IGS Satellite Metadata File Description

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Contents

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 (Romero, 2021), 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. 3.3. 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/PRN	SVN/PRN assignment, Sec. 2.3
SATELLITE/FREQUENCY_CHANNEL	GLONASS frequency channels, Sec. 2.4
SATELLITE/MASS	Spacecraft mass, Sec. 2.5
SATELLITE/CENTER_OF_MASS	Center-of-mass position, Sec. 2.6
SATELLITE/ECCENTRICITY	Sensor positions, Sec. 2.7
SATELLITE/TX_POWER	Total transmit power, Sec. 2.8

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 capability	
`GLO-K1A`	1st generation GLONASS-K with two antenna panels	
`GLO-K1B`	1st generation GLONASS-K with single antenna panel	
`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	Inaba et al. (2009)
`QZS-2I`	2nd generation QZSS IGSO	
`QZS-2G`	2nd generation QZSS GEO	
`QZS-2A`	QZSS Block IIA IGSO	
`QZS-3`	3rd generation QZSS IGSO	
`IRS-1G`	IRNSS GEO	Harde et al. (2015)
`IRS-1I`	IRNSS IGSO	Harde et al. (2015)

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/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
```

2.4. 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
```

2.5. 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
```

2.6. 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
```

2.7. 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. 3 and 5	**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**

The old GNSS sensor names are compatible with the current ANTEX file. New device names are proposed along with a new version of the ANTEX format to support multiple GNSS antennas on a single GNSS satellite like GLONASS K1A and the different QZSS satellites.
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 3 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+
GLO-K1A	**GLONASS-K1**	**LANT_GLO_K1A** **L3ANT_GLO_K1A**	GLONASS-K1 (two antennas)
GLO-K1B	**GLONASS-K1**	**LANT_GLO_K1B**	GLONASS-K1 (one 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**	**LANT_BDS_3G**	BeiDou-3 GEO
BDS-3I	**BEIDOU-3I**	**LANT_BDS_3I**	BeiDou-3 IGSO
QZS-1	**QZSS**	**LANT_QZS_1** **L1SANT_QZS_1**	QZSS Block I IGSO
QZS-2I	**QZSS-2I**	**LANT_QZS_2I** **L1SANT_QZS_2I** **L5SANT_QZS_2I**	QZSS Block II IGSO
QZS-2G	**QZSS-2G**	**LANT_QZS_2G** **L1SANT_QZS_2G** **L5SANT_QZS_2G**	QZSS Block II GEO
QZS-2A	**QZSS-2A**	**LANT_QZS_2A** **L1SANT_QZS_2A** **L5SANT_QZS_2A**	QZSS Block IIA IGSO
IRS-1I	**IRNSS-1I**	**LANT_IRNSS_1I**	NAVIC IGSO
IRS-1G	**IRNSS-1G**	**LANT_IRNSS_1G**	NAVIC GEO

Table 5 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_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 [1]	Porcelli et al. (2017) [2]

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

[2] `https://ilrs.cddis.eosdis.nasa.gov/docs/IRNSS_reflector_drawings.pdf`

2.8. 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. 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/`.

3.3. Center of Mass and Sensor Eccentricities

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

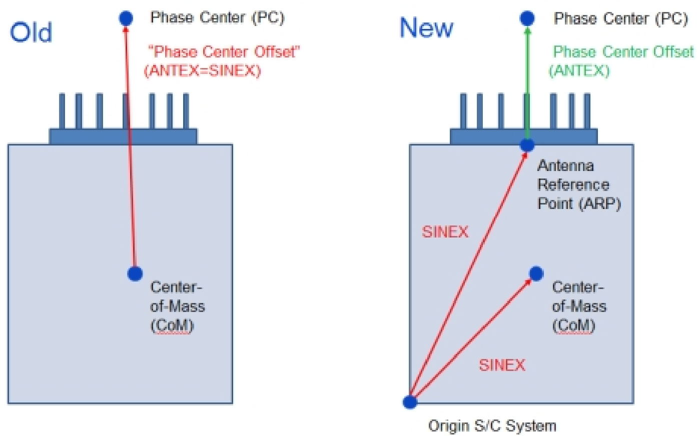

Figure 1 Current and future relation between CoM and phase center.

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 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, 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 Mass

An overview of GNSS satellite mass values is given in Table 7. 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).

