GALILEO GALILEI (GG)

REPORT ON FREQUENCY MANAGEMENT ISSUES

DRL/DRD: DEL-54

Written by	***Responsibility***
M. Ariagno	Author
Verified by	
n.a.	Checker
Approved by	
	Product Assurance
	Configuration Control
	Design Engineer
	System Engineering Manager
A. Anselmi	Study Manager
Documentation Manager	
R. Cavaglià	

Thalidations evidence are kept through the documentation management system.

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
01	05-Jun-09	First issue submitted to PRR	M. Ariagno

TABLE OF CONTENTS

1 SCOPE AND PURPOSE

This document is submitted in partial fulfilment of Work Package 1A–ADA/F of the GG Phase A2 Study (DRL item DEL-54).

The purpose of the document is to provide a preliminary approach to the issue of frequencies assignments to the Galileo Galilei (GG) satellite.

2 REFERENCES

2.1 Applicable Documents

[AD 1] ASI, “Progetto Galileo Galilei-GG Fase A-2, Capitolato Tecnico”, DC-IPC-2007-082, Rev. B, 10-10-2007 and applicable documents defined therein

2.2 Standards

[SD 1] ECSS-M-00-02A, Space Project Management – Tailoring of Space Standards, 25 April 2000

[SD 2] ECSS-E-ST-10C, Space Engineering - System Engineering General Requirements, 6 March 2009

[SD 3] ECSS-E-10-02A, Space Engineering – Verification

[SD 4] ECSS-Q-00A, Space Product Assurance - Policy and Principles, and related Level 2 standards.

2.3 ASI Reference Documents

[RD 1] GG Phase A Study Report, Nov. 1998, revised Jan. 2000, available at: http://eotvos.dm.unipi.it/nobili/ggweb/phaseA/index.html

[RD 2] Supplement to GG Phase A Study (GG in sun-synchronous Orbit) “Galileo Galilei-GG”: design, requirements, error budget and significance of the ground prototype”, A.M. Nobili et al., Physics Letters A 318 (2003) 172–183, available at: http://eotvos.dm.unipi.it/nobili/documents/generalpapers/GG_PLA2003.pdf

[RD 3] A. Nobili, DEL001: GG Science Requirements, Pisa, September 2008

2.4 GG Phase A2 Study Notes

[RD 4] SD-RP-AI-0625, GG Final Report / Satellite Detailed Architecture Report, Issue 1

[RD 5] SD-RP-AI-0626, GG Phase A2 Study Executive Summary, Issue 1

[RD 6] SD-TN-AI-1163, GG Experiment Concept and Requirements Document, Issue 3

[RD 7] SD-RP-AI-0620, GG System Performance Report, Issue 2

[RD 8] SD-TN-AI-1167, GG Mission Requirements Document, Issue 2

[RD 9] SD-RP-AI-0590, GG System Concept Report (Mission Description Document), Issue 3

[RD 10] SD-SY-AI-0014, GG System Functional Specification and Preliminary System Technical Specification, Issue 1

[RD 11] SD-RP-AI-0631, GG Consolidated Mission Description Document, Issue 1

[RD 12] SD-TN-AI-1168, GG Mission Analysis Report, Issue 2

[RD 13] DTM, GG Structure Design and Analysis Report, Issue 1

[RD 14] SD-RP-AI-0627, GG Thermal Design and Analysis Report, Issue 1

[RD 15] SD-RP-AI-0268, GG System Budgets Report, Issue 1

[RD 16] SD-RP-AI-0621, Technical Report on Drag and Attitude Control, Issue 2

[RD 17] TL25033, Payload Architectures and Trade-Off Report, Issue 3

[RD 18] SD-RP-AI-0629, Technical Report on Simulators, Issue 1

[RD 19] ALTA, FEEP Thruster Design and Accommodation Report, Issue 1

[RD 20] TASI-FI-44/09, Cold Gas Micro Thruster System for Galileo Galilei (GG) Spacecraft - Technical Report, Issue 1, May 2009

