RFI Site Survey at Tahiti Nui Telecom Papenoo/Tahiti 27 Feb – 3 March 2017

Participants

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Survey Objectives

The objective of this site survey was to investigate the Radio Frequency Impact (RFI) and electromagnetic compatibility between the following entities potentially co-located at the TNT Papenoo site in Tahiti/French Polynesia:

Objective 1: measure and quantify (if any) the impact of a potential future CNES DORIS beacon on the Galileo TTCF-6 S-band reception and transmission when transmitting from the specified candidate locations D1/3, D2, and D4.

Objective 2: measure and quantify (if any) the impact of the TTCF-6 S-band transmission on a potential future VLBI antenna (reception only)

Objective 3: measure and quantify (if any) the impact of the Galileo ULS-1 and ULS-2 C-band transmissions on the potential locations of a future VLBI antenna

Objective 4: to collect sufficient measurements to determine the best relative geometry between the VLBI and DORIS instruments to minimise interference.

Objective 5: to collect geodetic data to fully specify the site.

Date & Signatures

Name of Representative	**Bobby Nejad**	**Jaime Esper**	**Michel Starozinski**	**Clément Moune**	**Jérôme Saunier**
Organisation	**ESA**	**NASA**	**CNES**	**TNT**	**IGN**
Date of Signature					
Signature					

Test Set-Up

The principal RFI tests to characterise the VLBI and DORIS candidate locations were conducted during the first two days (i.e., 27 and 28 February 20017) according to the test schedule prepared by Michel Starozinski in coordination with NASA, ESA and TNT.

Additional tests focusing on line-of-sight visibility tests between the DORIS beacon, the VLBI test bed, and the TTCF-6 antenna (referred to as D5 location) were added on 1 and 3 March.

The tests involved the following equipment:

1) Galileo 13.5 m S-band TTC antenna (not yet operational and not connected to the GCC)
2) Galileo TTCF-6 Calibration Tower (Tx in S-Band Channel 5)
3) Galileo 5 m C-band ULS-1 and ULS-2 operational antennas (tests performed during the approved Galileo ILS slots ILS#24400 for ULS1 and ILS#24401 for ULS2)
4) DORIS UHF & S-band beacon
5) NASA spectrum analyser (SA) connected to an antenna
6) TNT C-band antennas

DORIS

The DORIS equipment consists of:

1) The transmitter beacon
2) The antenna

Figure 1: Doris Antenna and Supporting Equipment

The DORIS beacon transmits at 2 frequencies: the S-band transmission is at 2.036 263 GHz and the UHF transmission is at 401.252 MHz (out of range for this survey as not in the frequency band of any test equipment) (cf. [2])

VLBI Test Equipment

The main equipment consists of an Anritsu MS2720T Spectrum Analyser, a 1 to 18 GHz A. H. Systems Biconical Omnidirectional Antenna Model SAS-547, and a data acquisition

computer running LabView. A directional (hemispheric) ETS-Lindgren antenna, Model 3164-05 was also used to acquire H/V polarization data at selected locations.

Figure 2: VLBI Test Equipment

Galileo Uplink Stations (ULS)

The Galileo up-link stations ULS1 and ULS2 transmit in C-band at 5.005 GHz.

Figure 3: Galileo ULS Antenna

The transmit EIRP value of the ULS achieved during the test was 53 dbW.

Galileo TTCF-6 Antenna

Figure 4: Galileo TTCF-6 13.5 m Antenna

The Galileo TTCF-6 antenna transmits with an EIRP of 70 dBW. The receive and transmit frequencies of the Galileo TT&C Station are summarised in Table 1. It should be noted that Channel 5 is the only one used for Spread Spectrum Mode (DSSS) whereas all 9 channels are used for Phase Modulation (PM) Mode. The column marked with TC is applicable for uplink only (Tx) and the one marked with TM is applicable for downlink only (Rx).

Table 1: Galileo TTCF-6 TX/RX Frequencies [cf., 1];

Ch	TC (MHz)	TM (non-coherent)	TM (coherent)
1	2037.5730390	2212.74900	2212.749002
2	2040.3990760	2215.81800	2215.818001
3	2043.2251130	2218.88700	2218.887001
4	2046.0511500	2221.95600	2221.956
5	2048.8771870	2225.02500	2225.024999
6	2051.7032240	2228.09400	2228.093999
7	2054.5292610	2231.16300	2231.162998
8	2057.3552980	2234.23200	2234.231998
9	2060.1813350	2237.30100	2237.300997

Equipment Location & Pointing

The DORIS beacon occupied alternatively positions D1/3, D2, D4 positions. The NASA spectrum analyser (SA) was set up alternatively in positions 1001 and 1006. Electric current was supplied by two generators set up by TNT in both 1001 and 1006 clearings. A third generator from OGT was used for further locations as D1/D3.

Tests in line of sight visibility from the TTCF-6 antenna were performed from position D5 and considered as a worst case scenario. The DORIS beacon was set up westward from the TTC antenna at a distance of ~480 m from the TTCF-6 location for a few hours.

The exact locations of the candidate DORIS and VLBI spots, as well as the coordinates of the TTCF-6 and ULS antennas is summarized in **Table 2**.

Table 2: Test Equipment Location (WGS84)

Location	Latitude (deg)	Longitude (deg)	Height (m)
VLBI-1001	-17° 31' 05.0"	149° 26' 11.5"	200. (tbc)
VLBI-1006	-17° 31' 06.1"	149° 26' 19.2"	200. (tbc)
D1/D3	-17° 30' 60.0"	149° 26' 18.5"	183.
D2	-17° 31' 04.0"	149° 26' 19.9"	209.
D4	-17° 31' 02.1"	149° 26' 10.9”	207.
D5 (TTCF direct view)	-17° 30’ 43.4”	149° 26’ 21.3”	150.
D6 (Doris direct view)	-17° 31’ 00.0”	149° 26’ 20.35”	
TTCF-6	-17° 30’ 41.394828”	149° 26’ 05.21758”	124.033
ULS-1	-17° 30’ 41.97”	149° 26’ 08.52”	Ca. 133
ULS-2	-17° 30’ 41.41”	149° 26’ 10.44”	Ca. 135

