

Copyright 2017 Daniel Pascual

Permission is granted to copy, distribute and/or modify this document under the terms of the GNU Free Documentation License, Version 1.3 or any later version published by the Free Software Foundation; with no Invariant Sections, no Front-Cover Texts, and no Back-Cover Texts. A copy of the license is included in the section entitled "GNU Free Documentation License".

Author: Daniel Pascual (daniel.pascual at protonmail.com)

Date: 6 March 2017

# Chapter 1

## GNSS signals

The Global Navigation Satellite Systems (GNSS) data signals contains the ephemeris information of each satellite, which is then used by a receiver to obtain its position. The new signals also contain Forward Error Correction (FEC) techniques to mitigate the impact of the channel. These signals are transmitted using Binary Phase Shift Keying (BPSK) modulations with a very narrow spectrum (in the order of a few tens of Hz). The spectrum of these signals is then spread to a much larger bandwidth ( $\approx 10^6$  times more) with the Direct-sequence spread spectrum (DSSS) technique, but maintaining the transmitted power with the so-called ranging codes. Some of these signals and codes are only available for civilians, while others are conceived for military purposes. The receiver generates a clean replica of the transmitted code and despreads the signal back to its original shape. The reasons of this frequency expansion are several. First, the location accuracy is better as wider the spectrum is; second, it reduces the multipath impact in harsh environments; and third, it mitigates the effect of Radio Frequency Interference (RFI) signals.

In order to allow all the satellites to share the same bands, each satellite use a different ranging code (sometimes a time multiplex or an addition of more), technique known as Code Division Multiple Access (CDMA). The receiver finds the satellites in view by cross-correlating the received signal with all the possible codes, only those which are present, will be matched. The codes are called pseudo random noise (PRN) sequences because they are designed to mimic a pure random signal, so as to have good auto-correlation and cross-correlation properties with the other codes of the same system. The codes are cyclically repeated (in the order of few milliseconds) to allow the receiver to acquire and track the signals rapidly. Since the spread signals are affected by the bit phase change of the original data signals, some services are transmitted along with a dataless pilot signal which allows the receiver to perform a longer coherent search of the satellites.

The modulation of the spread signal depends on how the ranging codes are applied to the data signal. In the past, these modulations were also BPSK, and are used for the GPS L1 C/A, L1 P, L2C, L2 P, L5, BeiDou-2 B1, B1-2, B2, and B3. However, the new signals use improved modulations called Binary Offset Carrier (BOC) [1], which add square sub-carriers to the original ranging codes. This results in a frequency shift of the main spectrum lobe from the carrier frequency, and in a multi-peak auto-correlation functions (ACF). The BOC modulations were originally conceived to reduce interference with the BPSK signals emitted at the same band, but also to increase the positioning accuracy [2]. However, they require a more complicated acquisition and tracking scheme. The general expression for a BOC modulation is usually written as  $\text{BOC}(n,m)$  which refers to a code chipping rate of  $f_r = m \cdot 1.023 \text{ MHz}$  and a sub-carrier frequency of  $f_b = n \cdot 1.023 \text{ MHz}$ . Depending on the phase of the subcarrier, the modulation can be sine-phased ( $\text{BOC}_s$ ) or cosine-phased ( $\text{BOC}_c$ ). The expressions of the sub-carrier functions are

$$\begin{aligned} x_{\text{BOC}_s, f_b} &= \text{sign}(\sin(2\pi f_b t)), \\ x_{\text{BOC}_c, f_b} &= \text{sign}(\cos(2\pi f_b t)), \end{aligned} \tag{1.1}$$

where  $\text{sign}(t)$  is the sign function which extracts the sign of another function. The GPS M signals use a  $\text{BOC}_s(10,5)$ , the future versions of the BeiDou-2 B1 and B3A will use a  $\text{BOC}_s(14,2)$  and  $\text{BOC}_s(15,2.5)$

respectively, and the Galileo E6A uses a BOC<sub>c</sub>(10,5).

Some signals combine several BOC into a more complex modulations, such as the modified alternative BOC or AltBOC and the multiplexed BOC or MBOC(6,1,1/11). The modified AltBOC differs from a BOC by using two complex sub-carriers instead of a single real. Under *modified* it is understood that the sub-carriers are not square pulses but chosen to obtain a constant envelope. An AltBOC can also be processed as two independently QPSK signals with shifted carrier frequencies. The MBOC(6,1,1/11) modulation can be obtained by different ways. One is the composite BOC or CBOC(6,1,1/11) which is the addition of a BOC<sub>s</sub>(1,1) with a BOC<sub>s</sub>(6,1), with a power distribution of 10/11 and 1/11 respectively. The second method is called time multiplexed BOC or TMBOC(6,1,4/33), which is the addition of a BOC<sub>s</sub>(1,1) with a time multiplex of another BOC<sub>s</sub>(1,1) with a BOC<sub>s</sub>(6,1) with a time distribution of 29/33% and 4/33% respectively. The power distribution between the continuous BOC<sub>s</sub>(1,1) and the multiplexed signal is 3/4 and 1/4 respectively. The Galileo E5 signal uses an AltBOC, the GPS L1C implements the TMBOC(6,1,4/33), the Galileo E1 adopted CBOC(6,1,1/11), and the future BeiDou-2 B1 will also use a MBOC(6,1,1/11).

This documents explains the generation of the the GPS L1 C/A [3], L5 [4] and the Galileo E1OS and E5 [5]. The codes are written as  $c_x(t)$ , and the data signals with  $d_x(t)$ . The code generation are explained in next chapter.

