Recommendation ITU-R M.1787-5

(07/2024)

M Series: Mobile, radiodetermination, amateur and related satellite services

Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

Foreword

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P	Radiowave propagation
RA	Radio astronomy
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SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R M.1787-5

Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

(Questions ITU-R 217-2/4 and ITU-R 288/4)

(2009-2012-2014-2018-2022-2024)

Scope

The information on orbital parameters, navigation signals and technical characteristics of systems and networks in the radionavigation-satellite service (RNSS) (space-to-Earth, space-to-space) operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz are presented in this Recommendation. This information is intended for use in the assessment of the interference impact between systems and networks in the RNSS and with other services and systems.

Keywords

RNSS, orbital parameters, navigation signals, technical characteristics.

Abbreviations/Glossary

ABAS	Aircraft-based augmentation system
ECEF	Earth-centred, Earth-fixed
GBAS	Ground-based augmentation system
GMS	Ground monitoring station
GTRF	Galileo terrestrial reference frame
GUS	Ground uplink station
HA	High accuracy
ITRS	International terrestrial reference frame
MCS	Master control station
MRS	Monitor and ranging station
NCS	Network communication subsystem
OS	Open service
PNT	Positioning, navigation and timing
PRN	Pseudo-random noise
PRS	Public regulated service
PSD	Power spectral density
SA	Standard accuracy
SBAS	Satellite-based augmentation system
SiS	Signal-in-space
SPS	Standard positioning service
WAAS	Wide area augmentation system

Related ITU-R Recommendations and Reports

Recommendation ITU-R M.1318 – Evaluation model for continuous interference from radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz and 5 010-5 030 MHz bands

Recommendation ITU-R M.1831 – A coordination methodology for RNSS inter-system interference estimation

Recommendation ITU-R M.1901 – Guidance on ITU-R Recommendations related to systems and networks in the radionavigation-satellite service operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz

Recommendation ITU-R M.1902 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 215-1 300 MHz

Recommendation ITU-R M.1903 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service operating in the band 1 559-1 610 MHz

Recommendation ITU-R M.1904 – Characteristics, performance requirements and protection criteria for receiving stations of the radionavigation-satellite service (space-to-space) operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

Recommendation ITU-R M.1905 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 164-1 215 MHz

Recommendation ITU-R M.2030 – Evaluation method for pulsed interference from relevant radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands

Report ITU-R M.766 – Feasibility of frequency sharing between the GPS and other services

Report ITU-R M.2458 – Radionavigation-satellite service applications in the 1 164-1 215 MHz, 1 215-1 300 MHz, and 1 559-1 610 MHz frequency bands

The ITU Radiocommunication Assembly,

considering

a)   that systems and networks in the radionavigation-satellite service (RNSS) provide worldwide accurate information for many positioning, navigation and timing applications, including safety aspects for some frequency bands and under certain circumstances and applications;

b)   that there are several operating and planned systems and networks in the RNSS;

c)   that any properly equipped earth station may receive navigation information from systems and networks in the RNSS on a worldwide basis,

recognizing

a)   that the bands 1 164-1 215 MHz, 1 215-1 300 MHz, and 1 559-1 610 MHz are allocated on a primary basis to RNSS (space-to-Earth, space-to-space);

b)   that the bands 1 164-1 215 MHz, 1 215-1 300 MHz, and 1 559-1 610 MHz are also allocated on a primary basis to other services;

c)   that use of the RNSS in the band 1 215-1 300 MHz is subject to RR No. **5.329**;

d)   that under RR No. **5.328B** systems and networks in the RNSS intending to use the bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz and 5 010-5 030 MHz for which complete coordination or notification information, as appropriate, is received by the Radiocommunication

Bureau after 1 January 2005 are subject to the application of the provisions of RR Nos. **9.12**, **9.12A** and **9.13**;

e) that under RR No. **9.7**, stations in satellite networks in the RNSS using the GSO are subject to coordination with other such satellite networks;

f) that Recommendations ITU-R M.1905, ITU-R M.1902, ITU-R M.1903 and ITU-R M.1904 provide technical and operational characteristics of, and protection criteria for, receiving stations in the RNSS (space-to-Earth and space-to-space) operating in the bands 1 164-1 215 MHz, 1 215-1 300 MHz, and 1 559-1 610 MHz;

g) that Recommendation ITU-R M.1318 provides an evaluation model for continuous interference from radio sources other than in the RNSS to the RNSS systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz and 5 010-5 030 MHz bands;

h) that Recommendation ITU-R M.2030 provides an evaluation method for pulsed interference from relevant radio sources other than in the RNSS to the RNSS systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz bands;

i) that Recommendation ITU-R M.1901 provides guidance on this and other ITU-R Recommendations related to systems and networks in the RNSS operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz;

j) that Report ITU-R M.766 contains information that is relevant to RNSS operations in the band 1 215-1 300 MHz;

k) that Recommendation ITU-R M.1831 provides a methodology for RNSS intersystem interference estimation to be used in coordination between systems and networks in the RNSS;

l) that Report ITU-R M.2458 provides further information on the current and planned RNSS applications in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz, including additional RNSS applications not addressed in the M-Series Recommendations,

recommends

1 that, in the bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz, the characteristics of transmitting space stations and system descriptions of Annexes 1 to 14 should be considered:

1.1 in determination of methodology and criteria for mutual coordination of systems and networks in the RNSS;

1.2 in assessing the interference impact between systems and networks in the RNSS (space-to-Earth and space-to-space) and systems in other services, taking into account the status of RNSS with respect to these other services;

2 that the following Note should be considered as part of this Recommendation.

NOTE − In the Annexes of this Recommendation, the term 'signal frequency range' refers to the frequency range of the RNSS signal of interest (for CDMA systems: Carrier frequency ± Half the signal bandwidth (unless otherwise noted); for FDMA systems: Base frequency + (Channel number * Channel spacing) ± Half the signal bandwidth). Channel number range should also be given for FDMA systems. The signal frequency range is expressed in MHz.

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Annex 1

Technical description of system and characteristics of transmitting space stations of the GLONASS global navigation satellite system

1   Introduction

The GLONASS system consists of 24 satellites equally spaced in three orbital planes with eight satellites in each plane. The orbit inclination angle is 64.8 degrees. Each satellite transmits navigation signals in three frequency bands: L1 (1.6 GHz), L2 (1.2 GHz) and L3 (1.1 GHz). The satellites transmit two types of signals: with frequency division multiple access and code division multiple access. Signals with frequency division multiple access are differentiated by carrier frequency; the same carrier frequency may be used by antipodal satellites located in the same plane. Navigation signals are modulated with a continuous bit stream (which contains information about the satellite ephemeris and time), and also a pseudo-random code for pseudo-range measurements. Signals with code division multiple access have the same carrier frequency and are differentiated by code. These signals are modulated by structured binary sequence that contains coded data about ephemerides and time. A user receiving signals from four or more satellites is able to determine the three location coordinates and the three velocity vector constituents with high accuracy. Navigational determinations are possible when on or near the Earth's surface.

1.1   Frequency requirements

The frequency requirements for the GLONASS system were based upon ionosphere transparency, radio link budget, simplicity of user antennas, multipath suppression, equipment cost and Radio Regulations (RR) provisions.

1.1.1   Signals with frequency division multiple access

The carrier frequencies of navigation signals with frequency division multiple access vary by an integer multiple of 0.5625 MHz in the L1 band, by 0.4375 MHz in the L2 band and by 0.423 MHz in the L3 band.

Since 2006 new satellites in the GLONASS system use 14 to 20 carrier frequencies in different bands. In the L1 band carrier frequencies 1 598.0625 MHz (lowest) to 1 605.3750 MHz (highest) are used, in the L2 band carrier frequencies from 1 242.9375 MHz (lowest) to 1 248.6250 MHz (highest) are used and in the L3 band carrier frequencies from 1 201.7430 MHz (lowest) to 1 209.7800 MHz (highest) are used. Nominal values of carrier frequencies of radionavigation signals used in the GLONASS system are given in Table 1.

TABLE 1

Nominal values of carrier frequencies of radionavigation signals in the GLONASS system

K (No. of carrier frequency)	FKL1 (MHz)	FKL2 (MHz)	FKL3 (MHz)
12	–	–	1 209.7800
11	–	–	1 209.3570
10	–	–	1 208.9340
09	–	–	1 208.5110
08	–	–	1 208.0880
07	–	–	1 207.6650
06	1 605.3750	1 248.6250	1 207.2420
05	1 604.8125	1 248.1875	1 206.8190
04	1 604.2500	1 247.7500	1 206.3960
03	1 603.6875	1 247.3125	1 205.9730
02	1 603.1250	1 246.8750	1 205.5500
01	1 602.5625	1 246.4375	1 205.1270
00	1 602.0000	1 246.0000	1 204.7040
−01	1 601.4375	1 245.5625	1 204.2810
−02	1 600.8750	1 245.1250	1 203.8580
−03	1 600.3125	1 244.6875	1 203.4350
−04	1 599.7500	1 244.2500	1 203.0120
−05	1 599.1875	1 243.8125	1 202.5890
−06	1 598.6250	1 243.3750	1 202.1660
−07	1 598.0625	1 242.9375	1 201.7430

Two phase-shift keying (by 180 degrees of the phase) navigation signals shifted in phase by 90 degrees (in quadrature) are transmitted at each carrier frequency. They are a standard accuracy (SA) signal and a high accuracy (HA) one.

1.1.2 Signals with code division multiple access

The carrier frequencies of GLONASS navigation signals with code division multiple access are 1 600.995 MHz 1 248.06 MHz and 1 202,025 MHz in the L1, L2 and L3 bands, respectively.

The signal with code division multiple access in L1 band includes four components. These components are formed by BPSK(1), BOC (1,1) and BOC (5,2.5) modulations.

The signal with code division multiple access in L2 band includes four components. These components are formed by BPSK(1), BOC (1,1) and BOC (5,2.5) modulations.

The signal with code division multiple access in L3 band includes two components. These components are formed by BPSK(10) modulation.

2 System overview

The GLONASS system provides navigation data and accurate time signals for terrestrial, maritime, air and space users.

The system operates on the principle of passive trilateration. The GLONASS system user equipment measures the pseudo-ranges and radial pseudo-velocities from all visible satellites and receives information about the satellites' ephemeris and clock parameters. On the basis of these data, the three coordinates of the user's location and the three velocity vector constituents are calculated and user clock and frequency correction are made. Coordinate system PE-90 is used by GLONASS system.

3   System description

The GLONASS system consists of three major segments: the space segment, the control segment and the user segment.

3.1   Space segment

The GLONASS system is comprised of 24 satellites located in three orbital planes with eight satellites in each plane. The planes are separated from each other by 120-degree longitude. The orbit inclination angle is 64.8 degrees. The satellites are equally spaced by 45 degrees in a plane by argument of latitude. Their rotation period is 11 h 15 min. The height of the orbit is 19 100 km.

3.2   Control segment

The control segment consists of the system control centre and a monitoring station network. The monitoring stations measure the satellite's orbital parameters and clock shift relative to the main system clock. These data are transmitted to the system control centre. The centre calculates the ephemerides and clock correction parameters and then uploads messages to the satellites through the monitor stations on a daily basis.

3.3   User segment

The user segment consists of a great number of user terminals of different types. The user terminal consists of an antenna, a receiver, a processor and an input/output device. This equipment may be combined with other navigation devices to increase navigation accuracy and reliability. Such a combination can be especially useful for highly dynamic platforms.

4   Navigation signal structure

4.1   Signals with frequency division multiple access

The SA signal structure is the same for both the L1 and L2 bands and different in the L3 band. It is a pseudo-random sequence which is Modulo-2 added to a continuous digital data stream transmitted with a 50 bit/s (L1, L2) and 125 bit/s (L3) rate. The pseudo-random sequence has a chip rate of 0.511 MHz (for L1, L2) and of 4.095 MHz (for L3) and its period is 1 ms.

In the L1, L2 and L3 bands, the HA signal is also a pseudo-random sequence Modulo-2 added to a continuous data stream. The pseudo-random sequence chip rate is 5.11 MHz in the L1 and L2 bands and it is 4.095 MHz in the L3 band.

Digital data include information about the satellite's ephemerides, clock time and other useful information.

4.2   Signals with code division multiple access

In L1 band two signals with code division multiple access emitted at a single carrier frequency 1 600.995 MHz at different quadrature with 90 degrees shift. Each signal consists of two components

with a time-division multiplexing. The data transfer speed is 125 bit/s and it is identical for two signals.

In L2 band two signals with code division multiple access emitted at a single carrier frequency 1 248.06 MHz at different quadrature with 90 degrees shift. Each signal consists of two components with a time-division multiplexing. The data transfer speed in two signals is 125 bit/s and 250 bit/s respectively.