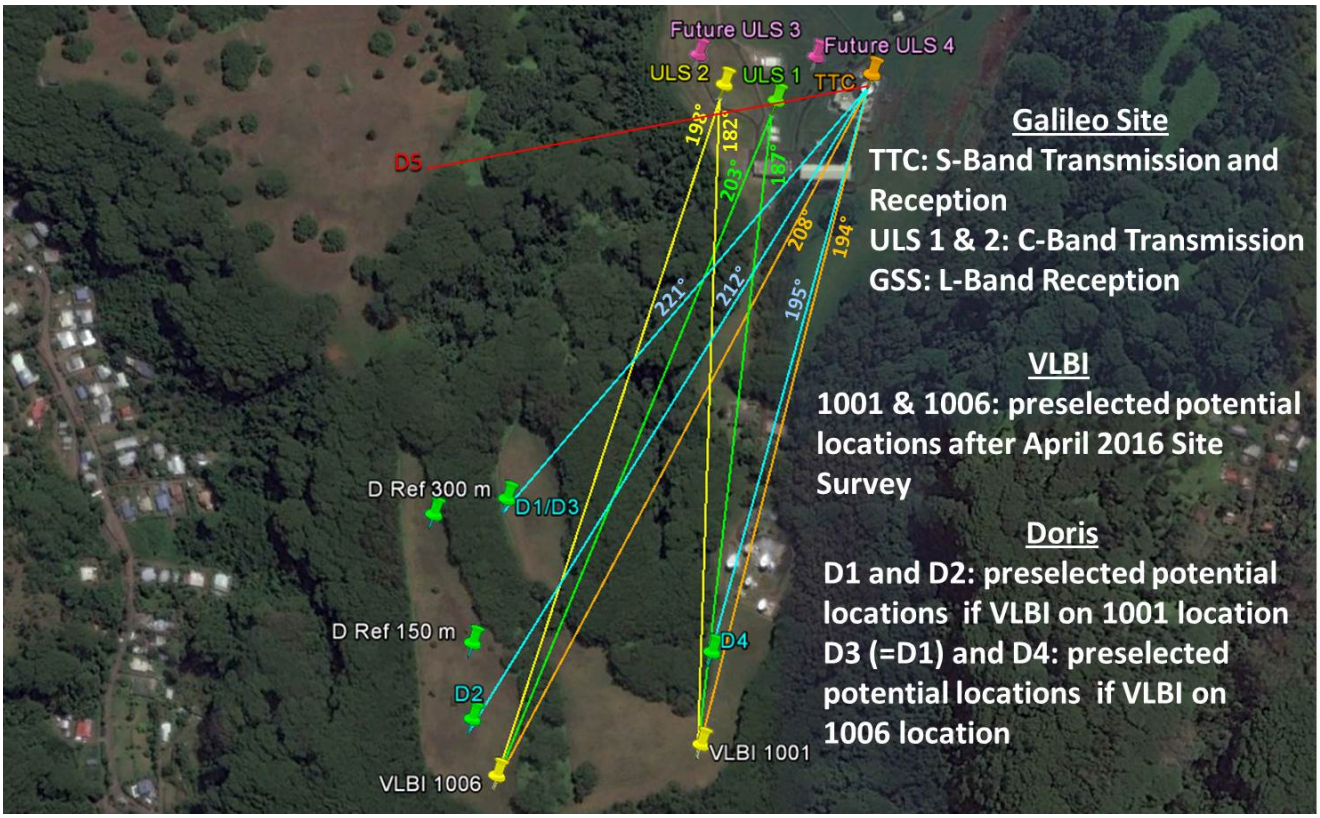


Figure 5: Pointing Angles for DORIS and VLBI locations

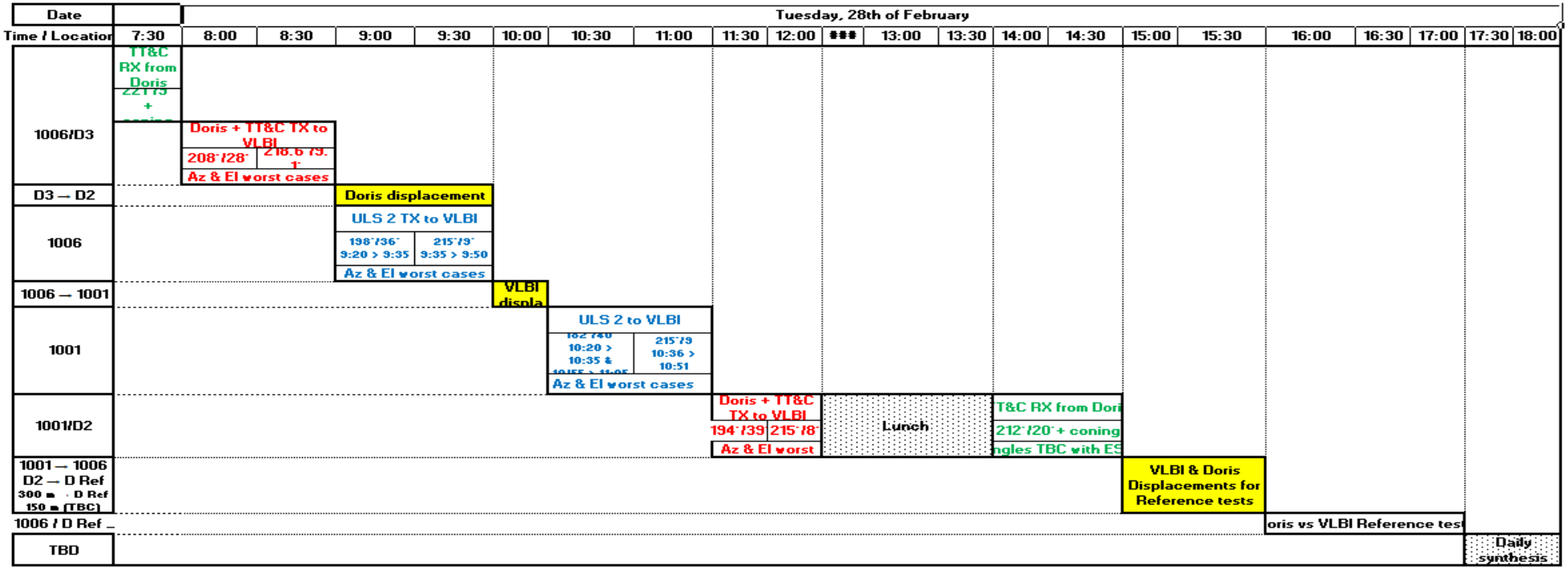
Remarks on location D5: the line-of-sight distance TTCF-was estimated to be 480 m. The pointing angles from the TTCF-6 antenna were estimated with Az: 262.4 deg and Elev: 5 deg. **It should be noted that the D5 location does not represent a real candidate location for a DORIS beacon but was chosen as a reference measurement location to study the impact of the DORIS transmission in case of a direct line-of-sight visibility.**

Figure 6: D5 direct Line-of-Sight (DORIS to TTCF-6) measurement point

Test Schedule: Day 1 (Monday 27 Feb)

Date	Monday, 27th of February																					
Time / Location	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	***	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00
TBD		Test Readiness Meeting		Installation Doris & VLBI test bench																		
1006/D4						Doris + TT&C TX to VLBI EIRP = 69.46 dBW 208°/28 218.6°/9.1° Az & El worst cases		TT&C RX from Doris (10 mn TX at the beginning) 195°/38° + coning		Lunch													
D4 → D3												Doris displacement										
1006												ULS 1 to VLBI EIRP = 53 dBW 203°/33 13:35 > 13:40 215°/15° 15 mn Az & El worst cases											
1006 → 1001														VLBI displa								
1001															ULS 1 to VLBI 187°/40 14:20 > 14:25 215°/19 a few min Az & El worst cases							
D01/D1 (D1 = D1																	Doris + TT&C TX to VLBI EIRP = 69.74 dBW 194°/39° 15:20 > 15:40 218.6°/9.1° 15:50 > 16:10 Az & El worst cases		TT&C RX from Doris 221°/9° + coning			
1001 → 1006																			LBI displaceme			
TNT Building																					Daily synthesis	

Test Schedule: Day 2 (Tuesday 28 Feb)



Pointing Angles

The pointing angles for TTCF-6 and ULS antennas were based on recent Galileo orbit information considering worst cases in azimuth and elevation.

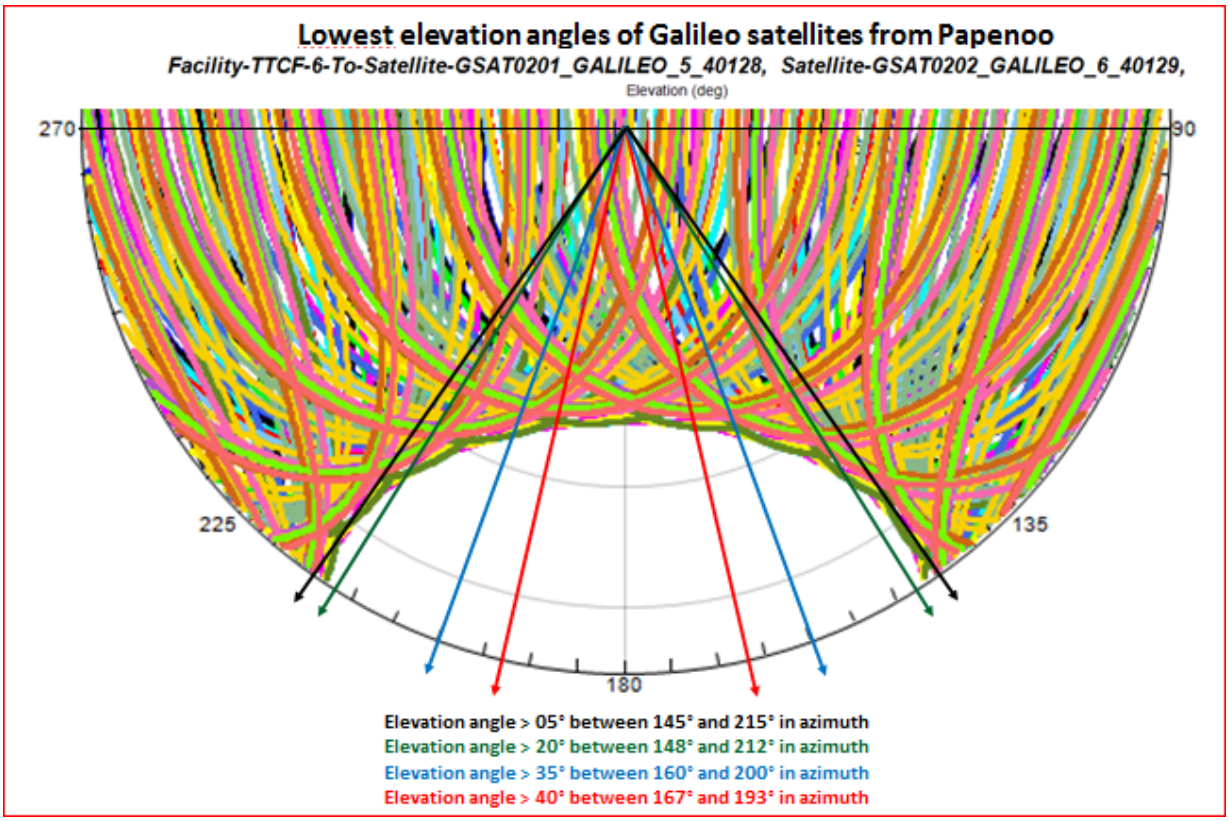


Figure 7: Galileo orbits tracks w.r.t. TTCF-6 antenna location.

