JASON3, a story of Telemetry and Telecommand interference handling

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Abstract: This paper describes the methodology and the results of the interferences analysis that the JASON3 spacecraft has to deal with, as part of the PROTEUS platform series, sharing frequencies, modulation schemes and ground network.

Keywords: Interference, S-band, PROTEUS, JASON3, Frequency, TT&C

1. Introduction

The joint CNES-NASA-NOAA-EUMETSAT JASON3 mission is based on a PROTEUS satellite platform and then uses its inherited Telemetry, Tracking and Control (TT&C) S-Band sub-system. Thanks to its instruments including the Poseidon altimeter, JASON3 is able to determine the height of the oceans and thus to contribute to the weather forecast, and to climatology.

2. JASON3 characteristics

2.1 Orbit and attitude

JASON3 will orbit at an altitude of roughly 1300 km with a near circular orbit at 66° of inclination. JASON3 attitude keeping is geocentric, with +Zs axis (payload pointing axis) being nadir oriented toward the velocity vector (+Ys).

2.2 TT&C subsystem

As for the other PROTEUS missions, the JASON3 TT&C system is composed of two S-band transceivers in redundancy both connected to two identical large aperture antennae. In order to offer the largest coverage (objective is 4π steradian), the antennae are operating in opposite circular polarization (left and right) and are pointing in opposite directions on the Zs axis as shown in Figure 2.

2.3 TT&C frequencies

Three frequency couples (TM/TC) have been allocated to the PROTEUS satellites in the International Telecommunication Union (ITU) assignated bands: 2200 MHz to 2290 MHz for the Telemetry (TM) link and 2025 MHz to 2110 MHz for the Telecommand (TC) link. Each frequency couple could be used by several PROTEUS satellites as seen in Table 1.

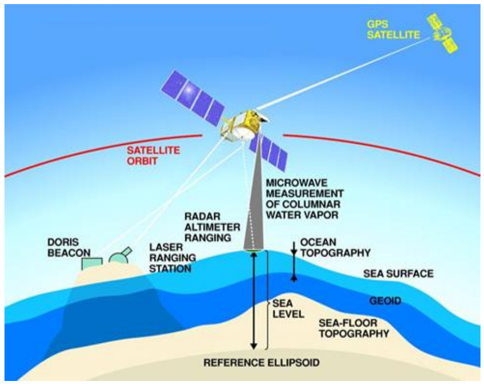

Figure 2. JASON3 Measurement System

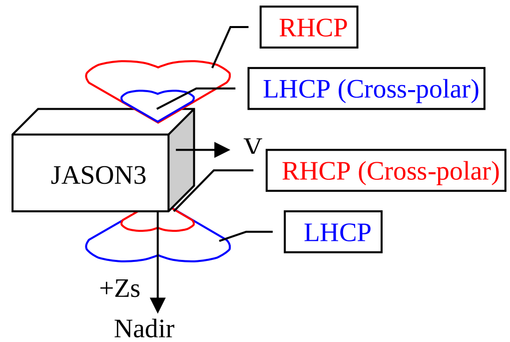

Figure 1. JASON3 attitude during nominal operations

	Calipso	Jason2	Jason1	Jason3	SMOS	Corot
TC frequency (MHz)	2088.878		2040.493			2101.71
TM frequency (MHz)	2268.465		2215.92			2282.4
Orbit	Circular, heliosynchronous i = 98.2°	Circular with high inclination i = 66°			Circular, heliosynchronous i = 98.4°	Circular, polar
Altitude (km)	H = 705	H= 1336			H = 755	H = 896

Table 1. PROTEUS frequencies and orbits

2.4 S-Band ground network

During nominal operations, the JASON3 ground network is composed of four earth stations:

- Usingen (USG) Telemetry TeleCommand Earth Terminal TTCET from Eumetsat network
- Wallops and Fairbanks Command and Data Acquisition Station (CDA) and Barrow (BRW) stations from NOAA network

During LEOP (Low Earth Orbit Operations) and SHM (Safe Hold Mode) situations, the network is complemented with stations of the CNES 2 GHz network (HBK, KRU, KER, AUS).

