INTERFACE SPECIFICATIONS BETWEEN THE DORIS NETWORK BEACONS AND THE ONBOARD INSTRUMENT

(Version 4.0)

ABREVIATIONS

Sigle	Definition
2GM	Second generation miniaturized
BL	Location beacon
BM	Master beacon
BMT	Master beacon Toulouse
BO	Orbitography beacon
BT	Time beacon
CTDP	DORIS POSEIDON Processing Center
DORIS	Détermination d'Orbite et Radiopositionnement Intégré par satellite – Doppler Orbitography and Radiopositioning Integrated by satellite
GECO	Operations Coordination Board
ISB	Intermediate Significant Bits
ITRF	International Terrestrial Reference Frame
LSB	Least Significant Bits
MSB	Most Significant Bits
MVR	Radial velocity measuring instrument (DORIS receiver)
NRZ	Non Return to Zero
TAI	International Atomic Time
TBC	To be confirmed
TBD	To be defined
TCH	Uploading (Telechargement)
USO	UltraStable Oscillator
UTC	Universal Time Coordinated

CONTENTS

1. PURPOSE OF THE DOCUMENT

This document defines the interface specifications between the DORIS network beacons and the onboard receiver.

The broadcasted data accepted only by instruments from 2GM generation are defined in a specific document.

2. APPLICABILITY

This document is applicable to the DORIS network beacons, to the onboard receivers, to the test methods and the DORIS Control center during development, system test, flight acceptance and exploitation phase.

3. DESCRIPTION OF THE DORIS SYSTEM

3.1. DORIS SYSTEM

DORIS is a positionning system that carries out Doppler measurements at 2 GHz and at 400 MHz between a satellite in orbit and a network of ground transmitter beacons and provide accurate location of the satellite. Furthermore, the system can locate customer ground beacons with precision up to 1 cm depending on the duration and local observation conditions.

3.2. BEACON NETWORK

The DORIS network can include up to 500 beacons which are of :

- different types:

orbitography beacons (BO):

These beacons located on geodesically stable points all around the world make possible to determine the precise orbit of the satellite.

Their coordinates are regularly monitored, broadcasted by the SSALTO via the Master Beacons and autonomously received by the current DORIS instruments.

customer beacons or Location Beacons (BL):

The customer beacons are installed according to the requirements of customers and provide them with a precise positioning of the beacon.

Their coordinates are not part of broadcasted data.

- different statuses :

  standard beacon :

  it is the general and default status of BO and BL

  Time Beacons (BT):

When time and frequency parameters are stable and reliable enough, a BO receives the status of time beacon. It is generally the case for the beacons slaved on atomic clocks. Their time and frequency parameters are monitored by the SSALTO which broadcast their time and frequency model to the current DORIS instruments.

System integrity is guaranteed by uploading a quality index estimated from off line observation of residuals w.r.t. the model.

A BL can not access to the status of BT

Master Beacons (BM):

The master beacon is a specific Time Beacon connected to the SSALTO via a transfer terminal to ensure uploading of the data (beacons coordinates of BO and time parameters of BT) necessary for the onboard receiver to function.

- Different generation :

3 different generations of beacons have been manufactured. The present issue of the present document only describes the 3rd generation which is the current generation deployed.