### GPS L1 C/A and L5

The GPS L1 C/A is the simplest one, and contains just one ranging code and one data signal. The GPS L5 contains two ranging codes and one data signal. Their complex baseband expressions are

$$x_{L1CA}(t) = c_{L1CA}(t) d_{L1CA}(t) \quad (1.2)$$

$$x_{L5}(t) = c_{L5I}(t) d_{L5}(t) + j c_{L5Q}(t). \quad (1.3)$$

### Galileo E1OS

The Galileo E1OS signal is generated with 2 ranging codes and one data signal

$$\begin{aligned} x_{E1}(t) = & \frac{1}{\sqrt{2}} e_{E1B}(t) \left( \sqrt{10/11} x_{BOCs,f_b^6}(t) \right) + \left( \sqrt{1/11} x_{BOCs,f_b^1}(t) \right) \\ & - \frac{1}{\sqrt{2}} e_{E1C}(t) \left( \sqrt{10/11} x_{BOCs,f_b^6}(t) \right) - \left( \sqrt{1/11} x_{BOCs,f_b^1}(t) \right) \end{aligned} \quad (1.4)$$

with  $f_b^1 = 1.023$  MHz and  $f_b^6 = 6.138$  MHz, and with

$$\begin{aligned} e_{E1B}(t) &= c_{E1B}(t) d_{E1}(t), \\ e_{E1C}(t) &= c_{E1C}(t). \end{aligned} \quad (1.5)$$

### Galileo E5

The Galileo E5 signal is constructed with 4 ranging codes and 2 data signals

$$\begin{aligned} x_{E5}(t) = & \frac{1}{2\sqrt{2}} (e_{E5aI}(t) + j e_{E5aQ}(t)) (b_1(t) - b_1(t - t_b^{E5}/4)) \\ & + \frac{1}{2\sqrt{2}} (e_{E5bI}(t) + j e_{E5bQ}(t)) (b_1(t) + b_1(t - t_b^{E5}/4)) \\ & + \frac{1}{2\sqrt{2}} (\bar{e}_{E5aI}(t) + j \bar{e}_{E5aQ}(t)) (b_2(t) - b_2(t - t_b^{E5}/4)) \\ & + \frac{1}{2\sqrt{2}} (\bar{e}_{E5bI}(t) + j \bar{e}_{E5bQ}(t)) (b_2(t) - b_2(t - t_b^{E5}/4)), \end{aligned} \quad (1.6)$$

where  $t_b^{E5} = 1/15.345$  MHz is the period of the sub-carrier frequencies, and with

$$\begin{aligned} e_{E5aI}(t) &= c_{E5aI}(t) d_{E5aI}(t), & \bar{e}_{E5aI}(t) &= e_{E5aQ}(t) e_{E5bI}(t) e_{E5bQ}(t), \\ e_{E5aQ}(t) &= c_{E5aQ}(t), & \bar{e}_{E5aQ}(t) &= e_{E5aI}(t) e_{E5bI}(t) e_{E5bQ}(t), \\ e_{E5bI}(t) &= c_{E5bI}(t) d_{E5bI}(t), & \bar{e}_{E5bI}(t) &= e_{E5bQ}(t) e_{E5aI}(t) e_{E5aQ}(t), \\ e_{E5bQ}(t) &= c_{E5bQ}(t), & \bar{e}_{E5bQ}(t) &= e_{E5bI}(t) e_{E5aI}(t) e_{E5aQ}(t), \end{aligned} \quad (1.7)$$

Table 1.1: Galileo E5 AltBOC sub-carrier coefficients.

<b>i</b>	<b>0</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>
$2\alpha$	$\sqrt{2} + 1$	1	-1	$-\sqrt{2} - 1$	$-\sqrt{2} - 1$	-1	1	$\sqrt{2} + 1$
$2\beta$	$-\sqrt{2} + 1$	1	-1	$\sqrt{2} - 1$	$\sqrt{2} - 1$	-1	1	$-\sqrt{2} + 1$

and where  $b_1(t)$  and  $b_2(t)$  are the sub-carrier functions

$$\begin{aligned} b_1(t) &= \sum_i \alpha \llcorner \llcorner (t - it_b^{E5}/8), \\ b_2(t) &= \sum_i \beta \llcorner \llcorner (t - it_b^{E5}/8), \end{aligned} \quad (1.8)$$

where  $\llcorner \llcorner(t)$  is a unitary pulse for  $0 < t < t_b^{E5}$ , and the coefficients  $\alpha$  and  $\beta$  are given in Table 1.1.

# Chapter 2

## GNSS codes

Most of the GNSS codes are generated with linear feedback shift registers (LFSR), but some of the modern ones are given as random memory codes which cannot be created with any LFSR. A LFSR produces a cycling sequence of a given length. The repetition period depends on the *taps* used to update the new value of the first register. For a LFSR of  $n$  registers, there is an optimum tap combination that generates a sequence of length  $2^n - 1$ . This sequence is called maximum length sequence (MLS) or *m*-sequence, and there is no other sequence of the same length. The initial value of the registers is called *seed*. Two LFSR with the same tap positions and different seeds, will generate the same sequences but one delayed with respect to the other. The speed at which the LFSR *shifts*, is given by a driven clock frequency.