3. JASON3, SMOS & JASON1 conflicts

3.1 Context

JASON3 transceiver is configured with the same frequency couple as JASON1 and SMOS leading to potential RF conflicts both in TC and TM links.

During early phase of JASON3 development, it was already known that at the JASON3 launch horizon in 2015, JASON1 will be deorbited, cancelling all interferences cases.

By against, as it was done for JASON2/CALIPSO and JASON1/SMOS previous pairs, JASON3/SMOS conflicts have to be studied. Both spacecrafts have indeed the same TM/TC frequencies, the same modulation and data rates and their transmitters are always transmitting.

SMOS is using the same 2 GHz network of ground stations plus TTCET ground stations. There are thus some overlapping areas during spacecraft visibilities periods. The risk is emphasized during LEOP by the fact that additional ground station sites may be used.

Station performances	NOAA Network			TTCET	CNES 2 GHz Network (KRU, HBK, KER, AUS)
	WCDA	FCDA	Barrow		
Antenna diameter (m)	13	13	5	3.1	12
θ_{3dB} (°)	<1	<1	1,76	3,2	<1
Spatial isolation (dB) C/I @ 5° (off-angle)	>>25	>>25	20	<20	>>25
Conflict risk	No risk	No risk	Risk	Risk	No risk

Table 2. Ground network characteristics and interference risk

Due to their small antenna diameter and then to their wider beam, the interference risk is higher over TTCET and BRW ground stations as seen in Table 2, the angular isolation between satellites being too low to avoid any disturbance on the link budget.

The following cases have thus emerged with a potential risk:

- Interfering over the TTCET stations (SMOS operations over AUS/KRN and JASON3 operations over USG)
- Interfering over the BRW station by SMOS telemetry signal on the JASON3 TM link.

3.2 Methodology and results

A link budget analysis has been done for conflict cases with a 5° separation between both spacecrafts taking into account the following points:

- Ground antenna gain isolation
- Distance isolation (Propagation losses)
- On-board antenna gain and polarization isolation
- Nominal or SHM/LEOP operations

The link budgets with and without interferer have been computed taking into account the three following sizing geometrical cases as shown on Figure 3.

- 5° angular separation at low elevation (case 1),
- 5° separation at high elevation (case 2),
- 90° separation, one satellite being at zenith, the other being at low elevation (case 3).

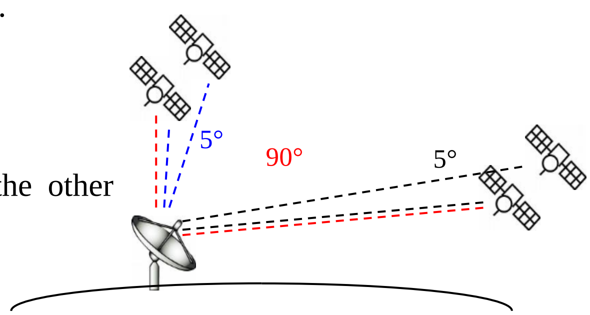

Figure 3. Sizing geometrical cases

For nominal operations, JASON3 attitude implies that during all pass duration, the main polarization seen from the ground is LHCP, whereas for SMOS it may be the LHCP or the RHCP one (Figure 4)

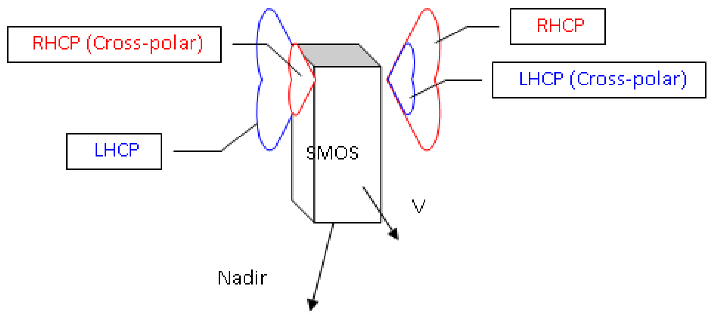

Figure 4. SMOS attitude during nominal operations

On the other side, during SHM and LEOP operations, PROTEUS spacecrafts are spinning around the Zs axis leading to a change of the onboard antenna seen from the ground and thus of the polarization.