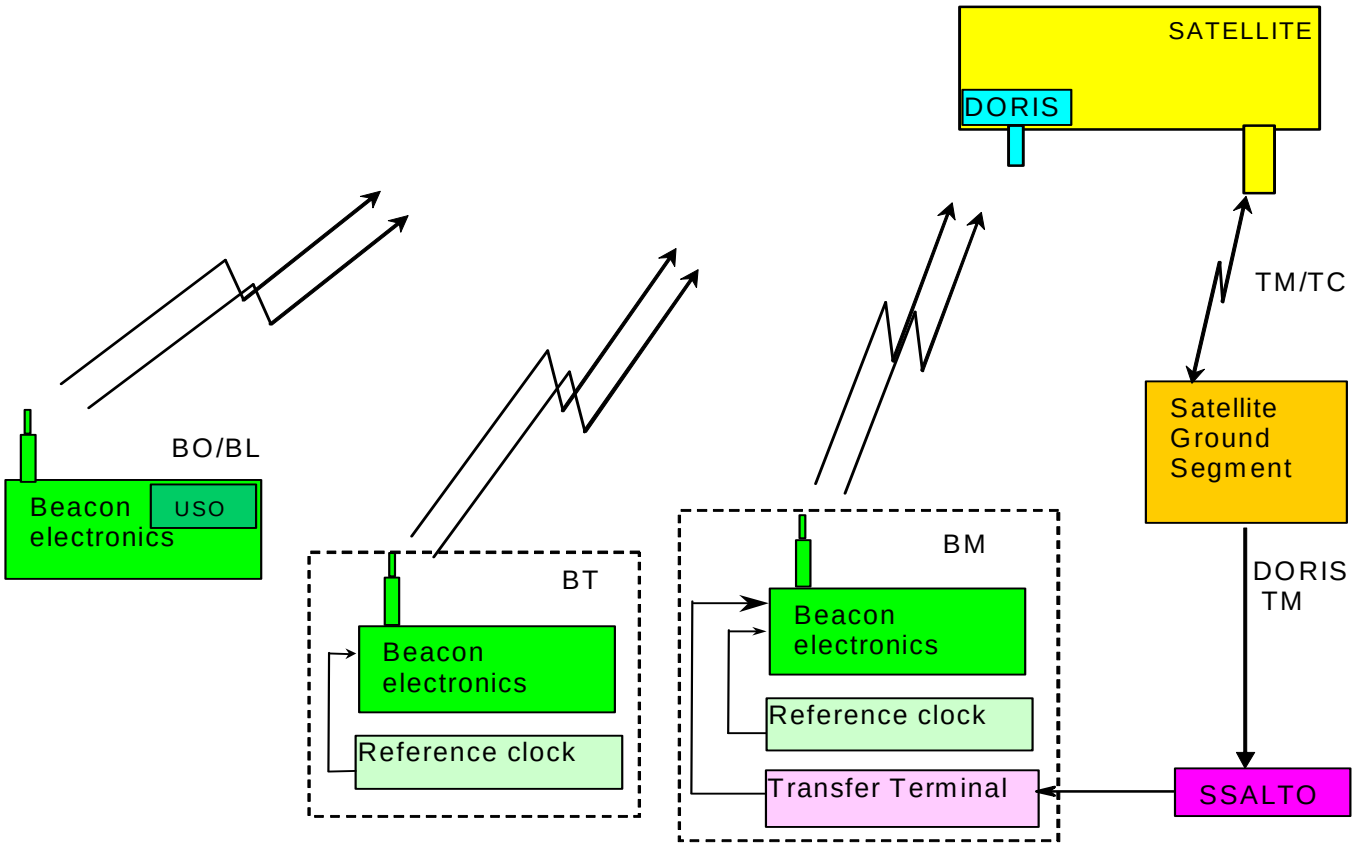


Figure 1: System block diagram

4. RADIOELECTRIC INTERFACE

4.1. FREQUENCIES

The DORIS beacons transmit signals on 2 channels called “400MHz channel” and “2GHz channel”. The signals are elaborated from either the internal (USO) or the external reference clock. The exact frequencies, expressed in Hz, transmitted by the beacons are:

$$F_1(k) = 107 * F_0(\frac{3}{4} + \frac{87k}{5 * 2^{26}})$$ on the 400 MHz channel,

$$F_2(k) = 543 * F_0(\frac{3}{4} + \frac{87k}{5 * 2^{26}})$$ on the 2 GHz channel,

with:

F_0 = clock frequency = 5 MHz +/- 2.10E-7

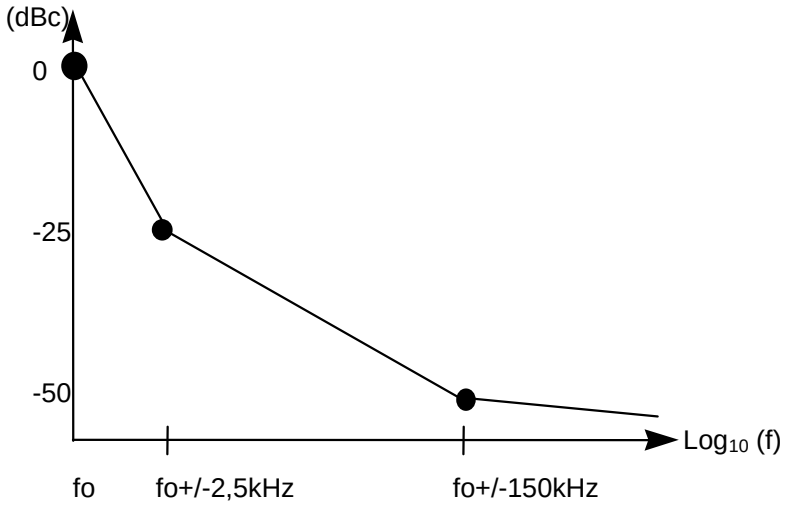
k = integer between - 90 and + 90 as per operations board (GECO) directives