[RD 21] SD-RP-AI-0630, Spin Sensor Design, Development and Test Report, Issue 1

[RD 22] SD-TN-AI-1169, GG Launcher Identification and Compatibility Analysis Report, Issue 1

[RD 23] ALTEC-AD-001, GG Ground Segment Architecture and Design Report, Issue 1

[RD 24] SD-TN-AI-1218, GG Preliminary Product Tree, Issue 1

[RD 25] SD-PL-AI-0227, GG System Engineering Plan (SEP), Issue 2

[RD 26] TAS-I, Payload Development and Verification Plan, Issue 1

[RD 27] SD-PL-AI-0228, GG System Verification and Validation Plan, Issue 1

[RD 28] SD-TN-AI-1219, Report on Frequency Management Issues, Issue 1

[RD 29] SD-RP-AI-0632, GG Mission Risk Assessment And Mitigation Strategies Report, Issue 1

[RD 30] SD-RP-AI-0633, Report on Mission Costs Estimates, Issue 1

2.5 External Reference Documents

[RD 31] “Frequency Management for ESA’s missions”, E. Marelli and E. Vassallo, ESA Bulletin 121 - February 2005

3 FREQUENCY ISSUE

The frequency bands available to satellites, the RF subsystems operation conditions and the protection criteria are fixed by the International Telecommunication Union (ITU) in the Radio Regulations.

In order to have the satellite frequencies assigned, request to ITU shall be made indicating all the RF parameters characterising the mission like: frequency band, transmitted power, satellite altitude above the Earth surface, transmitted signal spectrum (including modulation scheme, data rate and ranging tone preliminary selection) and selected ground stations.

In order to avoid problems with ITU at the time of frequencies allocation, formal procedure shall be followed starting from the application of ITU recommendation as traced for the Europe in ECSS Standards.

ITU requirements as guidelines for Radio Frequency and Modulations are traced, among the ECSS Standards examined in the frame of the tailoring, (Applicable document of [AD 1]), in ECSS-E-50-05A. The tailoring considers this document as not applicable to GG. Nevertheless the requirements deriving from ITU are not negotiable and no request for waiver/deviation can be raised against them; other requirements are design driving and, upon the demonstration that the hardware identified for GG already exists, can be judged not applicable.

A tentative of ECSS second level tailoring can be found in Table 3-1.

ECSS-E-50-05A	Radio frequency and modulation	Applicability	Notes
4.1	Frequency allocations to the Space Operation, Space Research and Earth Exploration Satellite services	NAR	Title
4.1.1	General	A	
4.1.2	Frequency bands allocated to the Space Radiocommunications services	NAR	Title
4.1.2.1	General	A	
4.1.2.2	Frequency band implementation	A	
4.1.2.3	Special conditions governing the use of particular frequency bands	N/A	No particular frequency bands will be used by GG
4.1.2.4	Use of frequency bands allocated to the Space Research (Deep Space) service	N/A	No deep space mission
4.1.2.5	Direction indicator	A	
4.1.2.6	Allocation status	A	
4.2	Specific conditions for the use of certain frequency bands	NAR	Title
4.2.1	2025 MHz – 2120 MHz and 2200 MHz – 2300 MHz bands	P/A	2025 MHz – 2120 MHz: depending on G/S output power regulation availability
4.2.2	8025 MHz – 8400 MHz band	N/A	X-Band is N/A to GG
4.2.3	8450 MHz – 8500 MHz band	N/A	X-Band is N/A to GG
4.2.4	16,6 GHz – 17,1 GHz and 14,0 GHz – 15,35 GHz bands	N/A	Ku-Band is N/A to GG
4.2.5	40,0 GHz – 40,5 GHz and 37,0 GHz – 38 GHz bands	N/A	Ka-Band is N/A to GG
4.3	Frequency assignment procedure	NAR	Title
4.3.1	Choice of frequencies	A	