After analysis, the following conclusions have been issued:

<table>
<tr><th colspan="2">JASON3 / SMOS TM LINK</th><th>Nom / Nom</th><th>SHM / Nom</th><th>Nom / SHM</th><th>SHM / SHM</th></tr>
<tr><td rowspan="2">TTCET</td><td>JASON3 JAMMER</td><td>Eb/No small degradation when both satellites at zenithal position</td><td>Eb/No small degradation when both satellites at zenithal position</td><td>No RF conflict risk</td><td>No RF conflict risk</td></tr>
<tr><td>SMOS JAMMER</td><td>No RF conflict risk</td><td>No RF conflict risk</td><td>No RF conflict risk</td><td>No RF conflict risk</td></tr>
<tr><td>BARROW LEO-T</td><td>SMOS JAMMER</td><td>No RF conflict risk</td><td>No RF conflict risk</td><td>No RF conflict risk</td><td>The SMOS jamming signal may be enough to lock the JASON3 ground receiver</td></tr>
</table>

<table>
<tr><th colspan="2">JASON3 / SMOS TC LINK</th><th>Nom / Nom</th><th>SHM / Nom</th><th>Nom / SHM</th><th>SHM / SHM</th></tr>
<tr><td rowspan="4">TTCET</td><td rowspan="3">JASON3 JAMMER</td><td colspan="2">Case 1 : TC link establishment
No RF conflict risk</td><td colspan="2">Case 1 : TC link establishment
Possible RF conflict risk</td></tr>
<tr><td colspan="4">Case 2 : High elevation phase
No RF conflict risk</td></tr>
<tr><td colspan="4">Case 3 : separation of 90° between spacecrafts
No RF conflict risk</td></tr>
<tr><td>SMOS JAMMER</td><td>No RF conflict risk</td><td>No RF conflict risk</td><td>No RF conflict risk</td><td>No RF conflict risk</td></tr>
</table>

Table 3. JASON3/SMOS interference conclusions

There is no serious risk of conflict for the TM link:

- Some low Eb/No degradation (1.5 dB) on the SMOS TM link by the JASON3 signal over KRN and AUS TTCET (but no TM loss) may occur.
- The JASON3 TM link over BRW may be disturbed by SMOS signal when both satellites are in SHM (very seldom case)

Concerning the uplink, the SMOS TC link, when in SHM mode may be difficult to establish in presence of the JASON3 interfering signal: the link establishment delays could be longer, but the perturbation would not have any consequences on the pass follow-up apart a false RF lock on the interfering signal when establishing the TC link..

A simulation with STK software was run over a 1 year period (2013/07/01 – 2014/07/01) to establish the conflict statistics. The number of conflicts where SMOS and JASON3 are separated by less than 5° over the previous ground stations was computed (Table 4)

	BARROW	USINGEN	KIRUNA	AUSSAGUEL
Number of conflicts	28	20	25	11
Loss ratio (*)	1%	<1%	<1%	<1%
Mean conflict duration	45s	40s	32s	47s
Mean period	17 days	13 days	14 days	31 days

(*) Considering passes with at least 8 min of visibility with elevation > 5° for JASON3 and 6 min for SMOS

Table 4. JASON3/SMOS conflicts statistics

The number of expected conflicts being low (statistics), it has been recommended to filter the passes with a delta angle less than 5° in order to avoid any telemetry loss or any bad lock on the TC link. This kind of operational filtering is already achieved on the in-flight PROTEUS spacecrafts, the same instructions will thus be applied to JASON3.

4. Tandem flight with JASON2

JASON2 was launched in June 2008 and has the same mission/architecture than JASON3.
During the first months of JASON3 in orbit (up to 6 months), JASON2 and JASON3 spacecrafts will fly on formation on the same orbit separated each other by 1 to 10 minutes in order to make instruments inter-calibration. Then they will be equi-located on the orbit.

JASON3 and JASON2 have different TM/TC frequencies but during the tandem flight, they will use co-localized ground stations (50m) for USG and WPS sites.
Potential RF interference cases may thus happen over these two ground stations.

