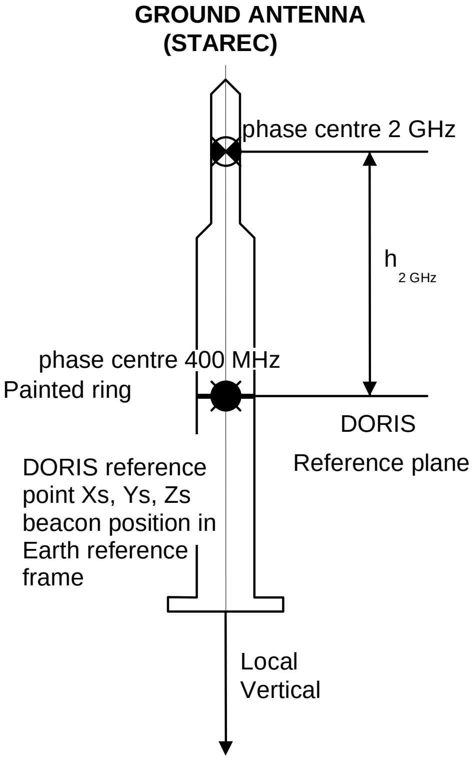

Figure 4

Antenna	ALCATEL	STAREC	STAREC-COBHAM type D
h (mm) 2 GHz	510	487	453
h (mm) 400 MHz	335	0	-39

The type of antenna is identified by the 4th character of the beacon mnemonic: letter 'A' for the Alcatel type; letter 'B' or letter ‘C’ for the Starec type; letter ’D’ for the Starec-Cobham TYPE D type

STAREC antennae B and C are identical in terms of design and specification, the difference is about the error budget in phase center position. For STAREC C, manufacturing process and error budget have been improved.

A complete description is given in the presentation : http://ids-doris.org/images/documents/report/ids_workshop_2014/IDS14_s2_Tourain_DORISgroundAntennasCharacterizationAndImpact.pdf

For STAREC-COBHAM type D antennae, a change in the manufacturing process induces different locations for the phase center position.

ALCATEL error budget

TBD

STAREC error budget

Error source	up	plan (N/E)
Antennas variability (2GHz phase center position) STAREC B	+4/-6 mm	
Antennas variability (2GHz phase center position) STAREC C	±1 mm	
Antenna characterization error (BCMA)	±2 mm	
Azimuthal dispersion	0mm	± 2mm
Total antenna alone		
STAREC B	+6/-8 mm max	± 2 mm max
STAREC C	**± 3 mm max**	**± 2 mm max**
STAREC-COBHAM type D (TBC)	**± 3 mm max**	**± 2 mm max**

5.2.2 GAINS

θ	ALCATEL (dBi)		STAREC (dBi)	
	401.25 MHz	**2036.25 MHz**	**401.25 MHz**	**2036.25 MHz**
0°	3.2	2.1	3.5	0
10°	3.5	2.6	3.6	0.4
20°	4	2	3.7	0.5
30°	4.4	4	3.8	1.5
40°	4.6	4.4	3.7	3.2
50°	4.2	4.6	3.2	3.9
60°	2.7	2.7	2.5	4
70°	0.6	- 0.1	1	3.2
80°	- 2.7	- 3.3	- 1.3	0.2
90°	- 6	- 7	- 4.2	- 5.6

5.2.3 PHASE LAWS

Position of phase centres : cf. **Figure 3**, and **Figure 4** for ground antennas

- ϕ : azimuth phase law

- $\Psi(\phi) = \text{Cte} - \phi$

- θ : site phase law

$$\Psi(\theta) = \text{Cte} + X(\theta)$$

$\Psi(\theta)$ is known with the precision of $\pm\,\varepsilon$ taken into account in the medium term error budget.

The phase law are given in accordance with antex format : in mm, function of zenith angle.
Antex format specification : `http://ids-doris.org/images/documents/report/AWG201403/IDSAWG1403-Tourain-PhaseLawSpecification.pdf`
The antex files give the phase law that should be applied in DORIS processing.