In L3 band signal with code division multiple access emitted at frequency 1 202.025 MHz and includes two phase-shift keying signals of equal power, that are shifted in phase by 90 degrees. The data transfer speed in signal is 100 bit/s.

5 Signal power and spectra

5.1 Signals with frequency division multiple access

Transmitted signals are elliptically right-hand polarized with an ellipticity factor no worse than 0.7 for L1, L2 and L3 bands. The minimum guaranteed power of a signal at the input of a receiver (assumes a 0 dBi gain antenna) is specified as −161 dBW (−131 dBm) for both SA and HA signals in the L1, L2 and L3 bands.

Three classes of emissions are used in the GLONASS system: 8M19G7X, 1M02G7X, 10M2G7X. Characteristics of these signals are given in Table 2.

TABLE 2

Characteristics of GLONASS signals with frequency division multiple access

Frequency range	Emission class	Tx bandwidth (MHz)	Maximum peak power of emission (dBW)	Maximum spectral power density (dB(W/Hz))	Antenna gain (dB)
L1	10M2G7X	10.2	15	−52	11
	1M02G7X	1.02	15	−42	
L2	10M2G7X	10.2	14	−53	10
	1M02G7X	1.02	14	−43	
L3 [(1)]	8M19G7X	8.2	15	−52.1	12
	8M19G7X	8.2	15	−52.1	

[(1)] Two GLONASS L3 signals are shifted relative to each other by 90 degrees (in quadrature).

The power spectrum envelope of the navigation signal is described by the function $(\sin x/x)^2$, where:

$$x = \pi(f - f_c)/f_t$$

in which:

f : frequency considered

f_c : carrier frequency of the signal

f_t : chip rate of the signal.

The main lobe of the spectrum forms the signal's operational spectrum. It occupies a bandwidth equal to $2f_t$. The lobes have a width equal to f_t.

5.2   Signals with code division multiple access

The GLONASS system uses four classes of emission: 2M05G7X, 4M10G7X, 15M4G7X, 20M5G7XCC. The characteristics of these signals are shown in Table 3.

TABLE 3

Characteristics of GLONASS signals with code division multiple access

Frequency range	Emission class	Tx bandwidth (MHz)	Maximum peak power of emission (dBW)	Maximum spectral power density (dB(W/Hz))	Antenna gain (dB)
L1	2M05G7X	2.05	15.6	–44.1	14
	4M10G7X	4.1	15.6	–46.7	
	15M4G7X	15.4	15.6	–51.3	
	15M4G7X	15.4	15.6	–51.3	
L2	2M05G7X	2.05	14	–45.6	12.5
	4M10G7X	4.1	14	–48.2	
	15M4G7X	15.4	14	–52.8	
	15M4G7X	15.4	14	–52.8	
L3	20M5G7XCC	20.5	13	–56.6	12.4
	20M5G7XCC	20.5	13	–56.6	

Annex 2

Technical description and characteristics
of the Navstar Global Positioning System (GPS)

1   Introduction

Current information on the Navstar Global Positioning System (GPS) is available at no charge at URL http://www.gps.gov. Information on the GPS operating in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz bands is documented in the latest version of GPS interface specification documents IS-GPS-200, IS-GPS-705, and IS-GPS-800 with their latest revision notices[1]. Information on the functional data transfer interface between the GPS Control Segment (CS) and the GPS user and user-support communities is documented in the latest version of GPS interface control documents ICD-GPS-240 and ICD-GPS-870 with their latest revision notices. The levels of Standard Positioning Service (SPS) are defined in terms of broadcast signal parameters and GPS constellation design. Additional information on the levels of Signal in Space (SIS) performance

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[1] IS-GPS-200, IS-GPS-705, IS-GPS-800, ICD-GPS-240, and ICD-GPS-870 can be found at https://www.gps.gov/technical/icwg/

provided by the USG to the SPS user community is documented in the latest version of the GPS SPS Performance Standard document with its latest revision notice[2].

The baseline GPS satellite constellation nominally consists of a minimum of 24 operational satellites in six 55 degrees inclined equally spaced orbital planes. GPS satellites circle the Earth every 12 hours emitting continuous navigation signals. The system provides accurate position determination in three dimensions and timing anywhere on or near the surface of the Earth.

1.1 GPS frequency requirements

The frequency requirements for the GPS system are based upon an assessment of user accuracy requirements, space-to-Earth propagation delay resolution, multipath suppression, and equipment cost and configurations. Three channels are centred at 1 575.42 MHz (GPS L1), 1 227.6 MHz (GPS L2) and 1 176.45 MHz (GPS L5).

The L1, L2 and L5 channels consist of space-based positioning, navigation, and timing (PNT) signals delivered free of direct user fees for peaceful civil, commercial, and scientific uses worldwide. Receivers can be designed to process one or several signals depending on the specific application, user requirements and/or targeted market. GPS signals provide the necessary frequency diversity and wide bandwidth for increased range and timing accuracy, improved multipath suppression, and SIS redundancy.

2 System overview

GPS is a continuous space-based, all-weather radio system for PNT service which provides extremely accurate three-dimensional position and velocity information together with a precise common time reference to suitably equipped users anywhere on or near the surface of the Earth.

The system operates on the principle of passive trilateration. The GPS user equipment first measures the pseudo-ranges to four satellites, computes their positions, and synchronizes its clock to GPS by the use of the received ephemeris and clock correction parameters. (The measurements are termed 'pseudo' because they are made by an imprecise user clock and contain fixed bias terms due to the user clock offsets from GPS time.) It then determines the three-dimensional user position in a Cartesian Earth-centred, Earth-fixed (ECEF) World Geodetic System 1984 (WGS-84) coordinate system, and the user clock offset from GPS time by essentially calculating the simultaneous solution of four range equations.

Similarly, the three-dimensional user velocity and user clock-rate offset can be estimated by solving four range rate equations given the pseudo-range rate measurements to four satellites.

3 System segments

The system consists of three major segments: the space segment, the control segment and the user segment. The principal function of each segment is as follows.

3.1 Space segment

The space segment comprises the GPS satellites, which function as 'celestial' reference points, emitting precisely time-encoded navigation signals from space. The operational constellation consists of a minimum of 24 satellites in 12-hour orbits with a semi-major axis of about 26 600 km. The

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[2] GPS Standard Positioning Service Performance Standard document can be found at https://www.gps.gov/technical/ps/

satellites are placed in six orbital planes inclined 55 degrees relative to the equatorial plane, and the orbital planes are equally spaced about the equator at a 60-degree separation. There are typically a minimum of four satellites per plane.

The satellite is a three-axis stabilized vehicle. The major elements of its principal navigation payload are the atomic frequency standard that generates the stable time base for the satellite, the mission computer that receives the uploaded navigation data (NAV) from the Control Segment, the Navigation Baseband subsystem that generates the pseudorandom noise (PRN) ranging codes and adds the NAV message data to the PRN ranging codes, and the L-Band subsystem that modulates the resulting binary sequences onto the L1 (1575.42 MHz), L2 (1227.6 MHz), and L5 (1176.45 MHz) carriers which are then broadcast by the helix array antenna.

3.2   Control segment

The Control Segment (CS) is comprised of four major subsystems: a Master Control Station (MCS), an Alternate Master Control Station (AMCS), a network of four ground antennas (GA), and a network of globally distributed monitor stations (MS). The MCS is responsible for all aspects of constellation command and control.

3.3   User segment

The user segment is the ensemble of all user sets and their support equipment. A user set typically consists of an antenna, receiver front end, processor, input/output devices, and a power supply. A set acquires and tracks the navigation signal from four or more satellites in view, measures their propagation times and Doppler frequency shifts, converts them to pseudo-ranges and pseudo-range rates, solves for three-dimensional position and velocity, and sets the GPS time. (GPS time is different than UTC time, but the difference is less than a second and the GPS signals carry the information for conversion between the two. Also, GPS time is continuous whereas UTC time has leap seconds.) User equipment ranges from relatively simple, light-weight receivers to sophisticated receivers which are integrated with other navigation sensors or systems for accurate performance in highly dynamic environments.

4   GPS signal structure

The GPS navigational signal transmitted from the satellites consists of three modulated carriers: L1 at centre frequency of 1 575.42 MHz (154 f_0), L2 at centre frequency of 1 227.6 MHz (120 f_0), and L5 at centre frequency of 1 176.45 MHz (115 f_0), where $f_0 = 10.23$ MHz. f_0 is the output of the on-board atomic frequency standard to which all signals generated are coherently related. In the text below, the signals on each GPS carrier frequency are listed (and those with more than one component are further described) and a short description of RF and signal-processing parameters is given.

On the L1 carrier, GPS transmits four signals. The signals include C/A, P(Y), L1C and M which are described in § 6.1 below.

On the L2 carrier, GPS transmits three signals. The signals include L2C or C/A (rarely), P(Y) and M which are described in § 6.2 below.

On the L5 carrier, GPS transmits a single signal, denoted L5. The L5 signal has two components transmitted in phase quadrature which are described in § 6.3 below.

Tables 4, 5 and 6 list values for the key parameters of the GPS L1, L2 and L5 signal transmissions, respectively. These parameters include the following RF characteristics: Signal frequency range; 3 dB bandwidth of the satellite RF transmit filter; signal modulation method; and minimum received power level at the output of a reference receiver antenna located on the Earth's surface.

Also included in the tables are digital signal processing parameters including the PRN code chipping rate and the navigation message data bit and data symbol rates. Furthermore, for each carrier frequency, the satellite transmit antenna parameters of polarization and maximum ellipticity are provided.

The functions of the ranging codes (also referred to as PRN codes) are twofold:

-        they provide good multiple access properties among different satellites, since all satellites transmit on the same carrier frequencies and are differentiated from one another only by the unique PRN codes they use; and

-        their correlation properties allow precision measurement of time of arrival and rejection of multipath and interference signals.

The values provided in Tables 4, 5 and 6 are those recommended for use in initial assessments of RF compatibility with the GPS.

5   Signal power and spectra

The GPS satellites employ a shaped-beam antenna that radiates near-uniform power to receivers near the Earth's surface. The signals transmitted on the L1, L2 and L5 carriers are right-hand circularly polarized with the worst-case ellipticity shown in Tables 4, 5 and 6 for the angular range of ±13.8° from nadir.

6   GPS transmission parameters

The characteristics of the GPS signal transmissions are provided below.

In addition to phase-shift keying (PSK) modulations, GPS employs binary offset carrier (BOC) modulations. BOC(m,n) denotes a binary offset carrier modulation with a square-wave frequency of $m \times 1.023$ (MHz) and code chipping rate of $n \times 1.023$ (Mchip/s). For sine-phased BOC modulated GPS signals, a normalized power spectral density given by:

$$BOC_{m,n}(f) = f_c \left[\frac{\sin\left(\frac{\pi f}{f_c}\right) \tan\left(\frac{\pi f}{2 f_s}\right)}{\pi f} \right]^2$$

where:

f :   frequency (Hz)

f_c :   chipping rate; i.e. $n \times 1.023$ Mchip/s

f_s :   square-wave frequency; i.e. $m \times 1.023$ MHz.

6.1   GPS L1 transmission parameters

GPS operates four signals in the 1 559-1 610 MHz RNSS band. The signals include C/A, L1C, P(Y) and M. The C/A signal uses a BPSK-R(1) modulation, and the P(Y) signal uses a BPSK-R(10) modulation, where the BPSK-R(n) denotes a binary phase-shift keying rectangular (BPSK-R) modulation with a chipping rate of $n \times 1.023$ (Mchip/s). The M signal uses a BOC(10,5) modulation. The L1C signal consists of two components. One component, denoted L1C$_D$, is modulated by a data message; and the other, denoted L1C$_P$, is dataless (i.e. a pilot signal only), and the two components use different PRN codes. (The dataless component improves RNSS acquisition and tracking performance.) P(Y) and both L1C components are transmitted in phase, while C/A is transmitted in quadrature to those signals and the signal carrier lags by 90 degrees. The key parameters of the GPS L1 transmissions are presented in Table 4.