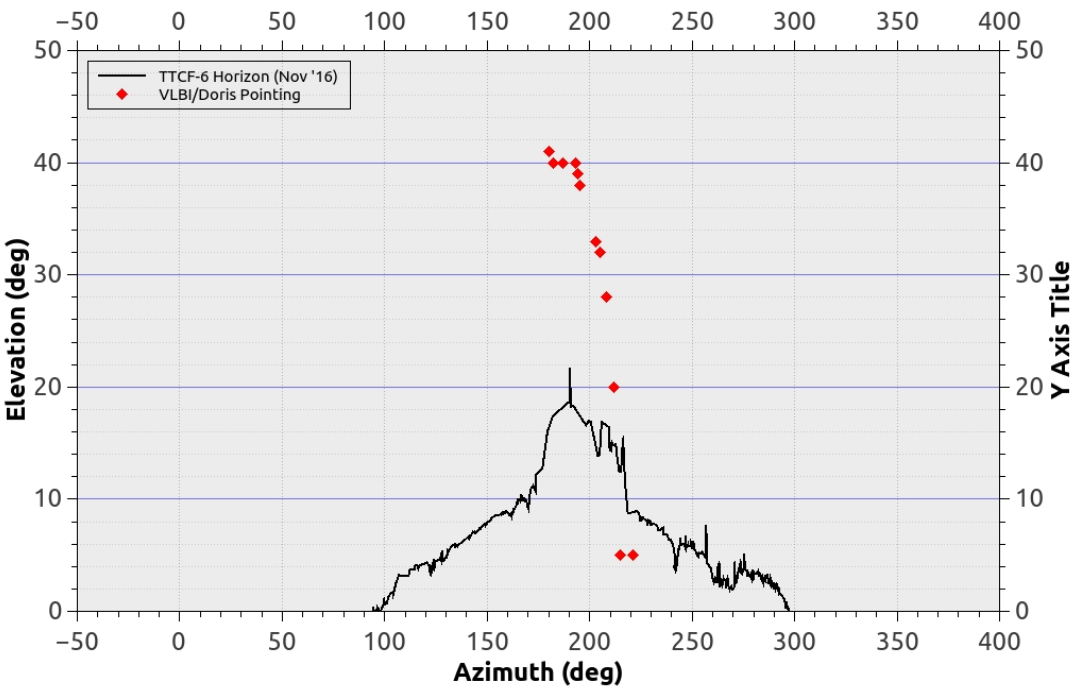


Figure 8: Nov 2016 Horizon Profile and Measurement Points (red).

Results VLBI Test Locations

Positions 1006 & 1001

The Galileo ULS antennas transmitting in C-band are not detectable at either 1006 or 1001 locations.

The Galileo TTCF-6 transmission is detectable at both locations, and the signal strength varies according to azimuth/elevation. The approximate maximum signal strength at location 1006 is -73 dBm, whereas the maximum at location 1001 is -76 dBm. The location of the DORIS beacon has by far the greatest effect on the RFI at the proposed VLBI locations, with peaks between -52 dBm (1001 vs. D2 – direct line-of-sight with trees along the way, distance = 250 m) to -63.6 dBm (1006 vs. D4 – tree line in between, distance = 275 m). As a reference the signal strength between 1006 and DORIS D6 is about -44.8 dBm without any obstacles in the line-of-sight (distance = 172 m). At 1006 vs. D3 (tree line in between, distance 300 m) a power level of -69.9 dBm has been measured.

However a spurious signal of 2.138 GHz has been detected at the 1001 spot. TNT identified its origin as coming from the 3G Femto transmitter in the Telecom area which will be decommissioned end of 2017 and will be replaced by a 3G 900 MHz double carrier transmitter.

VLBI	DORIS	Relative Distance (m)	Power Level (dBm)	Comment
1001	D2	250	-52.3	direct line-of-sight with trees along the way
1006	D4	275	-63.6	tree line in between
1006	D6	172	-44.8	without any obstacles in the line-of-sight
1006	D3/D1	300	-69.9	tree line in between
1001	D3/D1	300	-67.2	Tree line in between

VLBI @ Position D5

D5 is not a VLBI location candidate but offers the possibility to perform a line-of-sight measurement to the TTCF-6 antenna (reference measurement).

For both the PM and DSSS modulations the signal strength observed by the VLBI test set up was measured to be about -38 dBm.

TTCF-6 Results

Description of Measurement Methodology

The TTCF-6 antenna was pointed to the azimuth direction of the candidate DORIS beacon locations (D1,2,3,4) and an elevation which corresponds to the lowest expected Galileo satellite orbits in this direction. In case the lowest orbit elevation at a given azimuth was lower than the horizon mask, the elevation from the horizon mask took precedence. In addition to the pointing direction a coning around that direction of 1 deg was performed.

The signal analysis was performed using the TTCF integrated Spectrum Analyser (see Figure 9) which was connected to the following test points (see also Figure 10):

- **Test Points E and F**: LHCP and RHCP measurements right after the output of the Low Noise Amplifiers (LNA) around the DORIS beacon centre frequency (2036.25 MHz) and all of the TTCF receive frequencies (Channel 1 to 9)
- **Test Points H and G**: after the signal down-conversion to IF band (70 MHz) at the inputs to the Base Band Modems (BBM)

In case no signal was detected at points E/F (i.e., right after the LNA output) no further investigation at points H and C needed to be performed.

In all cases, a TM loop test was performed (both in LHCP and RHCP without diversity combiner) in order to estimate any negative impact of the DORIS signal on the TM decoding ability.

Justification:

The measurement strategy aimed to identify a **signal detection after the LNA** in order to verify whether the band-pass filters prior to the LNA would be able to fully reject the DORIS S-band transmission.

If not the case (i.e., only a partial rejection by the pre-LNA band-pass filters could be achieved), the impact of the DORIS signal after down-conversion into the IF frequency band was analysed in order to verify whether the D/C filters would be able to reject the remaining signal strength of the DORIS S-band transmission.

Finally the TM loop was used which is a TTCF-6 internal test mode that comprises the generation of simulated telemetry by the BBM, followed by up-conversion, amplification (SSPA) and loop back into the downlink path (via the Test Loop Translator) followed by subsequent decoding of the simulated TM in the BBM. The goal of the TM loop was to verify any potential impact of a spurious input signal (i.e., the DORIS beacon in this case) on the TM decoding of the BBM (i.e., in terms of lost TM frames).

Disturbances to the auto track ability of the TTCF-6 antennas were also verified by checking the AGC levels of the Digital Tracking Receiver (DTR).

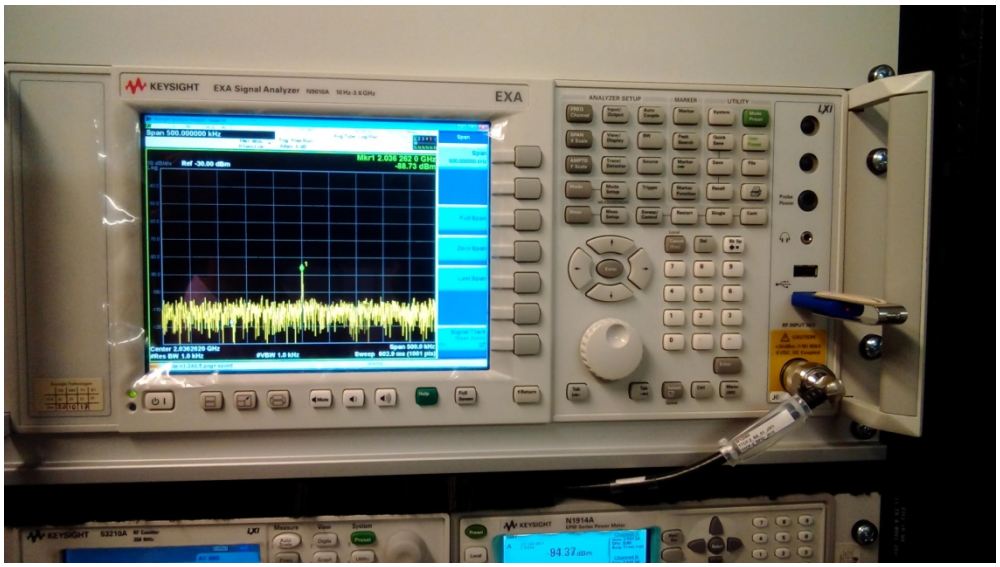


Figure 9: TTCF-6 integrated Spectrum Analyser.

