DORIS SYSTEM GROUND SEGMENT MODELS

(Issue 1.0)

TBC/TBD	Section	Brief description
TBD	5.1.1	Frequency of ground beacon (f_s) f_s (°bal) f_s (IOUS)

ACRONYMS

Acronym	Definition
BIH	Bureau International de l'Heure [International Time Bureau]
BM	Balise Maîtresse [Master beacon]
BMK	Balise Maîtresse de Kourou [Kourou Master beacon]
BMT	Balise Maîtresse de Toulouse [Toulouse Master Beacon]
CCDP	Centre de Contrôle DORIS POSEIDON [DORIS POSEIDON Control Centre]
CTD	TC de correction de temps directe (décalage du séquencement) [direct time correction TC (shift in sequencing]
GECO	Groupe d'Exploitation et Coordination des Opérations [Operations Control and Coordination Group]
MVR	Mesure de Vitesse Radiale [Radial Velocity Measurement]
RAZ	TC de remise à zéro de l'heure bord et du séquencement [Reset to zero TC of onboard time and sequencing]
SL	Satellite [Satellite]
TAB	Temps Atomique Balise maîtresse. Selon qu'il s'agit de celle de Toulouse ou de Kourou TAB = TAC ou TAK respectivement [Master Beacon Atomic Time. Depending on whether it is for Toulouse or Kourou TAB = TAC or TAK respectively]
TAC	Temps Atomique CNES (horloge du laboratoire TF qui pilote la BMT) [CNES Atomic Time (clock at the TF laboratory which controls the BMT)]
TAI	Temps Atomique International [International Atomic Time]
TAK	Temps Atomique Kourou (horloge Césium de la BMK) [Kourou Atomic Time (Caesium clock of the BMK)]
TM	TéléMesure [Telemetry]
TOUS	Heure bord DORIS [DORIS onboard time]

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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.

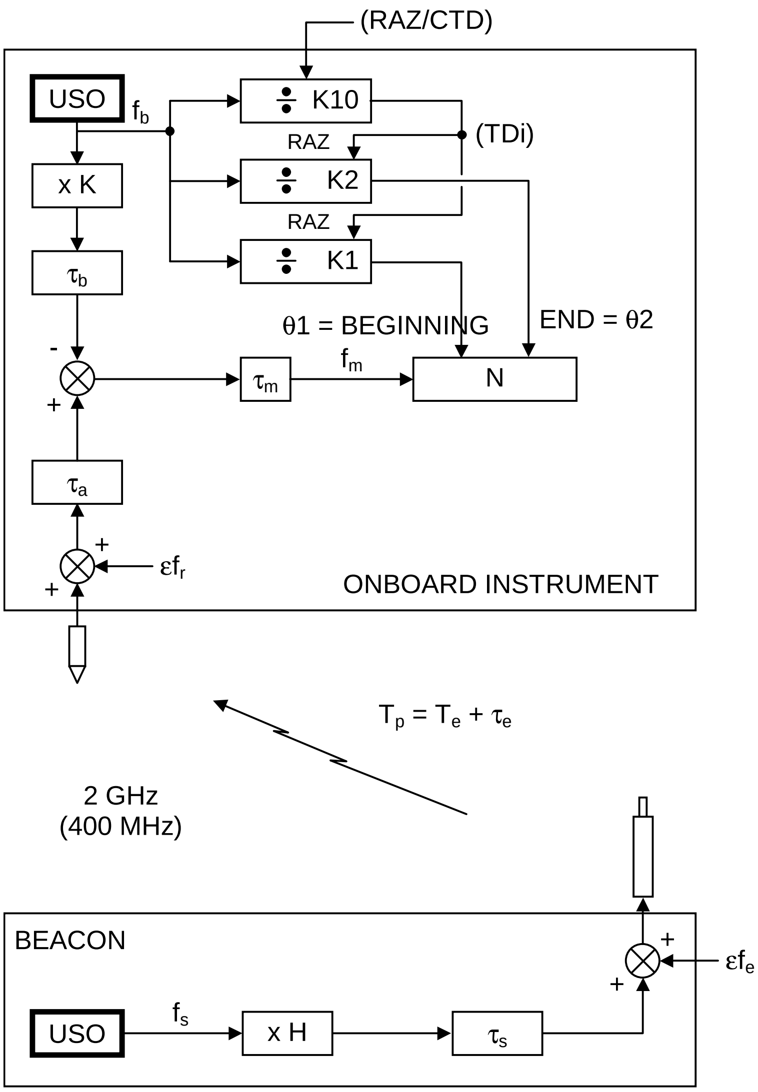


Figure 1: 2 GHz Doppler counting chain
(400 MHz Doppler counting chain)