L1C$_D$ uses a BOC(1,1) modulation. L1C$_P$ uses a modulation, referred to as multiplexed BOC (MBOC), and is multiplexed in time between a BOC(1,1) and BOC(6,1). MBOC has a normalized power spectral density (PSD) given by:

$$MBOC(f) = \frac{29}{33} BOC_{1,1}(f) + \frac{4}{33} BOC_{6,1}(f)$$

The total PSD of the L1C components is given by:

$$S(f) = \frac{1}{4} BOC_{1,1}(f) + \frac{3}{4} MBOC(f) = \frac{10}{11} BOC_{1,1}(f) + \frac{1}{11} BOC_{6,1}(f)$$

TABLE 4

GPS L1 transmissions in the 1 559-1 610 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 575.42 ± 15.345
PRN code chip rate (Mchip/s)	1.023 (C/A, L1C$_D$ and L1C$_P$) 10.23 (P(Y)) 5.115 (M)
Navigation data bit rates (bit/s)	50 (C/A, P(Y) and L1C$_D$)
Navigation data symbol rates (symbol/s)	50 (C/A and P(Y)) 100 (L1C$_D$)
Signal modulation method	BPSK-R(1) (C/A) BPSK-R(10) (P(Y)) BOC(10,5) (M) BOC(1,1) (L1C$_D$) MBOC (L1C$_P$) (see Note 3) (see Note 1)
Polarization	RHCP
Maximum ellipticity (dB)	1.8
Minimum received power level at the output of the reference antenna (dBW)	−158.5 (C/A) −163.0 (L1C$_D$) −158.25 (L1C$_P$) −161.5 (P(Y)) −158.0 (M) (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	30.69

Note 1: For GPS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s). BOC(m,n) denotes a binary offset carrier modulation with a square-wave frequency of $m \times 1.023$ (MHz) and chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The minimum received power is measured at the output of a 3 dBi linearly polarized reference user receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5 degree elevation angle above the Earth's horizon viewed from the Earth's surface.

Note 3: See § 6.1 for more details on MBOC.

6.2 GPS L2 transmission parameters

GPS transmits three signals in the 1 215-1 300 MHz RNSS band. The signals include L2C or C/A (rarely), P(Y) and M. The L2C signal uses a BPSK-R(1) modulation. The L2C signal consists of the data channel of the L2 civil-moderate (L2 CM) code, and the dataless channel of the L2 civil-long (L2 CL) code, combined using a chip-by-chip time-division multiplexing method. These two signal components use different PRN codes. The phase relationship of the two L2 carrier components (L2C and P(Y)) is indicated by means of bit 273 of the civil navigation (CNAV) Type 10 Message, where zero indicates phase quadrature, with the L2C lagging the P(Y) by 90 degrees, and one indicates that L2C and P(Y) are in-phase. If the CNAV message is not available, then the L2C and P(Y) will be in phase quadrature. The key parameters of the GPS L2 transmissions are presented in Table 5.

TABLE 5

GPS L2 transmissions in the 1 215-1 300 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 227.6 ± 15.345
PRN code chip rate (Mchip/s)	1.023 (C/A and L2C) 10.23 (P(Y)) 5.115 (M)
Navigation data bit rates (bit/s)	50 (C/A and P(Y)) 25 (L2C)
Navigation data symbol rates (symbol/s)	50 (C/A, P(Y) and L2C)
Signal modulation method	BPSK-R(1) (C/A and L2C) BPSK-R(10) (P(Y)) BOC(10,5) (M) (see Note 1)
Polarization	RHCP
Maximum ellipticity (dB)	2.2
Minimum received power level at the output of the reference antenna (dBW)	−161.5 (P(Y) −160.0 (L2C or C/A) −161.0 (M) (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	30.69

Note 1: For GPS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s). BOC(m,n) denotes a binary offset carrier modulation with a square-wave frequency of $m \times 1.023$ (MHz) and chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The minimum received power is measured at the output of a 3 dBi linearly polarized reference user receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5-degree elevation angle above the Earth's horizon viewed from the Earth's surface.

6.3 GPS L5 transmission parameters

GPS operates the L5 navigation signal in the 1 164-1 215 MHz RNSS band. The L5 signal uses a BPSK-R(10) modulation. The L5 signal consists of two components, L5I and L5Q, where L5Q is dataless (also called a pilot channel) and L5I is modulated by a data message. These two L5 components are transmitted in phase quadrature with each other and at equal power, and use different PRN codes. The key parameters of the GPS L5 transmissions are presented in Table 6.

TABLE 6

GPS L5 transmissions in the 1 164-1 215 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 176.45 ± 12
PRN code chip rate (Mchip/s)	10.23
Navigation data bit rates (bit/s)	50 (L5I)
Navigation data symbol rates (symbol/s)	100 (L5I)
Signal modulation method	BPSK-R(10) (see Note 1)
Polarization	RHCP
Maximum ellipticity (dB)	2.4
Minimum received power level at the output of the reference antenna (dBW)	−157.9 (L5I) −157.9 (L5Q) (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	24

Notes to Table 6:

Note 1: For GPS RNSS parameters, BPSK-R(*n*) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The minimum received power is measured at the output of a 3 dBi linearly polarized reference user receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5-degree elevation angle above the Earth's horizon viewed from the Earth's surface.

Annex 3

Technical description and characteristics of the Galileo system

1   Introduction

The Galileo system consists of a constellation of 30 satellite positions (24 transmitting satellites and six in-orbit active spares) with ten satellites positioned on each of three 56 degrees inclined equally spaced orbital planes. Each satellite transmits navigation signals on three carrier frequencies. These signals are modulated with a structured bit stream, containing coded ephemeris data and navigation messages, and have sufficient bandwidth to produce the necessary navigation precision without recourse to two-way transmission or Doppler integration. The system provides accurate timing and position determination in three dimensions anywhere on or near the surface of the Earth.

1.1   Frequency requirements

The frequency requirements for the Galileo system are based upon an assessment of user accuracy requirements, space-to-Earth propagation delay resolution, multipath suppression, and equipment cost and configurations. Galileo satellites continuously transmit four coherent, but independently usable, radio frequency signals centred at (corresponding signal names are given in round brackets) 1 176.45 MHz (E5a), 1 207.14 MHz (E5b), 1 278.75 MHz (E6) and 1 575.42 MHz (E1). Additionally, the E5a and E5b signals are multiplexed on a single modulation, called AltBOC (Alternate BOC signal) which uses a single carrier at 1 191.795 MHz.

Thus Galileo transmits on three carrier frequencies for its user signals:

–   E5: 1 191.795 MHz
        (the components of which can also be independently received using the virtual carriers E5a:
        1 176.450 MHz and E5b: 1 207.140 MHz)

–   E6: 1 278.750 MHz and

–   E1: 1 575.420 MHz.

A total of ten signals, multiplexed and modulated onto the three carriers, are transmitted and are mapped to provide the 'positioning/navigation/timing' (PNT)-services in different configurations; these are the Galileo 'services'. Receivers can be designed to process one or several signals depending on the specific application, user requirements, and/or targeted market.

All signal components (carriers, sub-carriers, ranging codes, data bit rates) are coherently derived from an on-board, common atomic clock generator.

Compared to narrowband, single frequency navigation signals, Galileo's frequency diversity and wide bandwidth signals allow better range accuracy for space-to-Earth propagation delay resolution, and improved multipath suppression, both of which increase the total accuracy.

2   System overview

Galileo is a space-based, all-weather, continuous radionavigation, positioning and time-transfer system which enables extremely accurate three-dimensional position and velocity information together with a precise common time reference to be provided to suitably equipped users.

The system operates on the principle of passive trilateration. Once the Galileo user equipment acquires the signals from at least four Galileo satellites, it measures the pseudo-ranges to the satellites, computes their positions, and synchronizes its clock to Galileo System Time using the received ephemeris and clock correction parameters. The receiver then determines the three-dimensional user position in a Galileo Terrestrial Reference Frame (GTRF) compatible with the International Terrestrial Reference Frame (ITRS), and the user clock offset from Galileo time, by essentially calculating the simultaneous solution of four range equations.

Similarly, the three-dimensional user velocity and user clock-rate offset can be estimated by solving four range rate equations given the pseudo-range rate measurements to four satellites. The measurements are termed "pseudo" because they are made by an imprecise (low-cost) user clock in the receiver and contain fixed bias terms due to the receiver's clock offsets from Galileo time.

2.1   Galileo applications

Mass market

Galileo provides an open, free of cost, positioning, navigation and timing (PNT) service, enabling a wide range of applications particularly those aimed at the general public. This service addresses the same user communities as those addressed by the GPS Standard Positioning Service; the signals transmitted are interoperable with GPS, so that combined GPS and Galileo PNT solutions will be possible.

Aviation, Maritime, Road and Rail

The Galileo E1, E5 and E6 signals are aimed at supporting demanding, safety related applications (particularly aviation) and in the long term will enable dual frequency receivers to provide more reliable, accurate and precise navigation fixes than single frequency receivers.

High precision applications

Galileo provides, through the E6-B signal, the High Accuracy Service (HAS). The Galileo HAS is an open-access and free service based on the provision of corrections to the Galileo signals. HAS data will include orbit, clock, phase biases and atmospheric corrections. These corrections enable users to perform a PVT process with decimetre-level accuracy. A wide variety of applications benefit from high precision RNSS, among them: automotive, construction, surveying, mapping and utility management.

Authentication

Galileo will deliver two levels of authentication through E1-B and E6-C signals:

> Open Service Navigation Message Authentication (OSNMA), which uses the digital signature of the OS navigation data, to ensure the data authenticity. It is easy to implement in receivers, and mainly oriented to mass market users. The OSNMA data will be transmitted on the E1-B signal and will be offered for free.

A Signal Authentication service to protect Galileo signals from advanced spoofing which will be based on the encryption of the E6-C spreading code. It is referred as Commercial Authentication Service (CAS).

Governmental

Galileo provides a robust and strongly encrypted "public regulated service (PRS)" restricted to access for use by public authorities responsible for civil protection, national security and law enforcement.

Search and rescue

The Galileo Search and Rescue Service (SAR) represents a significant contribution to the international Cospas-Sarsat system taking an important role in the Medium Earth Orbit Search and Rescue system (MEOSAR). Galileo satellites are able to detect emergency signals (in the 406 MHz band) transmitted from distress beacons carried on ships, planes or personal hand-held user terminals, whose location data is then sent back to national rescue centres. At any given moment in time at least one Galileo satellite is in view of any location on Earth, enabling near real-time distress alert detection, identification and location. Each received distress call can be actively acknowledged by a return message to indicate that the distress call has been received. This can also enable the emergency channel to be released by the beacon.

3   System segments

The system consists of three major segments: the space segment, the control segment and the user segment. The principal function of each segment is as follows.

3.1   Space segment

The space segment comprises the Galileo satellites, which function as "celestial" reference points, emitting precisely time-encoded navigation signals from space. The operational constellation of 24 satellites (plus six active spare satellites) operates in 14-hour orbits with a semi-major axis of about 30 000 km. Three equally spaced orbital planes are used, each plane containing ten satellites (including two spares), and which are inclined 56° relative to the Equator.

3.2   Ground segment

The Galileo ground segment controls the entire Galileo constellation, monitors each satellite's health status and up-loads data to each satellite for subsequent dissemination as the navigation message transmitted to user receivers. The key parameters of this navigation message, clock synchronization

and orbit ephemeris, are calculated based on measurements performed by a worldwide network of stations. The telemetry, tracking and command functions utilize the space operations allocations just above 2 GHz.

The ground segment comprises the following functions:

– constellation management and satellite control;

– navigation and system health data processing and control;

– spacecraft housekeeping and performance monitoring (Telemetry, Telecommand and Ranging);

– uplink of mission data in the 5 000-5 010 MHz RNSS band.

3.3 User segment

The user segment comprises all user terminals and their associated support equipment. The Galileo user terminal typically consists of an antenna, receiver, processor, and input/output devices, as appropriate. It acquires and tracks navigation signals from all Galileo satellites in view, calculates pseudo-ranges and pseudo-range rates, and provides instantaneous three-dimensional position, velocity, and system time.

4 Galileo signal structure

The following provides a description of Galileo signals for positioning, navigation and timing (PNT) applications.

4.1 Galileo E1 signal

The Galileo E1 signal is transmitted on the centre frequency of 1 575.42 MHz.

It comprises three components which can be used as standalone or in combination with other signals depending on the performance demanded by the application. The components are primarily provided for the Open Service (OS) and the Public Regulated Service (PRS), including navigation messages. The Galileo E1 carrier is modulated with a MBOC modulation (consisting of the E1-B data component and the E1-C dataless component) for the OS service, and a cosine BOC (15, 2.5) modulation (consisting of the E1-A component) for the PRS. The E1-B data stream can be populated with additional messages to offer enhanced navigation and timing functionality.

A BOC modulation is used to form the required spectral shape (power spectral density distribution over frequency) for the transmitted signal. BOC type signals are expressed in the form BOC(f_{sub},f_{chip}) where frequencies are indicated as multiples of the GPS C/A code chip rate of 1.023 Mchip/s.

The power spectral density of the Galileo E1-A signal is given by:

$$G_{BOC_{\cos(f_s, f_c)}}(f) = f_c \left[\frac{2\sin\left(\frac{\pi f}{f_c}\right)\sin^2\left(\frac{\pi f}{4f_s}\right)}{\pi f \cos\left(\frac{\pi f}{2f_s}\right)} \right]^2$$

where $f_s = 15 \times 1.023$ MHz is the subcarrier frequency and $f_c = 2.5 \times 1.023$ MHz is the chip rate.