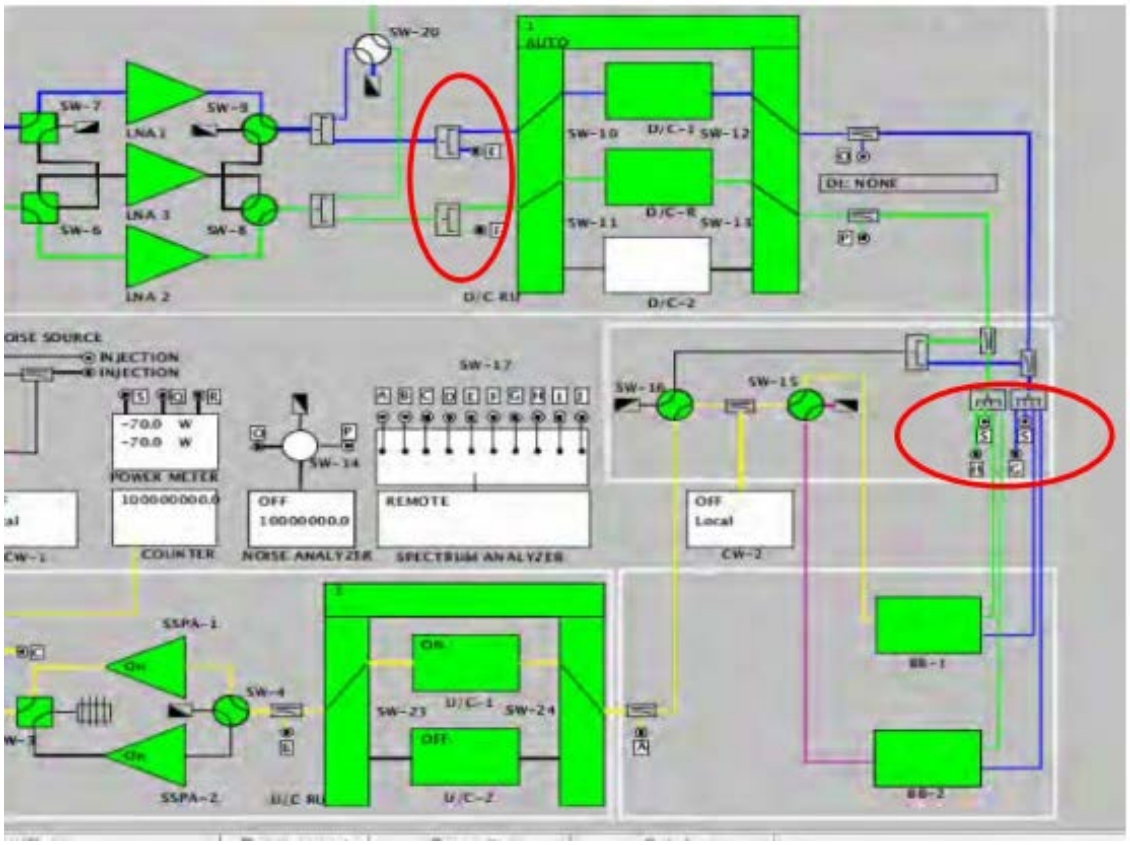


Figure 10: Spectrum Analyser Test Point Location E/F at LNA output and H/G after down-conversion to IF frequency (70 MHz).

D1/3 Measurements

Position Az 221 deg, El: 9.05 deg

1) Spectrum measured at points E and F for every Rx channel and around DORIS Beacon frequency (2036.25MHz) – (refer to Annex Figure 14)

2) Coning moving 1 degree for each direction, measuring around DORIS Beacon frequency at point E
3) AGC received at the DTR-ACU is always -100dBm. No influence.
4) TM loop with RF received power maximum and minimum (i.e. Tx BBM set from -18 dBm to -39 dBm). Forcing LHCP or RHCP only in the BBM; No Reed Salomon Error observed. No influence.

No difference observed when DORIS transmission stopped.

D2 Measurements

Pointing: Az 212 deg, El 20 deg

1) Spectrum measured at points E and F for every Rx channel and around DORIS Beacon frequency (2036.25MHz) – (refer to Annex Figure 15)
2) Coning of 1 degree for each direction, measuring around DORIS Beacon frequency at point E
3) AGC received at the DTR-ACU is always -100dBm. No influence.
4) TM loop with RF received power maximum and minimum (i.e. Tx BBM set from -18 dBm to -39 dBm). No Reed Salomon Error observed. No influence.
5) For Position 195º, 18º measuring around DORIS Beacon frequency at points E and F

D4 Measurements

Pointing: Az 195 deg, El 38 deg

1) Spectrum measured at points E and F for every Rx channel and around DORIS Beacon frequency (2036.25MHz) – (refer to Figure 16).
2) Coning moving 1 degree for each direction, measuring around DORIS Beacon frequency at point E
3) AGC received at the DTR-ACU is always -100dBm. No influence.
4) TM loop with RF received power maximum and minimum (i.e. Tx BBM set from -18 dBm to -39 dBm). Forcing LHCP or RHCP only in the BBM; No Reed Salomon Error observed. No influence.
5) For Position 195º, 18º measured around DORIS Beacon frequency at points E and F

D5 Measurements (direct-line-of-sight)

Pointing: Az 262.2 deg/0 deg

It should be noted that the D5 location **does not represent a real candidate DORIS location** for a DORIS beacon but was chosen as a reference measurement location to study the impact of the DORIS transmission in case of a direct line-of-sight visibility. **In this "extreme case" scenario the DORIS beacon would not be attenuated by terrain height differences, buildings, or tree lines.**

The Spectrum Analyser measurement tuned into LHCP could observe the **DORIS beacon** emission at the expected frequency of 2036.26 GHz at a power level of **-84.95 dBm** when the antenna was at an elevation of about 20 deg (refer to Figure 11).

The analysis was therefore carried forward to assess the beacon signal strength after the down-conversion to the IF frequency of 70 MHz (i.e., test point H) as shown in Figure 12.
The same region was observed when the DORIS beacon was turned off (refer to Figure 13) and no difference could be observed.

No difference can be seen when comparing Figure 12 (DORIS beacon on) to Figure 13 (DORIS beacon off).

It can therefore be concluded that the DORIS signal, when observed from the direct-line-of-sight location D5, visible at the post-LNA measurement point in the HF range (Figure 11) was fully supressed during the down-conversion to the IF range (potentially by the filters built into the D/C units).