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

εf_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

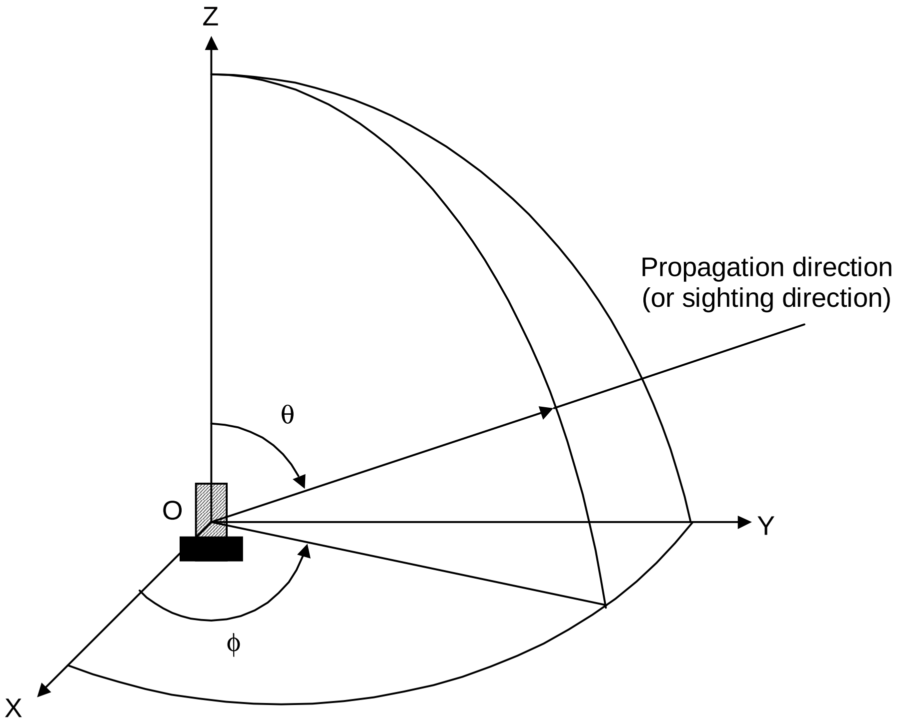


Figure 4: Antennas reference frame
(O = phase centre)

5.2.1 GEOMETRY OF GROUND ANTENNAS

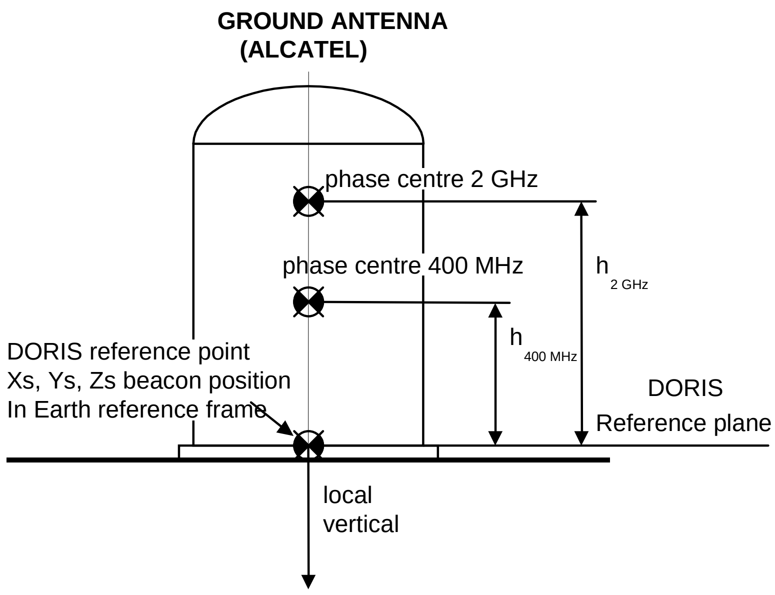


Figure 5

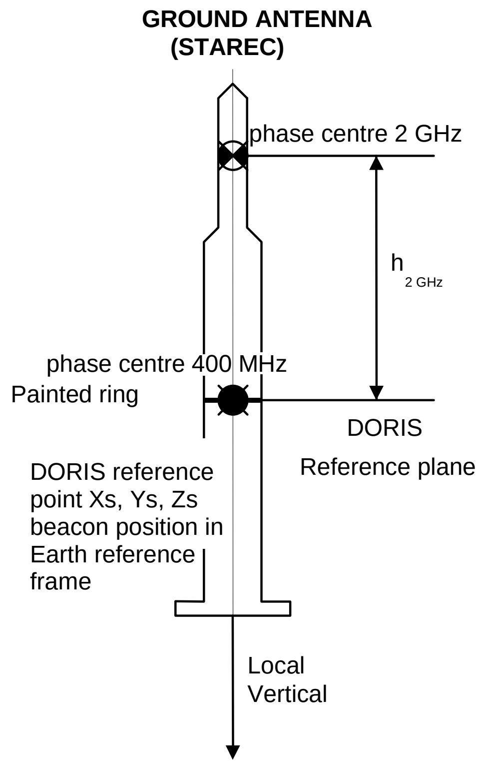


Figure 6

Antenna	ALCATEL	STAREC
h (mm) 2 GHz	510	487
h (mm) 400 MHz	335	0

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.