Since the *m*-sequence is unique, the GNSS codes are actually a complex combination of several codes, sometimes even a time multiplex between them. These basic codes can be memory codes or the combination of several LFSR. The LFSR are designed by means of the driven clock frequency, seeds, taps, and *phases*, which are the registers used to generate the output. In some cases, is also desirable to reset the LFSR to its original state before its natural end. The codes that are explained in this document are  $c_{L1CA}$ ,  $c_{L5I}$ ,  $c_{L5Q}$ ,  $c_{E1B}$ ,  $c_{E1C}$ , and  $c_{E5x}$ . Their construction are given in Figs. 2.1, 2.2 and 2.3, and are explained next.

### GPS L1 C/A

The GPS L1 C/A codes are formed with two LFSR of 10 registers driven with a clock frequency of 1.023 MHz. The tap positions of both registers are fixed, and their seeds are all one for all the PRN. The code is created by adding the last register of the first LFSR with two registers of the second LFSR. The two phases are different for each PRN. This results in a code of length 1023 chips and 1 ms. These codes generated with these LFSR combination are called Gold codes after the name of their inventor.

### GPS L5

The GPS L5I and GPS L5Q codes are the addition of two codes. The principal codes are formed with

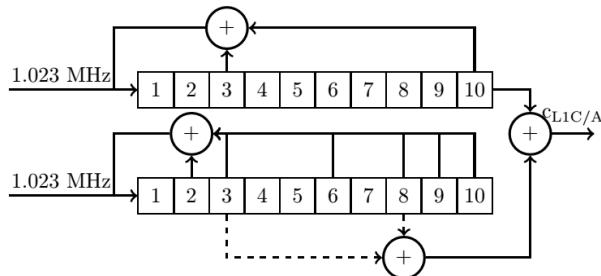


Figure 2.1: L1 C/A code generation

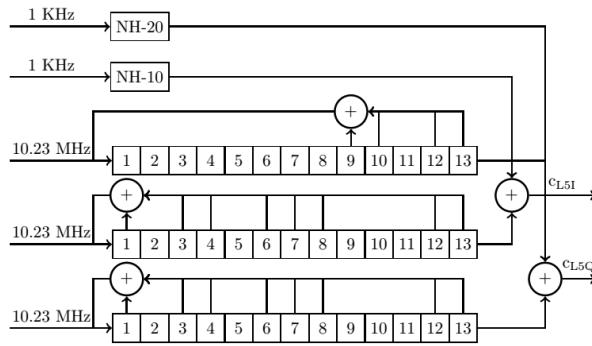


Figure 2.2: E5I/E5Q code generation

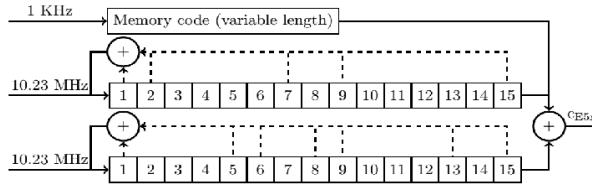


Figure 2.3: E5 code generation of each component

2 LFSR of 13 registers driven with a clock frequency of 10.23 MHz. One LFSR is shared between both components, has fixed taps, and its seed is all ones for all the PRN. The register is reset before its natural end. The other two LFSR have also fixed taps, but their seeds are different for each satellite. The code is created from the last registers of the LFSR. This results in a code of length 10230 chips and 1 ms. The secondary codes are memory codes named Neufarm Huffman codes, and are driven with a clock frequency of 1 kHz. The codes have a different length for both components: 10 chips and 10 ms for the I, and 20 chips and 20 ms for the Q, and are the same for all the PRN.

#### Galileo E1B and E1C

The Galileo E1B is created with one code, whereas the E1C is also a tiered code. The preliminary codes are random memory codes of length 4092 chips, different for each PRN, and driven with a clock frequency of 1.023 MHz, resulting in a duration of 4 ms. The secondary code of the E1C is a memory code of length 25 chips, fixed for all the PRN and driven with a clock frequency of 250 Hz, resulting in a duration of 100 ms.

#### Galileo E5aI, E5aQ, E5bI, E5bQ

The codes of the E5 signal components are all tiered codes constructed from two codes. The preliminary codes are created with two LFSR of 15 registers driven with a clock frequency of 10.23 MHz. The tap positions of both registers are different for each component but fixed for all the PRN. The seeds are different for each component and satellite. The code is created from the last position of both registers. This results in a code of length 10230 chips and 1 ms. The secondary codes are memory codes driven with a clock frequency of 1 kHz. Each code has a different length: 20 chips for the E5aI, 100 chips for the E5aQ, 4 chips for the E5bI, and 100 chips for the E5bQ, resulting in a duration of 4, 20 or 100 ms. The codes of the E5aI and E5bI are fixed for all PRN, whereas for the E5aQ and E5bQ are different.

## Chapter 3

# GNSS signals summary tale

This Appendix includes a summary table of the GNSS signals and their spectra plots. This information is only valid for the MEO constellations. The signals transmitted by the augmentation systems (SBAS), regional systems (RNSS), and GEO or GSO satellites, may have different properties. The data is mainly obtained from the official ICD of the respective systems. Some information of the restricted signals has been found on other sources (references are given in the footnotes), and likely assumptions have been done on some bandwidth and power values (indicated when proceeds). All the bandwidths are referred to RF (i.e. double-sideband). The powers values depend on the reference antenna and elevation angle (see footnotes), but also depend on the satellite age. Nominal and maximum values can be up to 6 dB larger. Abbreviations are: N/A stands for Non Available, and DNF stands for Data Not Found (which may actually be also N/A values).

---

<sup>1</sup>GPS Interface Control Documents. GPS L1C/A, L2C and both P signals: IS-GPS-200 [3]; GPS L5: IS-GPS-705 [4]; GPS L1C: IS-GPS-800 [6].

