IGS Satellite Metadata File Description

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Contents

Revision History

Revision	Date	Author(s)	Description
1.01	18 July 2023	PS	QZSS pre-maneuver mass IRS-2G block type added
1.10 draft	10 July 2024	PS	GLONASS K2 details added, GLONASS K1+ added Homogenization of transmit antenna sensor names Table 6 updated **`SATELLITE/PLANE`** block added
1.10	30 September 2024	IGS GB	Approval by IGS Governing Board

1. Introduction

Satellite metadata are vital for accurate modeling of Global Navigation Satellite System (GNSS) data (Montenbruck and Steigenberger, 2020) and are a prerequisite for generation of high-precision products like orbits and clocks used for Precise Point Positioning (PPP), as an example. They include unique identifiers, mapping of the Pseudo-Random Noise (PRN) number to the Space Vehicle Number (SVN), SVN/frequency channel mapping for GLONASS, satellite mass, center of mass information, transmit antenna and laser retro-reflector array eccentricities, transmit power, and active clock history.

1.1. Satellite Metadata

Satellite Identifier Observations and navigation data of GNSS satellites are commonly identified in a GNSS receiver by a satellite number that refers to the transmitted PRN code (for GPS, Galileo, BeiDou, QZSS, and IRNSS) or the ”slot number” for GLONASS. In the Receiver Independent Exchange (RINEX) format (Gini, 2023), a 3-character designation comprising the constellation letter and a two-digit PRN or slot number is used to specify the transmitting satellite. By its very nature, this satellite identifier is not tied to a given spacecraft but may vary over its lifetime. The primary unique satellite identifier in this document is the Space Vehicle Number (SVN), additional identifiers are the COSPAR ID, and the Satellite Catalog Number (NORAD ID).

Satellite Mass Knowledge of the mass of a GNSS satellite is required to compute the acceleration caused by non-gravitational forces (such as solar radiation pressure, radiation thrust, or Earth radiation pressure). In line with the quality of other model parameters, a $1\,\%$ accuracy is typically deemed adequate for this purpose. Updates following the start of initial operations are only required after maneuvers and incremental mass changes of more than $1\,\mathrm{kg}$.

Satellite Center-of-Mass Dynamic orbit models describe the motion of a satellite’s center of mass. Therefore, knowledge of the potentially time-varying Center-of-Mass (CoM) location w.r.t. the origin of the spacecraft reference frame is required to express the position of other reference points (e.g., transmit antennas or laser retroreflectors) relative to the CoM. To exploit the precision of GNSS carrier-phase measurements and the technical capabilities of CoM measurements, knowledge of the CoM location is desired with a representative accuracy of 1 to $10\,\mathrm{mm}$.

Sensor Eccentricities The modeling of GNSS measurements requires concise information on the location of the antenna phase center and potential line-of-sight dependent phase variations. Such information is currently provided in the Antenna Exchange (ANTEX) format. However, as the Phase Center Offsets (PCOs) given in the current International GNSS Service (IGS) ANTEX files refer to CoM, time-variable PCOs are required if the CoM position changes. Therefore, time-invariable eccentricities of an Antenna Reference Point (ARP) can be specified together with PCOs referring to this ARP. Together with the current CoM values, the antenna position can be computed. Details on this topic are given in Sect. 3.5. The sensor eccentricities also include the offset of Laser Retroreflector Arrays (LRAs) for Satellite Laser Ranging (SLR).

Transmit Power Knowledge of the GNSS satellite transmit power is a prerequisite for the computation of antenna thrust caused by the transmission of navigation signals. Antenna thrust mainly acts in the radial direction and depends on the satellite mass and the transmit power (Milani et al., 1987).

1.2. Metadata SINEX Blocks

The satellite metadata are stored in dedicated blocks of an extension to the Solution INdependent EXchange (SINEX) format (Rothacher and Thaller, 2006). Version 2.02 of this format provides a **SATELLITE/ID** block including a very limited set of metadata. In the metadata extension of the SINEX format, the PRN number is moved to a separate block and a new **SATELLITE/IDENTIFIER** block is introduced with the following changes:

- NORAD ID added
- Transition from 2-digit year to 4-digit year
- Replaced antenna name by satellite block name

The satellite metadata extension consists of the following blocks:

Name	Description
SATELLITE/IDENTIFIER	Satellite designations (static), Sec. 2.2
SATELLITE/PLANE	Orbital plane and slot, Sec. 2.3
SATELLITE/PRN	SVN/PRN assignment, Sec. 2.4
SATELLITE/FREQUENCY_CHANNEL	GLONASS frequency channels, Sec. 2.5
SATELLITE/MASS	Spacecraft mass, Sec. 2.6
SATELLITE/CENTER_OF_MASS	Center-of-mass position, Sec. 2.7
SATELLITE/ECCENTRICITY	Sensor positions, Sec. 2.8
SATELLITE/TX_POWER	Total transmit power, Sec. 2.9

2. SINEX Metadata Format Extension

2.1. General

Date and Time All dates are given in the format **YYYY:DDD:SSSSS** with

YYYY: 4-digit year

DDD: 3-digit day of year

SSSSS: 5-digit seconds of day

Validity intervals are provided for time varying data assuming half-open intervals $[t_{start}, t_{end}[$ and constant parameter values in each interval (no slopes).

SVN The 4-digit Space Vehicle Number (SVN) is used as a unique primary key for accessing the individual information. The SVN is composed of a constellation letter for identifying the GNSS (consistent with RINEX) and a 3-digit number for each individual satellite.

G Global Positioning System (GPS)

R Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS)

E Galileo

C BeiDou

J Quasi-Zenith Satellite System (QZSS)

I Indian Regional Navigation Satellite System (IRNSS)

2.2. SATELLITE/IDENTIFIER Block

This block contains only unique information that does not require a validity interval.