The MBOC modulation results in a spectrum G$_{MBOC}$(f) of the signal given by:

$$G_{MBOC}(f) = \frac{10}{11} G_{BOC(1,1)}(f) + \frac{1}{11} G_{BOC(6,1)}(f)$$

where:

$$G_{BOC_{\cos(f_s, f_c)}}(f) = f_c \left[\frac{\tan\left(\frac{\pi f}{2 f_s}\right) \sin\left(\frac{\pi f}{f_c}\right)}{\pi f} \right]^2$$

with:

$f_s =$ 1×1.023 MHz as the subcarrier frequency and $f_c = 1 \times 1.023$ MHz as the chip rate for BOC(1,1)

$f_s =$ 6×1.023 MHz as the subcarrier frequency and $f_c = 1 \times 1.023$ MHz as the chip rate for BOC(6,1).

TABLE 7

Galileo E1 transmissions in the 1 559-1 610 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 559-1 591
PRN code chip rate (Mchip/s)	1.023 (MBOC) 2.5575 ($BOC_{\cos}(15,2.5)$)
Navigation data bit rates (bit/s)	125 (E1-B)
Navigation data symbol rates (symbol/s)	250 (E1-B)
Signal modulation method	MBOC (OS) $BOC_{\cos}(15,2.5)$ (E1-A)
Polarization	RHCP
Minimum received power level at the output of the reference antenna (dBW)	-157.25 (MBOC) (see Note 2)

Notes to Table 7:

Note 1: See the text of the section above this Table for more details on MBOC.

Note 2: The minimum received power on the surface of the Earth is measured at the output of an isotropic 0 dBic receiver antenna for any elevation angle equal or greater than 5 degrees.

4.2 Galileo E6 signal

The Galileo E6 signal baseline is transmitted at the carrier frequency 1 278.75 MHz. The E6 signal baseline includes three different signals, the E6-A signal carrying the Public Regulated Service (PRS), E6-B carrying the newly defined High Accuracy Service (HAS) and E6-C with the Commercial Authentication Service (CAS). The E6 carrier is modulated with a BPSK(5) modulation to provide the E6-B and E6-C signal components. The Galileo E6 carrier is also modulated with a $BOC_{\cos}(10, 5)$ code to provide the E6-A component (the spectrum for the Galileo E6-A follows the same equation as that of the E1-A signal above, but with $f_s = 10 \times 1.023$ MHz and $f_c = 5 \times 1.023$ MHz).

TABLE 8

Galileo E6 transmissions in the 1 215-1 300 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 260-1 300
PRN code chip rate (Mchip/s)	5.115 (BPSK(5)) 10.23 (BOC_{COS} (10,5))
Navigation data bit rates (bit/s)	500 (E6-B)
Navigation data symbol rates (symbol/s)	1000 (E6-B)
Signal modulation method	BPSK(5) (E6-B and E6-C) BOC_{COS} (10,5) (E6-A)
Polarization	RHCP
Minimum received power level at the output of the reference antenna (dBW)	−155.25 (BPSK(5)) (see Note)

Note: The minimum received power on the surface of the Earth is measured at the output of an isotropic 0 dBic receiver antenna for any elevation angle equal or above 5 degrees.

4.3 Galileo E5 signal

The Galileo E5 signal is centred on 1 191.795 MHz and is generated with an AltBOC modulation of side-band sub-carrier rate of 15.345 MHz. This scheme provides two side lobes.

The lower side lobe of Galileo E5 signal is called Galileo E5a, and provides a second signal (for dual frequency reception) to the open service (OS), also including navigation data messages.

The E5a signal is an open access signal that includes a data channel and a pilot (or dataless) channel.

The upper side lobe of Galileo E5 signal is called Galileo E5b, providing an additional component to the Open Service (OS).

The E5b signal is an open access signal band that includes a data channel and a pilot (or dataless) channel.

The power spectral density of the Galileo E5 AltBOC signal is given by:

$$G_{AltBOC}(f) = \frac{f_c}{2\pi^2 f^2} \frac{\cos^2\left(\frac{3\pi f}{2f_s}\right)}{\cos^2\left(\frac{\pi f}{2f_s}\right)} \left[\cos^2\left(\frac{\pi f}{2f_s}\right) - \cos\left(\frac{\pi f}{2f_s}\right) - 2\cos\left(\frac{\pi f}{2f_s}\right)\cos\left(\frac{\pi f}{4f_s}\right) + 2 \right]$$

where:

$f_s =$ 15 × 1.023 MHz is the subcarrier frequency and $f_c = 10 \times 1.023$ MHz is the chip rate.

TABLE 9

Galileo E5 transmissions in the 1 164-1 215 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 164-1 219
PRN code chip rate (Mchip/s)	10.23 (G_{AltBOC}(15,10))
Navigation data bit rates (bit/s)	25 (E5a), 125 (E5b)
Navigation data symbol rates (symbol/s)	50 (E5a), 250 (E5b)
Signal modulation method	AltBOC(15,10) (see Note 1)
Polarization	RHCP
Minimum received power level at the output of the reference antenna (dBW)	−155.25 for E5a (see Note 2) −155.25 for E5b (see Note 2)

Notes to Table 9:

Note 1: See the text of the section above this Table for more details on G_{AltBOC}.

Note 2: The minimum received power on the surface of the Earth is measured at the output of an isotropic 0 dBi receiver antenna for any elevation angle equal or above 5 degrees.

Annex 4

Technical description and characteristics of the quasi-zenith satellite system (QZSS)

1   Introduction

The quasi-zenith satellite system (QZSS) consists of seven satellites and two active back-up satellites. The satellites are either in a 45 degrees inclined non-geostationary orbit or in the geostationary orbit. Each satellite transmits the same four carrier frequencies for navigational signals. These navigational signals are modulated with a predetermined bit stream, containing coded ephemeris data and time, and having a sufficient bandwidth to produce the necessary navigation precision without recourse to two-way transmission or Doppler integration.

1.1   Frequency requirements

The frequency requirements for the QZSS system are based upon an assessment of user accuracy requirements, space-to-Earth propagation delay resolution, multipath suppression, and equipment cost and configurations. Three initial channels are used for QZSS operations: 1 575.42 MHz (L1), 1 227.6 MHz (L2) and 1 176.45 MHz (L5). A high data rate signal will be added, centred at 1 278.75 MHz (L6).

QZSS provides a navigation service for the East Asia and Oceania Regions that includes Japan.

2 System overview

QZSS is a space-based, all-weather, continuous radionavigation, positioning and time-transfer system which provides interoperable signals for GPS (L1, L2 and L5), and an augmentation signal having a higher data rate message (L6).

The system operates on the principle of passive trilateration. A QZSS user receiver set first measures the pseudo-ranges, the pseudo-range rates or the delta pseudo-ranges to at least four satellites, and computes the satellites' positions, velocities and time offsets of their clocks to the reference time-frame by the use of the received ephemeris and clock correction parameters. It then determines the three-dimensional user position and velocity in a Cartesian Earth-centred, Earth-fixed (ECEF) International Terrestrial Reference Frame (ITRF) coordinate system, and the user clock offset to the reference timeframe.

3 System segments

The system consists of three major segments: the space segment, the control segment and the user segment. The principal function of each segment is as follows.

3.1 Space segment

The space segment comprises the QZSS satellites, which function as "celestial" reference points, emitting precisely time-encoded navigation signals from space. The operational constellation of seven satellites consists of both non-geostationary orbit and geostationary orbit satellites. The non-geostationary orbit satellites operate in 24-hour orbits with an apogee altitude of 39 970 km and a perigee altitude of 31 602 km. Each of the non-geostationary orbit satellites is placed in its own separate orbital plane inclined 45 degrees relative to the Equator. The orbital planes are equally separated and the satellites are phased such that there is always one satellite visible at a high elevation angle from Japan. The geostationary orbit locations are under investigation.

Two active back-up satellites are also under investigation to satisfy the system requirement to provide navigation capabilities with the QZSS constellation with a minimum of seven satellites.

The satellite is a three-axis stabilized vehicle. The major elements of its principal navigation payload are the atomic frequency standard for accurate timing, the processor to store navigation data, the PRN signal assembly for generating the ranging signal, and the 1.2/1.6 GHz band transmitting antenna whose shaped-beam gain pattern radiates near-uniform power of signals at the four 1.2/1.6 GHz band frequencies to users on or near the surface of the Earth. The dual-frequency transmission (e.g. L1 and L2) is to permit correction of ionospheric delays in signal propagation time.

3.2 Control segment

The control segment performs the tracking, computation, updating and monitoring functions needed to control all of the satellites in the system on a day-to-day basis. It consists of a Master Control Station (MCS) in Japan where all data processing is performed, and some widely deployed monitor stations in the area that are visible from the space segment.

The monitor stations passively track all satellites in view and measure ranging and Doppler data. These data are processed at the MCS for calculation of the satellite's ephemerides, clock offsets, clock drifts, and propagation delay and are then used to generate upload messages. This updated information is transmitted to the satellites for memory storage and subsequent transmission by the satellites as part of the navigation messages to the users.

3.3 User segment

The user segment is the collection of all user receiver sets and their support equipment. The user receiver set typically consists of an antenna, QZSS receiver/processor (also accommodates GPS signals) computer and input/output devices.

It acquires and tracks the navigation signal from more than four satellites that include one (or more) QZSS satellites and one (or more) GPS satellites in view, measures their RF transit times, phases of RF signals and Doppler frequency shifts, converts them to pseudo-ranges, carrier phases and pseudo-range rates and/or delta pseudo-ranges, and solves for three-dimensional position, velocity, and receiver time offset to the reference time-frame.

User equipment ranges from relatively simple, light-weight and mobile receivers to sophisticated receivers which are integrated with other navigation sensors or systems for accurate performance in highly dynamic environments.

4 QZSS signal structure

The QZSS navigation signals transmitted from the satellites consist of four modulated carriers: L1 at centre frequency 1 575.42 MHz (154 f_0), L2 at centre frequency 1 227.6 MHz (120 f_0), L5 at centre frequency 1 176.45 MHz (115 f_0) and L6 at centre frequency 1 278.75 MHz (125 f_0) where $f_0 = 10.23$ MHz. f_0 is the output of the on-board frequency reference unit to which all signals generated are coherently related.

The L1 signal consists of four bi-phase shift keying modulation (BPSK) signals multiplexed in quadrature. Two of them (L1-C/A and L1S) are modulated with two different PRN spreading codes which are Modulo-2 add sequences of the outputs of two 10-bit-linear-feedback-shift-registers (10-bit-LFSRs) having a clock rate of 1.023 MHz and a period of 1 ms. Each of them is Modulo-2 added to a 50 bit/s/50 Symbol/s or 250 bit/s/500 Symbol/s binary navigation data stream prior to BPSK. The other two signals (L1C data component and L1C dataless component) are modulated with two different spreading codes having a clock rate of 1.023 MHz and with two same square waves having a clock rate of 0.5115 MHz. Data stream is Modulo-2 added to one of them.

The L2 signal is BPSK with an L2C spreading code. The L2C code has a clock rate of 1.023 MHz with alternating spreading codes having a clock rate of 0.5115 MHz: L2CM with a period of 20 ms and L2CL with a period of 1.5 s. A 25 bit/s/50 Symbol/s data stream is Modulo-2 added to the code prior to phase modulation.

The L5 signal consists of two BPSK signals (I and Q) multiplexed in quadrature and one QPSK signal (L5S signal). The signals in both I and Q channels are modulated with two different L5 spreading codes. Both of the L5 spreading codes have a clock rate of 10.23 MHz and a period of 1 ms. A 50 bit/s/100 Symbol/s binary navigation data stream is transmitted on the I channel and no data (i.e. a dataless "pilot" signal) on the Q channel. The one QPSK signal also has a clock rate of 10.23 MHz and a period of 1 ms and contains augmentation messages.

The L6 signal is also BPSK. A set of small Kasami Code sequences is employed for the spreading code having a clock rate of 5.115 MHz.

5 Signal power and spectra

The QZSS satellites employ a shaped-beam antenna that radiates near-uniform power to system users. Transmitted signals are RHCP with ellipticity better than 1.2 dB for L1 and better than 2.2 dB for the L2, L5 and L6 signals. The user received signal powers (URPs) for angles of arrival to satellites larger than 10 degrees are defined under the assumption of a 0 dBi RHCP receiver antenna.

The minimum guaranteed URP for L1, L2, L5 and L6 signals are described in Tables 10, 11 and 12.

6 Operating frequency

QZSS has an L1 signal operating in a segment of 1 559-1 610 MHz, an L2 signal and an L6 signal operating in a segment of 1 215-1 300 MHz and an L5 signal operating in a segment of 1 164-1 215 MHz allocated to the RNSS.

7 Telemetry functions

There is no need for QZSS to operate telemetry signals in 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz.