<sup>2</sup>Galileo Open Service Signal In Space Interface Control Document (OS SIS ICD) [5].

<sup>3</sup>BeiDou-2 Interface Control Document [7]. Code lengths and data rates are obtained from [8]

<sup>4</sup>Obtained from [9]

<sup>5</sup>These bandwidths are actually a reference receiver bandwidths for a commercial receiver. The ICD does not tell the transmitted bandwidths. Note for example that the nominal bandwidth of the modulation used by E1 PRS is 35.806 MHz, much larger than the given 24.552 MHz, which is only useful for receiving the open signals. The E5 signal is similar to a QPSK-R10 at Fca and Fcb with a RF bandwidth of 20.46 MHz

<sup>6</sup>These values are actually the reserved bands for the BeiDou-2 system referred to a central frequency of 1575.42 MHz for the B1/B1-2, 1191.795 MHz for the B2, and 1268.52 MHz for the B3.

<sup>7</sup>Bandwidth defined at -1 dB. At -3 dB is 16.368 MHz for the B1/B1-2 and 36.828 for the B2.

<sup>8</sup>Assumed likely values.

<sup>9</sup>The ITU bandwidths are found on [2].

<sup>10</sup>Referred to a central frequency of 1189 MHz.

<sup>11</sup>Restricted services are marked with asterisk.

<sup>12</sup>Minimum received signal power level on Earth by a receiver using an ideally matched RHCP antenna with a gain of 3 dBi (GPS) and 0 dBi (Galileo). Values are valid for elevations between the ones listed in column *REF. ELEV* and 90 degrees.

<sup>13</sup>From [10].

<sup>14</sup>From [2].

<sup>15</sup>For the BOC-based signals, the bandwidth is defined between the outer nulls of the largest spectral lobes. This translates into that not all of them are in the same power percentile.