Field	Description	Format
SVN	Space Vehicle Number as primary unique identifier	**1X,A4**
COSPAR_ID	COSPAR number: **YYYY-NNNL** **YYYY**: 4-digit launch year **NNN**: 3-digit number for the launch within this year **L**: character identifying the object of the launch	**1X,A9**
SatCat	Satellite catalog number, also known as NORAD ID	**1X,I6**
Satellite block type	see Table 1	**1X,A15**
Comment	e.g., launch date, satellite names in TLEs	**1X,A41**

Table 1: GNSS satellite block names.

Block	Description	Reference
`GPS-I`	GPS test satellite	
`GPS-II`	operational GPS satellite	
`GPS-IIA`	modified Block II satellites	
`GPS-IIR-A`	replenishment GPS satellite with legacy antenna panel	
`GPS-IIR-B`	replenishment GPS satellite with new antenna panel	Marquis and Reigh (2015)
`GPS-IIR-M`	modernized GPS-IIR satellite	Hartman et al. (2000)
`GPS-II-F`	follow-on GPS satellite	Fisher and Ghasemi (1999)
`GPS-III`	3rd generation GPS satellite	Marquis and Shaw (2011)
`GPS-IIIF`	3rd generation follow-on GPS satellite	
`GLO`	1st generation GLONASS satellite	
`GLO-M`	modernized GLONASS satellite	Fatkulin et al. (2012)
`GLO-M+`	GLONASS-M with L3 CDMA capability	
`GLO-K1A`	1st generation GLONASS-K with two antenna panels	
`GLO-K1B`	1st generation GLONASS-K with single antenna panel	
`GLO-K1+`	1st generation GLONASS-K with L2 CDMA capability	
`GLO-K2`	2nd generation GLONASS-K	
`GAL-0A`	GIOVE-A	Benedicto et al. (2006)
`GAL-0B`	GIOVE-B	Malik et al. (2009)
`GAL-1`	Galileo IOV	ESA (2012)
`GAL-2`	Galileo FOC	Berlin et al. (2017)
`BDS-2G`	BeiDou-2 GEO	
`BDS-2I`	BeiDou-2 IGSO	
`BDS-2M`	BeiDou-2 MEO	
`BDS-3SI-CAST`	BeiDou-3S IGSO by CAST	
`BDS-3SI-SECM`	BeiDou-3S IGSO by SECM	
`BDS-3SM-CAST`	BeiDou-3S MEO by CAST	
`BDS-3SM-SECM`	BeiDou-3S MEO by SECM	
`BDS-3G`	BeiDou-3 GEO	
`BDS-3I`	BeiDou-3 IGSO	
`BDS-3M-CAST`	BeiDou-3 MEO by CAST	
`BDS-3M-SECM-A`	BeiDou-3 MEO by SECM	SECM (2018)
`BDS-3M-SECM-B`	BeiDou-3 MEO by SECM, modified bus	
`QZS-1`	1st generation QZSS IGSO	Cabinet Office (2022a)
`QZS-2I`	2nd generation QZSS IGSO	Cabinet Office (2019a,b)
`QZS-2G`	2nd generation QZSS GEO	Cabinet Office (2022c)
`QZS-2A`	QZSS Block IIA IGSO	Cabinet Office (2022b)
`QZS-3I`	3rd generation QZSS IGSO	
`QZS-3G`	3rd generation QZSS GEO	
`IRS-1G`	1st generation IRNSS GEO	Harde et al. (2015)
`IRS-1I`	1st generation IRNSS IGSO	Harde et al. (2015)
`IRS-2G`	2nd generation IRNSS GEO	

Example:

```
+SATELLITE/IDENTIFIER
*
*SVN_ COSPAR_ID SatCat Block__________ Comment__________________________________
 G073 2015-062A  41019 GPS-IIF         Launched 2015-10-31; NAVSTAR 75
 G074 2018-109A  43873 GPS-IIIA        Launched 2018-12-23; NAVSTAR 77
 R857 2018-086A  43687 GLO-M           Launched 2018-11-03; COSMOS 2529
 R858 2019-030A  44299 GLO-M+          Launched 2019-05-27; COSMOS 2534
 E221 2018-060A  43564 GAL-2           Launched 2018-07-25; GALILEO 25 (2C1)
 E222 2018-060B  43565 GAL-2           Launched 2018-07-25; GALILEO 24 (2C0)
 C222 2019-061A  44542 BDS-3M-CAST     Launched 2019-09-22; BEIDOU 3M23
 C223 2019-061B  44543 BDS-3M-CAST     Launched 2019-09-22; BEIDOU 3M24
 J004 2017-062A  42965 QZS-2I          Launched 2017-10-09; MICHIBIKI-4
 I009 2018-035A  43286 IRS-1I          Launched 2018-04-11; IRNSS-1I
*
-SATELLITE/IDENTIFIER
```

2.3. SATELLITE/PLANE Block

This block provides provides information about the orbital plane of a satellite within the constellation as well as the slot within the plane.

Field	Description	Format
SVN	Space vehicle number as unique identifier	**1X,A4**
Valid_From	Begin time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Valid_To	End time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
P	Orbital plane	**1X,I1**
Slot	Orbital slot	**1X,A6**
Comment	e.g., information source	**1X,A35**

Example:

```
+SATELLITE/PLANE
*
*SVN_ Valid_From____ Valid_To______ P Slot__ Comment____________________________
 G032 2000:028:00000 2004:181:00000 6 F4     [PL05]
 G032 2004:181:00000 2004:323:00000 6 REPOS  [PL05] repositioning
 G032 2004:323:00000 0000:000:00000 6 F6     [PL05]
 R860 2020:076:00000 0000:000:00000 3 24     [PL02]
 R861 2022:332:00000 0000:000:00000 2 16     [PL02]
 C224 2019:308:00000 0000:000:00000 I        [PL04]
 C228 2019:350:00000 0000:000:00000 2 B-4    [PL04]
 C230 2020:175:00000 0000:000:00000 G 111E   [PL04]
 E223 2021:339:00000 0000:000:00000 2 B03    [PL03]
 E224 2021:339:00000 0000:000:00000 2 B15    [PL03]
 J005 2021:299:00000 0000:000:00000 I 139E   [PL06]
 I009 2018:101:00000 0000:000:00000 I 055E   [PL04]
 I010 2023:149:00000 0000:000:00000 G 130E   [PL04]
-SATELLITE/PLANE
```

2.4. SATELLITE/PRN Block

This block provides provides the RINEX satellite identifier (PRN) associated with a given space vehicle at a certain time.