4.3. 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

Table 7 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 (2022a)
	QZS-2	2261[b]	Cabinet Office (2021)
	QZS-3	2546[b]	Cabinet Office (2022b)
	QZS-4	2278[b]	Cabinet Office (2022c)
	QZS-1R	2357[b]	Cabinet Office (2022e)
IRNSS	IGSO	700	Best guess from dry mass of 614 kg in Harde et al. (2015)
	GEO	700	Best guess from dry mass of 614 kg in Harde et al. (2015)

[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`

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 8 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 8 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. 2.8 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 8 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-K1-A utilizes a dedicated transmit antenna for L3, GLONASS-K1-B 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 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, 2022d, 2019a, 2022f, 2019b, 2022e).

Table 8 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	
	K1		R801	135 W	
			R802	105 W	
	M+		R855	100 W	
	M+		R856	120 W	
	M+		R858	110 W	
	M+		R805, R806, R807, R859, R860	110 W	a
GAL	IOV	nominal	E101 – E104	160 W	b
		reduced	E101 and E102	135 W	c
		back-off	E103	95 W	d
	FOC		E201 – E224	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, 227/8	310 W	e
	MEO SECM		C203/4, C207/8, C211/2, C215/6, C225/6	280 W	e
	IGSO		C220, C221, C224	310 W	f
	GEO		C217, C229, C230	310 W	f
QZSS	QZS-I		J001	250 W	g
	QZS-II	IGSO	J002, J004	500 W	h
	QZS-II	GEO	J003	550 W	i
	QZS-IIA	IGSO	J005	460 W	j

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

References

Adhya S (2005) Thermal re-radiation modelling for the precise prediction and determination of spacecraft orbits. URL https://discovery.ucl.ac.uk/id/eprint/1445243/1/U592563.pdf

Alexander K, Martin HW III (2018) GPS program update. 13th Meeting of the International Committee on Global Navigation Satellite Systems URL http://www.unoosa.org/documents/pdf/icg/2018/icg13/02.pdf

Benedicto J, Gatti G, Garutti A, Paffet J, Bradford A, Jackson C, Rooney E (2006) The triumph of GIOVE-A – the first Galileo satellite. ESA Bulletin 127:62–69

Berlin M, Burnett CM, de Rocco L, Rodríguez J (2017) Galileo: Work order 1 finished and deployed. In: GNC 2017

Cabinet Office (2019a) QZS-2 satellite information. Tech. Rep. SPI-QZS2_C, Government of Japan, National Space Policy Secretariat, URL https://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/spi-qzs2_c.pdf

Cabinet Office (2019b) QZS-4 satellite information. Tech. Rep. SPI-QZS4_C, Government of Japan, National Space Policy Secretariat, URL https://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/spi-qzs4_c.pdf

Cabinet Office (2021) The history information of QZS-2 operation. Tech. Rep. OHI-QZS2, Government of Japan, National Space Policy Secretariat, URL http://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/ohi-qzs2_211227.pdf

Cabinet Office (2022a) The history information of QZS-1 operation. Tech. Rep. OHI-QZS1, Government of Japan, National Space Policy Secretariat, URL http://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/ohi-qzs1_220328.pdf

Cabinet Office (2022b) The history information of QZS-3 operation. Tech. Rep. OHI-QZS3, Government of Japan, National Space Policy Secretariat, URL http://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/ohi-qzs3_220501.pdf

Cabinet Office (2022c) The history information of QZS-4 operation. Tech. Rep. OHI-QZS4, Government of Japan, National Space Policy Secretariat, URL http://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/ohi-qzs4_220501.pdf

Cabinet Office (2022d) QZS-1 satellite information. Tech. Rep. SPI_QZS1_B, Government of Japan, National Space Policy Secretariat, URL https://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/spi-qzs1_b.pdf

Cabinet Office (2022e) QZS-1R satellite information. Tech. Rep. SPI-QZS1R_A, Government of Japan, National Space Policy Secretariat, URL https://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/spi-qzs1r_a_220120.pdf

Cabinet Office (2022f) QZS-3 satellite information. Tech. Rep. SPI-QZS3_E, Government of Japan, National Space Policy Secretariat, URL http://qzss.go.jp/en/technical/qzssinfo/khp0mf0000000wuf-att/spi-qzs3_e.pdf