GNSS	BAND	F <sub>c</sub> [MHz]	λ [cm]	T <sub>x</sub> BW [MHz]	ITU BW [MHz] <sup>10</sup>	SERVICES <sup>11</sup>	I/Q	COMPONENT	MODULATION	f <sub>c</sub> [MHz]	f <sub>s</sub> [MHz]	1st CODE FAMILY	2nd CODE LENGTH [chips/ms]	DATA RATE [bps/spo]	MIN. POWER [dBW] <sup>12</sup>	POWER RELAT.	REF. ELEV. [deg]	MODULATION BW [MHz] <sup>15</sup>		
GPS <sup>1</sup>	L1	1575.42	19.04	IIA/IIR/IIR-M/ IIF: 20.46 III: also 30.69	24	P(Y)*	I	DATA	BPSK-R10	10.23	-	short-cycled + m-Sequence	6.9E12/~1 week	-	50/50	IIA/IIR/IIR-M/ IIF/IIF: -161.5	1	5	20.460	
						C/A	Q	DATA	BPSK-R1	1.023	-	Gold	1023/1	-	50/50	IIA/IIR/IIR-M/ IIF/IIF: -158.5	1	5	2.046	
						L1C	I	DATA (L1 <sub>D</sub> )	BOCs(1,1) MBOC(6,1,1/11) TMBOC(6,1,4/33) (time mux.)	1.023	1.023 & 6.138	Weil	10230/10 1800	-	50/100	III: -157 1/4 (with 29/33 and 4/33 inside)	3/4	5	4.092	
							Q	PILOT (L1 <sub>p</sub> )		-				14.322						
	L2	1227.6	24.43	IIA/IIR/IIR-M/ IIF: 20.46 III: also 30.69	24	M*	I	N/A	BOCs(10,5)	5.115	10.23	N/A	N/A	N/A	IIIR-M/IIF/ III: -157 <sup>13</sup>	1	N/A	30.690		
						L2C	P(Y)*	DATA	BPSK-R10	10.23	-	short-cycled + m-Sequence	6.9E12/~1 week	-	50/50	IIA/IIR: -164.5 IIR-M/IIF: -161.5	1	5	20.460	
							Q	DATA (L2CM)	BPSK-R1 (result of multiplexing 2 streams at 511.5 kHz)	0.5115	-	m-Sequence	10230/20 767250/1500	-	IIIF: 50/50 IIR-M: also 25/50	IIA/IIR: -164.5 IIR-M/IIF: -160.0 III: -158.5	0.5	5	2.046	
						M*	I	N/A	BOCs(10,5)	5.115	10.23	N/A	N/A	N/A	N/A	1	N/A	30.690		
	L5	1176.45	25.50	24.00	25	SoL	I	DATA (L5I)	BPSK-R10	10.23	-	short-cycled + m-Sequence	10230/1	10	50/100	IIIF: -157.9 III: -157.0	1	5	20.460	
							Q	PILOT (L5Q)						20	-	IIIF: -157.9 III: -157.0	1			
Galileo <sup>2</sup>	E1	1575.42	19.04	24.552 <sup>5</sup>	32.0	PRS*	Q	DATA (E1A)	BOCc(15,2.5)	25.5575	15.345	-	N/A	N/A	50/100	-157 <sup>14</sup>	1	N/A	35.805	
						OS, SoL, CS	I	DATA (E1B)	CBOC(6,1,1/11)	1.023	6.138	Random	4092/4	-	125/250	-157	10/11	10	4.092	
	E6	1278.75	23.46	40.92 <sup>5</sup>	40		PRS*	Q	DATA (E6A)	BOCc(10,5)	5.115	10.23	N/A	N/A	N/A	50/100	-155 <sup>14</sup>	1	N/A	30.690
					CS*	I	DATA (E6B)	BPSK-R5	5.115	-	Memory	5115/1	-	500/1000	-155	0.5	10	10.230		
	E5	Fc = 1191.795 Fc <sub>a</sub> = 1176.45 Fc <sub>b</sub> = 1207.14	λ = 25.17 λ <sub>a</sub> = 25.50 λ <sub>b</sub> = 24.85	BW = 51.15 <sup>5</sup> BW <sub>a/b</sub> = 20.46 <sup>5</sup>	50 <sup>10</sup>	OS, CS	I	DATA (E5a)	BPSK-R5	10.23	15.345	short-cycled + m-Sequence	10230/1	20	25/50	-155	0.5	10	51.150	
							Q	PILOT (E5aQ)						100	-		0.5			
						OS, SoL, CS	I	DATA (E5b)						4	125/250		0.5			
							Q	PILOT (E5bQ)						100	-		0.5			
BeiDou-2 (current) <sup>3</sup>	B1	Fc <sub>B1</sub> = 1561.098 Fc <sub>B1-2</sub> = 1589.742	λ <sub>B1</sub> = 19.22 λ <sub>B1-2</sub> = 18.87	BW = 32.736 <sup>6</sup> BW <sub>B1-2</sub> = 4.092 <sup>7</sup>	DNF	B1(Q)*	Q	DNF	QPSK-R2	2.046	-	DNF	DNF/>400	-	-	-163 <sup>8</sup>	1	5 <sup>8</sup>	4.092	
						B1(I)	I	DATA		Gold	2046/1	20/20	DNF/50	-163	1	5				
						B1-2(Q)*	Q	DNF	QPSK-R2	2.046	-	DNF	DNF/>400	-	-	-163 <sup>8</sup>	1	5 <sup>8</sup>		
						B1-2(I)	I	DATA		Gold	2046/1	20/20	DNF/50	-163	1	5				
	B2	1207.14	24.85	BW = 51.15 <sup>6</sup> BW <sub>B2</sub> = 20.46 <sup>7</sup>	DNF	B2-Q*	Q	DNF	BPSK-R10	10.23	-	DNF	DNF/>160	-	-	-163 <sup>8</sup>	1	5 <sup>8</sup>	20.460	
						B2-I	I	DATA	BPSK-R2	2.046	-	DNF	2046/1	20/20	DNF/50	-163	1	5 <sup>8</sup>	4.092	
	B3	1268.52	23.65	BW = 35.805 <sup>6</sup> BW <sub>B3</sub> = 20.46 <sup>8</sup>	DNF	B3*	Q	DNF	QPSK-R10	10.23	-	DNF	DNF/>160	-	-	-163 <sup>8</sup>	1	5 <sup>8</sup>	20.460	
							I	DATA			DNF	10230/1	20/20	DNF/50	-163 <sup>8</sup>	1	5 <sup>8</sup>			
BeiDou-2 (future) <sup>4</sup>	B1	1575.42	19.04	32.736	DNF	B1-C <sub>D</sub>	I	DATA	MBOC(6,1,1/11)	1.023	1.023	DNF	DNF	DNF	50/100	DNF	10/11	DNF	4.092	
						B1-C <sub>p</sub>	PILOT	BOCs(6,1)		6.138	6.138	DNF	DNF	DNF	-		1/11	DNF	14.322	
						B1*	I	DATA		DNF	DNF	DNF	50/100	DNF	0.5	DNF	51.150			
	B2	1191.795	25.17	51.15	DNF	B2a <sub>D</sub>	I	DATA	AltBOCs(15,10)	10.23	15.345	DNF	DNF	DNF	25/50	DNF	0.25	DNF	51.150	
						B2a <sub>P</sub>	Q	PILOT				DNF	DNF	DNF	-		0.25	DNF		
						B2b <sub>D</sub>	I	DATA				DNF	DNF	DNF	50/100		0.25	DNF		
						B2b <sub>P</sub>	Q	PILOT				DNF	DNF	DNF	-		0.25	DNF		
	B3	1268.52	23.65	35.805	DNF	B3*	I	DNF	QPSK-R10	10.23	-	DNF	DNF	DNF	500/-	DNF	0.5	DNF	20.460	
						B3-A <sub>D</sub> *	I	DATA	BOCs(15,2.5)	2.5575	15.345	DNF	DNF	DNF	50/100		0.5	DNF	35.805	
						B3-A <sub>P</sub> *	PILOT	DNF				DNF	DNF	-	DNF	0.5	DNF			

## Chapter 4

# GNU Free Documentation License

Version 1.3, 3 November 2008  
Copyright © 2000, 2001, 2002, 2007, 2008 Free Software Foundation, Inc.

<http://fsf.org/>

Everyone is permitted to copy and distribute verbatim copies of this license document, but changing it is not allowed.

### Preamble

The purpose of this License is to make a manual, textbook, or other functional and useful document “free” in the sense of freedom: to assure everyone the effective freedom to copy and redistribute it, with or without modifying it, either commercially or noncommercially. Secondarily, this License preserves for the author and publisher a way to get credit for their work, while not being considered responsible for modifications made by others.

This License is a kind of “copyleft”, which means that derivative works of the document must themselves be free in the same sense. It complements the GNU General Public License, which is a copyleft license designed for free software.