Field	Description	Format
SVN	Space vehicle number as unique identifier	**1X,A4**
Valid_From	Begin time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Valid_To	End time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
PRN	Pseudo-Random Noise number	**1X,A3**
Comment	e.g., source of PRN switch	**1X,A40**

Example:

```
+SATELLITE/PRN
*
*SVN_ Valid_From____ Valid_To______ PRN Comment_________________________________________
 R802 2014:334:00000 2016:027:00000 R27
 R802 2016:027:00000 2016:046:48600 R17
 R802 2016:046:52200 0000:000:00000 R09
 C101 2015:089:00000 2018:114:36000 C31
 C101 2018:114:36060 2018:191:28800 C16
 C101 2018:191:28860 0000:000:00000 C31
*
-SATELLITE/PRN
```

2.5. SATELLITE/FREQUENCY_CHANNEL Block

This block provides information about the Frequency Channel Number (FCN) used for the GLONASS FDMA signals.

Field	Description	Format
SVN	Space vehicle number as unique identifier	**1X,A4**
Valid_From	Start time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Valid_To	End time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
chn	Frequency Channel Number	**1X,A3**
Comment	e.g., source of FCN switch	**1X,A40**

Example:

```
+SATELLITE/FREQUENCY_CHANNEL
*
*SVN_ Valid_From____ Valid_To______ chn Comment________________________________________
 R717 2007:011:00000 2007:016:86399   0 [Const_070111.glo]
 R717 2007:017:00000 2009:069:86399   4 [Const_070117.glo]
 R717 2009:070:00000 2019:275:86399  -7 [Const_090311.glo]
*
-SATELLITE/FREQUENCY_CHANNEL
```

2.6. SATELLITE/MASS Block

This block lists the mass history (if available) or a static mass value of the spacecraft.

Field	**Description**	**Format**
SVN	Space Vehicle Number	**1X,A4**
Valid_From	Start time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Valid_To	End time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Mass	Satellite mass in kg	**1X,F9.3**
Comment	Reference, issue date, etc.	**1X,A34**

Example:

```
+SATELLITE/MASS
*
*SVN_ Valid_From____ Valid_To______ Mass_[kg] Comment___________________________
 E101 2011:294:00000 2019:091:00000   696.815 [MA08], Issue Date: 2011-10-21
 E101 2019:091:00000 0000:000:00000   696.806 [MA28], April 2019
 E102 2011:294:00000 2016:288:00000   695.328 [MA08], Issue Date: 2011-10-21
 E102 2016:288:00000 0000:000:00000   695.318 [MA08], Issue Date: 2016-10-14
 E103 2012:286:00000 0000:000:00000   697.632 [MA08], Issue Date: 2012-10-12
 E104 2012:286:00000 0000:000:00000   695.652 [MA08], Issue Date: 2012-10-12
*
-SATELLITE/MASS
```

2.7. SATELLITE/COM Block

This block gives the position of the Center-of-Mass (CoM) w.r.t. the spacecraft reference frame and a history if available.

Field	**Description**	**Format**
SVN	Space Vehicle Number	**1X,A4**
Valid_From	Start time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Valid_To	End time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
X	X-component of CoM in meter	**1X,F9.4**
Y	Y-component of CoM in meter	**1X,F9.4**
Z	Z-component of CoM in meter	**1X,F9.4**
Comment	Reference, etc.	**1X,A14**

Example:

```
+SATELLITE/COM
*
*SVN_ Valid_From____ Valid_To______ ____X_[m] ____Y_[m] ____Z_[m] Comment_______
 J001 2018:075:00542 2018:254:28080   -0.0011    0.0016    1.8252 [CM07] + dMass
 J001 2018:254:28080 2019:070:01864   -0.0011    0.0016    1.8257 [CM07] + dMass
 J001 2019:070:01864 2019:250:43853   -0.0011    0.0016    1.8265 [CM07] + dMass
 J001 2019:250:43853 0000:000:00000   -0.0011    0.0016    1.8291 [CM07] + dMass
*
-SATELLITE/COM
```

2.8. SATELLITE/ECCENTRICITY Block

This block provides information about the eccentricities of passive and active sensors like SLR retroreflectors and reference points for microwave transmit antennas.

Field	Description	Format
SVN	Space Vehicle Number	**1X,A4**
Equipment	Sensor name, see Tab. 2 and 3	**1X,A20**
Type	SINEX technique code: **D** – DORIS **L** – SLR **P** – GNSS	**1X,A1**
X	X-component of eccentricity in meter	**1X,F9.4**
Y	Y-component of eccentricity in meter	**1X,F9.4**
Z	Z-component of eccentricity in meter	**1X,F9.4**
Comment	Reference, etc.	**1X,A21**

Conventional IGS names for GNSS transmit antennas are summarized in Table 2. The old GNSS sensor names are compatible with the current IGS ANTEX file. New device names are proposed for use along with the next generation ANTEX format supporting multiple GNSS antennas on a single GNSS satellite like GLONASS K2 and the various QZSS satellites. Conventional names for SLR retroreflector arrays used on GNSS satellites are given in Table 3.