8 QZSS transmission parameters

Since QZSS transmits space-to-Earth RNSS navigation signals in four bands, QZSS transmission parameters are provided in four tables representing the four RNSS bands in which QZSS transmits navigation signals.

8.1 QZSS L1 transmission parameters

QZSS will operate several signals in the 1 559-1 610 MHz RNSS band. The signals include L1 C/A, L1C, and L1S. The non-geostationary orbit QZSS satellites employ one L1-C/A, one L1C and one L1S signal per satellite. The geostationary orbit QZSS satellites employ one L1-C/A, one L1C and two L1S (L1Sa and L1Sb) signals per satellite.

TABLE 10

QZSS transmissions in the 1 559-1 610 MHz band

Parameter	Parameter value (see Note 1)
Carrier frequency (MHz)	1 575.42
PRN code chip rate (Mchip/s)	1.023
Navigation data bit rates (bit/s)	50 (C/A), 250 (L1S), 25 (L1C)
Navigation data symbol rates (symbol/s)	50 (C/A), 500 (L1S), 50 (L1C)
Signal modulation method	BPSK-R(1) (C/A and L1S) BOC(1,1) (L1C data component) MBOC (L1C pilot signal (dataless component) of 2nd and follow-on QZSS satellites. The first satellite employs BOC(1,1) for its dataless component.) (see Note 2)
Polarization and ellipticity (dB)	RHCP, maximum 1.2
Minimum received power level at input of antenna (dBW)	−158.5 (C/A), −163 (L1C data), −158.25 (L1C dataless), −161 (L1S) (see Note 3)
RF transmitter filter 3 dB bandwidth (MHz)	32

TABLE 10 (*end*)

Notes to Table 10:

Note 1: Signal name L1S is applied for 2nd and follow-on QZSS satellites. The first QZSS satellite employs the same RF signal characteristics as that of L1S but the signal name is called L1-SAIF instead.

Note 2: For QZSS RNSS parameters, BPSK-R(*n*) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s). BOC(m,n) denotes a binary offset carrier modulation with a carrier frequency offset of $m \times 1.023$ (MHz) and chipping rate of $n \times 1.023$ (Mchip/s).

Note 3: The QZSS minimum received power assumes the minimum receiver-antenna gain is at angles of 10 degrees or more above the Earth's horizon viewed from the Earth's surface.

8.2 QZSS L2 transmission parameters

QZSS will operate two signals in the 1 215-1 300 MHz RNSS band. The signals include L2C and L6.

TABLE 11

QZSS L2C transmissions in the 1 215-1 300 MHz band

Parameter	RNSS parameter description
Carrier frequency (MHz)	1 227.6
PRN code chip rate (Mchip/s)	1.023 (L2C)
Navigation data bit rates (bit/s)	25 (L2C)
Navigation data symbol rates (symbol/s)	50 (L2C)
Signal modulation method	BPSK-R(1) (L2C) (see Note 1)
Polarization and ellipticity (dB)	RHCP; maximum 2.2
Minimum received power level at input of antenna (dBW)	−160 total power (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	32

Notes to Table 11:

Note 1: For QZSS RNSS parameters, BPSK-R(*n*) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The QZSS minimum received power assumes the minimum receiver-antenna gain is at angles of 10 degrees or more above the Earth's horizon viewed from the Earth's surface.

TABLE 12

QZSS L6 transmissions in the 1 215-1 300 MHz band (see Note 1)

Parameter	RNSS parameter description
Carrier frequency (MHz)	1 278.75
PRN code chip rate (Mchip/s)	5.115 (L6)
Navigation data bit rates (bit/s)	2 000 (L6)
Navigation data symbol rates (symbol/s)	250 (L6)
Signal modulation method	BPSK-R(5) (L6) (see Note 2)

TABLE 12 (*end*)

Parameter	RNSS parameter description
Polarization and ellipticity (dB)	RHCP; maximum 2.2
Minimum received power level at input of antenna (dBW)	−155.7 total power (see Note 3)
RF transmitter filter 3 dB bandwidth (MHz)	56 (see Note 4)

Notes to Table 12:

Note 1: Signal name L6 is applied for 2nd and follow-on QZSS satellites. The first QZSS satellite employs the same RF signal characteristics as that of L6 but the signal name is called LEX instead.

Note 2: For QZSS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 3: The QZSS minimum received power assumes the minimum receiver-antenna gain is at angles of 10 degrees or more above the Earth's horizon viewed from the Earth's surface.

Note 4: The value of 56 MHz is not representative of the 3 dB bandwidth of the transmit signal.

8.3 QZSS L5 transmission parameters

QZSS will operate three navigation signals (L5I, L5Q and L5S) in the 1 164-1 215 MHz RNSS band. The signals, L5I and L5Q, operate in quadrature and are transmitted at equal power. L5Q is dataless (also called a 'pilot' channel). L5I, on the other hand, has navigation data providing timing, navigation and positioning information. L5S also has navigation data providing timing, navigation and positioning information.

TABLE 13

QZSS transmissions in the 1 164-1 215 MHz band

Parameter	RNSS parameter description
Carrier frequency (MHz)	1 176.45
PRN code chip rate (Mchip/s)	10.23
Navigation data bit rates (bit/s)	50 (L5I), 250 (L5S)
Navigation data symbol rates (symbol/s)	100 (L5I), 500 (L5S)
Signal modulation method	BPSK-R(10) (L5) QPSK-R(10) (L5S) (see Note 1)
Polarization and ellipticity (dB)	RHCP, 2.2
Minimum received power level at input of antenna (dBW)	−157.9 per channel (L5I or L5Q) −157 (L5S) (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	38.0

Notes to Table 13:

Note 1: For QZSS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s). QPSK-R(n) denotes a quadrature phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The QZSS minimum received power assumes the minimum receiver antenna gain is at angles of 10° or more above the Earth's horizon viewed from the Earth's surface.

Annex 5

Technical description and characteristics of the Michibiki satellite-based augmentation system (MSAS)

1 Introduction

International Civil Aviation Organization (ICAO) defined Global Navigation Satellite System (GNSS) as "a worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation", and developed the International Standards and Recommended Practices (SARPs) for seamless worldwide air navigation service.

GNSS navigation service will be provided using various combinations of the following GNSS elements installed on the ground, the space and/or the aircraft:

a)   Global Positioning System (GPS).

b)   Global Navigation Satellite System (GLONASS).

c)   Aircraft-Based Augmentation System (ABAS).

d)   Satellite-Based Augmentation System (SBAS).

e)   Ground-Based Augmentation System (GBAS).

f)   Aircraft GNSS receiver.

The Michibiki satellite-based augmentation service (MSAS) is an SBAS defined as "a wide coverage augmentation system in which the user receives augmentation information from a satellite-based transmitter".

MSAS utilizes two geostationary orbit satellite and one small inclined geosynchronous orbit satellite of QZSS, which is contained in Annex 4, to enhance the system reliability and robustness. Each QZSS satellite transmit GPS augmentation signals. These signals include following information; GPS satellite status, GPS satellite ephemeris and clock corrections and ionospheric corrections.

1.1 Frequency requirements

The frequency requirements for MSAS are based upon ICAO SARPs.

2 System overview

MSAS provides "Safety of Life" service for aircraft in all phases of flight including airport landing which is required precise three-dimensional (3D) positioning in a Cartesian Earth-centred, Earth-fixed (ECEF) World Geodetic System (WGS-84) coordinate system, and the user clock offset to the reference timeframe and integrity.

The Dual Frequency Multi Constellation MSAS (DFMC MSAS) signals are operated by the Electronic Navigation Research Institute (ENRI).

3 System segments

MSAS system consists of three major segments: the space segment, the ground segments and the SBAS airborne receiver (User segment). The principal function of each segment is as follows.

3.1 Space segment

MSAS space segment navigation payload transmits L1/L5 signal.

3.2 Ground segments

The ground segments is comprised of three major subsystem: Two Master Control Station (MCS), Twenty six Ground Monitoring Station (GMS), and network communication subsystem (NCS). MCS is responsible for all aspects of MSAS operation.

3.3 User segment

The aviation users depend on MSAS for increased accuracy and integrity for navigation, aircraft/ground system based on airborne surveillance and safe operation.

4 MSAS signal structure

MSAS signals are compliant to the ICAO SARPs.

The MSAS broadcast shall consist of two single carrier frequency of 1 575.42 MHz (L1) and 1 176.45 MHz (L5).

The L1 signal consists of a bi-phase shift keying modulation (BPSK) signal. The L1 signal is modulated with PRN spreading codes having a clock rate of 1.023 MHz and is Modulo-2 added to a 500 Symbol/s binary navigation data stream prior to BPSK.

The L5 signal consists of two BPSK signals (I and Q) multiplexed in quadrature and one QPSK signal. The signals in both I and Q channels are modulated with two different L5 spreading codes. Both of the L5 spreading codes have a clock rate of 10.23 MHz and a period of 1 ms. A 50 bit/s/100 Symbol/s binary navigation data stream is transmitted on the I channel and no data (i.e. a dataless "pilot" signal) on the Q channel. The one QPSK signal also has a clock rate of 10.23 MHz and a period of 1 ms and contains augmentation messages.

5 Signal power and spectra

Characteristics of MSAS signal transmitted from QZSS payloads are given as L1S/L5S signal in Tables 10 and 13 in Annex 4.

6 Operating frequency

MSAS space segment operated in L1 frequency at centre carrier frequency of 1 575.42 MHz with 24 MHz bandwidth, in a segment of the 1 559-1 610 MHz band allocated to the RNSS.

MSAS space segment operated in L5 frequency at centre carrier frequency of 1 176.45 MHz with 38 MHz bandwidth, in a segment of the 1 164-1 215 MHz band allocated to the Aeronautical Radio Navigation Service (ARNS).

Annex 6

Technical description and characteristics of the LM-RPS networks

1   Introduction

The LM-RPS networks consist of multichannel RNSS payload satellites in geostationary orbit, and two ground uplink stations (GUS) supporting each navigational payload. The current implementation has a satellite located at 133° W longitude (WL) and a second satellite located at 107.3° WL.

The LM-RPS networks at 107.3° WL and 133° WL provide a unique broadcast RNSS service to the United States of America (US) Federal Aviation Administration (FAA) by providing a broadcast which covers the US National Airspace System (NAS). The LM-RPS networks are part of the FAA's Wide Area Augmentation System (WAAS). Additional LM-RPS networks may be added in the future to provide similar SBAS service to aviation administrations and national airspaces in other areas of the world. The LM-RPS networks provide augmentation data, which augments the GPS data by providing integrity information on GPS broadcasts, and accuracy enhancement and augmentation to the GPS ranging signals, for aviation users. The aviation users depend on SBAS for increased accuracy and integrity for navigation and safe operation.

2   System overview

The LM-RPS networks are operated as a commercial service providing a needed RNSS broadcast service to aviation administrations.

The LM-RPS network space stations' broadcast of the WAAS message provides required national airspace coverage with a minimal number of transmitters and eliminates a multitude of technical problems associated with ground-based augmentation systems. The LM-RPS network is a hybrid broadcast service using both FSS uplinks and RNSS downlinks thus making it slightly more complex than normal FSS broadcasts. The unformatted WAAS message data is received from the WAAS master stations by the LM-RPS ground stations on a ground communications network and verified before transmission to the satellite. The ground stations apply forward error correction on the WAAS message and time align it to the GPS broadcast sub-frame epoch and then uplink the message to the navigation payload which receives and rebroadcasts the message to the Earth's surface and aviation users in the covered national airspace systems.

3   System configuration

The LM-RPS network is comprised of two parts: the satellites or space segment and the ground stations or ground segment.

3.1   Space segment

The individual satellites, initially LM-RPS133W and LM-RPS 107.3 W, and potentially additional LM-RPS serving other areas of the world, make up the space segment of the LM-RPS networks. Each satellite operates independently, as part of the greater WAAS, to provide a reliable signal-in-space (SiS) nearly all the time (99.9995% reliability).

The satellites receive the WAAS message from one of two ground uplink stations and re-transmit it to the Earth, providing dual SiS in the coverage area. Future plans call for the addition of a third SiS to provide a very high SiS reliability (> 99.9995%).

Each Navigation Payload is a simple loop back or 'bent pipe' type transponder. Each receives the uplinked WAAS message on pair of fixed frequency channels in the 6 GHz FSS uplink band, designated LM-RPS C1 and LM-RPS C5, which are filtered and translated to the LM-RPS L1 (in the 1 559-1 610 MHz band) and LM-RPS L5 (in the 1 164-1 215 MHz band) frequencies. These are the same frequencies identified in Annex 2 as GPS L1 and GPS L5 respectively. Amplifiers and dedicated transmit antennae transmit the RNSS signals to the Earth providing global beam coverage over the entire Earth's surface to an altitude of 100 000', which encompasses the desired airspace coverage. The coverage area is defined by a cone with 8.75 degrees boresight angle.