We have designed this License in order to use it for manuals for free software, because free software needs free documentation: a free program should come with manuals providing the same freedoms that the software does. But this License is not limited to software manuals; it can be used for any textual work, regardless of subject matter or whether it is published as a printed book. We recommend this License principally for works whose purpose is instruction or reference.

## 1. APPLICABILITY AND DEFINITIONS

This License applies to any manual or other work, in any medium, that contains a notice placed by the copyright holder saying it can be distributed under the terms of this License. Such a notice grants a world-wide, royalty-free license, unlimited in duration, to use that work under the conditions stated herein. The “**Document**”, below, refers to any such manual or work. Any member of the public is a licensee, and is addressed as “**you**”. You accept the license if you copy, modify or distribute the work in a way requiring permission under copyright law.

A “**Modified Version**” of the Document means any work containing the Document or a portion of it, either copied verbatim, or with modifications and/or translated into another language.

A “**Secondary Section**” is a named appendix or a front-matter section of the Document that deals exclusively with the relationship of the publishers or authors of the Document to the Document’s overall subject (or to related matters) and contains nothing that could fall directly within that overall subject. (Thus, if the Document is in part a textbook of mathematics, a Secondary Section may not explain any mathematics.) The relationship could be a matter of historical connection with the subject or with related matters, or of legal, commercial, philosophical, ethical or political position regarding them.

The “**Invariant Sections**” are certain Secondary Sections whose titles are designated, as being those of Invariant Sections, in the notice that says that the Document is released under this License. If a section does not fit the above definition of Secondary then it is not allowed to be designated as Invariant. The Document may contain zero Invariant Sections. If the Document does not identify any Invariant Sections then there are none.

The “**Cover Texts**” are certain short passages of text that are listed, as Front-Cover Texts or Back-Cover Texts, in the notice that says that the Document is released under this License. A Front-Cover Text may be at most 5 words, and a Back-Cover Text may be at most 25 words.

A “**Transparent**” copy of the Document means a machine-readable copy, represented in a format whose specification is available to the general public, that is suitable for revising the document straightforwardly with generic text editors or (for images composed of pixels) generic paint programs or (for drawings) some widely available drawing editor, and that is suitable for input to text formatters or for automatic translation to a variety of formats suitable for input to text formatters. A copy made in an otherwise Transparent file format whose markup, or absence of markup, has been arranged to thwart or discourage subsequent modification by readers is not Transparent. An image format is not Transparent if used for any substantial amount of text. A copy that is not “Transparent” is called “**Opaque**”.

Examples of suitable formats for Transparent copies include plain ASCII without markup, Texinfo input format, LaTeX input format, SGML or XML using a publicly available DTD, and standard-conforming simple HTML, PostScript or PDF designed for human modification. Examples of transparent image formats include PNG, XCF and JPG. Opaque formats include proprietary formats that can be read and edited only by proprietary word processors, SGML or XML for which the DTD and/or processing tools are not generally available, and the machine-generated HTML, PostScript or PDF produced by some word processors for output purposes only.

The “**Title Page**” means, for a printed book, the title page itself, plus such following pages as are needed to hold, legibly, the material this License requires to appear in the title page. For works in formats which do not have any title page as such, “Title Page” means the text near the most prominent appearance of the work’s title, preceding the beginning of the body of the text.

The “**publisher**” means any person or entity that distributes copies of the Document to the public.

A section “**Entitled XYZ**” means a named subunit of the Document whose title either is precisely XYZ or contains XYZ in parentheses following text that translates XYZ in another language. (Here XYZ stands for a specific section name mentioned below, such as “**Acknowledgements**”, “**Dedications**”, “**Endorsements**”, or “**History**”.) To “**Preserve the Title**” of such a section when you modify the Document means that it remains a section “Entitled XYZ” according to this definition.

The Document may include Warranty Disclaimers next to the notice which states that this License applies to the Document. These Warranty Disclaimers are considered to be included by reference in this License, but only as regards disclaiming warranties: any other implication that these Warranty Disclaimers may have is void and has no effect on the meaning of this License.

## 2. VERBATIM COPYING

You may copy and distribute the Document in any medium, either commercially or noncommercially, provided that this License, the copyright notices, and the license notice saying this License applies to the Document are reproduced in all copies, and that you add no other conditions whatsoever to those of this License. You may not use technical measures to obstruct or control the reading or further copying of the copies you make or distribute. However, you may accept compensation in exchange for copies. If you distribute a large enough number of copies you must also follow the conditions in section 3.

You may also lend copies, under the same conditions stated above, and you may publicly display copies.

## 3. COPYING IN QUANTITY

If you publish printed copies (or copies in media that commonly have printed covers) of the Document, numbering more than 100, and the Document’s license notice requires Cover Texts, you must enclose the copies in covers that carry, clearly and legibly, all these Cover Texts: Front-Cover Texts on the front

cover, and Back-Cover Texts on the back cover. Both covers must also clearly and legibly identify you as the publisher of these copies. The front cover must present the full title with all words of the title equally prominent and visible. You may add other material on the covers in addition. Copying with changes limited to the covers, as long as they preserve the title of the Document and satisfy these conditions, can be treated as verbatim copying in other respects.

If the required texts for either cover are too voluminous to fit legibly, you should put the first ones listed (as many as fit reasonably) on the actual cover, and continue the rest onto adjacent pages.

If you publish or distribute Opaque copies of the Document numbering more than 100, you must either include a machine-readable Transparent copy along with each Opaque copy, or state in or with each Opaque copy a computer-network location from which the general network-using public has access to download using public-standard network protocols a complete Transparent copy of the Document, free of added material. If you use the latter option, you must take reasonably prudent steps, when you begin distribution of Opaque copies in quantity, to ensure that this Transparent copy will remain thus accessible at the stated location until at least one year after the last time you distribute an Opaque copy (directly or through your agents or retailers) of that edition to the public.