An isolation budget analysis has been done to assess or not the risk of interference during this tandem phase:

SPATIAL ISOLATION	SPECTRAL ISOLATION
Ground antenna gain isolation - GSI	ΔFrequency
Range isolation (Propagation losses) - RI	Transmission mask
On-board antenna gain isolation – OBSI	Filtering

Considering the spatial isolation budgets, the following hypotheses have been taken into consideration:

- Only Nominal mode for spacecrafts
- Same station location for the TC link
- ITU antenna pattern mask for off-axis losses, JASON antenna pattern
- JASON3 one minute behind JASON2

The following table (Table 5) summarizes the computed spatial isolation budget:

Worst Case Spatial Isolation (dB)				TM	TC
Usingen (TTCET)	JASON2	Interfering on	JASON3	11.7	12.3
	JASON3	Interfering on	JASON2	12.3	
Wallops (CDA)	JASON2	Interfering on	JASON3	27.9	27.2
	JASON3	Interfering on	JASON2	28	

Table 5. Spatial isolation budgets (dB)

Thanks to their large antenna, the worst case of spatial isolation for the CDA stations is 15 dB higher than for the TTCET stations.

For the spectral isolation budget, it is necessary to look at the transmitted spectrums and their occupied bandwidth and at the filtering done at reception:

	TM link	TC link
Modulation	Not-filtered QPSK	BPSK/PM, subcarrier @ 16kHz
Coding	RS+CV (7;1/2)	No coding
Data Rate	838861 kb/s (with RS)	4 kb/s
Occupied Bandwidth	99% of the power in 2Rs	100 kHz @-20 dBc

Table 6. JASON3 RF waveforms

The following tables (Table 7) summarize the different isolation budget items:

JASON3 interfering on JASON2	**TM**		**TC**	
	TTCET	CDA	TTCET	CDA
Transmitted power ratio (dB)	0		0	
Spatial Isolation (dB) (Worst case) incl. transmitting gain and propagation losses	12.2	28	12.3	27.2
In-Band Spectral Isolation (dB)	70		70	
Out-Of-Band rejection (dB)	> 25		> 70	
Polarisation (dB)	0		0	
Total (dB)	**> 80**	**> 95**	**> 80**	**> 95**

JASON2 interfering on JASON3	**TM**		**TC**	
	TTCET	CDA	TTCET	CDA
Transmitted power ratio (dB)	0		0	
Spatial Isolation (dB) (Worst case) incl. transmitting gain and propagation losses	11.7	27.9	12.3	27.2
In-Band Spectral Isolation (dB)	70		70	
Out-Of-Band rejection (dB)	> 25		> 70	
Polarisation (dB)	0		0	
Total (dB)	**> 80**	**> 95**	**> 80**	**> 95**

Table 7. JASON3/JASON2 isolation budgets

The isolation budgets are thus very high: signal to interference ratio C/I > 80 dB even for TTCET where the spatial isolation would not be enough to prevent from a conflict (C/I ~ 12 dB)
So no interference between both spacecrafts either for USG or for WPS sites is expected.
But if the risk of interferences for the data link is very low, the tracking sub-system may have been disturbed. Indeed as both satellites signals may be received in the main antenna lobe, confirmation that the tracking receiver is not going to lock on the interfering signal has to be assessed.
For the TTCET network stations, as they are working on ephemerides, and not by means of "autotrack" systems, there is no risk of lock of the nominal antenna on the interferent signal.
The WPS station can operate either on ephemerides or in "autotrack", but in this case, thanks to its big antenna diameter (13m or 14m), and thus of its small beamwidth at 3 dB, the spatial isolation (> 25 dB) between both signals will ensure a "zero" risk of interference.

On the other hand, some RF tests done in lab environment have confirmed that the presence of both signals (nominal and interferent) in the reception chain (LNA, down-conversion..) of onboard but also of ground equipment, is not going to generate intermodulation products and/or saturation levels which could disturb the link quality.

5. No TM at separation risk

Interference mitigation being one of the JASON3 motto because of its last in the family status, it has to face a last interference case on the launch pad because of the SpaceX Falcon9 launcher transmitter characteristics.

Indeed, at separation, the JASON3 TT&C link is established for the first time with the station in visibility; only telemetry service is achieved during this first pass.