3.2 Ground segment

Each pair of LM-RPS GUSs work as a redundant set providing one high reliability uplink to one LM-RPS satellite.

The GUSs are networked together via a land-based network which connects them to the WAAS system. The GUS communicate with each other and with the WAAS Master control station to determine which GUS is designated as the Primary GUS broadcasting the WAAS message to the navigation payload, and which is the Backup GUS. The Backup GUS broadcasts its WAAS message into a RF load and is a hot standby if the Primary should fail.

The GUS is comprised of two basic groups of equipment, network and processing equipment, and Radio-Frequency (RF) transmission equipment. The network and processing equipment receives and verifies the WAAS message data via the land-based network, and then formats it into the proper broadcast signal structure, resulting in an intermediate frequency (IF) signal at 70 MHz. The IF signal is translated to the LM-RPS C1 and C5 frequencies, amplified, and transmitted to the navigation payload by a C-band dish antenna (the RF equipment).

The GUS has an antenna to receive the navigation payload transmission (downlink) on both the LM-RPS and GPS L1 and L5 signals to calculate and correct for ionospheric delays in signal propagation time. This loop-back of the signal to the GUS from the navigation payload enables the SiS to be used for ranging to increase the availability of a navigation signal in locations and at times when insufficient GPS coverage is available. The GUS also receives the GUS transmission (6 GHz band), and the L1 and L5 satellite downlink signals to ensure that the signal was not corrupted. Corrupted signals trigger the processing equipment to switch the Primary GUS to Backup and the Backup GUS to Primary. If the signal is still corrupted the processing equipment will broadcast a do not use message in place of the WAAS augmentation message. The combination of four GUSs and two LM-RPS satellites, at 133 W and 107.3 W, ensure that one reliable SiS will be present in the NAS at nearly all times, achieving the FAA's desired reliability. Potential future LM-RPS space stations at other orbital locations, will work to provide similar reliabilities for aviation administrations in other regions.

4 LM-RPS signal

The LM-RPS networks broadcast the WAAS augmentation messages on each of the two frequencies, LM-RPS L1 and LM-RPS L5. The aviation community determines the signal structure for the SBAS messages. The SBAS messages are in the same basic format and structure, as the GPS navigational signal transmitted on these frequencies by the GPS satellites. They use a GPS format and structure since they are intended to be received by the suitably equipped user receivers like a GPS message.

The common signal structure includes a C/A code with the incorporated WAAS Message and a GPS-like Civil code. The system is designed so that either or both of the C/A and P(Y) code signals can be incorporated on the uplinks and therefore be transmitted on the LM-RPS L1 and LM-RPS L5 downlinks.

The signal format for the LM-RPS L1 broadcast is further described in the WAAS specification for L1 (FAA-E-2892B) and the signal format for the LM-RPS L5 broadcast is defined in the RTCA prepared signal specification for L5 (RTCA/DO-261).

The signal levels of the LM-RPS broadcasts on L1 and L5 channels from the LM-RPS-133W and LM-RPS-107.3W space stations are listed in Table 14. The transmit signal level decreases by approximately 3 dB from the peak, at the satellite nadir point, to edge of coverage at 8.75 degrees boresight angle. The other LM-RPS networks can be expected to perform in a similar fashion.

TABLE 14

Signal strength for the L1 and L5 signals from the LM-RPS satellites

Peak effective isotropic radiated power (dBW) [1]	LM-RPS L1	LM-RPS L5
LM-RPS-133W	36.6	33.0
LM-RPS-107.3W	34.2	34.9

[1] Peak power is at the nadir point of the transmit coverage.

5   LM-RPS operating frequencies

The LM-RPS uplink frequencies were carefully chosen to use available bandwidth in the fixed satellite service bands but not to interfere with RNSS uplinks or other FSS providers. LM-RPS uses extended C-band (6 425-6 700 MHz) uplinks for the LM-RPS-133 W and LM-RPS-107.3 W satellites. These uplink frequencies, which are regulated as FSS frequencies, are noted here for reference. For LM-RPS-133W, C1, which translates to L1, uses 6 639.27 MHz as the carrier frequency, and C5, which translates to L5, is transmitted on 6 690.42 MHz. For LM-RPS-107.3W, C1 is transmitted on 6 625.45 MHz and C5 on 6 676.45 MHz.

The downlink frequencies as previously noted are GPS-L1 on 1 575.42 MHz, and GPS-L5 1 176.45 MHz. Since they use the same frequencies as GPS, the LM-RPS signals are differentiated from the other GPS signals on L1 and L5 through the use of a unique PRN code. This is identical to the GPS system and its application of PRNs for each individual satellite. The PRN code is coordinated with the operator of the GPS system to insure compatibility with GPS and other GPS like signal broadcasts.

6   Command and telemetry spectrum

The LM-RPS satellites at 133 WL and 107.3 WL are hosted navigation payloads which operate as 'condo satellites'. They share facilities of two commercial FSS satellites. The command and telemetry functions are integrated with the spacecrafts' TT&C systems. By sharing the TT&C functions, LM-RPS does not require additional spectrum to control its satellites. Future LM-RPS satellites serving other areas of the world could operate either in a similar "condo satellite" fashion or as stand-alone satellites with dedicated TT&C frequencies in the 4/6 GHz range.

7   LM-RPS transmission parameters

Since LM-RPS transmits space-to-Earth RNSS navigation signals in two bands, LM-RPS transmission parameters are provided in two tables representing the two RNSS bands in which LM-RPS transmits navigation signals.

7.1 LM-RPS L1 transmission parameters

The key parameters of the LM-RPS L1 transmissions are presented in Table 15.

TABLE 15

LM-RPS L1 transmissions in the 1 559-1 610 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 575.42 ± 12
PRN code chip rate (Mchip/s)	1.023
Navigation data bit rates (bit/s)	250
Navigation data symbol rates (symbol/s)	500
Signal modulation method	BPSK-R(1) (see Note 1)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−158.5 (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	24.0

Notes to Table 15:

Note 1: For LM-RPS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The LM-RPS minimum received power is measured at the output of a 3 dBi linearly polarized reference user receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5-degree elevation angle or more above the Earth's horizon viewed from the Earth's surface.

7.2 LM-RPS L5 transmission parameters

The key parameters of the LM-RPS L5 transmissions are presented in Table 16.

TABLE 16

LM-RPS L5 transmissions in the 1 164-1 215 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 176.45 ± 12
PRN code chip rate (Mchip/s)	10.23
Navigation data bit rates (bit/s)	250
Navigation data symbol rates (symbol/s)	500
Signal modulation method	BPSK-R(10) (see Note 1)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−157.9 (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	24.0

Notes to Table 16:

Note 1: For LM-RPS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The LM-RPS minimum received power is measured at the output of a 3 dBi linearly polarized user reference receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5 degrees elevation angle or more above the Earth's horizon viewed from the Earth's surface.

Annex 7

Technical description of system and characteristics of transmitting space stations of the COMPASS system

1   Introduction

The COMPASS consists of a constellation of 30 non-geostationary satellites and five geostationary satellites with positions at 58.75°E, 80°E, 110.5°E, 140°E and 160°E. Each satellite transmits navigation signals in three frequency bands. These navigation signals are modulated with a predetermined bit stream, containing coded ephemeris data and time, and having a sufficient bandwidth to produce the necessary navigation precision without recourse to two-way transmission or Doppler integration. The system provides accurate three-dimensional position, velocity and time anywhere on or near the surface of the Earth.

1.1   Frequency requirements

The frequency requirements for the COMPASS system are based upon an assessment of user accuracy requirements, space-to-Earth propagation delay resolution, multipath suppression, and equipment cost and configurations. COMPASS system transmits navigation signals in three frequency bands, namely, B1, B2, B3 bands, respectively.

–   B1: 1 561.098 MHz (B1I), 1 575.42 MHz (B1C, B1A)
         B2: 1 176.45 MHz (B2a), 1 207.14 MHz (B2b) (the B2a and B2b signals are multiplexed into B2 signal centred at 1 191.795 MHz)

–   B3: 1 268.52 MHz (B3I, B3Q, B3A).

NOTE – Corresponding signal names are given in round brackets.

This frequency diversity and the wide bandwidth used by the COMPASS will increase the range accuracy for space-to-Earth propagation delay resolution and will improve the multipath suppression to increase the total accuracy.

2   System overview

The COMPASS system is a space-based, all-weather, continuous radionavigation, positioning and time-transfer system which provides extremely accurate three-dimensional position and velocity information together with a precise common time reference to suitably equipped users anywhere on or near the surface of the Earth.

The COMPASS operates on the principle of passive trilateration. The COMPASS user equipment first measures the pseudo-ranges to four satellites, computes their positions, and synchronizes its clock to COMPASS by the use of the received ephemeris and clock correction parameters. It then determines the three-dimensional user position and the user clock offset from COMPASS time by essentially calculating the simultaneous solution of four range equations.

Similarly, the three-dimensional user velocity and user clock-rate offset can be estimated by solving four range rate equations given the pseudo-range rate measurements to four satellites.

3 System segment

The system consists of three major segments: the space segment, the control segment and the user segment. The principal function of each segment is as follows.

3.1 Space segment

The space segment comprises five geostationary satellites and a constellation of 30 non-geostationary satellites, which function as 'celestial' reference points, emitting precisely time-encoded navigation signals from space. The five geostationary satellites are respectively positioned at 58.75°E, 80°E, 110.5°E, 140°E and 160°E, while two non-active spare satellites at 144.5°E and 84°E. The operational constellation of 30 non-geostationary satellites comprises 27 MEO satellites and three inclined GSO (IGSO) satellites. The 27 MEO satellites are placed in three orbital planes, nine satellites per plane, inclined approximately 55 degrees relative to the Equator and the orbit height is about 21 500 km. The three inclined GSO satellites are placed in the orbital planes inclined approximately 55 degrees relative to the Equator and the crossing longitude is about 118°E.

3.2 Control segment

The control segment performs the tracking, computation, updating and monitoring functions needed to control all of the satellites in the system on a day-to-day basis. It consists of two MCSs in China, where all data processing is performed, and some widely separated monitor stations in the area that is visible from the space segment.

The monitor stations passively track all satellites in view and measure ranging and Doppler data. These data are processed at the MCS for calculation of the satellites' ephemerides, clock offsets, clock drifts, and propagation delay and then used to generate upload messages. This updated information is transmitted to the satellites for memory storage and subsequent transmission by the satellites as part of the navigation messages to the users.

3.3 User segment

The user segment is the collection of all user sets and their support equipment. The user set typically consists of an antenna, COMPASS receiver/processor, computer and input/output devices. It acquires and tracks the navigation signal from four or more satellites in view, measures their RF transit times, phases of RF signals and Doppler frequency shifts, converts them to pseudo-ranges, carrier phases and pseudo-range rates, and solves for three-dimensional position, velocity, and system time. User equipment ranges from relatively simple, light-weight receivers to sophisticated receivers which are integrated with other navigation sensors or systems for accurate performance in highly dynamic environments.

4 COMPASS signal structure

The following provides a brief description of the COMPASS signals available for use in positioning, navigation and timing (PNT) applications.

4.1 COMPASS B1 transmissions in the frequency band 1 559-1 610 MHz

COMPASS operates three signals (B1I, B1C, B1A) in the 1 559-1 610 MHz RNSS band. The key parameters of the COMPASS B1 transmissions are presented in Table 17.

The open service (OS) B1I signal is broadcast at 1 561.098 MHz with BPSK-R(2) modulation. MEO/IGSO satellites transmit B1I signal with 50 bit/s navigation data, while GSO satellites transmit B1I signal with 500 bit/s navigation data.

The OS B1C signal and the authorized service (AS) B1A signal are broadcast at 1 575.42 MHz.

The B1C signal, transmitted by MEO and IGSO satellites, consists of pilot and data components. The pilot component $B1C_P$ uses quadrature multiplexed BOC (QMBOC) modulation, which comprises BOC(1,1) and BOC(6,1) components modulated in phase quadrature. The data component $B1C_D$ employs BOC(1,1) modulation.

QMBOC(6,1,4/33) used by $B1C_P$ has a normalized power spectral density (PSD) given by:

$$QMBOC(f) = \frac{29}{33}BOC_{1,1}(f) + \frac{4}{33}BOC_{6,1}(f)$$

The total PSD of the B1C signal is given by:

$$S(f) = \frac{1}{4}BOC_{1,1}(f) + \frac{3}{4}QMBOC(f) = \frac{10}{11}BOC_{1,1}(f) + \frac{1}{11}BOC_{6,1}(f)$$

The SBAS-B1C signal is transmitted by GSO satellites for SBAS service and adopts BPSK-R(1) modulation.

The B1A signal employs BOC(14,2) modulation and consists of pilot and data components in phase quadrature.