It is requested, but not required, that you contact the authors of the Document well before redistributing any large number of copies, to give them a chance to provide you with an updated version of the Document.

## 4. MODIFICATIONS

You may copy and distribute a Modified Version of the Document under the conditions of sections 2 and 3 above, provided that you release the Modified Version under precisely this License, with the Modified Version filling the role of the Document, thus licensing distribution and modification of the Modified Version to whoever possesses a copy of it. In addition, you must do these things in the Modified Version:

- A. Use in the Title Page (and on the covers, if any) a title distinct from that of the Document, and from those of previous versions (which should, if there were any, be listed in the History section of the Document). You may use the same title as a previous version if the original publisher of that version gives permission.
- B. List on the Title Page, as authors, one or more persons or entities responsible for authorship of the modifications in the Modified Version, together with at least five of the principal authors of the Document (all of its principal authors, if it has fewer than five), unless they release you from this requirement.
- C. State on the Title page the name of the publisher of the Modified Version, as the publisher.
- D. Preserve all the copyright notices of the Document.
- E. Add an appropriate copyright notice for your modifications adjacent to the other copyright notices.
- F. Include, immediately after the copyright notices, a license notice giving the public permission to use the Modified Version under the terms of this License, in the form shown in the Addendum below.
- G. Preserve in that license notice the full lists of Invariant Sections and required Cover Texts given in the Document's license notice.
- H. Include an unaltered copy of this License.
- I. Preserve the section Entitled "History", Preserve its Title, and add to it an item stating at least the title, year, new authors, and publisher of the Modified Version as given on the Title Page. If there is no section Entitled "History" in the Document, create one stating the title, year, authors, and publisher of the Document as given on its Title Page, then add an item describing the Modified Version as stated in the previous sentence.

- J. Preserve the network location, if any, given in the Document for public access to a Transparent copy of the Document, and likewise the network locations given in the Document for previous versions it was based on. These may be placed in the “History” section. You may omit a network location for a work that was published at least four years before the Document itself, or if the original publisher of the version it refers to gives permission.
- K. For any section Entitled “Acknowledgements” or “Dedications”, Preserve the Title of the section, and preserve in the section all the substance and tone of each of the contributor acknowledgements and/or dedications given therein.
- L. Preserve all the Invariant Sections of the Document, unaltered in their text and in their titles. Section numbers or the equivalent are not considered part of the section titles.
- M. Delete any section Entitled “Endorsements”. Such a section may not be included in the Modified Version.
- N. Do not retitle any existing section to be Entitled “Endorsements” or to conflict in title with any Invariant Section.
- O. Preserve any Warranty Disclaimers.

If the Modified Version includes new front-matter sections or appendices that qualify as Secondary Sections and contain no material copied from the Document, you may at your option designate some or all of these sections as invariant. To do this, add their titles to the list of Invariant Sections in the Modified Version’s license notice. These titles must be distinct from any other section titles.

You may add a section Entitled “Endorsements”, provided it contains nothing but endorsements of your Modified Version by various parties—for example, statements of peer review or that the text has been approved by an organization as the authoritative definition of a standard.

You may add a passage of up to five words as a Front-Cover Text, and a passage of up to 25 words as a Back-Cover Text, to the end of the list of Cover Texts in the Modified Version. Only one passage of Front-Cover Text and one of Back-Cover Text may be added by (or through arrangements made by) any one entity. If the Document already includes a cover text for the same cover, previously added by you or by arrangement made by the same entity you are acting on behalf of, you may not add another; but you may replace the old one, on explicit permission from the previous publisher that added the old one.

The author(s) and publisher(s) of the Document do not by this License give permission to use their names for publicity for or to assert or imply endorsement of any Modified Version.

## 5. COMBINING DOCUMENTS

You may combine the Document with other documents released under this License, under the terms defined in section 4 above for modified versions, provided that you include in the combination all of the Invariant Sections of all of the original documents, unmodified, and list them all as Invariant Sections of your combined work in its license notice, and that you preserve all their Warranty Disclaimers.

The combined work need only contain one copy of this License, and multiple identical Invariant Sections may be replaced with a single copy. If there are multiple Invariant Sections with the same name but different contents, make the title of each such section unique by adding at the end of it, in parentheses, the name of the original author or publisher of that section if known, or else a unique number. Make the same adjustment to the section titles in the list of Invariant Sections in the license notice of the combined work.

In the combination, you must combine any sections Entitled “History” in the various original documents, forming one section Entitled “History”; likewise combine any sections Entitled “Acknowledgements”, and any sections Entitled “Dedications”. You must delete all sections Entitled “Endorsements”.

## 6. COLLECTIONS OF DOCUMENTS

You may make a collection consisting of the Document and other documents released under this License, and replace the individual copies of this License in the various documents with a single copy that is included in the collection, provided that you follow the rules of this License for verbatim copying of each of the documents in all other respects.

You may extract a single document from such a collection, and distribute it individually under this License, provided you insert a copy of this License into the extracted document, and follow this License in all other respects regarding verbatim copying of that document.

## 7. AGGREGATION WITH INDEPENDENT WORKS

A compilation of the Document or its derivatives with other separate and independent documents or works, in or on a volume of a storage or distribution medium, is called an “aggregate” if the copyright resulting from the compilation is not used to limit the legal rights of the compilation’s users beyond what the individual works permit. When the Document is included in an aggregate, this License does not apply to the other works in the aggregate which are not themselves derivative works of the Document.