As a reminder, JASON3 TT&C frequencies are the following:

- TC link : 2040.493 MHz / TM link : 2215.92 MHZ

Concerning the launcher, only the second stage of the rocket is still present at separation. Thus according to Falcon9 figures two TX frequencies may potentially disturb JASON3 TM link or vice-versa: S2TX1 and S2TX2 (Figure 5)
Concerning the S2TX2 transmitter, the delta frequency with the JASON3 TM frequency being about 35 MHz and the Falcon9 signal bandwidth being 3 MHz, the frequency isolation is big enough to avoid any interference between both signals.
The potential disturbance may come from the S2TX1 Falcon9 signal whose frequency is about 2 MHz away from the JASON3 TM frequency. Moreover, as the Falcon9 signal has a width bandwidth of 3 MHz compared to the JASON3 QPSK spectrum at low rate (about 800 kHz), both signals are overlapping. The interference cases shall thus be investigated.

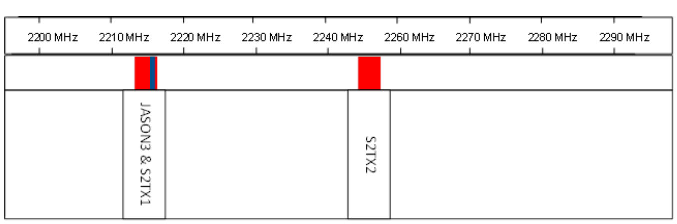

Figure 5. JASON3/Falcon9 frequencies

Several potential anomalies could occur due to this interference context:

- Bad antenna tracking
- LNA saturation and/or intermodulation
- Receiver lock disturbance
- Noise addition in the reception chain

5.1. Spatial Isolation Budget

As this potential case of interference will occur during JASON3 spacecraft separation, the spatial isolation is very low. At the beginning of operations, JASON3 and Falcon9 are still attached, and then following the separation, they will slowly move away at a speed of about 0,4 m/s leading to a few hundredth of degree separation after 5 min.

The separation will happen over HBK ground station which uses a 12 meters antenna. The 3 dB bandwidth lobe is 0.75° wide. Thus no isolation from the antenna could be expected. Both signals will be received in the main lobe of the antenna and so with the same gain.

5.2. Spectral Isolation Budget

Both signals may be superposed as seen on Figure 6. In-band isolation will then depends on the delta of EIRP between both signals; JASON3 EIRP is between -4.2 dBW and 9 dBW depending on the antenna gain in direction of the station. Falcon9 transmitter computed EIRP is 11 dBW, leading to a delta of power between both signals of 2 dB to 15 dB.

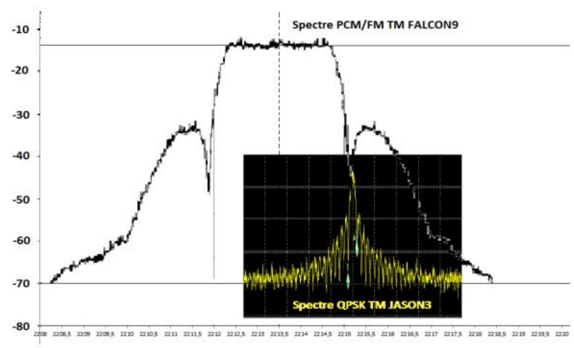

Figure 6. JASON3 and Falcon9 TM spectrums

Concerning ground isolation, the in-band interfering signal being only spaced from the nominal one by 2 MHz, it is not filtered by the different input stages of the receiver. No isolation can be considered between both signals at receiver level.

In order to characterize the receiver behavior in this interference case, performances have been measured with a lab test setup.

Both JASON3 and Falcon9 signals are generated with lab means, the delta of power between both signals is set up between 2 and 15 dB. Tests are done at several frequency shifts between both signals in order to cope with the interfering spectrum bandwidth uncertainty.

We observe during these tests different kind of interference issues on our telemetry link:

- Unlock of the JASON3 TM signal as soon as the interfering signal is received.
- Degradation of the TM link performances (Eb/No, Bit Error Rate BER) in presence of the interfering signal (Figure 7)
- Impossibility to lock the receiver on the nominal signal in presence of the interfering signal
- Lock of the nominal JASON3 receiver on a bad frequency eventually leading to no frame synchronization.