Example:

```
+SATELLITE/ECCENTRICITY
*
*SVN_ Equipment___________ T ____X_[m] ____Y_[m] ____Z_[m] Comment______________
 J001 QZSS                 P    0.0011   -0.0016    1.8184 [EG06]
 J001 LRA_QZS_1            L    1.1500    0.5500    4.5053 qzs1; [M,p,EL11]
 J002 QZSS-2I              P   -0.0030    0.0019    1.7711 [EG06]
 J002 LRA_QZS_2            L    0.9882    0.8608    4.3733 qzs2; [M,p,EL12]
 J003 QZSS-2G              P   -0.0002   -0.0010    1.7759 [EG06]
 J003 LRA_QZS_2            L   -1.0818    0.4608    4.3733 qzs3; [M,p,EL14]
 J004 QZSS-2I              P   -0.0033    0.0014    1.7681 [EG06]
 J004 LRA_QZS_2            L    0.9882    0.8608    4.3733 qzs4; [M,p,EL15]
*
-SATELLITE/ECCENTRICITY
```

Table 2: Sensor names of GNSS satellite transmit antennas.

Block	Old Sensor Name	New Sensor Name	Description
GPS-I	BLOCK I	LANT_GPS_I	GPS Block I
GPS-II	BLOCK II	LANT_GPS_II	GPS Block II
GPS-IIA	BLOCK IIA	LANT_GPS_IIA	GPS Block IIA
GPS-IIR-A	BLOCK IIR-A	LANT_GPS_IIR-A	GPS Block IIR (original antenna)
GPS-IIR-B	BLOCK IIR-B	LANT_GPS_IIR-B	GPS Block IIR (new antenna)
GPS-IIR-M	BLOCK IIR-M	LANT_GPS_IIR-M	GPS Block IIR-M
GPS-IIF	BLOCK IIF	LANT_GPS_IIF	GPS Block IIF
GPS-III	BLOCK IIIA	LANT_GPS_III	GPS Block III
GLO	GLONASS	LANT_GLO	GLONASS
GLO-M	GLONASS-M	LANT_GLO_M	GLONASS-M
GLO-M+	GLONASS-M	LANT_GLO_M+	GLONASS-M+ main antenna
		L3CANT_GLO_M+	GLONASS-M+ L3 CDMA antenna
GLO-K1A	GLONASS-K1	LANT_GLO_K1A	GLONASS-K1 main antenna
		L3CANT_GLO_K1A	GLONASS-K1 L3 CDMA antenna
GLO-K1B	GLONASS-K1	LANT_GLO_K1B	GLONASS-K1 (one antenna)
GLO-K1+	GLONASS-K1	LANT_GLO_K1+	GLONASS-K1+ main antenna
		L2CANT_GLO_K1+	GLONASS-K1+ L2 CDMA antenna
GLO-K2	GLONASS-K2	LCANT_GLO_K2	GLONASS K2 CDMA antenna
		LFANT_GLO_K2	GLONASS K2 FDMA antenna
GAL-0A	GALILEO-0A	LANT_GIOVEA	GIOVE-A
GAL-0B	GALILEO-0B	LANT_GIOVEB	GIOVE-B
GAL-1	GALILEO-1	LANT_GAL_1	Galileo IOV
GAL-2	GALILEO-2	LANT_GAL_2	Galileo FOC
BDS-2M	BEIDOU-2M	LANT_BDS_2M	BeiDou-2 MEO
BDS-2I	BEIDOU-2I	LANT_BDS_2I	BeiDou-2 IGSO
BDS-2G	BEIDOU-2G	LANT_BDS_2G	BeiDou-2 GEO
BDS-3SI-CAST	BEIDOU-3SI-CAST	LANT_BDS_3SI_CAST	BeiDou-3 exp. IGSO, CAST
BDS-3SI-SECM	BEIDOU-3SI-SECM	LANT_BDS_3SI_SECM	BeiDou-3 exp. IGSO, SECM
BDS-3SM-CAST	BEIDOU-3SM-CAST	LANT_BDS_3SM_CAST	BeiDou-3 exp. MEO, CAST
BDS-3SM-SECM	BEIDOU-3SM-SECM	LANT_BDS_3SM_SECM	BeiDou-3 exp. MEO, SECM
BDS-3M-CAST	BEIDOU-3M-CAST	LANT_BDS_3M_CAST	BeiDou-3 MEO, CAST
BDS-3M-SECM-A	BEIDOU-3M-SECM	LANT_BDS_3M_SECM_A	BeiDou-3 MEO, SECM (orig. bus)
BDS-3M-SECM-B		LANT_BDS_3M_SECM_B	BeiDou-3 MEO, SECM (new bus)
BDS-3G	BEIDOU-3G-CAST	LANT_BDS_3G	BeiDou-3 GEO
BDS-3I	BEIDOU-3I	LANT_BDS_3I	BeiDou-3 IGSO
QZS-1	QZSS	LANT_QZS_1	QZSS Block I IGSO
		L1SANT_QZS_1	
QZS-2I	QZSS-2I	LANT_QZS_2I	QZSS Block II IGSO
		L1SANT_QZS_2I	
		L5SANT_QZS_2I	
QZS-2G	QZSS-2G	LANT_QZS_2G	QZSS Block II GEO
		L1SANT_QZS_2G	
		L5SANT_QZS_2G	
QZS-2A	QZSS-2A	LANT_QZS_2A	QZSS Block IIA IGSO
		L1SANT_QZS_2A	

Block	Old Sensor Name	New Sensor Name	Description
		L5SANT_QZS_2A	
IRS-1G	**IRNSS-1GEO**	**LANT_IRNSS_1G**	NavIC Block I GEO
IRS-1I	**IRNSS-1IGSO**	**LANT_IRNSS_1I**	NavIC Block I IGSO
IRS-2G	**IRNSS-2GEO**	**LANT_IRNSS_2G**	NavIC Block II GEO
IRS-2I		**LANT_IRNSS_2I**	NavIC Block II IGSO

Table 3: Sensor names of SLR retroreflector arrays used on GNSS satellites.