TABLE 17

COMPASS B1 transmissions in the 1 559-1 610 MHz band

Parameter	B1I	B1C	SBAS-B1C	B1A
Carrier frequency (MHz)	1561.098	1575.42	1575.42	1575.42
PRN code chip rate (Mchip/s)	2.046	1.023	1.023	2.046
Navigation data bit rates (bit/s)	MEO/IGSO: 50 GSO: 500	50	250	50 (MEO/IGSO) 125 (GSO)
Signal modulation method	BPSK-R(2)	QMBOC(6,1,4/33) (B1CP) BOC(1,1) (B1CD)	BPSK-R(1)	BOC(14,2)
Polarization	RHCP	RHCP	RHCP	RHCP
Minimum received power level at the output of the reference antenna (dBW)	MEO: −158.5 GSO/IGSO: −160.3 (see Note)	MEO: −158.0 IGSO: −157.7 (see Note)	GSO: −158.5 (see Note)	MEO: −156.9 GSO/IGSO: −157.7 (see Note)

Note: The minimum received power on the surface of the Earth is measured at the output of an isotropic 0 dBic receiver antenna for any elevation angle equal or above 5 degrees.

4.2 COMPASS B2 transmissions in the frequency band 1 164-1 215 MHz

COMPASS operates two signals in the 1 164-1 215 MHz RNSS band, namely, B2a and B2b, broadcast at 1 176.45 MHz and 1 207.14 MHz, respectively. An asymmetric constant envelope BOC (ACE-BOC) modulation with subcarrier rate of 15.345 MHz is employed to multiplex B2a and B2b signals into B2 signal centred on 1 191.795 MHz. The key parameters of the COMPASS B2 transmissions are presented in Table 18.

The B2a signal adopts QPSK-R(10) modulation and consists of $B2a_P$ pilot component and $B2a_D$ data component in phase quadrature. MEO/IGSO satellites transmit B2a signal for providing OS and GSO satellites transmit B2a signal for providing SBAS service.

The B2b signal adopts QPSK-R(10) modulation and consists of $B2b_I$ and $B2b_Q$ components in phase quadrature. MEO/IGSO satellites transmit B2b signal for providing OS and GSO satellites transmit B2b signal for providing precise point positioning (PPP) service.

TABLE 18

COMPASS B2 transmissions in the 1 164-1 215 MHz band

Parameter	B2			
	B2a		B2b	
	B2a$_P$	**B2a$_D$**	**B2b$_I$**	**B2b$_Q$**
Carrier frequency (MHz)	1176.45		1207.14	
PRN code chip rate (Mchip/s)	10.23			
Navigation data bit rates (bit/s)	No Data	MEO/IGSO: 100 GSO: 250	500	500
Signal modulation method	BPSK-R(10)	BPSK-R(10)	BPSK-R(10)	BPSK-R(10)
Polarization	RHCP			
Minimum received power level at the output of the reference antenna (dBW)	MEO: −154.0 GSO/IGSO: −156.3 (see Note)		MEO: −155.0 GSO/IGSO: −157.3 (see Note)	

Note: The minimum received power on the surface of the Earth is measured at the output of an isotropic 0 dBic receiver antenna for any elevation angle equal or above 5 degrees.

4.3 COMPASS B3 transmissions in the frequency band 1 215-1 300 MHz

COMPASS operates three signals (B3I, B3Q, B3A) in the 1 215-1 300 MHz RNSS band, which are all broadcast at 1 268.52 MHz. The key parameters of the COMPASS B3 transmissions are presented in Table 19.

The OS B3I signal employs BPSK-R(10) modulation. MEO/IGSO satellites transmit B3I signal with 50 bit/s navigation data, while GSO satellites transmit B3I signal with 500 bit/s navigation data.

The AS B3Q signal also employs BPSK-R(10) modulation.

The AS B3A signal employs QPSK-R(10) modulation.

TABLE 19

COMPASS B3 transmissions in the 1 215-1 300 MHz band

Parameter	B3I	B3Q	B3A
Carrier frequency (MHz)	1 268.52		
PRN code chip rate (Mchip/s)	10.23	10.23	10.23
Navigation data bit rates (bit/s)	MEO/IGSO: 50 GSO: 500	500	50
Signal modulation method	BPSK-R(10)	BPSK-R(10)	QPSK-R(10)
Polarization	RHCP		
Minimum received power level at the output of the reference antenna (dBW)	MEO: −157.3 GSO/IGSO: −159.1 (see Note)	MEO: −157.3 GSO/IGSO: −159.1 (see Note)	MEO: −157.3 GSO/IGSO: −159.1 (see Note)

Note: The minimum received power on the surface of the Earth is measured at the output of an isotropic 0 dBic receiver antenna for any elevation angle equal or above 5 degrees.

Annex 8

Technical description and characteristics of the Inmarsat navigation networks

1 Introduction

The Inmarsat navigation transponder networks consist of seven RNSS payload satellites in geostationary orbit for the provision of space capacity to SBAS systems. Four RNSS payloads are single-channel payloads on Inmarsat third-generation satellites (Inm-3) and three RNSS payloads are multichannel payloads on the Inmarsat fourth-generation satellites (Inm-4). In addition to providing service in the RNSS, the same satellites provide mobile satellite communications service in the 1.5/1.6 GHz MSS frequency bands. This information may change in the future.

The satellite orbital locations are as shown in Table 20. It should be noted that satellites may be moved from time to time, depending on overall system requirements. All emissions are coordinated in accordance with the ITU RR. The relevant advance publication, request for coordination and notification information is submitted by the United Kingdom Administration.

TABLE 20

Satellite orbital longitudes

Satellite	Orbital position
3F1	64°E
3F2	15.5°W
3F3	178°E
3F5	54°E
4F1	143.5°E
4F2	64°E
4F3	98°W

1.1 System overview

Inmarsat provides four navigation payloads for SBAS, namely two navigation payloads for the European Geostationary Navigation Overlay Service (EGNOS), one payload for the Wide Area Augmentation System (WAAS) until November 2017 and one navigation payload for the Australia and New Zealand SBAS Testbed.

In the current EGNOS, the GNSS Supervisory Agency (GSA) is utilizing one Inm-3 navigation transponder covering the Atlantic Ocean Region East (AOR-E) at 15.5°W (satellite 3F2) and one Inm-4 navigation transponder covering the Middle East and Asia region (MEAS) at 64°E (satellite 4F2).

In the WAAS, the Federal Aviation Administration (FAA) is utilizing one Inm-4 navigation transponder covering the Americas Region (AMER) at 98°W (satellite 4F3) until November 2017.

In the Australia and New Zealand SBAS Testbed, Geoscience Australia (GA) is utilizing one Inm-4 navigation transponder covering the Asia-Pacific Region (APAC) at 143.5°E (satellite 4F1).

2 System configuration

The Inmarsat navigation transponder network consists of the navigation transponders (or space segment) on Inmarsat-3 and Inmarsat-4 satellites available for SBAS functions.

2.1 Space segment

The navigation transponder on each of the Inm-3 series of satellites is a simple frequency translation or 'bent-pipe' type transponder. Each satellite receives the uplinked SBAS signal on a single fixed frequency channel within the FSS frequency band 5 925-6 700 MHz. This signal is filtered and translated to the GPS-L1 frequency (centred on 1 575.42 MHz) and is also downlinked in the FSS frequency band, 3 400-4 200 MHz.

The navigation transponders on each of the Inm-4 satellites are also simple frequency translation or 'bent-pipe' type transponders. Each satellite receives the uplinked SBAS signals on a pair of fixed frequency channels, within the FSS band 5 925-6 700 MHz. The signals are filtered and translated to the GPS-L1 frequency (centred on 1 575.42 MHz) and the GPS-L5 frequency (centred on 1 176.45 MHz).

In the case of both the Inm-3 and Inm-4 satellites, the RNSS signal is amplified and transmitted to the Earth through a 'global beam' antenna, providing coverage over the visible Earth's surface and to aircraft at an altitude of up to about 100 000 feet (about 30 000 m). These systems have been

designed to enhance the integrity and accuracy of the primary GPS and GLONASS navigation signals.

2.2 Ground segment

The associated SBAS ground infrastructure that receives the RNSS signals and computes the appropriate correction data is provided by the relevant SBAS operator before being incorporated into the uplinked signal.

3 SBAS signals

The Inmarsat navigation transponder networks transmit the SBAS augmentation messages on either the GPS-L1 frequency only (Inm-3) or both GPS-L1 and GPS-L5 frequencies (Inm-4). The aviation community determines the signal structure for the SBAS messages. The SBAS messages are in the same basic format and structure, as the GPS navigational signal transmitted on these frequencies by the GPS satellites. They use a GPS format and structure since they are intended to be received by the suitably equipped user receivers, like a GPS message.

The common signal structure includes a C/A code with the incorporated SBAS message and a GPS-like Civil code. The system is designed so that either of the C/A and P(Y) code signals can be incorporated on the uplinks and therefore be transmitted on the L1 and L5 downlinks.

The format for the L1 signal is further described in the WAAS specification for L1 (FAA-E-2892B) and the format for the L5 signal is defined in the RTCA prepared signal specification for L5 (RTCA/DO-261).

The power levels of the navigation signals transmitted on L1 and L5 from the Inm-3 and Inm-4 space stations are listed in Table 21. The transmit signal level decreases by approximately 3 dB from the peak at the satellite nadir point to the edge of coverage at about 8.75 degrees off-axis angle.

TABLE 21

Nominal [1] e.i.r.p. (dBW) of the L1 and L5 signals (beam peak)

Satellite	L1	L5
Inm-3F1	33	N/A
Inm-3F2	33	N/A
Inm-3F3	33	N/A
Inm-3F5	33	N/A
Inm-4F1	31.4	29.9
Inm-4F2	31.4	29.9
Inm-4F3	31.4	29.9

[1] As per Inmarsat ITU filings.

NOTE − Peak power is at the nadir point of the transmit coverage.

The signals are differentiated from the other GPS signals through the use of a unique PRN code. This is identical to the GPS system with its application of different PRN codes for each individual satellite. The PRN code is coordinated with the operator of the GPS system to ensure compatibility with GPS and other GPS-like signal broadcasts.

4 Command and telemetry spectrum

The navigation transponders are part of a larger satellite payload, which includes transponders providing mobile satellite services. The command and telemetry functions for the navigation part are integrated with the spacecraft's overall TT&C systems. By sharing the TT&C functions, additional spectrum to control the navigation transponders is not required.

Annex 9

Technical description and characteristics of the NIGCOMSAT SBAS network

1 Introduction

The Nigcomsat Satellite-Based Augmentation System networks (NigSAS), consists of three RNSS payload geostationary satellites. The current implementation is NIGCOMSAT-1G (42.5°E) launched into orbit on 13 May 2007. NIGCOMSAT-1A (19.2°W) and NIGCOMSAT-1D (22°E) are in the planning stage. The three satellites will have the same RNSS payloads.

2 Frequency and polarization plan

As shown in Table 22, each satellite receives the uplinked SBAS signal in the C-Band and downlinks the navigation signal in the L-Band.

TABLE 22

Channel	Frequency (MHz)	Polarization	Bandwidth (MHz)
C1-uplink	6 698.42	LHCP	4
C5-uplink	6 639.45	LHCP	20
L1-downlink	1 575.42	RHCP	4
L5-downlink	1 176.45	RHCP	20

3 User segment

NigSAS is designed to be compatible with GPS and Galileo augmentation systems. Hence it will provide integrity and correction data to GPS/Galileo-compatible receivers.

4 Ground segment

This is not applicable, since the purpose of NigSAS is to provide space capacity to existing SBAS networks.

5   Navigation service

Receive coverage on the L-Band includes Africa, West and Eastern Europe and Asia for NIGCOMSAT-1G RNSS payload.

6   Navigation signal

NigSAS transmits SBAS messages at L1 and L5 carrier frequencies that use GPS formatted structure. The modulation methods of the in-phase (I) and quadrature (Q) components of the signal are modulated depending on the choice of carrier frequency. The SBAS signal from each satellite is differentiated from other SBAS signals by the use of pseudo-random noise codes (PRN codes). The navigation data bit rate at both frequencies is 50 bit/s.

6.1   L1 signal

The L1 frequency of 1 575.42 MHz is BPSK modulated in the I channel, by the coarse acquisition L1 PRN code with a chip rate of 1.023 Mchip/s and a code length of 1 023. The choice of modulating the Q channel is left for the lessee of the RNSS payload, whose existing GNSS/SBAS network will be augmented. Table 23 provides further related information.