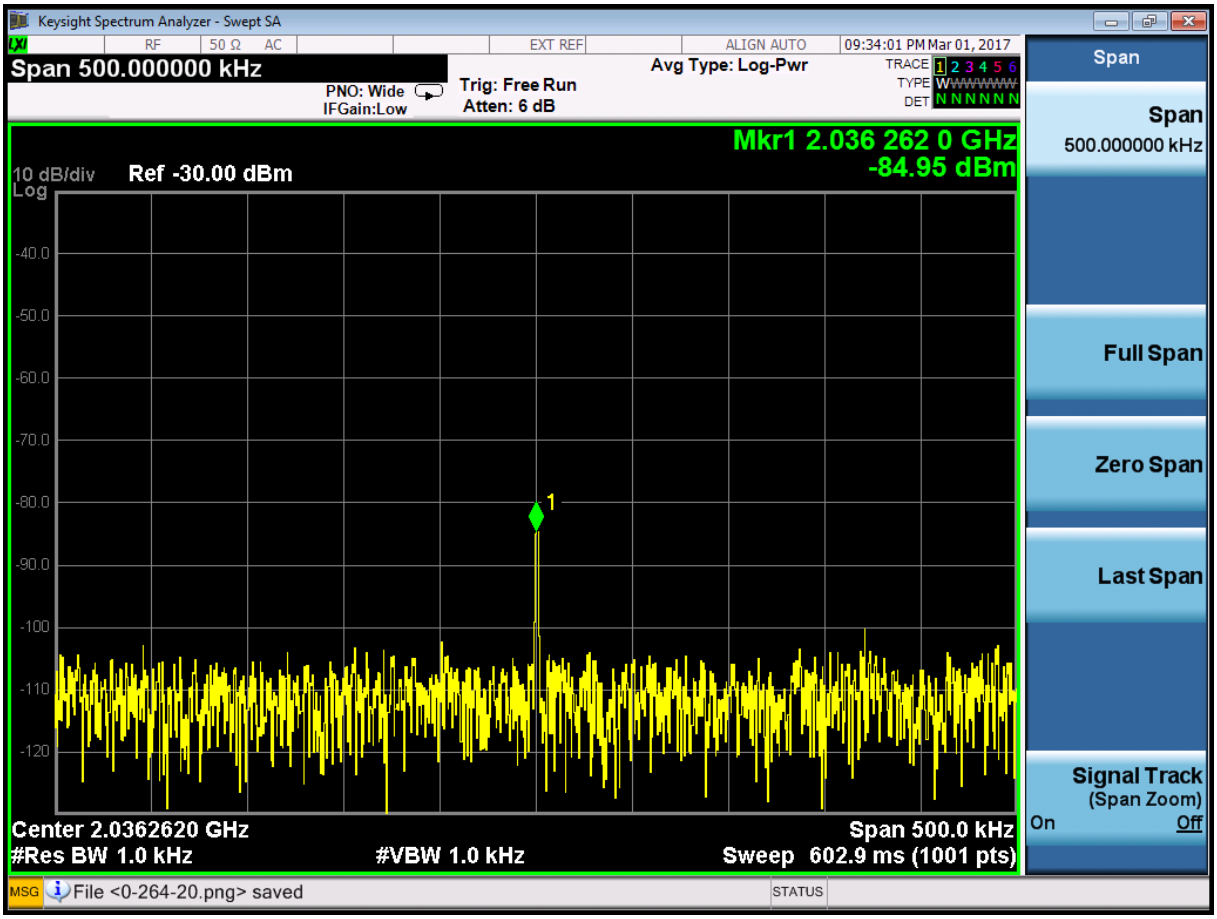


Figure 11: TTCF-6 spectrum analyser output at post-LNA measurement point for D5.

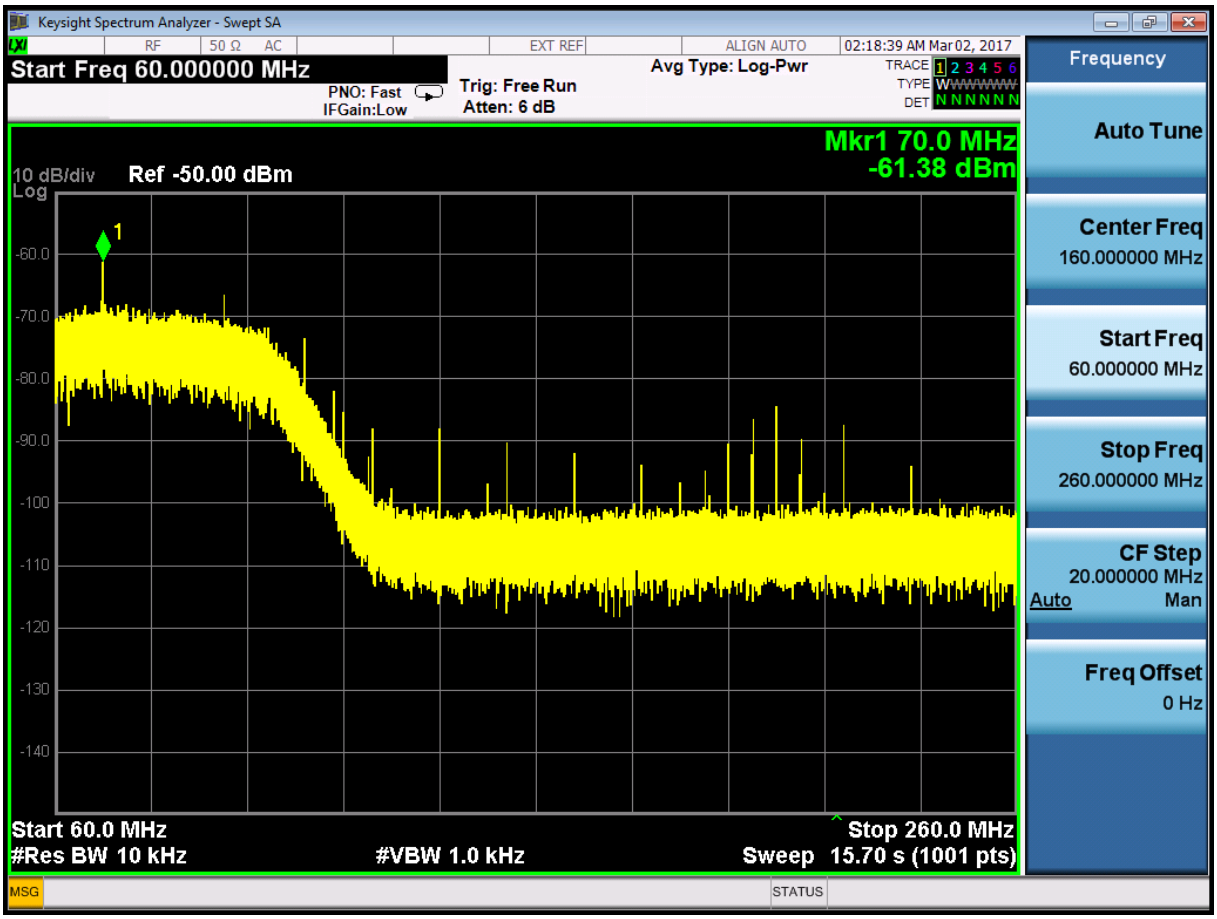


Figure 12: TTCF-6 Spectrum Analyser output at Point H (after D/C prior to BBM input) for D5.

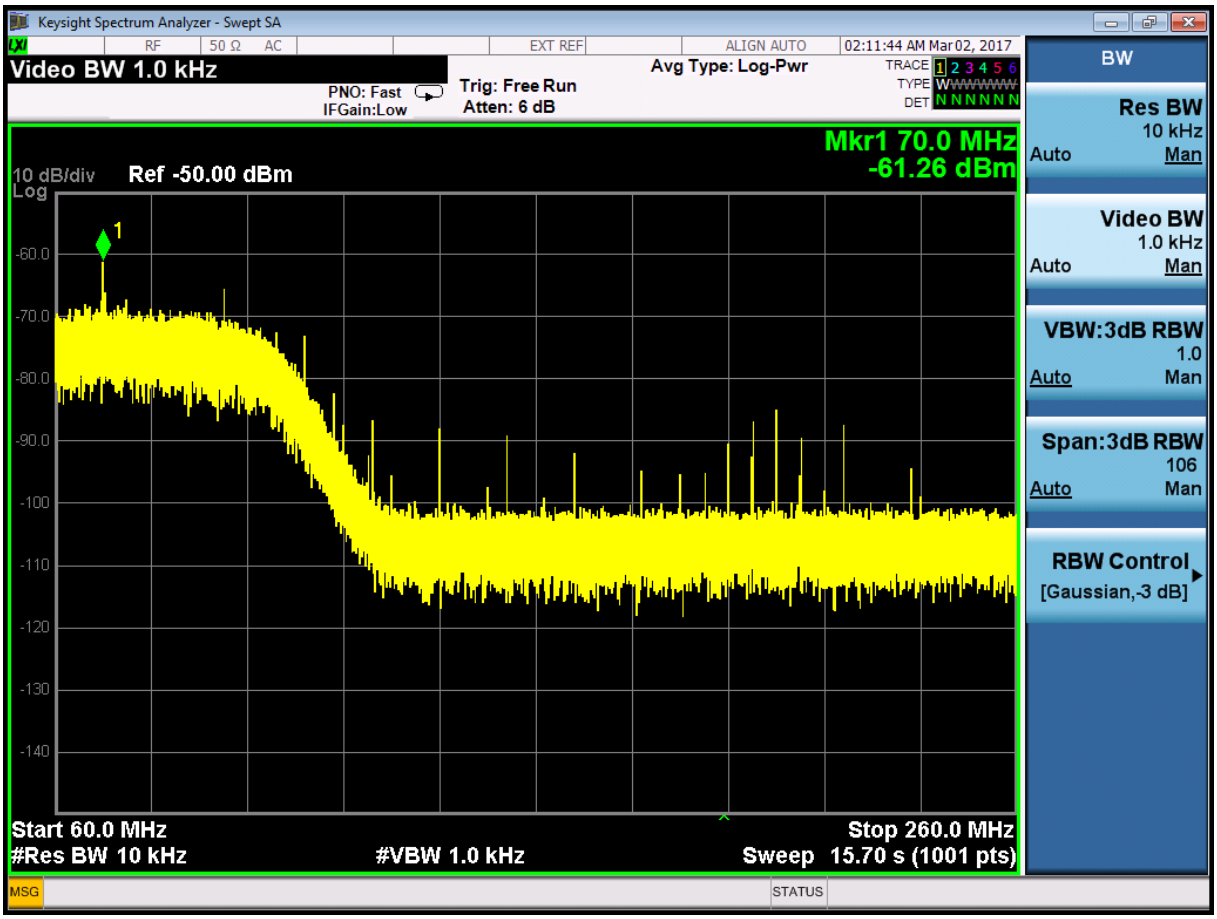


Figure 13: TTCF-6 Spectrum Analyser output at Point H (after D/C prior to BBM input) for D5 **- DORIS switched off.**