Name	Description	Reference
LRA_GPS_IIA	GPS IIA, 32 prisms	Degnan and Pavlis (1994)
LRA_GPS_III	GPS III, 48 prisms	
LRA_GLO_396_AL	GLONASS, 396 prisms, irreg. planar, Al coating	Sosnica et al. (2015)
LRA_GLO_132_AL	GLONASS, 132 prisms, irreg. circle, Al coating	Sosnica et al. (2015)
LRA_GLO_M_AL	GLONASS-M, 112 prisms, rectangular, Al coating	Sosnica et al. (2015)
LRA_GLO_M	GLONASS-M, 112 prisms, rectangular, uncoated	Sosnica et al. (2015)
LRA_GLO_K1	GLONASS-K1, 123 prisms, ring array, uncoated	Sosnica et al. (2015)
LRA_GLO_K2	GLONASS-K2, 36 prisms, ring array	Shargorodsky (2014)
LRA_GIOVEA	GIOVE-A, 76 prisms, coated	Galileo Project Office (2008)
LRA_GIOVEB	GIOVE-B, 67 prisms, Al coating	Galileo Project Office (2008)
LRA_GAL_1	Galileo IOV, 84 prisms	Navarro-Reyes et al. (2011)
LRA_GAL_2	Galileo FOC, 60 prisms	Navarro-Reyes (2014)
LRA_BDS_SHAO_42	BeiDou MEO, SHAO, 42 prisms	Zhang et al. (2014)
LRA_BDS_SHAO_90	BeiDou GEO/IGSO satellites, SHAO, 90 prisms	Zhang et al. (2014)
LRA_BDS_NCRIEO_38	BeiDou MEO, NCRIEO, 38 prisms	
LRA_QZSS_1	QZSS Block I, II, IIA, 56 prisms	Nakamura and Kishimoto (2010)
LRA_IRNSS	IRNSS, 40 prisms [a]	Porcelli et al. (2017) [b]

[a] IRNSS-1G does not have a retroreflector array: https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_missions/current_missions/irnb_general.html
[b] https://ilrs.cddis.eosdis.nasa.gov/docs/IRNSS_reflector_drawings.pdf

2.9. SATELLITE/TX_POWER Block

This block provides information about the total transmitted power.

Field	Description	Format
SVN	Space Vehicle Number	**1X,A4**
Valid_From	Start time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
Valid_To	End time of validity interval: **YYYY:DDD:SSSSS**	**1X,I4,1H:,I3,1H:,I5**
P	Total transmit power in Watt	**1X,I4**
Comment	Reference, etc.	**1X,A39**

Example:

```
+SATELLITE/TX_POWER
*
*SVN_ Valid_From____ Valid_To______ P[W] Comment________________________________
 E101 2011:294:00000 2014:148:00000  150 [TP01]; nominal power
 E101 2014:148:00000 2015:138:00000   95 [TP01,TP02]; temporary back off
 E101 2015:138:00000 0000:000:00000  135 [TP01]; reduced power
 R720 2007:299:00000 2019:094:18000   60 [TP01]
 R720 2019:094:18000 0000:000:00000   40 [TP08]; reduced L1 power
 J004 2017:282:00000 0000:000:00000  550 [TP07]
*
-SATELLITE/TX_POWER
```

3. Conventions and Explanations

This section discusses conventions used for the generation of the IGS satellite metadata file available at the IGS file server `https://files.igs.org/pub/station/general/igs_satellite_metadata.snx`.

3.1. Satellite Identifier

SVN For Galileo and BeiDou, the satellite generation can be identified from the first two characters of the SVN:

- Galileo In-Orbit Validation (IOV): **`E1nn`**
- Galileo Full Operational Capability (FOC): **`E2nn`**
- BeiDou-2: **`C0nn`**
- BeiDou-3S: **`C1nn`**
- BeiDou-3: **`C2nn`**

For GLONASS, the SVN used within the IGS and also in the satellite metadata format differs for newer spacecraft from the Russian spacecraft numbers (see `https://www.glonass-iac.ru/en/GLONASS/`) by 100 in order to guarantee unique numbers.

TLE Satellite Name The satellite name used in the Two-Line Elements (TLEs) is given as additional information in the comment field as it is not relevant for high-precision applications to justify inclusion in the format definition.

3.2. Satellite Orbital Plane and Slot

Regular orbital planes of GNSS MEO satellites are identified by integer numbers as given in Tab. 5. Irregular planes like the eccentric orbits of Galileo E201 and E202 are identified by the character **`X`**. For IGSO and GEO satellites, the characters **`I`** and **`G`** are given as plane and the longitude is given as slot. Slot designators as used by the system providers and listed in Tab. 5 are used for the MEO satellites. Satellites being repositioned are identified by the tag **`REPOS`**.

Table 5: Orbital planes and slots of MEO, IGSO, and GEO satellites.

	Planes	Slots
GPS	**1 – 6**	[**A-F**][**1-4**][**A**,**F**] [a]
GLONASS	**1 – 3**	[**1-24**] [b]
Galileo	**1 – 3**, **X**	[**A-C**][**0-1**][**1-8**], **Ext0**[**1**,**2**] [c]
BeiDou MEO	**1 – 3**	[**A-C**]–[**1-8**]
IGSO	**I**	**nnn**[**E**,**W**] [c]
GEO	**G**	**nnn**[**E**,**W**] [c]

[a] the third character is optional and indicates extended slots
[b] slots 1 – 8 in orbital plane 1, slots 9 – 16 in orbital plane 2, slots 17 – 24 in orbital plane 3
[c] **nnn** indicates the three-digit longitude in degrees

3.3. GLONASS Frequency Channel Number

In contrast to other GNSSs, GLONASS uses the Frequency Division Multiple Access (FDMA) approach to distinguish individual satellites for its legacy L1 and L2 signals. The frequency of the L1 and L2 signals are given by

$$f_{L1}(k) = 1602.0\text{ MHz} + k \cdot 0.5625\text{ MHz} \quad (1)$$

$$f_{L2}(k) = 1246.0\text{ MHz} + k \cdot 0.4375\text{ MHz} \quad (2)$$

where k stand for the channel number. In the initial GLONASS design, channel numbers $k = 0, \ldots, 24$ were used. Due to interference with astronomical observations, the channel numbers were changed to $k = 0, \ldots, 12$ in 1998 and to $k = -7, \ldots, +6$ in 2005 (Revnivykh et al., 2017). A history of GLONASS channel numbers starting with 2005 is available at `ftp://ftp.glonass-iac.ru/MCC/STATUS/`.