N.B. Whatever the value of k, $\frac{F_2(k)}{F_1(k)} = \frac{543}{107}$

4.2. POWER LEVEL

The spectrum transmitted around this central frequency, resulting from transmission and spurious modulation is limited by:

- a pattern



- a limitation above +/-2.5 kHz on both sides of the central frequency at 1% of the total power transmitted on the channel.

The power transmitted at transmitter box output is:

7 W ± 1 W on the 400 MHz channel

15 W ± 1 W on the 2 GHz channel

Comments:

Cable losses between the transmitter box and the ground antenna are assessed to be between 0.5 dB and 3 dB on any of both channels according to station configuration.

The ground antenna gain varies from 0 to 5 dB on both channels for a site coverage from 20° up to 90°.

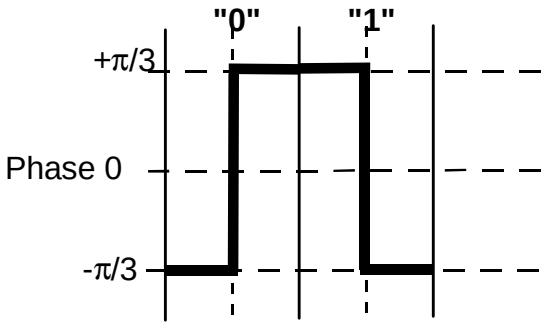
4.3. MODULATION

Modulation is synchronous with the carrier signal as both are generated from reference clock signal.

4.3.1. CURRENT BEACONS TRANSMIT A MODULATION ON BOTH CHANNELS. TYPE OF MODULATION

The modulation is PCM/SPL/PM bi-phase.

Modulation direction is given in the following timing diagram:



"0" is represented by a positive transition (- π/3 towards + π/3) in the middle of NRZ bit,
"1" is represented by a negative transition (+π/3 towards - π /3) in the middle of NRZ bit.

4.3.2. MODULATION INDEX

The modulation index is π/3 with a tolerance of : ± 1 %

The onboard instruments shall be compatible with these tolerances.

4.3.3. BIT RATE

The bit rate is 200 bits/s synchronous with the reference clock (USO or external atomic clock).

4.3.4. MODULATED SIGNAL RISING TIME

The rising time of the modulated signal is less than 1 microsecond

4.4. CARRIER STABILITY

The carrier stability is directly linked to the reference clock (USO or external atomic clock) stability.

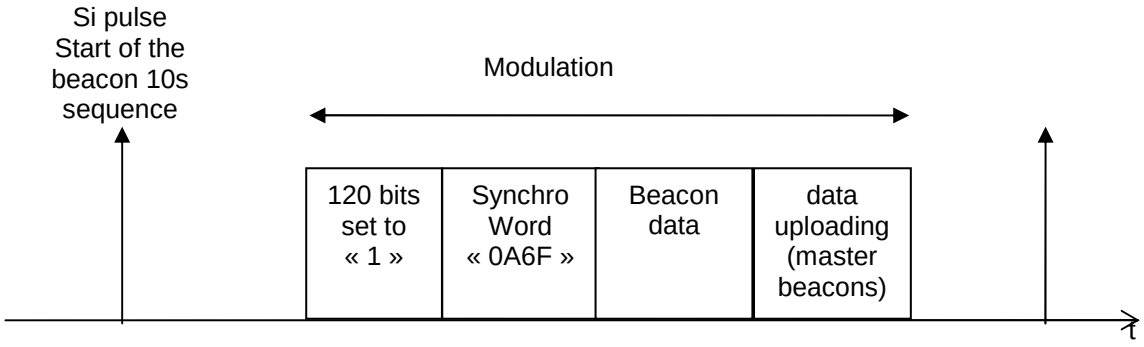
5. STRUCTURE OF TRANSMITTED MESSAGES

5.1. TIMING DIAGRAM

The times indicated hereafter in seconds suppose that the reference clock (USO or external atomic clock) frequency is exactly 5 MHz.