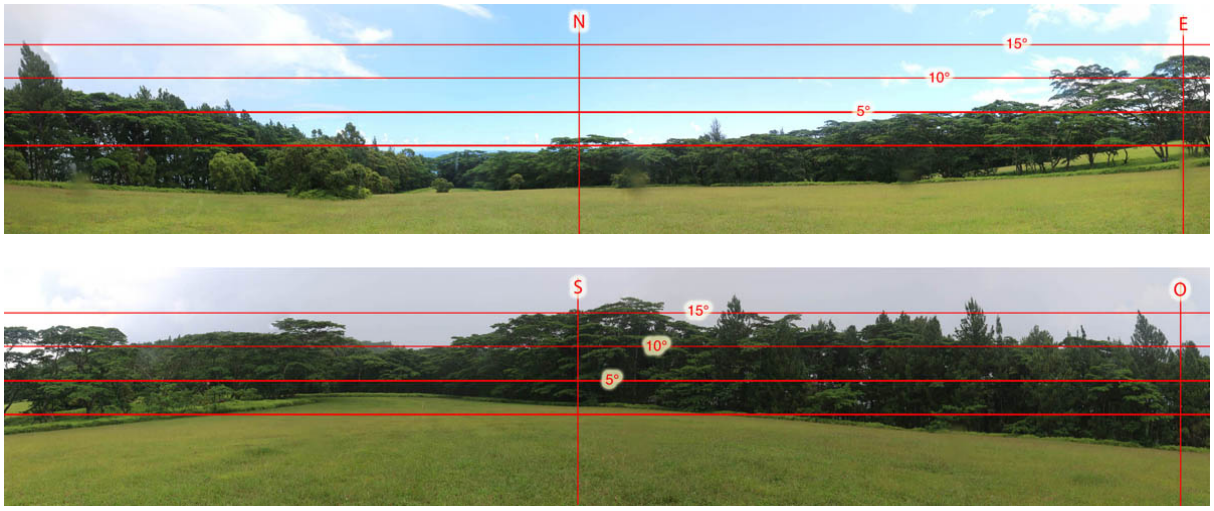
Summary

With the removal of this TNT C-band signal, either location (1001 or 1006) appears viable, otherwise (i.e., in case of TNT C-band transmission) location 1001 is not favourable.

For VLBI the preference continues to be location 1006, due to a lower background level, minimum spurious signals, and recession from cellular transmissions. However, a detailed consideration of all factors, including location of a possible SLR Radar, will need to weigh into the final decision.

For VLBI a maximum approximate power level of -60 dBm from DORIS can be accepted.

D2 is the preferred option for DORIS: clear skyview (the main DORIS system requirement), no need for felling trees. The following panoramic views show the difference:



From D2

From D3

It could be confirmed during this survey that the TNT Telecom facility was not at all impacted by DORIS transmission.

TNT states that there is no constraints on their side to clear the horizon mask by removing trees for any instrument layout.

From a Galileo TTCF-6 point-of-view it can be stated that the Doris beacon could be observed from the direct-line-of sight location (referred to as D5) at the post-LNA measurement point. It could however be demonstrated that it was entirely supressed after the D/C into the IF frequency range. Also no impact on the Digital Tracking Receiver used for the antenna auto-track mode could be seen during this survey.

No DORIS beacon signal was observed by Galileo TTCF-6 from any of the candidate locations D1/D3, D2, and D4 during this survey. It is most likely due to the fact that sufficient signal attenuation was caused by buildings, trees, or terrain height differences in the line-of-sight of the TTCF-6 location to the candidate DORIS locations D1/D3, D2, and D4.

References

- [1] Galileo Ground Control Segment to Space Segment ICD (GAL-ICD-ESA-SYST-X-0030, Issue 2.5)
- [2] DORIS Beacon RF Characteristics, Version 1.1, CNES.

Assessment of Objectives

Objective	Achieved (Yes/No)	Comment
Objective 1: measure and quantify (if any) the impact of a potential future CNES DORIS beacon on the Galileo TTCF-6 S-band reception and transmission when transmitting from the specified candidate locations D1/3, D2, and D4.	Yes	No signal has been observed from any of the candidate Doris location D1/3, D2, and D4 in the TTCF-6 signal reception path and the Digital tracking receiver path during this survey. The DORIS beacon **could be seen** from the **D5** location at the expected frequency (post LNA measurement point). Further analysis showed that the remaining signal strength was fully supressed by the D/C filters when measuring at the IF frequency range of 70 MHz (post D/C measurement point). No adverse impact (i.e., loss of TM frame) has been seen when doing a TM loop back. D5 is the direct-line-of sight location but **not** a real DORIS candidate location. This location was simply used as a reference location to study the impact of the DORIS beacon on the TTCF-6 reception if not attenuated by any tree lines, buildings, or terrain height differences (as in the case of the real DORIS candidate locations D1 – D4).
Objective 2: measure and quantify (if any) the impact of the Galileo TTCF-6 S-band transmission on the candidate VLBI antenna locations referred to as 1001 and 1006.	Yes	The Galileo TTCF-6 signal was observed at both VLBI candidate locations (1001 and 1006) with a signal strength ranging between –72.7 dBm (observed at the 1006 location with TTCF-6 Az/El 215/8) and -90.2 dBm (observed at the 1006 location with TTCF-6 Az/El 208/28). Detailed analysis to be provided.
Objective 3: measure and quantify (if any) the impact of the Galileo ULS-1 and ULS-2 C-band transmissions on the potential locations of a future VLBI antenna.	Yes	No signal has been detected from the Galileo ULS-1 and ULS-2 antennas on any of the VLBI candidate locations.
Objective 4: to collect sufficient measurements to determine the best relative geometry between the VLBI and DORIS instruments to minimise interference.	Yes	Sufficient data has been collected by VLBI to perform an analysis.
Objective 5: to collect geodetic data to fully specify the site.	Yes	A topographical survey was performed.