3.4. Satellite Mass

Until 2022, it was assumed that the satellite mass given in the history information of QZSS operation (Cabinet Office, 2023a,c,d,e,b) refers to the mass after the maneuver. Therefore, the end time of the last orbit maneuver was used as epoch for a change in the mass. End of 2022, CAO started to publish the mass history all QZSS satellites in a machine-readable format in a dedicated SATELLITE/MASS block. From the mass change epochs and the epochs of the maneuvers in the SATELLITE/MANEUVER block, it evident, that the mass values refer to the mass *before* the maneuver. This was implemented in the satellite metadata file on 30 January 2023.

3.5. Center of Mass and Sensor Eccentricities

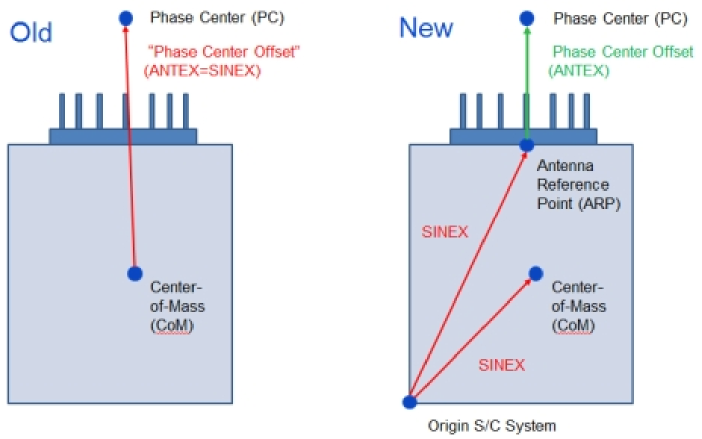

Figure 1: Current and future relation between CoM and phase center.

Sensors in the context of the **SATELLITE/ECCENTRICITY** block are any passive or active equipment that is used for any kind of measurements, e.g., the GNSS microwave transmit antennas as well as SLR LRAs. The sensor eccentricities describe the coordinates of an equipment reference point w.r.t. the same origin that is used for CoM coordinates in the **SATELLITE/COM** block. Users are advised to ensure that the eccentricity information is used with consistent CoM data. In accord with current IGS conventions and the provision of CoM-related antenna phase-center information for GNSS satellites in the ANTEX 1.4 format (Rothacher and Schmid, 2010), the CoM is adopted as antenna reference point for all GNSS antennas in the present **SATELLITE/ECCENTRICITY** block. All coordinates refer to the IGS conventions of the spacecraft body axis orientations as defined in Montenbruck et al. (2015).

For Galileo and QZSS, the use of time-varying CoM information causes an inherent incompatibility with the current ANTEX concept of constant phase center offsets relative to the CoM. This discrepancy will only be removed in future ANTEX model versions that will make use of a mechanical antenna reference point for phase center offset specifications, see Fig 1.

For some satellites, a detailed history of mass changes is provided but only Beginning of Life (BoL) and End of Life (EoL) values for the CoM. The current CoM position $\mathrm{CoM}(t)$ can be computed by

$$\mathrm{CoM}(t) = \mathrm{CoM}_{\mathrm{EoL}} + \Delta\mathrm{CoM} \cdot \mu(t) \cdot (1 - \mu(t)) \tag{3}$$

with

$$\mu(t) = \frac{m(t) - m_{\mathrm{EoL}}}{m_{\mathrm{EoL}}} \tag{4}$$

and

$$\Delta\mathrm{CoM} = \frac{\mathrm{CoM}_{\mathrm{BoL}} - \mathrm{CoM}_{\mathrm{EoL}}}{\mu_{\mathrm{BoL}} \cdot (1 - \mu_{\mathrm{BoL}})} \tag{5}$$

4. Metadata Sources

The providers of Galileo, BeiDou, and QZSS have published GNSS satellite metadata on dedicated websites:

Galileo	`https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata`
BeiDou	`http://en.beidou.gov.cn/SYSTEMS/Officialdocument/`
GPS	`https://www.navcen.uscg.gov/?pageName=gpsTechnicalReferences`
QZSS	`https://qzss.go.jp/en/technical/qzssinfo/index.html`

4.1. Satellite Identifiers

NORAD ID The satellite catalog number is also known as NORAD ID and is assigned by the United States Space Command. This catalog is publicly available at `https://www.space-track.org`.

COSPAR ID The COSPAR ID is assigned by the Committee on Space Research. It consists of a 3-digit number for the launch within the current year and one or two characters identifying the object of the launch (usually **`A`** for single, **`A`** or **`B`** for twin, **`A`**, **`B`** or **`C`** for triple, and **`A`**, **`B`**, **`C`** or **`D`** for quadruple launches of GNSS satellites).