ECSS-E-50-05A	Radio frequency and modulation	Applicability	Notes
4.3.2	Advance publication, coordination and notification of frequencies	A	
5	Transmitted signals	NAR	Title
5.1	Turnaround frequency ratio for coherent transponders	NAR	Title
5.1.1	Generation of the transmitted carrier	A	
5.1.2	Band pairs	A	
5.2	Carrier frequency stability	NAR	Title
5.2.1	Spacecraft transmitter	P/A	Not an ITU Article
5.2.2	Spacecraft receiver	P/A	Not an ITU Article
5.2.3	Ground station equipment	P/A	Not an ITU Article
5.2.4	Requirements for Doppler tracking	N/A	ECSS-E-50-02A already issued
5.3	Polarization	A	Not an ITU Article
5.4	Bandwidth considerations	NAR	Title
5.4.1	Occupied bandwidth	A	
5.4.2	Special case of bandwidth efficient modulations	A	
5.5	Emissions	NAR	Title
5.5.1	Unwanted emission power level	NAR	Title
5.5.1.1	Transmitter spurious emissions and harmonics	A	
5.5.1.2	Protection of radio astronomy bands	A	
5.5.1.3	Protection of Deep Space Research bands	A	
5.5.1.4	Protection of launcher RF systems	A	
5.5.2	Cessation of emissions	A	
5.5.3	Power flux density limits	A	
5.5.4	Power limits for Earth station emissions	NAR	Title
5.5.4.1	Frequency bands between 1 GHz and 15 GHz	A	
5.5.4.2	Frequency bands above 15 GHz	N/A	GG downlink frequency is below 15 GHz
5.5.4.3	Limits to elevation angles	A	
5.5.5	Time limitations on transmissions	A	
6	Modulation	NAR	Title
6.1	Phase modulation with residual carriers	NAR	Title
6.1.1	Application	A	
6.1.2	Modulating waveforms	A	
6.1.3	PCM waveforms and data rates	A	
6.1.4	Use of subcarriers	NAR	Title
6.1.4.1	Subcarriers	NAR	Title
6.1.4.1.1	General	A	
6.1.4.1.2	Telecommand	A	Not an ITU Article
6.1.4.1.3	Telemetry	A	Not an ITU Article
6.1.4.2	Subcarrier frequency stability	A	Not an ITU Article
6.1.5	Data transition density	A	Not an ITU Article
6.1.6	Carrier modulation index	A	Not an ITU Article
6.1.7.	Sense of modulation	A	Not an ITU Article
6.1.8	Modulation linearity	A	Not an ITU Article
6.1.9	Residual amplitude modulation	A	Not an ITU Article
6.1.10	Carrier phase noise	A	Not an ITU Article
6.1.11	Residual carrier and discrete spectral lines	A	Not an ITU Article
6.2	Suppressed carrier modulation	N/A	No carrier suppressed modulations are foreseen for GG

ECSS-E-50-05A	Radio frequency and modulation	Applicability	Notes
6.3	Spectral roll-off	A	
A	Link acquisition procedures	NAR	Title
A.1	Space-Earth	NAR	Title
A.1.1	Normal operation	A	
A.1.2	Alternative mode of operation	A	
A.1.3	Coherent mode	MR	Coherent mode can be activated also before link acquisition and become active once on board receiver is locked
A.2	Earth-space	NAR	Title
A.2.1	2025 MHz - 2110 MHz category A	A	
A.2.2	2110 MHz - 2120 MHz category B	N/A	GG is not a Category B mission
A.2.3	7190 MHz – 7235 MHz category A	N/A	X-Band N/A to GG
A.2.4	7145 MHz - 7190 MHz category B	N/A	X-Band N/A to GG
B	Cross support from other networks	NAR	Informative only
C	Protection of Ariane-5 RF system	N/A	Ariane-5 is N/A to GG
D	RF interface control	A	
E	GMSK modulation format	N/A	GMKS is not foreseen for GG
F	8PSK TCM modulation format	N/A	Modulation not used
G	Tailoring	A	

Table 3-1: ECSS-E-50-05A tailoring

The approach to the issue of Frequency Management starts from the AD1 disposition where the altitude of GG is fixed to 520 km; therefore this quote drops in the altitude above the Earth's surface of less than 2×10^6 km, that, according to ITU definition, is "non deep space mission".

According to AD1, among the frequencies ranges allocated to this class of missions, S-Band for uplink and downlink has been selected as baseline together with the use of Malindi ground station.