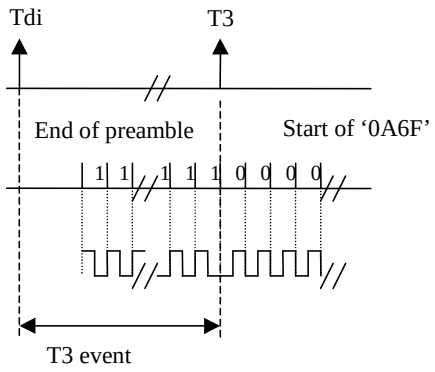
The reference instant is the "top Si" signal of the 10 second beacon sequencing.

The Master beacons have the capacity to upload data to the flying DORIS instruments. These data are transmitted at the end of the master beacon message.

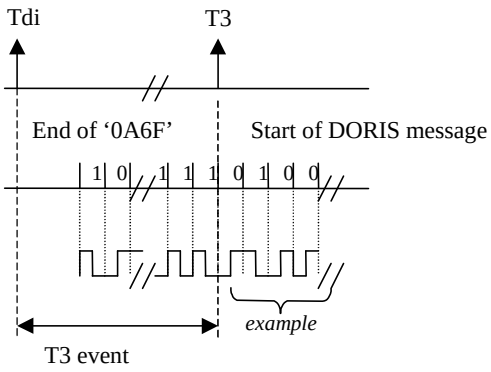


		400MHz channel	2GHz channel
Standard beacon	Start of modulation	Si + 4,7s	Si + 4,7s
	Modulation duration	1s	1,32s
	End of modulation	Si + 5,7s	Si + 6,02s
	Beacon data Length	64	128
Master beacon	Start of modulation	Si + 2,1s	Si + 2,1s
	Modulation duration (max)	6,2s	6,52s
	End of modulation (max)	Si + 8,3s	Si + 8,62s
	Beacon data length	64 bits	128 bits
	Data uploading length	0 to 1040 bits	0 to 1040 bits

Note: For the 1st and 2nd generation instruments, "the T3 event", as dated onboard, is the end of the last bit of the synchronization word "0A6F". For the 2GM instruments and following generations, "the T3 event" is the beginning of the 1st bit of the synchronization word.



Datation for 2GM instruments



Datation for the 1st and 2nd generation instruments

"T3 event" datation by onboard instrument

5.2. BEACON DATA

5.2.1. 400MHZ CHANNEL

The data is transmitted cyclically according to the XY values which successively take the values 00, 01 and 10 (value "11" of XY is never transmitted).

For XY = 00 :

BITS / WORDS	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3	BEACON_ID															
2	Reserved						IN (MSB)									
1	IN (ISB)								DOUS			RS	TYP		VM	H
0	IN (LSB)								X	Y	P4	P2	VR	SY	AS	AM

For XY = 01 :

BITS / WORDS	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3	BEACON_ID															
2	ITEMP											IPRESS (MSB)				
1	IPRESS (LSB)							Res.	PR	DOUS		RS	TYP		VM	H
0	IHUM								X	Y	P4	P2	VR	SY	AS	AM

For XY = 10 :

BITS / WORDS	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
3	BEACON_ID															
2	VBAT								ITEMPB							
1	IOUS								DOUS			RS	TYP		VM	H
0	P400					P2G			X	Y	P4	P2	VR	SY	AS	AM

The first transmitted bit is bit 15 of word 3; the last transmitted bit is bit 0 of word 0

BEACON_ID : Beacon identification ; 16 bits ; see appendix 1

IN: 27 bit binary integer
number of 10 s sequences passed since the 1st of January 2000 at 0 h 00 TAI

$$IN = \text{Integer}\left\{\frac{(Current\_date\_TAI\_beacon)s - (Reference\_date\_TAI)s}{10s}\right\}$$

At the TAI date = 01/01/2000 at 00:00:00 h, IN = 0,
At the TAI date = 01/01/2000 at 00:00:10 h, IN = 1.

The counter will go back to zero in 2042
The beacon changes the value of IN on the ‘top Si’ signal.