CSNO (2019a) Announcement on the release of Beidou satellite related parameters. URL http://www.beidou.gov.cn/yw/gfgg/201912/t20191209_19613.html, in Chinese

CSNO (2019b) Announcement: Release of the BDS-2 satellite related parameters. URL http://en.beidou.gov.cn/WHATSNEWS/201912/t20191209_19641.html

Degnan JJ, Pavlis EC (1994) Laser ranging to GPS satellites with centimeter accuracy. GPS World 5(9):62–70

ESA (2012) Fact sheet: Galileo In-Orbit Validation. URL http://download.esa.int/docs/Galileo_IOV_Launch/Galileo_IOV_factsheet_2012.pdf

European GNSS Service Center (2019) Galileo satellite metadata. European Global Navigation Satellite Systems Agency, URL https://www.gsc-europa.eu/support-to-developers/galileo-satellite-metadata

Fatkulin R, Kossenko V, Storozhev S, Zvonar V, Chebotarev V (2012) GLONASS space segment: satellite constellation, Glonass-M and Glonass-K spacecraft main features. In: ION GNSS 2012, pp 3912–3930

Fisher SC, Ghasemi K (1999) GPS IIF – the next generation. Proceedings of the IEEE 87(1):24–47, DOI 10.1109/5.736340

Fliegel H, Gallini T, Swift E (1992) Global Positioning System radiation force model for geodetic applications. Journal of Geophysical Research 97(B1):559–568, DOI 10.1029/91JB02564

Galileo Project Office (2008) Specification of Galileo and GIOVE space segment properties relevant for Satellite Laser Ranging. Tech. Rep. 3.2, European Space Agency, URL https://ilrs.cddis.eosdis.nasa.gov/docs/ESA-EUING-TN-10206_Issue_3.2.pdf

Harde H, Shahade M, Badnore D (2015) Indian regional navigation satellite system. International Journal of Research In Science & Engineering 1(1)

Hartman T, Boyd LR, Koster D (2000) Modernizing the GPS Block IIR spacecraft. In: ION GPS 2000, pp 2115–2121

Hegarty C (2017) The Global Positioning System (GPS). In: Teunissen P, Montenbruck O (eds) Springer Handbook of Global Navigation Satellite Systems, Springer, chap 7, pp 197–218, DOI 10.1007/978-3-319-42928-1_7

Inaba N, Matsumoto A, Hase H, Kogure S, Sawabe M, Terada K (2009) Design concept of Quasi Zenith Satellite System. Acta Astronautica 65(7-8):1068–1075, DOI 10.1016/j.actaastro.2009.03.068

IS-GPS-200L (2020) Interface Specification IS-GPS-200: Navstar GPS Space Segment/Navigation User Segment Interfaces. URL https://www.gps.gov/technical/icwg/IS-GPS-200L.pdf

Kramer HJ (2002) Observation of the Earth and Its Environment: Survey of Missions and Sensors, 4th edn. Springer, DOI 10.1007/978-3-642-56294-5

Malik M, Gatti G, Alpe V, Johansson M, Kieffer R, Robertson G (2009) GIOVE-B Satellite & Payload Overview. In: Proceedings of the European Navigation Conference – Global Navigation Satellite Systems

Marquis W, Shaw M (2011) Design of the GPS III Space Vehicle. In: ION ITM 2011, pp 3067–3075

Marquis WA, Reigh DL (2015) The GPS Block IIR and IIR-M broadcast L-band antenna panel: Its pattern and performance. Navigation 62(4):329–347, DOI 10.1002/navi.123

Milani A, Nobili AM, Farinella P (1987) Non-gravivational Perturbations and Satellite Geodesy. Adam Hilger

Montenbruck O, Steigenberger P (2020) IGS white paper on satellite and operations information for generation of precise GNSS orbit and clock products. Tech. rep., IGS Multi-GNSS Working Group, URL https://files.igs.org/pub/resource/working_groups/multi_gnss/Whitepaper_SatelliteMetaData_IGS_200204.pdf, version 2020/02/04

Montenbruck O, Schmid R, Mercier F, Steigenberger P, Noll C, Fatkulin R, Kogure S, Ganeshan A (2015) GNSS satellite geometry and attitude models. Advances in Space Research 56(6):1015–1029, DOI 10.1016/j.asr.2015.06.019