The implication of this is the definition of the frequency range within GG uplink and downlink frequencies shall be within the range:

- Uplink: 2025 – 2110 MHz
- Downlink: 2 200 – 2 290 MHz
- With uplink over downlink frequency turn around ratio in case of coherent mode operation equal to 221/240.

3.1 Implications on uplink

Since S-Band is very crowded because of the huge number of satellites using frequencies around 2 GHz, particular care shall be taken in order to avoid Radio Frequency Interference (RFI onwards) with the other missions. Compatibility with other services shall be verified as well but as far as concerns the impact on terrestrial applications like 3rd-generation mobile telephones (UMTS), this doesn't represent an issue because those frequencies are allocated in the range 2110-2120 MHz that is out of GG range.

ECSS Standard would recommend reducing the ground station EIRP in order to not exceed 3 dB on uplink budget margins. If this is not applicable to Malindi ground station because for instance, RF transmitter output power is not adjustable in steps of 3 dB, the ITU specification of interrupting the transmission out of the contact periods shall be adopted because an excessive ground station EIRP could also prevent the operations for some sites.

3.2 Implications on downlink

On the satellite / Earth link side, called also downlink, the rule to be respected is the same: no emissions shall be allowed out of contact periods. As a consequence of this requirement, the devices on spacecraft used to switch-off RF signal shall be designed with high reliability and be qualified for a large number of switching cycles during the spacecraft lifetime. In particular, the so called S-Band (2 200 MHz – 2 290 MHz), as selected for GG, is one of the most densely occupied bands allocated to the space science services. Frequently the only efficient means of RFI mitigation is to limit the emissions from a spacecraft in this band to those periods, when it is over the coverage area of a receiving Earth station.

4 FREQUENCY ASSIGNMENT PROCEDURE

4.1 Choice of frequencies

Assuming the same procedure followed for ESA projects, the frequency coordinator shall be contact for the assignments of the satellite frequencies. Frequencies shall be allocated to the mission before the design phase of the spacecraft.

At the beginning of a satellite mission's design, it is necessary to prepare a so called 'Request for Frequency Assignment', containing preliminary data on the satellite's telecommunication systems, the preferred frequency bands, the station network to be used, and the orbital characteristics of the mission. This request is checked to assess compliance with the ITU radio regulations and international radio frequency and modulation standards of the Consultative Committee for Space Data Systems (CCSDS) and of the European Cooperation for Space Standardization (ECSS). Compliance is also checked with the interagency agreements of the Space Frequency Coordination Group (SFCG). If needed, changes are requested to the project. The amended document then forms the basis for conducting inter-agency coordination and an evaluation of potential radio-frequency interference with ESA missions and missions by other space agencies (NASA, JAXA, etc).

The final goal of such pre-ITU coordination is to find a reasonable frequency assignment that avoids the need for operational coordination in the future. Having completed this task, the next step is the preparation of the ITU advance publication (API) filing and notification (Article 11) filing. This operation is typically done three years before the launch date.

4.2 Advance publication, coordination and notification of frequencies

Not later than three years before the planned launch date, the final data provided to the frequency coordinator regarding the frequencies used by the spacecraft shall be confirmed, to allow the advance publication, coordination and notification procedures of ITU/RR/S9 and ITU/RR/S11. These procedures shall be carried out by the frequency coordinator for the satellites and ground stations, in conformity with frequency management procedures.

5 OCCUPIED BANDWIDTH DEFINITION

5.1 Modulation proposed

5.1.1 Uplink modulation

TC modulation scheme requested is PCM/PSK/PM with bit rate of 4 kb/s and subcarrier frequency of 16 kHz. According to ECSS-E-50-05A, the occupied bandwidth for uplink TC only for such a bit rate shall be less than 100 kHz.
Occupied bandwidth can increase in presence of ranging modulation on the uplink, but this issue is treated in § 5.2.