Annex A – TTCF-6 Spectrum Analyser Exports

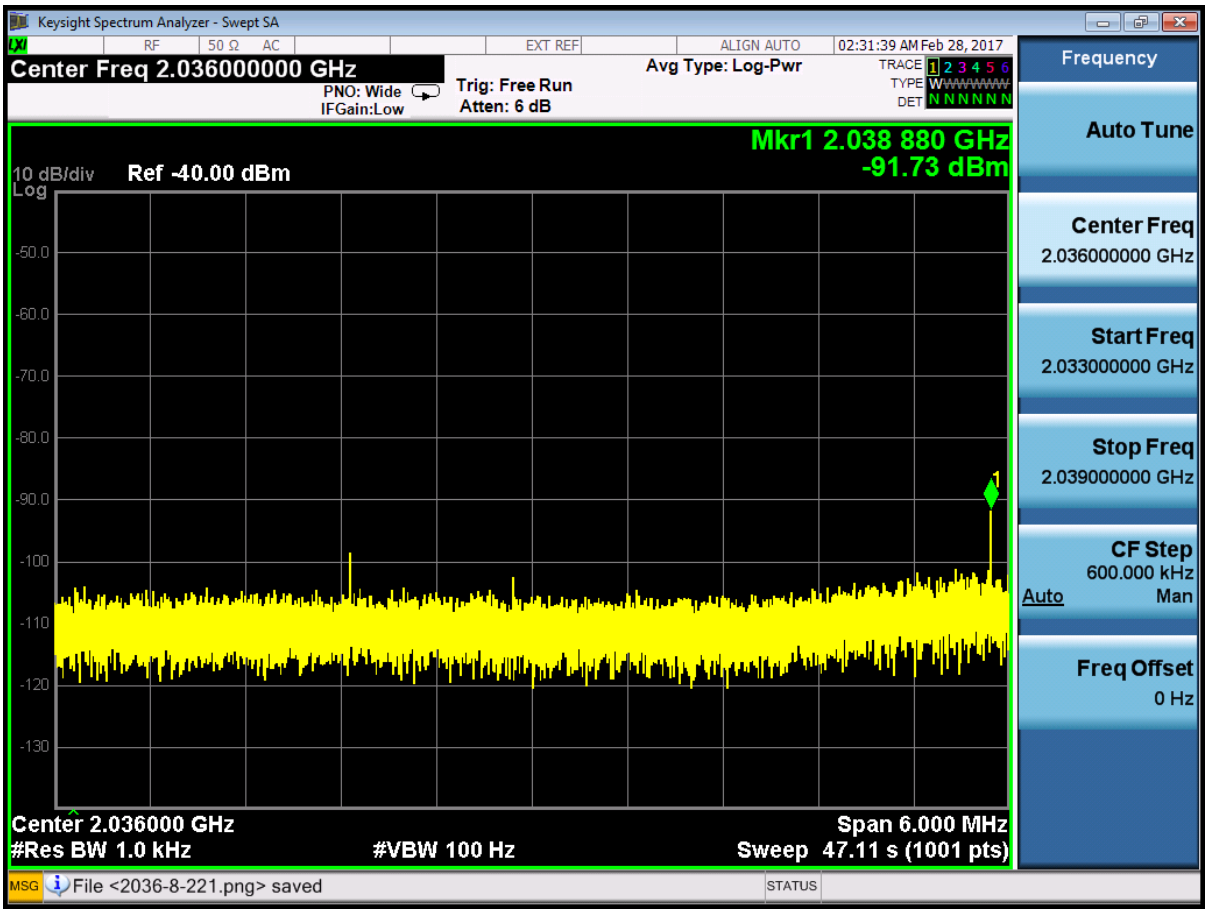


Figure 14: TTCF-6 Spectrum Analyser (post LNA point E - LHCP) pointing to DORIS D1/D3

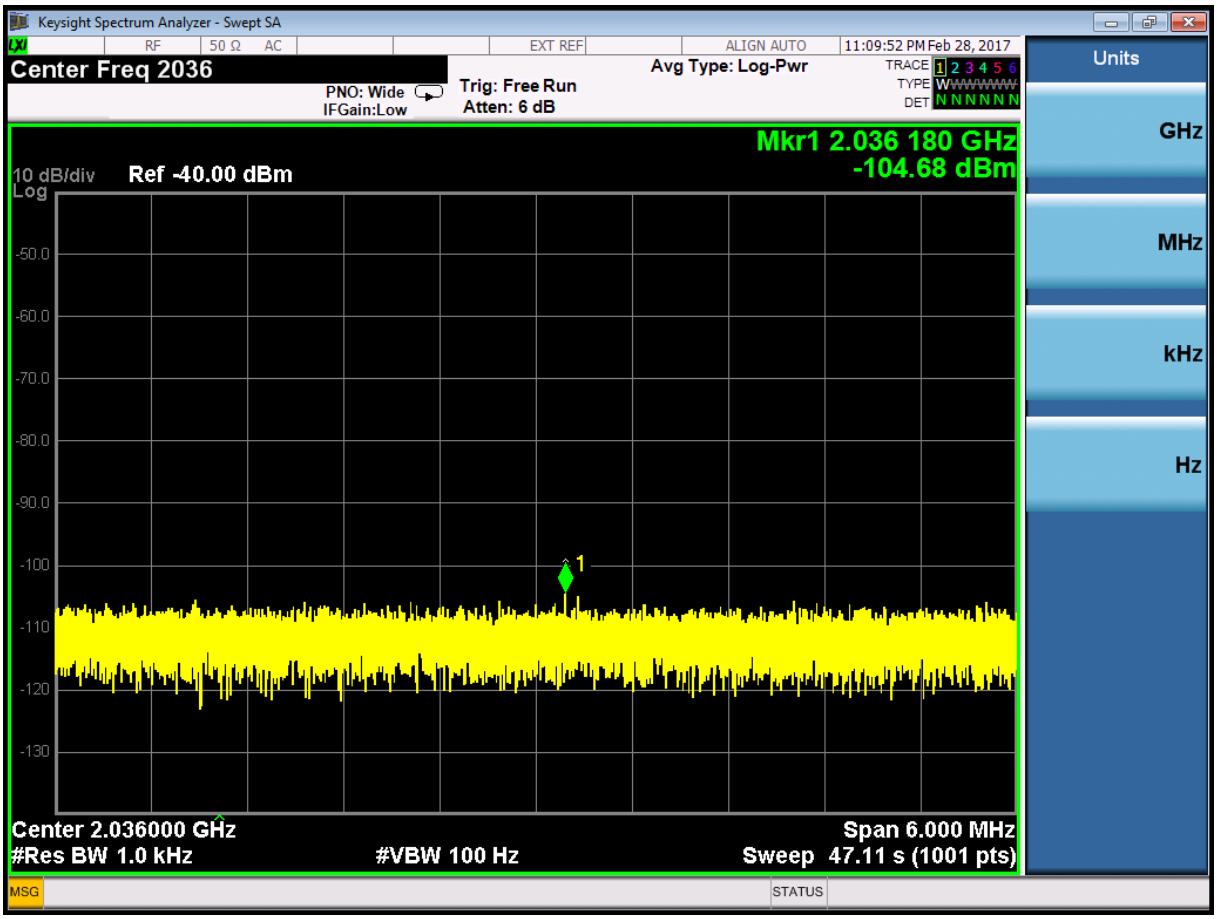


Figure 15: TTCF-6 Spectrum Analyser (post LNA point E - LHCP) pointing to DORIS D2.

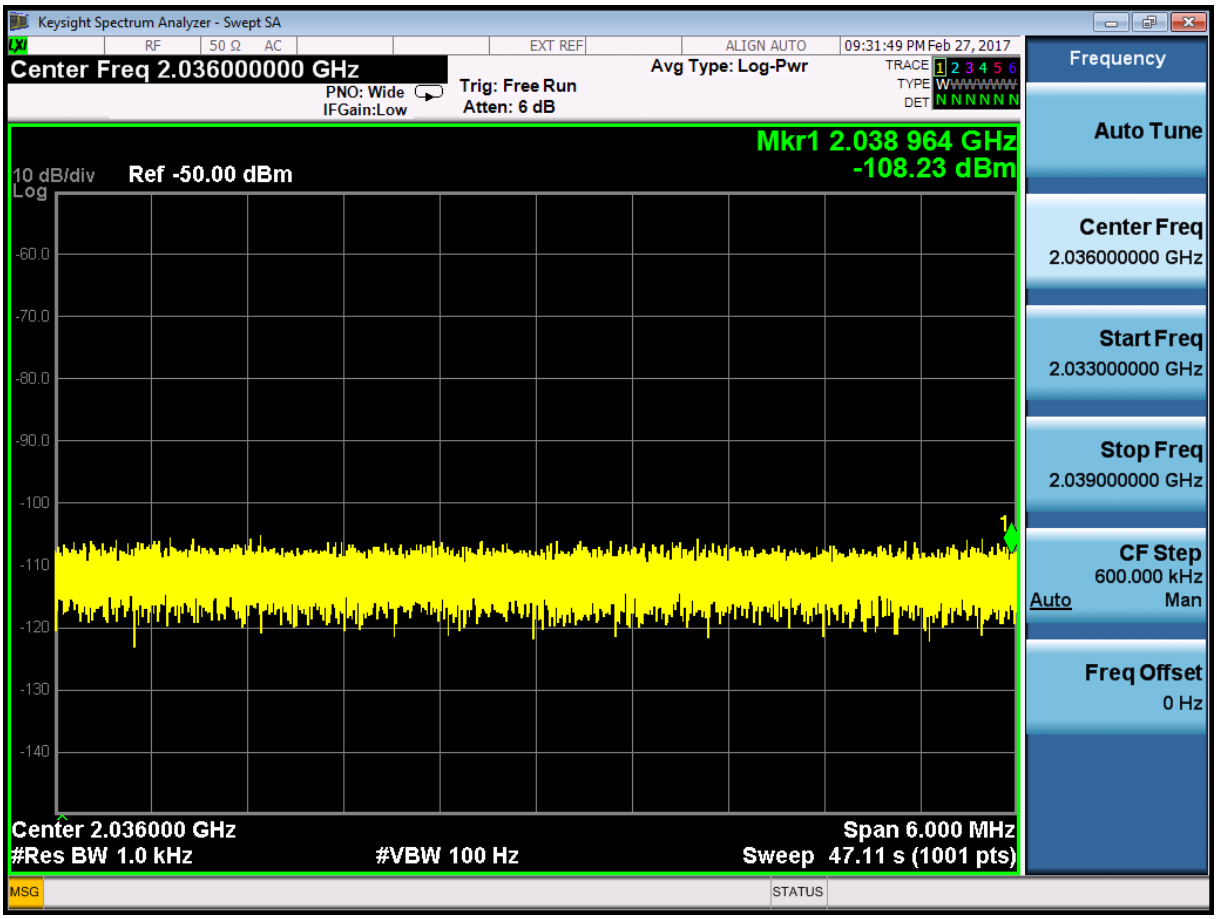


Figure 16: TTCF-6 Spectrum Analyser (post LNA point E - LHCP) pointing to Doris D4.