N.B. when the beacon is put "ON", it takes the last IN value that it had just before it was put "OFF"

DOUS: 3 bit integer
USO warming time indicator according to 8 possible time length ranges (USO running time since it was last put on)

USO warming time (hours)	DOUS
< 4 h	0
From 4 h to 24 h inclusive	1
From 25 h to 72 h inclusive	2
From 73 h to 240 h inclusive	3
From 241 h to 720 h inclusive	4
From 721 h to 1440 h inclusive	5
From 1441 h to 2046 h inclusive	6
> 2046 h	7

Nota : For a Master Beacon, DOUS = 7

RS: Boolean variable indicating automatic beacon restart.
"0" = beacon in nominal transmission (Fixed Si instant, linked to TAI)
"1" = beacon restart after time loss
The beacon is in specific transmission
(modulation slot shifted 1 s at each sequence of 10 s).

VM: indicates the modulation channel
= "0"B: modulation on channel 400 MHz
(= "1"B for modulation on channel 2 GHz)

H: 1 Hz synchronization
H = "1": external synchronization
H = "0": no external synchronization

ITEMP: 10 bit binary integer + sign
represents the external temperature: $T(℃)=0.1*ITEM\ P*(-1)^{MSB}$

NOTE: for 3.1 beacons (and further on), there is no temperature sensor anymore : default value is -100℃

IPRESS: 11 bit binary integer
Real atmospheric pressure (mb) = IPRESS
Step = 1 millibar

IHUM: 8 bit integer
Relative humidity
Step = 1%

NOTE: for 3.1 beacons (and further on), there is no humidity sensor anymore: default value is 0 %

PR: "0" = beacon in transmitter mode without pass forecast
"1" = beacon in transmission on visibility

VBAT: 8 bit binary integer
Represents the beacon's supply voltage (V) = 0.097*VBAT

P400: 4 bit binary integer
Represents the power transmitted at beacon output on channel 400 MHZ
Real power (W) = (0.5*P400) + 4
Nota: for power < 4 W, P400 = 0
for power ≥ 11.5 W, P400 = 15

P2G: 4 bit binary integer
Represents the power transmitted at beacon output on channel 2 GHZ
Real power (W) = (0.5*P2G) + 10
Nota: for power < 10 W, P2G = 0
for power ≥ 17.5 W, P2G = 15

ITEMPB: 8 bit binary integer
Represents the internal temperature of the beacon
Real temperature (℃) = (0.3125*ITEMPB) – 10
Nota: for real temperature ≤ -10℃, ITEMPB = 0
for real temperature ≥ 69.68℃, ITEMPB = 255

IOUS: 8 bit binary integer
Represents the current consumed by the USO in mA (taking into account a 24V main power)
Real current (mA) = IOUS
Nota: if real current ≥ 255 mA, IOUS = 255

TYP: Type of beacon (2 bits)
"01" B: 3rd generation beacon

("00" and "10" were used in the past for previous beacon generations)

AS: Anomaly Status: Memory failure indicator
"0" = Memory failure (failure of flash Memory)
"1" = No memory failure

AM: Meteorological station failure indicator
"0" = Meteorological station failure (failure in sequencing and/or communication)
"1" = No meteorological station failure

P4: Power failure indicator on channel 400 MHz
= "1" if Power of 400 MHz channel > 4 W
= "0" if not (power failure)

P2: Power failure indicator on channel 2 GHz
= "1" if Power of 2 GHz channel > 5 W
= "0" if not (power failure)

VR: Mains voltage indicator or adjusted voltage or exterior d.c. supply
= "1" if Voltage between 11 V and 15 V and presence of power on supply box
= "0" if not (supply failure)

SY: Synchronization indicator of the beacon on TAI
"0" = beacon not useable as a Time Beacon
"1" = beacon may be used as a Time Beacon

N.B. For 3.0 beacon, this bit is set to "1" when the external 1 Hz signal is present on the beacon or if the beacon is not configured on external synchro. It is repositioned to "1" if the operator confirms the “internal synchro” on the keyboard.

For 3.1 beacon and further on, this bit is set to 1 by the operator in order to indicate that the beacon may be used as a Time Beacon. This bit is automatically set to 0 when the beacon detects a fault in its synchronisation or in case of a new synchronisation request.

5.2.2. 2 GHZ CHANNEL

BITS WORDS	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
7	RESERVE															
6	RESERVE															
5 4 3 2	400MHz channel data (1)															
1	ICCE (MSB)															
0	ICCE (LSB)															

The first transmitted bit is bit 15 of word 7, the last transmitted bit is bit 0 of word 0.