5.1.2 Downlink modulation and spectral emissions

TM Modulation requested is SP-L, as utilized in the PRIMA satellite platform. According to CCSDS Standard CCSDS 401.0-B, the SP-L 99% occupied bandwidth without filtering for TM modulation index 0.4 rad ≤ *m* ≤ 1.4 rad, can be described with an accuracy of 90%, by Equation 5-1:

$$BW = 2 \times (26.2m - 5.16)R_S \qquad \textbf{Equation 5-1}$$

where:

BW = Occupied Bandwidth is the band of frequencies containing 99% of the total radiated power,
R_S = Modulated Symbol Rate,
m = Modulation Index (in radians).

In this specific case, R_S = 512 kHz and m = 1.1 rad, therefore BW = 24.3 MHz whereas the maximum occupied bandwidth for S-Band missions is fixed to 5 MHz. The conclusion is that SP-L shall be filtered onboard otherwise its occupied band exceeds by far the allocated bandwidth.

5.2 Ranging tone frequency determination

Once fixed TM and TC modulations, bit rates and subcarrier frequencies (if applicable to the modulations selected), ranging tone frequency shall be determined as well.

ECSS standard for ranging, ECSS-E-05-02A, states requirements that shall be met in order to avoid interferences among: ranging, TC and TM signals.

Ranging tone selected shall satisfy the following conditions in uplink and downlink:

1) $| D f_t - 3 f_{sc} | \geq f_{symb}$

2) $|k f_{symb} - D f_t | \geq 5$ Hz

3) | D f_t - f_{sc} | ≥ 2.5 f_{symb}

Where *k* is an integer, f_{sc} is the subcarrier frequency (for SP-L equal to the symbol rate), f_{symb} is the symbol rate, f_t is the ranging tone and *D* the Doppler rate

For TM SP-L with data rate of 512 kbps, no ranging tone frequencies are compatible, while with 256 kbps, ranging tone of 1024.1 kHz is feasible.

4) |2 m * f_{sc_TC} - f_t|>= 5 Hz

5) | (2 n - 1) f_{sc_TC} - f_t | ≥ 2 f_b

Where *n* and *m* are two integers, f_{sc_TC} = 16 kHz is the TC subcarrier frequency, f_t the ranging tone frequency, f_b = 4 kbps the TC bit frequency.

Results of this calculations conducting to a preliminary ranging tone selection of 1024.1 kHz are given in Annex A.

ANNEX A – RANGING TONE COMPATIBILITY WITH TC AND TM VERIFICATION

Once determined TM and ranging frequencies, it shall be verified that they don't interfere, so they shall meet the requirement: $|k\ f_{symb} - D\ f_t| \geq 5$ Hz.
Where k is an integer, f_{symb} = 256 kbps is the symbol rate, f_t is the ranging tone = 1024.1 kHz and D the Doppler rate.
Table A-1 shows that, with this tone frequency selection, no interferences occur among ranging tone, TM frequency and relevant harmonics.
The parameter k has been varied from 0 to 10 in order to cover a large number of cases. This number is considered sufficient because the argument, that shall be bigger than 5 Hz, increases when k increased while it has a minimum corresponding to k = 5.
Moreover, for k higher than 10, the product $k * f_{symb} > 5$ MHz i.e. out of S-Band allocated bandwidth.

k	| k fsymb - D ft | ≥ 5 Hz?	| k fsymb - D ft | [Hz]
0	OK	1209.97
1	OK	953.97
2	OK	697.97
3	OK	441.97
4	OK	185.97
5	OK	70.03
6	OK	326.03
7	OK	582.03
8	OK	838.03
9	OK	1094.03
10	OK	1350.03

Table A-1: Calculation of interferences between ranging and TM frequencies

The same process has been activated for TC as well: in this case, two conditions shall be met:
$|2\ m * f_{sc\_TC} - f_t| >= 5$ Hz and $|(2\ n - 1)\ f_{sc\_TC} - f_t| \geq 2\ f_b$

Where n and m are two integers, f_{sc_TC} = 16 kHz is the TC subcarrier frequency, f_t the ranging tone frequency = 1024.1 kHz, f_b = 4 kbps the TC bit rate.
The values assumed by m and n have been reported in Table A-2 until 80; beyond this value, the arguments increase and the frequencies drop out of TC + ranging allocated range = 2.5 * f_t i.e. 2560.25 kHz
.