The correction has to be applied as following:

- observational + phase correction
- theoretical - phase correction

Detailed description can be found on the ids website : http://ids-doris.org/documents/report/AWG201403/IDSAWG1403-Tourain-PhaseLawSpecification.pdf

- **Alcatel Phase laws**

ftp://ftp.ids-doris.org/pub/ids/stations/doris_phase_law_antex_alcatel.txt

The corrections given in the files are represented in the following graph :

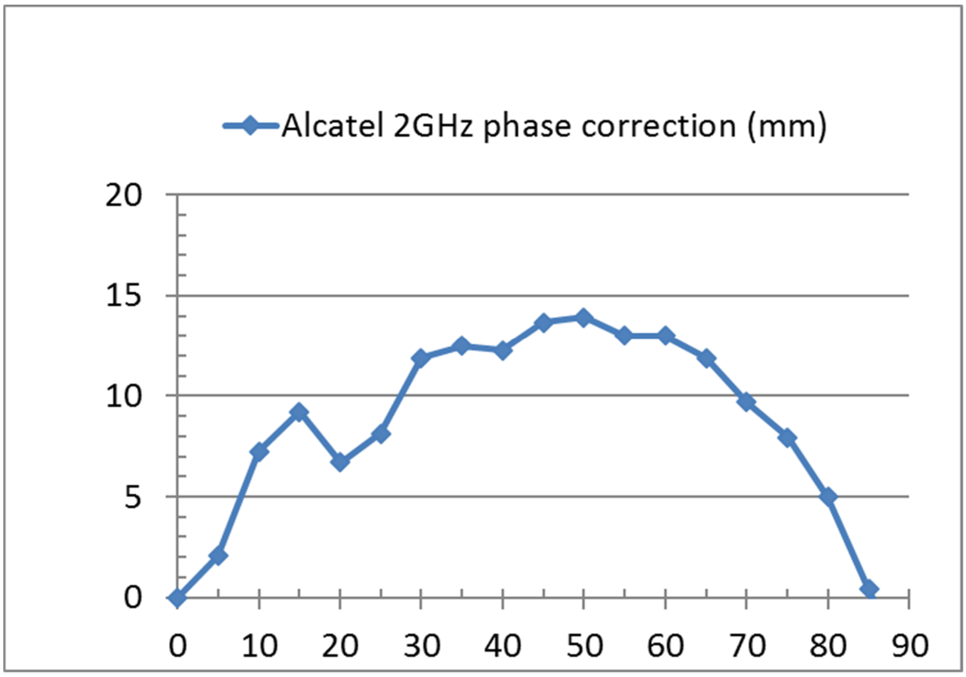

Figure 5: Alcatel 2 GHz phase correction

Only 2 GHz corrections are given, as 400 MHz corrections are equal to zero.

Values :

Elevation (deg)	Phase variation (mm)
0	0.00
5	2.05
10	7.24
15	9.21
20	6.71
25	8.14
30	11.87
35	12.48
40	12.28
45	13.67
50	13.91
55	13.01
60	13.01
65	11.87
70	9.70
75	7.94
80	4.99
85	0.41
90	-3.93

- **Starec Phase laws (type B and type C)**

ftp://ftp.ids-doris.org/pub/ids/stations/doris_phase_law_antex_starec.txt

The corrections given in the files are represented in the following graph :