The bits of the reserved words are "0" by default

(1) Copy of the 4 words transmitted in the modulation of channel 400 MHz except VM bit (= "1"B)

ICCE: Error correcting code BCH (128,96) correcting 4 errors. The generating polynomial is "75626641375" (octal representation).

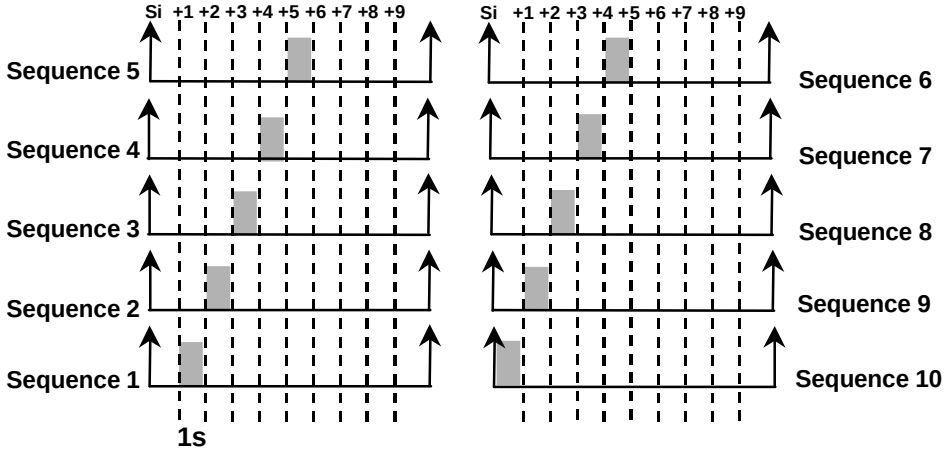
Coding convention:

- for bit 15 of Word 7 at "1" and all the other bits of words 2 to 7 at "0",
  we shall have WORD 1 = "1 1 1 1 0 1 1 1 0 0 1 0 1 1 0 1" (ICCE (MSB))
  and WORD 0 = "1 0 1 0 0 0 0 1 0 1 1 1 1 1 1 0"
- 1 shift to the right of the data causes a right circular permutation of the ICCE code, i.e. for example: for bit 14 of word 7 at “1” and the other bits of words 2 to 7,
  we should have: WORD 1 = "0 1 1 1 1 0 1 1 1 0 0 1 0 1 1 0"
  and WORD 0 = "1 1 0 1 0 0 0 0 1 0 1 1 1 1 1 1"

5.3. TRANSMISSION ON AUTOMATIC RESTART

This type of transmission is applied on automatic restart without time setting or with time outage.

In this type of transmission, the modulation window (containing the Doris message to be transmitted) shifts at each transmission sequence. This shift consists in delaying the modulation window by 1 s, for 5 consecutive transmission sequences then in shifting the modulation window the other way (forward) for 5 other consecutive sequences and so on. The sequence 10 occurs when the IN field of the message is equal to 0 modulo 10.



= modulation window

Si = reference instant of the 10 second beacon sequencing

Indeed, in automatic restart the beacon is not synchronized on the TAI with the required precision. Thanks to this specific transmission mode, the modulation will be received by the onboard instruments and time tagging information transmitted to the CCD. This latter will calculate the 'DELTA_t' shift value to be applied to synchronize the beacon.