If the Cover Text requirement of section 3 is applicable to these copies of the Document, then if the Document is less than one half of the entire aggregate, the Document’s Cover Texts may be placed on covers that bracket the Document within the aggregate, or the electronic equivalent of covers if the Document is in electronic form. Otherwise they must appear on printed covers that bracket the whole aggregate.

## 8. TRANSLATION

Translation is considered a kind of modification, so you may distribute translations of the Document under the terms of section 4. Replacing Invariant Sections with translations requires special permission from their copyright holders, but you may include translations of some or all Invariant Sections in addition to the original versions of these Invariant Sections. You may include a translation of this License, and all the license notices in the Document, and any Warranty Disclaimers, provided that you also include the original English version of this License and the original versions of those notices and disclaimers. In case of a disagreement between the translation and the original version of this License or a notice or disclaimer, the original version will prevail.

If a section in the Document is Entitled “Acknowledgements”, “Dedications”, or “History”, the requirement (section 4) to Preserve its Title (section 1) will typically require changing the actual title.

## 9. TERMINATION

You may not copy, modify, sublicense, or distribute the Document except as expressly provided under this License. Any attempt otherwise to copy, modify, sublicense, or distribute it is void, and will automatically terminate your rights under this License.

However, if you cease all violation of this License, then your license from a particular copyright holder is reinstated (a) provisionally, unless and until the copyright holder explicitly and finally terminates your license, and (b) permanently, if the copyright holder fails to notify you of the violation by some reasonable means prior to 60 days after the cessation.

Moreover, your license from a particular copyright holder is reinstated permanently if the copyright holder notifies you of the violation by some reasonable means, this is the first time you have received notice of violation of this License (for any work) from that copyright holder, and you cure the violation prior to 30 days after your receipt of the notice.

Termination of your rights under this section does not terminate the licenses of parties who have received copies or rights from you under this License. If your rights have been terminated and not permanently reinstated, receipt of a copy of some or all of the same material does not give you any rights to use it.

## 10. FUTURE REVISIONS OF THIS LICENSE

The Free Software Foundation may publish new, revised versions of the GNU Free Documentation License from time to time. Such new versions will be similar in spirit to the present version, but may differ in detail to address new problems or concerns. See <http://www.gnu.org/copyleft/>.

Each version of the License is given a distinguishing version number. If the Document specifies that a particular numbered version of this License “or any later version” applies to it, you have the option of following the terms and conditions either of that specified version or of any later version that has been published (not as a draft) by the Free Software Foundation. If the Document does not specify a version number of this License, you may choose any version ever published (not as a draft) by the Free Software Foundation. If the Document specifies that a proxy can decide which future versions of this License can be used, that proxy’s public statement of acceptance of a version permanently authorizes you to choose that version for the Document.

## 11. RELICENSING

“Massive Multiauthor Collaboration Site” (or “MMC Site”) means any World Wide Web server that publishes copyrightable works and also provides prominent facilities for anybody to edit those works. A public wiki that anybody can edit is an example of such a server. A “Massive Multiauthor Collaboration” (or “MMC”) contained in the site means any set of copyrightable works thus published on the MMC site.

“CC-BY-SA” means the Creative Commons Attribution-Share Alike 3.0 license published by Creative Commons Corporation, a not-for-profit corporation with a principal place of business in San Francisco, California, as well as future copyleft versions of that license published by that same organization.

“Incorporate” means to publish or republish a Document, in whole or in part, as part of another Document.

An MMC is “eligible for relicensing” if it is licensed under this License, and if all works that were first published under this License somewhere other than this MMC, and subsequently incorporated in whole or in part into the MMC, (1) had no cover texts or invariant sections, and (2) were thus incorporated prior to November 1, 2008.

The operator of an MMC Site may republish an MMC contained in the site under CC-BY-SA on the same site at any time before August 1, 2009, provided the MMC is eligible for relicensing.

# Bibliography

- [1] J. W. Betz, “Binary Offset Carrier Modulations for Radionavigation,” *Navigation*, vol. 48, pp. 227–246, Dec. 2001.
- [2] J. A. Avila-Rodriguez, *On Generalized Signal Waveforms for Satellite Navigation*. PhD thesis, Universität der Bundeswehr, München, Neubiberg, 2000.
- [3] “Navstar GPS Space Segment Navigation User Segment Interfaces, Interface Specification (IS-GPS-200G),” 2013.
- [4] “Navstar GPS Space Segment - User Segment L5 Interfaces, Interface Specification (IS-GPS-705C),” 2013.
- [5] “Galileo Open Service, Signal in Space Interface Control Document (OS-SIS-ICD),” 2010.
- [6] “Navstar GPS Space Segment - User Segment L1C Interfaces, Interface Specification (IS-GPS-800C),” 2013.
- [7] “BeiDou Navigation Satellite System Signal In Space Interface Control Document 2.0,” 2013.
- [8] T. G. Alain Ghion, Antonie De latour, Joel Dantepal, Lionel Ries, “Compass MEO Satellite Signals Initial Observations and Analysis,” *Inside GNSS*, pp. 39–43.
- [9] “Navipedia.”
- [10] M. Martin-Neira, S. D’Addio, C. Buck, N. Flouri, and R. Prieto-Cerdeira, “The PARIS Ocean Altimeter In-Orbit Demonstrator,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, pp. 2209–2237, June 2011.