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

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**

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 5** and **Figure 6** for ground antennas

- ϕ : azimuth phase law

$$\Psi(\phi) = Cte - \phi$$

- θ : site phase law

$$\Psi(\theta) = Cte + X(\theta)$$

$\Psi(\theta)$ 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:

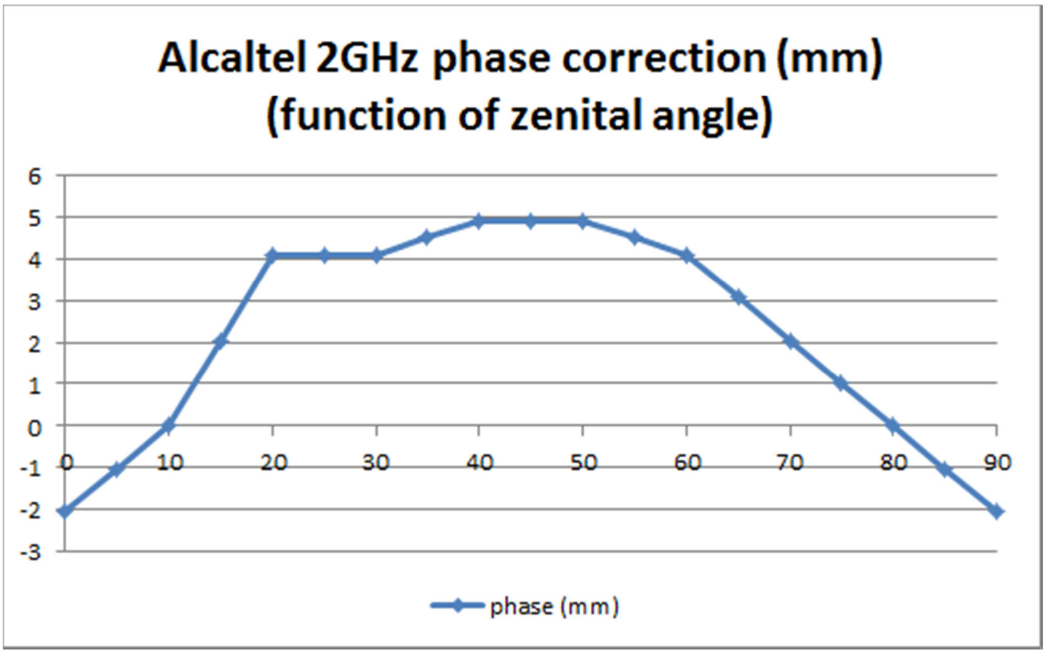
- observational + phase correction
- theoretical - phase correction

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 :

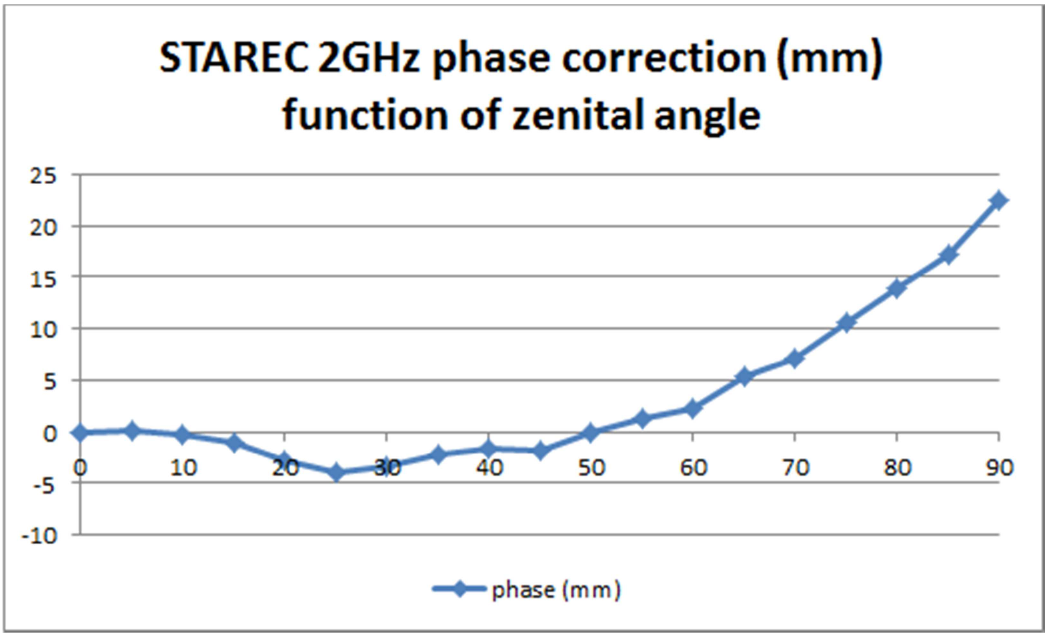


Only 2 GHz corrections are given, as 400 MHz corrections are equal to zero.

- **Starec Phase laws**

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 :



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

5.3 LOSSES DUE TO GROUND CABLES

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