APPENDIX 1 DORIS BEACON NUMBER CODING

FAMILY 0		FAMILY 1		FAMILY 2		FAMILY 3		
NUMBER (DEC)	Beacon_ID (HEX)	NUMBER (DEC)	Beacon_ID (HEX)	NUMBER (DEC)	Beacon_ID (HEX)	NUMBER (DEC)	Beacon_ID (HEX)	
0	**0000**	**128**	**01C0**	**256**	**0038**	**384**	**0007**	prohibited codes
1	**03A3**	**129**	**0263**	**257**	**039B**	**385**	**03A4**	codes reserved for master beacons
2	**04E6**	**130**	**0526**	**258**	**04DE**	**386**	**04E1**	
3	**0745**	**131**	**0685**	**259**	**077D**	**387**	**0742**	
4	**09CC**	**132**	**080C**	**260**	**09F4**	**388**	**09CB**	
5	0A6F	133	0BAF	261	0A57	389	0A68	
6	0D2A	134	0CEA	262	0D12	390	0D2D	
7	0E89	135	0F49	263	0EB1	391	0E8E	
8	103B	136	11FB	264	1003	392	103C	
9	1398	137	1258	265	13A0	393	139F	
10	14DD	138	151D	266	14E5	394	14DA	
11	177E	139	16BE	267	1746	395	1779	
12	19F7	140	1837	268	19CF	396	19F0	
13	1A54	141	1B94	269	1A6C	397	1A53	
14	1D11	142	1CD1	270	1D29	398	1D16	
15	1EB2	143	1F72	271	1E8A	399	1EB5	
16	2075	144	21B5	272	204D	400	2072	
17	23D6	145	2216	273	23EE	401	23D1	
18	2493	146	2553	274	24AB	402	2494	
19	2730	147	26F0	275	2708	403	2737	
20	29B9	148	2879	276	2981	404	29BE	
21	2A1A	149	2BDA	277	2A22	405	2A1D	
22	2D5F	150	2C9F	278	2D67	406	2D58	
23	2EFC	151	2F3C	279	2EC4	407	2EFB	
24	304E	152	318E	280	3076	408	3049	
25	33ED	153	322D	281	33D5	409	33EA	
26	34A8	154	3568	282	3490	410	34AF	
27	370B	155	36CB	283	3733	411	370C	
28	3982	156	3842	284	39BA	412	3985	
29	3A21	157	3BE1	285	3A19	413	3A26	
30	3D64	158	3CA4	286	3D5C	414	3D63	
31	3EC7	159	3F07	287	3EFF	415	3EC0	
32	40E9	160	4129	288	40D1	416	40EE	
33	434A	161	428A	289	4372	417	434D	
34	440F	162	45CF	290	4437	418	4408	
35	47AC	163	466C	291	4794	419	47AB	
36	4925	164	48E5	292	491D	420	4922	
37	4A86	165	4B46	293	4ABE	421	4A81	
38	4DC3	166	4C03	294	4DFB	422	4DC4	
39	4E60	167	4FA0	295	4E58	423	4E67	
40	50D2	168	5112	296	50EA	424	50D5	
41	5371	169	52B1	297	5349	425	5376	

42	5434	170	55F4	298	540C	426	5433
43	5797	171	5657	299	57AF	427	5790
44	591E	172	58DE	300	5926	428	5919
45	5ABD	173	5B7D	301	5A85	429	5ABA
46	5DF8	174	5C38	302	5DC0	430	5DFF
47	5E5B	175	5F9B	303	5E63	431	5E5C
48	609C	176	615C	304	60A4	432	609B
49	633F	177	62FF	305	6307	433	6338
50	647A	178	65BA	306	6442	434	647D
51	67D9	179	6619	307	67E1	435	67DE
52	6950	180	6890	308	6968	436	6957
53	6AF3	181	6B33	309	6ACB	437	6AF4
54	6DB6	182	6C76	310	6D8E	438	6DB1
55	6E15	183	6FD5	311	6E2D	439	6E12
56	70A7	184	7167	312	709F	440	70A0
57	7304	185	72C4	313	733C	441	7303
58	7441	186	7581	314	7479	442	7446
59	77E2	187	7622	315	77DA	443	77E5
60	796B	188	78AB	316	7953	444	796C
61	7AC8	189	7B08	317	7AF0	445	7ACF
62	7D8D	190	7C4D	318	7DB5	446	7D8A
63	7E2E	191	7FEE	319	7E16	447	7E29
64	81D1	192	8011	320	81E9	448	81D6
65	8272	193	83B2	321	824A	449	8275
66	8537	194	84F7	322	850F	450	8530
67	8694	195	8754	323	86AC	451	8693
68	881D	196	89DD	324	8825	452	881A
69	8BBE	197	8A7E	325	8B86	453	8BB9
70	8CFB	198	8D3B	326	8CC3	454	8CFC
71	8F58	199	8E98	327	8F60	455	8F5F
72	91EA	200	902A	328	91D2	456	91ED
73	9249	201	9389	329	9271	457	924E
74	950C	202	94CC	330	9534	458	950B
75	96AF	203	976F	331	9697	459	96A8
76	9826	204	99E6	332	981E	460	9821
77	9B85	205	9A45	333	9BBD	461	9B82
78	9CC0	206	9D00	334	9CF8	462	9CC7
79	9F63	207	9EA3	335	9F5B	463	9F64
80	A1A4	208	A064	336	A19C	464	A1A3
81	A207	209	A3C7	337	A23F	465	A200
82	A542	210	A482	338	A57A	466	A545
83	A6E1	211	A721	339	A6D9	467	A6E6
84	A868	212	A9A8	340	A850	468	A86F
85	ABCB	213	AA0B	341	ABF3	469	ABCC
86	AC8E	214	AD4E	342	ACB6	470	AC89
87	AF2D	215	AEED	343	AF15	471	AF2A
88	B19F	216	B05F	344	B1A7	472	B198
89	B23C	217	B3FC	345	B204	473	B23B
90	B579	218	B4B9	346	B541	474	B57E
91	B6DA	219	B71A	347	B6E2	475	B6DD
92	B853	220	B993	348	B86B	476	B854
93	BBF0	221	BA30	349	BBC8	477	BBF7
94	BCB5	222	BD75	350	BC8D	478	BCB2