m	|2 m * fsc_TC - ft| >= 5 Hz?	|2 m * fsc_TC - ft| [kHz]	n	| (2 n - 1) fsc_TC - ft | ≥ 2 fb ?	| (2 n - 1) fsc_TC - ft | [kHz]
0	OK	1024.1	0	OK	1226
1	OK	992.1	1	OK	1194
2	OK	960.1	2	OK	1162
3	OK	928.1	3	OK	1130
4	OK	896.1	4	OK	1098
5	OK	864.1	5	OK	1066
6	OK	832.1	6	OK	1034
7	OK	800.1	7	OK	1002
8	OK	768.1	8	OK	970
9	OK	736.1	9	OK	938
10	OK	704.1	10	OK	906
11	OK	672.1	11	OK	874
12	OK	640.1	12	OK	842
13	OK	608.1	13	OK	810
14	OK	576.1	14	OK	778
15	OK	544.1	15	OK	746
16	OK	512.1	16	OK	714
17	OK	480.1	17	OK	682
18	OK	448.1	18	OK	650
19	OK	416.1	19	OK	618
20	OK	384.1	20	OK	586
21	OK	352.1	21	OK	554
22	OK	320.1	22	OK	522
23	OK	288.1	23	OK	490
24	OK	256.1	24	OK	458
25	OK	224.1	25	OK	426
26	OK	192.1	26	OK	394
27	OK	160.1	27	OK	362
28	OK	128.1	28	OK	330
29	OK	96.1	29	OK	298
30	OK	64.1	30	OK	266
31	OK	32.1	31	OK	234
32	OK	0.1	32	OK	202
33	OK	31.9	33	OK	170
34	OK	63.9	34	OK	138
35	OK	95.9	35	OK	106
36	OK	127.9	36	OK	74
37	OK	159.9	37	OK	42
38	OK	191.9	38	OK	10
39	OK	223.9	39	OK	22
40	OK	255.9	40	OK	54
41	OK	287.9	41	OK	86
42	OK	319.9	42	OK	118
43	OK	351.9	43	OK	150
44	OK	383.9	44	OK	182
45	OK	415.9	45	OK	214
46	OK	447.9	46	OK	246
47	OK	479.9	47	OK	278

m	|2 m * fsc_TC - ft| >= 5 Hz?	|2 m * fsc_TC - ft| [kHz]	n	| (2 n - 1) fsc_TC - ft | ≥ 2 fb ?	| (2 n - 1) fsc_TC - ft | [kHz]
48	OK	511.9	48	OK	310
49	OK	543.9	49	OK	342
50	OK	575.9	50	OK	374
51	OK	607.9	51	OK	406
52	OK	639.9	52	OK	438
53	OK	671.9	53	OK	470
54	OK	703.9	54	OK	502
55	OK	735.9	55	OK	534
56	OK	767.9	56	OK	566
57	OK	799.9	57	OK	598
58	OK	831.9	58	OK	630
59	OK	863.9	59	OK	662
60	OK	895.9	60	OK	694
61	OK	927.9	61	OK	726
62	OK	959.9	62	OK	758
63	OK	991.9	63	OK	790
64	OK	1023.9	64	OK	822
65	OK	1055.9	65	OK	854
66	OK	1087.9	66	OK	886
67	OK	1119.9	67	OK	918
68	OK	1151.9	68	OK	950
69	OK	1183.9	69	OK	982
70	OK	1215.9	70	OK	1014
71	OK	1247.9	71	OK	1046
72	OK	1279.9	72	OK	1078
73	OK	1311.9	73	OK	1110
74	OK	1343.9	74	OK	1142
75	OK	1375.9	75	OK	1174
76	OK	1407.9	76	OK	1206
77	OK	1439.9	77	OK	1238
78	OK	1471.9	78	OK	1270
79	OK	1503.9	79	OK	1302
80	OK	1535.9	80	OK	1334

Table A-2: Calculation of interferences between ranging tone and TC subcarrier frequencies

END OF DOCUMENT