PRN Observations and navigation data of GNSS satellites are commonly identfied in a GNSS receiver by a satellite number that refers to the transmitted PRN code (for GPS, Galileo, BeiDou, QZSS, and IRNSS) or the “slot number” for GLONASS. In the RINEX format (Gini, 2023), a 3-character designation comprising the constellation letter and a two-digit PRN or slot number is used to specifiy the transmitting satellite. By its very nature, this satellite identifier is not tied to a given spacecraft but may vary over its lifetime. The **`SATELLITE/PRN`** block provides the RINEX satellite identifier (“PRN”) associated with a given space vehicle at a certain time. Information on the SVN/PRN association for active satellites can be obtained from the following constellation status websites of the system providers:

GPS	`https://www.navcen.uscg.gov/gps-constellation`
GLONASS	`https://www.glonass-iac.ru/en/sostavOG/`
Galileo	`https://www.gsc-europa.eu/system-service-status/constellation-information`
BeiDou	`http://www.csno-tarc.cn/en/system/constellation`
QZSS	`https://sys.qzss.go.jp/dod/en/constellation.html`

4.2. Satellite Orbital Plane and Slot

Information on the orbital plane and slot are partly given by the system providers:

GPS	`https://www.navcen.uscg.gov/sites/default/files/pdf/gps/current.pdf`
GLONASS	`https://www.glonass-iac.ru/en/sostavOG/`
Galileo	`https://www.gsc-europa.eu/system-service-status/orbital-and-technical-parameters`

Changes in GPS slot positions after 01 July 2019 are taken from the document mentioned above. The release date is taken as start and end date, no time periods for repositioning are given anymore. Orbital slot and orbital plane are swapped in the English version of the GLONASS constellation status website.

4.3. Satellite Mass

An overview of GNSS satellite mass values is given in Table 5. A mass history is currently available for selected Galileo and all QZSS satellites. For QZSS, the mass after each orbit maintenance maneuver is given. As each maneuver can consist of up to three individual burns, the stop date of the last burn is used for the satellite mass history.
The following mass information is currently not considered in the **`SATELLITE/MASS`** block:

- Individual mass values for specific Block I, II, and IIA spacecraft given in Fliegel et al. (1992).
- Individual mass values for Block IIR satellites G041, G043, G044, G046, G051 as of March 2004 given in Adhya (2005).

4.4. Transmit Power

The received power of a GNSS satellite on the Earth's surface can be measured with a high-gain antenna. The Equivalent Isotropically Radiated Power (EIRP) can be obtained by correcting these measurements for freespace and atmospheric losses along the propagation path between satellite and ground antenna. The transmit power can be estimated as an offset between the measured EIRP and the satellite antenna gain pattern. Such measurements have been made by Steigenberger et al. (2018) and are summarized in Table 6 together with more recent measurements, published metadata as well as assumptions for satellites without measurements or other sources for the transmit power.

GPS No EIRP measurements are available for the GPS Block I and Block II satellites. Therefore, the measured mean value of the Block IIA satellites with 50 W is assumed for both blocks. Block-specific transmit power values obtained from EIRP measurements of individual Block IIA, IIR, IIR-M, and IIF satellites are given in Steigenberger et al. (2018). For GPS III, no measured transmit power is available, the value in Table 6 is based on the Block IIF transmit power, increased power levels specified in IS-GPS-200L (2020) as well as the additional L1C signal.
GPS satellites are able to redistribute power between different signals, a capability called flex power. Thoelert et al. (2018) and Steigenberger et al. (2019) report different modes of flex power on Block IIR-M and IIF satellites. Although the SINEX transmit power block described in Sec. 2.9 allows for time-varying power levels, flex power is currently not considered in the IGS satellite metadata file.

GLONASS For the first generation GLONASS satellites, no EIRP measurements are available. Therefore, they are not included in the satellite metadata file. The current GLONASS-M satellites have significantly different levels of transmitted power: three different power levels (low, medium, high) are present for the L1 and L2 frequency band, respectively (Steigenberger et al., 2018). Six different combinations of L1 and L2 transmit power are listed in Table 6 with values between 20 and 85 W. GLONASS-M+ satellites are capable of transmitting on a third frequency, namely L3. For the second GLONASS-M+ satellite R856, a total power of 120 W was measured in 2019. This is an increase of 20 % compared to the first GLONASS-M+ satellite R855. The GLONASS-K satellites are also able to transmit L3 signals. Whereas GLONASS-K1A utilizes a dedicated transmit antenna for L3, GLONASS-K1B has a common antenna for all three L-band frequencies (Montenbruck et al., 2015).
In view of the upcoming 3rd IGS reprocessing campaign, eight GLONASS satellites have been observed in early 2019. Results for three of them have already been reported in Steigenberger et al. (2018), namely R802, R851, R853, the other five are newly observed (R723, R852, R854, R856, R857). The transmit power values of the re-observed satellites agree within the formal errors with the previous measurements. Therefore, the original values of Steigenberger et al. (2018) are kept.

BeiDou For BeiDou-2 MEO and IGSO satellites, the transmit powers of Steigenberger et al. (2018) are used. No transmit power measurements of GEO satellites are available due to the low elevation angle or even no visibility at the Weilheim dish antenna used by Steigenberger et al. (2018). A best-guess value of 250 W is used for the BeiDou-3S China Academy of Space Technology (CAST) MEO satellites. Due to the lack of BDS-3 transmit antenna gain

Table 5: In-orbit masses of different types of GNSS satellites. FOCe denotes the Galileo FOC satellites in eccentric orbit (E201 and E202).