95	BF16	223	BED6	351	BF2E	479	BF11	
96	C138	224	C0F8	352	C100	480	C13F	
97	C29B	225	C35B	353	C2A3	481	C29C	
98	C5DE	226	C41E	354	C5E6	482	C5D9	
99	**C67D**	**227**	**C7BD**	**355**	**C645**	**483**	**C67A**	**reserved for tests**
100	C8F4	228	C934	356	C8CC	484	C8F3	
101	CB57	229	CA97	357	CB6F	485	CB50	
102	CC12	230	CDD2	358	CC2A	486	CC15	
103	CFB1	231	CE71	359	CF89	487	CFB6	
104	D103	232	D0C3	360	D13B	488	D104	
105	D2A0	233	D360	361	D298	489	D2A7	
106	D5E5	234	D425	362	D5DD	490	D5E2	
107	D646	235	D786	363	D67E	491	D641	
108	D8CF	236	D90F	364	D8F7	492	D8C8	
109	DB6C	237	DAAC	365	DB54	493	DB6B	
110	DC29	238	DDE9	366	DC11	494	DC2E	
111	DF8A	239	DE4A	367	DFB2	495	DF8D	
112	E14D	240	E08D	368	E175	496	E14A	
113	E2EE	241	E32E	369	E2D6	497	E2E9	
114	E5AB	242	E46B	370	E593	498	E5AC	
115	E608	243	E7C8	371	E630	499	E60F	
116	E881	244	E941	372	E8B9	500	E886	
117	EB22	245	EAE2	373	EB1A	501	EB25	
118	EC67	246	EDA7	374	EC5F	502	EC60	
119	EFC4	247	EE04	375	EFFC	503	EFC3	
120	F176	248	F0B6	376	F14E	504	F171	
121	F2D5	249	F315	377	F2ED	505	F2D2	
122	F590	250	F450	378	F5A8	506	F597	
123	F633	251	F7F3	379	F60B	507	F634	
124	F8BA	252	F97A	380	F882	508	F8BD	
125	FB19	253	FAD9	381	FB21	509	FB1E	
126	FC5C	254	FD9C	382	FC64	510	FC5B	
127	FFFF	255	FE3F	383	FFC7	511	FFF8	

Note : The Beacon_ID (16 bits) is composed of 3 fields:

INBAL: bits 9 to 15 : 7 bit binary integer; number of the beacon modulo 128 ; certain numbers are reserved for specific beacons as following :

0 :	prohibited
1 , 2 (*) :	reserved for master beacon, message followed by uploading
3 , 4 (*) :	reserved respectively for master beacon, message only
5 to 98, 100 to 127 :	Other beacons
99 :	reserved for tests

(*) during a pass, a master beacon can change to number 1/3 or 2/4 according to whether the beacon message is followed by data uploading or not.

ICODEC: bits 1 to 8 : 8 bits; Error corrector code applied to INBAL: $(x^4 + x^3 + x^2 + x + 1)(x^4 + x + 1)$

IPARB: bit 0 : Parity bit on INBAL and ICODEC; even parity

The beacon families 1,2,3 are derived from family0 by carrying out an "XOR " between the 16 bits of INBAL, ICODEC, IPARB and:

- "0000000111000000" for family 1,
- "0000000000111000" for family 2,
- "0000000000000111" for family 3.

This allows to code 512 numbers with a distance between each of them avoiding to confuse them in case of bad transmission conditions.