Annex B – TTCF-6 Gain Patterns

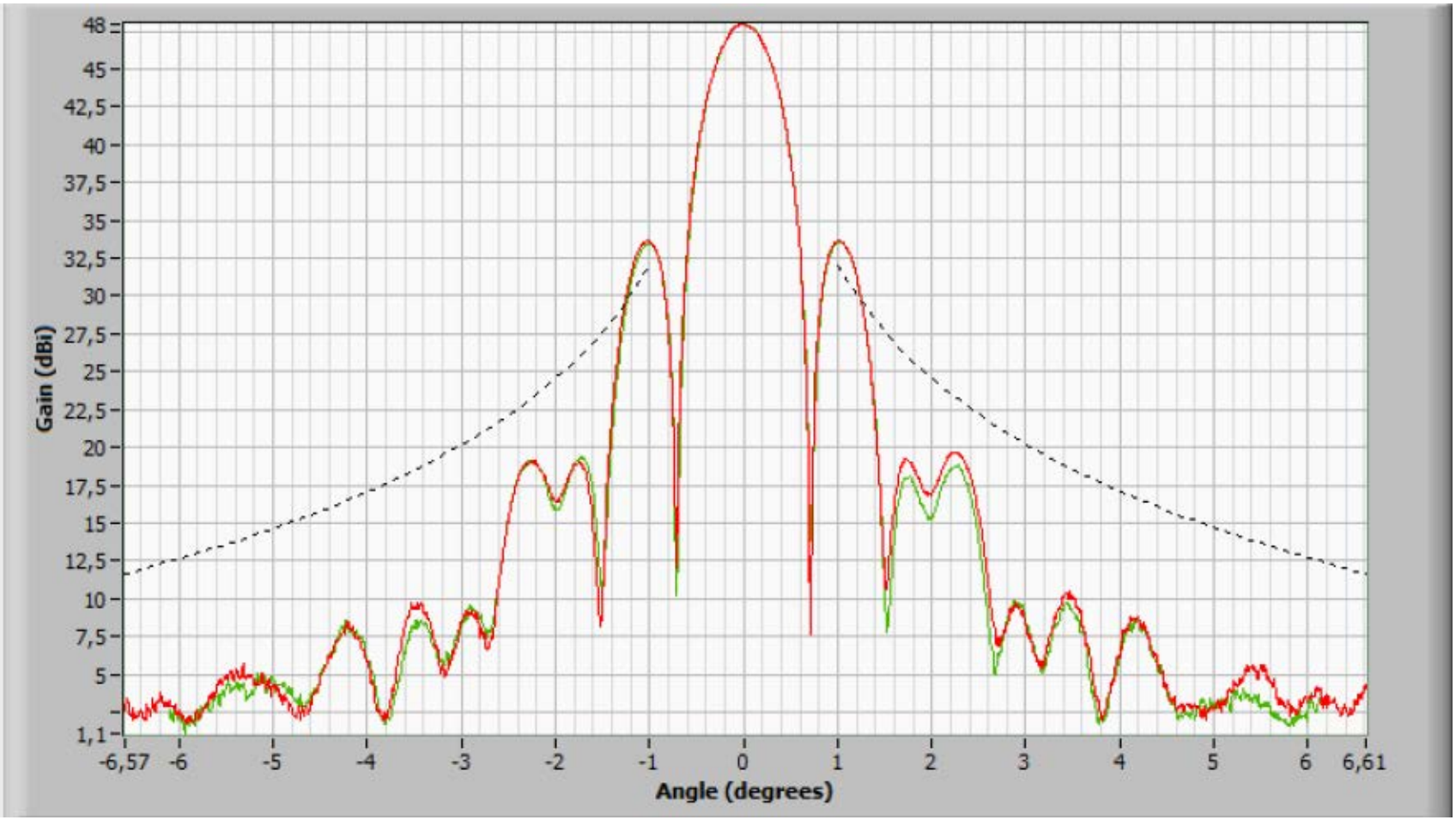


Figure 17: TTCF-6 Antenna Gain Pattern (Azimuth in Red, Elevation in Green)

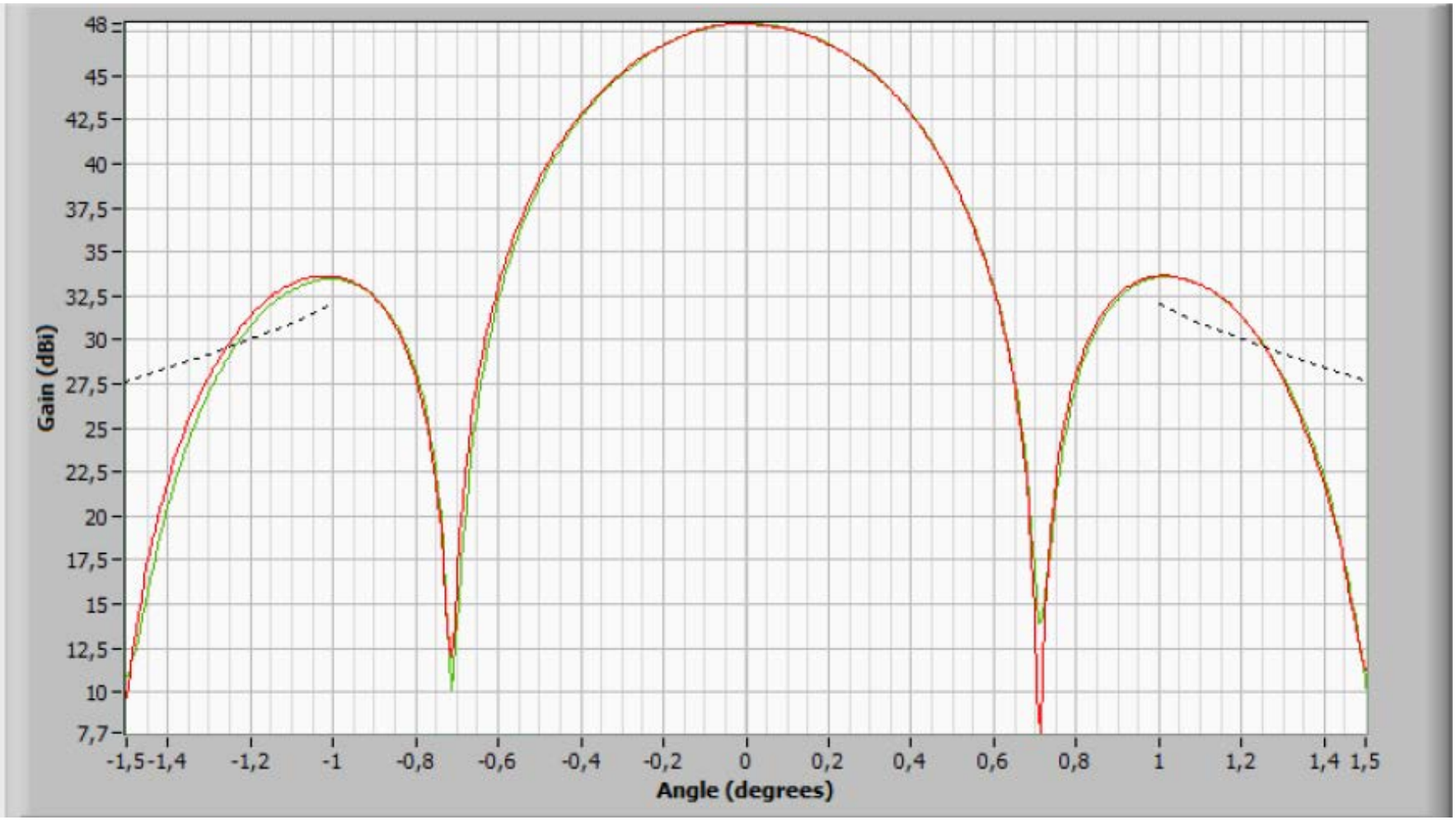


Figure 18: TTCF-6 Antenna Gain Pattern – Narrow Beam (Azimuth in Red, Elevation in Green)