System	Type	Mass [kg]	Reference
GPS	I	455	Kramer (2002)
	II	843	Kramer (2002)
	IIA	930	Kramer (2002)
	IIR	1080	Hegarty (2017)
	IIR-M	1080	Hegarty (2017)
	IIF	1633	[a]
	III	2161	Alexander and Martin (2018)
GLONASS	M	1415	Fatkulin et al. (2012)
	K1	995	Revnivykh et al. (2017)
	M+	$\geq$1415	Revnivykh et al. (2017)
	K1+	$\geq$995	Revnivykh et al. (2017)
	K2	1645	Fatkulin et al. (2012)
Galileo	IOV	695 – 698	European GNSS Service Center (2019)
	FOCe	661, 662	European GNSS Service Center (2019)
	FOC	706 – 712	European GNSS Service Center (2019)
BDS-2	MEO	1176 – 1193	CSNO (2019b)
	IGSO	1272 – 1284	CSNO (2019b)
	GEO	1382 – 1551	CSNO (2019b)
BDS-3S	IGSO CAST	2800	Zhao et al. (2018)
	IGSO SECM	848	Zhao et al. (2018)
	MEO CAST	1014	
BDS-3	MEO CAST	941 – 1061	CSNO (2019a)
	MEO SECM	1009 – 1079	CSNO (2019a)
	IGSO	2870 – 2952	CSNO (2019a)
	GEO	2968	CSNO (2019a)
QZSS	QZS-1	2197[b]	Cabinet Office (2023a)
	QZS-2	2261[b]	Cabinet Office (2023c)
	QZS-3	2546[b]	Cabinet Office (2023d)
	QZS-4	2278[b]	Cabinet Office (2023e)
	QZS-1R	2357[b]	Cabinet Office (2022b)
IRNSS	IRS-1 IGSO	700	Best guess from dry mass of 614 kg in Harde et al. (2015)
	IRS-1 GEO	700	Best guess from dry mass of 614 kg in Harde et al. (2015)
	IRS-2 GEO	1500	Best guess from launch mass of 2232 kg in ISRO (2023)

[a] http://www.boeing.com/space/global-positioning-system/#/technical-specifications
[b] Value as of May 2022, full history available at http://qzss.go.jp/en/technical/qzssinfo/index.html

pattern, preliminary transmit power values of BDS-3 MEO satellites obtained with BDS-2 gain pattern are given. The

QZSS QZSS is the only navigation system with transmit power values provided by the system operator (Cabinet Office, 2022a, 2019a, 2022c, 2019b, 2022b).

Table 6: Average transmit power of different types of GNSS satellites. All measured values are rounded to 5 W. Measured values are given in black, assumed values in red, and provider values in blue.

System	Type	Group	SVN	Power	
GPS	I		G001 – G006, G008 – G011	50 W	
	II		G013 – G021	50 W	
	IIA		G022 – G040	50 W	
	IIR-A/B		G041, G043 – G047, G051, G054, G056, G059 – G061	60 W	
	IIR-M		G048 – G050, G052, G053, G055, G057, G058	145 W	
	IIF		G062 – G073	240 W	
	III		G074 – G083	300 W	
GLO	M	L1L/L2L	R735 since 2 Feb. 2016	20 W	
		L1L/L2M	R715, R721, R733, R734, R736	25 W	
		L1L/L2H	R719	40 W	
		L1M/L2H	R716, R720	60 W	
		L1H/L2M	R717, R730, R732	65 W	
		L1H/L2H	R731, R742 – R745, R747, R851, R852, R853, R857	85 W	
			R854	70 W	
		default	default value for all other GLONASS-M satellites	50 W	
	M+		R855	100 W	
	M+		R856	120 W	
	M+		R858	110 W	
	M+		R805, R806, R859, R860, R861	110 W	[a]
	K1		R801	135 W	
			R802	105 W	
			R805, R806	105 W	[b]
GAL	IOV	nominal	E101 – E104	160 W	[c]
		reduced	E101 and E102	135 W	[d]
		back-off	E103	95 W	[e]
	FOC		E201 – E234	265 W	
BDS-2	MEO		C012 – C015	130 W	
	IGSO		C005, C007 – C010, C017	185 W	
BDS-3	MEO CAST		C201/2, C205/6, C209/10, C213/4, C218/9, C222/3, C227/8, C332/3	310 W	[f]
	MEO SECM		C203/4, C207/8, C211/2, C215/6, C225/6	280 W	[f]
	IGSO		C220, C221, C224	310 W	[g]
	GEO		C217, C229, C230, C231	310 W	[g]
QZSS	QZS-I	IGSO	J001	250 W	[h]
	QZS-II	IGSO	J002, J004	500 W	[i]
	QZS-II	GEO	J003	550 W	[j]
	QZS-IIA	IGSO	J005	460 W	[k]

[a] average of R855, R856, R858
[b] copy of R802
[c] until approximately 27 May 2014
[d] measured in Dec. 2015 and Oct. 2016
[e] measured in Oct. 2016
[f] obtained with BDS-2 gain pattern
[g] MEO CAST value as first guess
[h] Cabinet Office (2022a)
[i] Cabinet Office (2019a,b)
[j] Cabinet Office (2022c)
[k] Cabinet Office (2022b)

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A. Abbreviations

ANTEX	Antenna Exchange
ARP	Antenna Reference Point
BoL	Beginning of Life
CAO	Cabinet Office (Government of Japan)
CAST	China Academy of Space Technology
CDMA	Code Division Multiple Access
CoM	Center-of-Mass
COSPAR	Committee on Space Research
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EIRP	Equivalent Isotropically Radiated Power
EoL	End of Life
FCN	Frequency Channel Number
FOC	Full Operational Capability
FDMA	Frequency Division Multiple Access
GEO	Geostationary Earth Orbit
GIOVE	Galileo in Orbit Validation Element
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IGS	International GNSS Service
IGSO	Inclined Geosynchronous Earth Orbit
IOV	In-Orbit Validation
IRNSS	Indian Regional Navigation Satellite System
LRA	Laser Retroreflector Array
MEO	Medium Earth Orbit
NavIC	Navigation with Indian Constellation
NCRIEO	North China Research Institute of Electro-Optic
NORAD	North American Aerospace Defense Command
PCO	Phase Center Offset
PPP	Precise Point Positioning
PRN	Pseudo-Random Noise
QZSS	Quasi-Zenith Satellite System
RINEX	Receiver Independent Exchange
SECM	Shanghai Engineering Center for Microsatellites
SHAO	Shanghai Observatory
SINEX	Solution INdependent EXchange
SLR	Satellite Laser Ranging
SVN	Space Vehicle Number
TLE	Two-Line Elements