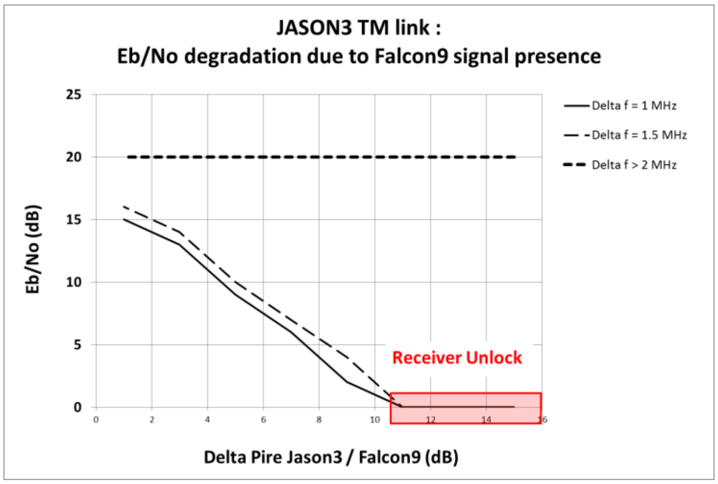

Figure 7. Eb/No degradation on the JASON3 TM link

The gravity of the disturbance depends principally of the position of the QPSK JASON3 signal according to the interfering signal bandwidth.

Indeed, in the theoretical case, the JASON3 signal is in a low amplitude lobe of the interfering signal, this case being also not so unfavourable. But due to the uncertainty in the Falcon9 spectrum (filtering, exact bandwidth), the JASON3 signal may be more or less disturbed by the interferer.

Following these tests, the risk of interference between the Falcon9 telemetry signal from S2TX1 and the JASON3 transmitter has been proved. There was thus a non-null probability to have no spacecraft telemetry at separation during the first pass over HBK. The contingency case NO TM at separation shall in this case be addressed with the process of specific operations to check the satellite status. Of course this kind of procedure has to be avoided if possible because it comes with a lot of stressful operations. It was thus decided to ask SpaceX if they could change their transmitter frequencies to cancel any risk.

Based on the previous analysis and conclusions, SpaceX offered to switch the first and second stage transmitters leading to a zero risk of interference at separation.

6. Conclusion

The analysis conducted in this paper shows us that spectral bandwidth sharing is now a challenge in the S-band, especially in a spacecraft family where frequencies, rates, modulation and ground

networks are shared. JASON3, as part and last of the PROTEUS family hasn't escaped to multiple interference studies and experimentations. Happily, the documented cases are seldom and may be handled with simple operational rules like pass filtering according to spacecraft preference.
By proceeding this way, this ensures a risk reduction with family's spacecrafts but unfortunately not with the hundred ones sharing the same S-band frequency slot.
S-band frequencies may also be shared with launcher transmitters; in this case the coordination is crucial because operations at separation and during first pass are really critical. Some minutes of lost telemetry may lead to tough recovery operations and thus stress to the teams. Hopefully in the JASON3/Falcon9 case, it has been easy to find an alternative solution to avoid any risk. This shows the importance of analysis and coordination like the ones presented in that paper to use for a long time the vital TT&C S-band spectrum resource. The JASON3 launch is foreseen end of 2015, the 6 first months of in-orbit life will allow us to confirm the status of the operations and the interference risk management.

6. Glossary

AUS: Aussaguel, France

BER: Bit Error Rate

BRW: Barrow, Alaska

CDA: Command and Data Acquisition Station

Eb/No : Power per bit to Noise density ratio (in dB)

EIRP: Equivalent Isotropic Radiated Power

FBK: Fairbanks, Alaska

HBK: Hartebeeshoek, South Afrika

KER: Kerguelen, French Southern and Antartic Lands

KRN: Kiruna, Sweden

KRU: Kourou, French Guyana

LHCP: Left Hand Circular Polarization

LNA: Low Noise Amplifier

RHCP: Right Hand Circular Polarization

RF: Radio Frequency

STK: System Tool Kit

TC: Telecommand

TM: Telemetry

TTCET: Telemetry TeleCommand Earth Terminal

TT&C: Telemetry, Tracking and Control

USG: Usingen, Germany

WPS: Wallops, Virginia