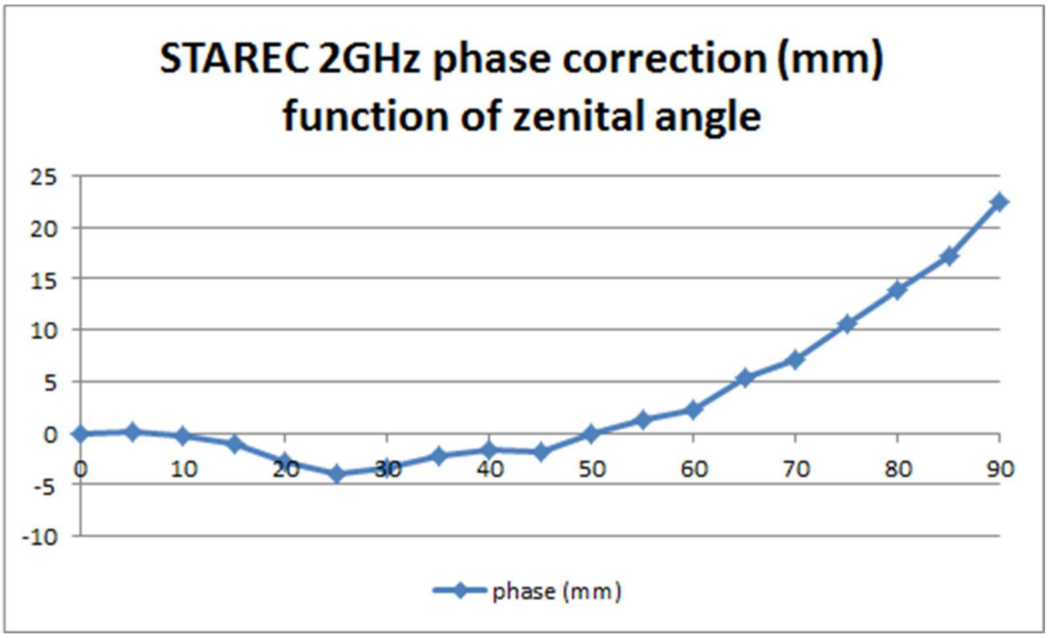

Figure 6: Starec TYPE B and TYPE C 2 GHz phase correction

Only 2 GHz corrections are given, as 400 MHz corrections are equal to zero.

- **Starec-Cobham type D Phase laws**

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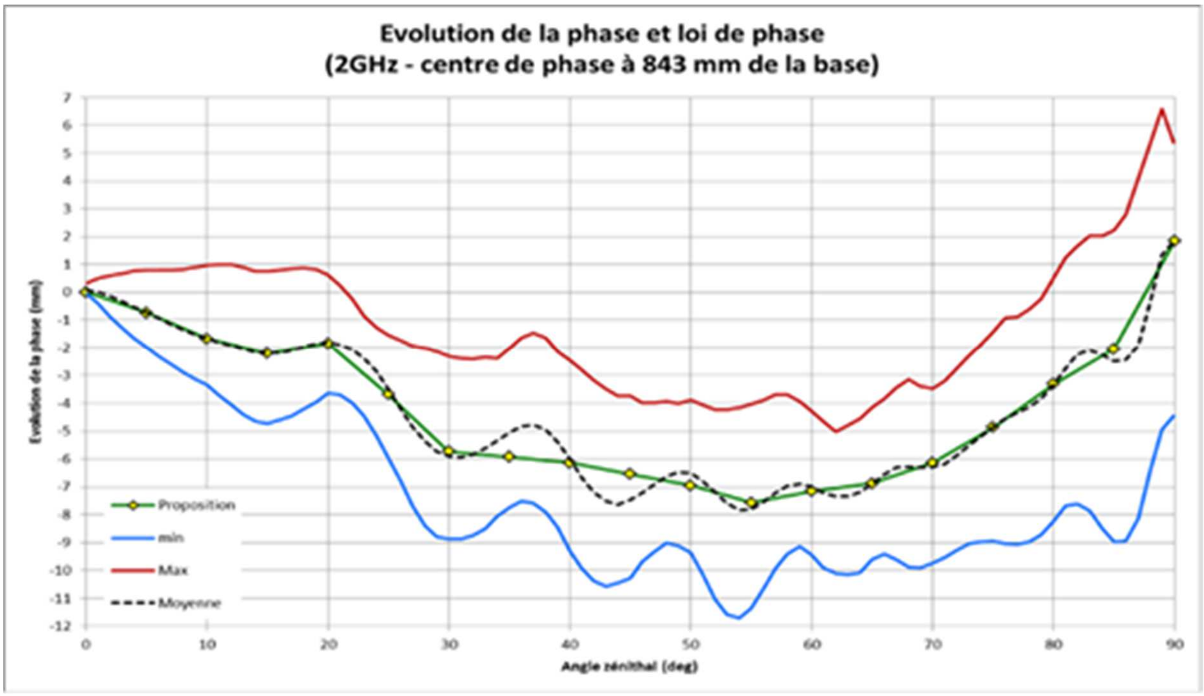

Figure 7: Starec-Cobham TYPE D 2 GHz phase correction

Only 2 GHz corrections are given, as 400 MHz corrections are equal to zero.

Values :

Elevation (deg)	Phase variation (deg)	Phase variation (mm)
0	0	0
5	-1.8	-0.73664825
10	-4.1	-1.67792101
15	-5.4	-2.20994475
20	-4.5	-1.84162063
25	-9	-3.68324125
30	-14	-5.72948639
35	-14.5	-5.93411091
40	-15	-6.13873542
45	-16	-6.54798445
50	-17	-6.95723348
55	-18.5	-7.57110702
60	-17.5	-7.16185799
65	-16.8	-6.87538367
70	-15	-6.13873542
75	-11.9	-4.87006343
80	-8.1	-3.31491713
85	-5	-2.04624514
90	4.5	1.84162063

5.3 LOSSES DUE TO GROUND CABLES

Channel	**Length (m)**	**Losses (dB)**
401.25 MHz	15	- 1.3
2036.25 MHz	15	- 3

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