Nakamura S, Kishimoto M (2010) ILRS SLR Mission Support Request for QZS-1. URL http://ilrs.gsfc.nasa.gov/docs/ILRS_retroreflector_QZS_20100729.pdf

Navarro-Reyes D (2014) Galileo FOC satellite's LRA additional information. Tech. Rep. ESA-DTEN-NG-MEMO/0017611, ESA, URL https://ilrs.cddis.eosdis.nasa.gov/docs/2014/Galileo_FOC_LRA_additional_information_signed.pdf

Navarro-Reyes D, Gonzalez F, Svehla D, Zandberben R (2011) ILRS SLR Mission Support Request for Galileo-101 and Galileo-102. URL http://ilrs.gsfc.nasa.gov//docs/ILRS_MSR_Galileo_201106.pdf

Porcelli L, Boni A, Ciocci E, Contessa S, Dell'Agnello S, Monache GD, Intaglietta N, Martini M, Mondaini C, Patrizi G, Salvatori L, Tibuzzi M, Lops C, Cantone C, Tuscano P, Maiello M, Venkateswaran R, Chakraborty P, Reddy CR, Sriram K (2017) Thermo-optical vacuum testing of IRNSS laser retroreflector array qualification model. Advances in Space Research 60(5):1054–1061, DOI 10.1016/j.asr.2017.05.012

Revnivykh S, Bolkunov A, Serdyukov A, Montenbruck O (2017) GLONASS. In: Teunissen P, Montenbruck O (eds) Springer Handbook of Global Navigation Satellite Systems, Springer, chap 8, pp 219–245, DOI 10.1007/978-3-319-42928-1_8

Romero I (2021) RINEX, The Receiver Independent Exchange Format, Version 4.00. Tech. rep., IGS/RTCM RINEX WG Chair, URL https://files.igs.org/pub/data/format/rinex_4.00.pdf

Rothacher M, Schmid R (2010) ANTEX: The antenna exchange format, version 1.4. URL https://files.igs.org/pub/data/format/antex14.txt

Rothacher M, Thaller D (2006) SINEX – Solution (software/technique) INdependent EXchange format version 2.02 (december 01, 2006). URL https://www.iers.org/SharedDocs/Publikationen/EN/IERS/Documents/ac/sinex/sinex_v202_pdf

Shanghai Engineering Center for Microsatellites (2018) Satellite geometry and attitude mode of MEO satellites of BDS-3 developed by SECM. In: ION GNSS+ 2018, ION, pp 1268–1289, DOI 10.33012/2018.16118

Sosnica K, Thaller D, Dach R, Steigenberger P, Beutler G, Arnold D, Jäggi A (2015) Satellite laser ranging to GPS and GLONASS. Journal of Geodesy 89(7):725–743, DOI 10.1007/s00190-015-0810-8

Steigenberger P, Thoelert S, Montenbruck O (2018) GNSS satellite transmit power and its impact on orbit determination. Journal of Geodesy 92(6):609–624, DOI 10.1007/s00190-017-1082-2

Steigenberger P, Thölert S, Montenbruck O (2019) Flex power on GPS block IIR-M and IIF. GPS Solutions 23(1), DOI 10.1007/s10291-018-0797-8

Thoelert S, Hauschild A, Steigenberger P, Langley RB, Antreich F (2018) GPS IIR-M L1 transmit power redistribution: Analysis of GNSS receiver and high-gain antenna data. Navigation 65(3):423–430, DOI 10.1002/navi.250

Zhang ZP, Zhang HF, Chen WZ, Li P, Meng WD, Wang YM, Wang J, Hu W, Yang FM (2014) Design and performances of laser retro-reflector arrays for Beidou navigation satellites and SLR observations. Advances in Space Research 54(5):811–817, DOI 10.1016/j.asr.2013.12.025

Zhao Q, Wang C, Guo J, Wang B, Liu J (2018) Precise orbit and clock determination for BeiDou-3 experimental satellites with yaw attitude analysis. GPS Solutions 22(1), DOI 10.1007/s10291-017-0673-y

A. Abbreviations

ANTEX	Antenna Exchange
ARP	Antenna Reference Point
BoL	Beginning of Life
CAST	China Academy of Space Technology
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
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