TABLE 23

Carrier frequency (MHz)	Designation of emission	Assigned bandwidth (MHz)	Maximum peak power (dBW)	Maximum power density (dB(W/Hz))	Antenna gain (dBi)
1 575.42	4M00X2D	4.0	17.9	−42.1	13.5
	2M20X2D	2.2	17.9	−42.1	

6.2   L5 signal

The L5 frequency of 1 176.42 MHz is modulated, in both I and Q channels, by two different L5 PRN codes. The chip rate of each L5 PRN code is 10.23 Mchip/s with a code length of 10 230. But only the in-phase component is modulated by the navigation data. The faster code rate of the L5 signal improves the autocorrelation function of the user segment. Table 24 provides further related information.

TABLE 24

Carrier frequency (MHz)	Designation of emission	Assigned bandwidth (MHz)	Maximum peak power (dBW)	Maximum power density (dB(W/Hz))	Antenna gain (dBi)
1 176.45	20M0X2D	20	16.5	−53.5	13.0
	4M00X2D	4	16.5	−43.5	

Annex 10

Technical description of the Indian Regional Navigation Satellite System (IRNSS) and the Indian SBAS System, GAGAN (GPS-Aided Geo-Augmented Navigation)

1 Introduction

India is implementing its Regional Navigation Satellite System (IRNSS) over the Indian sub-continent and adjoining areas. IRNSS shall operate in the 1 164-1 215 MHz band and possibly in the band 1 559-1 610 MHz. The baseline IRNSS constellation consists of three GSO and four Inclined GSO (I-GSO) satellites inclined at 29° E to the Equator. The baseline constellation of seven satellites is being planned to be augmented with four additional I-GSO satellites making a constellation of eleven satellites. The system is aimed at providing accurate position, navigation and timing service.

India is implementing a Space-Based Augmentation System (SBAS), GAGAN (GPS-Aided GEO-Augmented Navigation) over the Indian Airspace. The Indian SBAS GAGAN is meant to provide improved accuracy, reliability, integrity and continuity over and above the core GPS. The space segment and ground segment characteristics are similar to the other SBASs implemented, such as WAAS, over the US airspace, EGNOS over the European ECAC region and MSAS over Japan.

1.1 IRNSS and GAGAN frequency requirements

The frequency requirements of IRNSS are based on an assessment of the position, navigation and timing accuracy requirements, space-to-earth propagation delay estimates, multipath and receiver noise estimates, equipment cost and configuration.

On the L5 carrier, IRNSS transmits two signals with centre frequency 1 176.45 MHz. The signals include a Standard Positioning Service (SPS) signal with 1 MHz BPSK modulation and a Restricted Service (RS) signal with BOC(5,2) modulation.

On the L1 carrier, it is planned to transmit two signals in IRNSS with centre frequency 1 575.42 MHz. The planned signals include a SPS signal which can be either BOC(1,1) or CBOC(6,1,1/11) or TMBOC (6,1,1/11) and a RS signal which can be either $BOC_s(5,2)$ or BOC_c (4,2) or BOC_c(12,2) (one modulation scheme will be selected out of these three options depending on the coordination outcome with other GNSS operators).

The Indian SBAS GAGAN transmits GPS augmentation signals in the 1 559-1 610 MHz band (with centre frequency of 1 575.42 MHz) and in the 1 164-1 215 MHz band (with centre frequency of 1 176.45 MHz).

2 Systems overview

IRNSS is a continuous space-based all-weather radio navigation satellite system for positioning, navigation and timing service for any user equipped with a suitable receiver, anywhere in the service area.

The system operates on the principle of passive trilateration. The IRNSS user equipment measures the pseudo-ranges to four or more satellites and computes its position after synchronizing its clock with the IRNSS system time by the use of received ephemeris and clock correction parameters.

It then determines the three-dimensional user position in the WGS-84 reference frame and user clock offset from the IRNSS time by essentially calculating the simultaneous solution of four ranging equations.

The three-dimensional user velocity and user clock rate offset can be estimated by solving four range rate equations given the pseudo-range rate measurements to four satellites. The measurements are termed 'pseudo' because they are made by an imprecise (low cost) user clock in the receiver and contain fixed bias terms due to receivers clock offsets from the IRNSS time.

The Indian SBAS GAGAN payloads are carried on three geostationary Indian communication satellites. The augmentation GAGAN payloads transmit corrections to the signals received from the core GPS for improved accuracy, integrity, availability and continuity.

2.1   IRNSS and GAGAN applications

The IRNSS services are meant to provide positioning, navigation and timing service for the general public and services of general interest.

3   System segments

The IRNSS and GAGAN systems consist of three major segments: the space segment, the control segment and the user segment. The principal function of each segment is as follows:

3.1   Space segment

The IRNSS space segment comprises seven satellites (three GSO satellites and four I-GSO satellites) which function as celestial reference points transmitting precisely time encoded navigation signals from space. The IRNSS constellation is visible from all points over the service area all the time. Four more I-GSO satellites are planned to be added to the constellation in the near future.

3.2   Ground segment

The IRNSS ground segment controls the entire IRNSS constellation, monitors satellite health and uploads data for subsequent broadcast to the users. The ground segment receives the satellite transmissions and the key elements such as data, clock synchronization and orbit ephemeris are calculated from measurements made by a network of ground stations deployed in the service area.

Main elements of the ground segment are given below:

–   IRNSS Satellite Control Facility (IRSCF) provides the functions of constellation management and satellite control, spacecraft housekeeping and performance monitoring and mission data uplinks.

–   Indian Navigation Centre (INC) houses the navigation software which does the functions of navigation and integrity processing and control.

–   IRNSS range and Integrity Monitoring Stations (IRIMS) are used for facilitating continuous one-way ranging of the IRNSS satellite and for integrity determination of the IRNSS constellation. These IRIMS continually track navigation signals of the IRNSS constellation and transmit data containing pseudo-range and carrier phase information to INC.

–   IRNSS Network Timing (IRNWT) facility provides stable timing reference to IRNSS.

–   IRNSS CDMA Ranging Stations (IRCDR) carry out precise two-way ranging operations.

The GAGAN ground segment consists of satellite control stations called Indian Land Uplink Stations (INLUS) and a set of Indian Reference Stations called INRESs. The data from the INRESs is collected

and analysed at the Master Control Center (MCC) and the necessary corrections are uplinked to the GAGAN navigation payloads.

3.3 User segment

The IRNSS user segment and the GAGAN user segment consist of a collection of all user sets and their support equipment. The user segment typically consists of an antenna, IRNSS/GAGAN receiver, computer and input/output device. An integrated GNSS receiver capable of receiving data from IRNSS, GAGAN, GPS, Galileo, GLONASS and other constellations is also envisaged as part of the user segment.

4 IRNSS and GAGAN signals structures

4.1 IRNSS signal structure

The IRNSS signals are centred at 1 176.45 MHz and 1 575.42 MHz. The narrowband signal is a 1 MHz BPSK signal transmitting Gold codes.

The wider IRNSS signal is modulated with BOC (5,2) modulations. The BOC modulation is a measure to form the spectral shape of a transmitted signal. BOC type signals are usually expressed in the form BOC (f_{sub}, f_{chip}) where frequencies are indicated as multiples of the chip rate of 1.023 Mchip/s.

The PSD of the BOC signal is given by:

$$G_{BOC_{\sin(f_s, f_c)}}(f) = f_c \left[\frac{\sin\left(\frac{\pi f}{2 f_s}\right)}{\cos\left(\frac{\pi f}{2 f_s}\right)} \frac{\cos\left(\frac{\pi f}{f_c}\right)}{\pi f} \right]^2$$

where:

$f_s = $ 5×1.023 MHz is the subcarrier frequency

$f_c = $ 2.0×1.023 MHz is the chip rate.

4.1.1 IRNSS signal description

TABLE 25

IRNSS L5 signal parameters

Parameter	RNSS parameter description	
	SPS	RS
Signal frequency range (MHz)	1 176.45 ± 12	
PRN code chip rates (Mchip/s)	1.023	2.046
Navigation data bitrates (bit/s)	25	
Navigation data symbol rates (symbol/s)	50	
Signal modulation method	BPSK (1 MHz)	BOC (5,2)
Polarization	RHCP	
Ellipticity (dB)	1.8 maximum	

TABLE 25 (*end*)

Parameter	RNSS parameter description	
	SPS	RS
Minimum received power level at the output of the reference antenna (dBW)	−156.37	−159.30
RF transmitter filter 3 dB bandwidth (MHz)	24	

TABLE 26

IRNSS L1 signal parameters

Parameter	RNSS parameter description	
	SPS	RS
Signal frequency range (MHz)	1 575.42 ± 12	1 575.42 ± 12 (for BOC$_s$(5,2)/BOC$_c$(4,2)) / 1 575.42 ± 15 (for BOC$_c$(12,2))
PRN code chip rates (Mchip/s)	1.023	2.046
Navigation data bit rates (bit/s)	25	
Navigation data symbol rates (symbol/s)	50	
Signal modulation method [1]	BOC (1,1)/CBOC(6,1,1/11) / TMBOC(6,1,1/11) [2]	BOC$_s$(5,2)/BOC$_c$(4,2)/ BOC$_c$(12,2)
Polarization	RHCP	
Ellipticity (dB)	1.8 maximum	
Minimum received power level at the output of the reference antenna (dBW)	−156.37 −161.74	
RF transmitter filter 3 dB bandwidth (MHz)	24	24 (for BOC$_s$(5,2)/BOC$_c$(4,2)) / 30 (for BOC$_c$(12,2))

[1] One of the modulation options will be selected based on the coordination outcome with other RNSS operators.

[2] MBOC modulation is a combination of two BOC modulation signals. Time Multiplexed BOC (TMBOC) and Composite BOC (CBOC) are two types of implementing MBOC. In TMBOC signal, two BOC signals are multiplexed in time. In CBOC signal, the signal power is shared between two BOC signals.

TMBOC(6,1,1/11) signal comprises of (i) BOC(6,1) modulation for 1/11 of the time and (ii) BOC(1,1) modulation for 10/11 of the time.

CBOC(6,1,1/11) signal comprises the sum of (i) 1/11 power of BOC(6,1) modulation and (ii) 10/11 power of BOC(1,1) modulation.

4.2 GAGAN transmissions

TABLE 27

GAGAN L1 transmissions in the 1 559-1 610 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 575.42 ± 9 (C/A)
PRN code chip rate (Mchip/s)	1.023 (C/A)
Navigation data bit rates (bit/s)	250 (C/A)
Navigation data symbol rates (symbol/s)	500 (C/A)
Signal modulation method	BPSK-R(1) (C/A)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−157.37 (C/A)
RF transmitter filter 3 dB bandwidth (MHz)	18

TABLE 28

GAGAN L5 transmissions in the 1 164-1 215 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 176.45 ± 12
PRN code chip rate (Mchip/s)	10.23
Navigation data bit rates (bit/s)	250 (L5I)
Navigation data symbol rates (symbol/s)	500 (L5I)
Signal modulation method	BPSK-R(10)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−156.3 (L5I)
RF transmitter filter 3 dB bandwidth (MHz)	24

Annex 11

Technical description and characteristics of the Korea augmentation satellite system (KASS)

1 Introduction

The Korea Augmentation Satellite System (KASS), for aviation application mainly, will be implemented by the Korean satellite in around 2022.

The KASS will transmit two carriers for GPS augmentation signals (RNSS signals). These signals include ranging information, GPS satellite status, basic differential correction (GPS satellite ephemeris and clock corrections) and precise differential correction (ionospheric corrections).

1.1 Frequency and polarization plan

The frequency requirements for the KASS are based upon GPS L1 and GPS L5 channels centred 1 575.42 MHz and 1 176.45 MHz, respectively.

The KASS RNSS function requires feeder-link frequency in uplink from ground segment to space segment. C and Ku bands will be used for feeder-link of foreign commercial operating satellites and the Korean satellite, respectively.

The frequency and polarization type for the KASS carriers are shown in Table 29.

TABLE 29

Frequency and polarization type for the KASS carriers

Carrier	Frequency (MHz)	Polarization type	Bandwidth (MHz)
L1	1 575.42	RHCP	24
L5	1 176.45	RHCP	24

2 System overview

The space station of the KASS broadcasts GPS augmentation information to suitably equipped users anywhere on or near the Korean Peninsula.

The KASS user equipment measures GPS three-dimensional user position in a Cartesian Earth-centred, Earth-fixed (ECEF) WGS-84 coordinate system and obtain GPS integrity information generated at the KASS Processing Stations (KPS) using GPS data received at the KASS Reference Station (KRS) on real time base.

3 System segments

The KASS consists of three major segments: the space segment, the ground segment and the user segment. The principal function of each segment is as follows.

3.1 Space segment

The KASS space segment navigation payload receives and transmits RNSS signals generated by the ground segment. The Korean payloads will be located at two locations out of 91.5 E, 113 E, 116 E

and 128.2 E which have been used for the FSS (Fixed-satellite service) and BSS (Broadcasting-satellite service).

The navigation payload consists of receiving antenna for feeder-link signal uplinked from the earth stations, frequency down converter transformed from 6 GHz or 14 GHz bands to 1.5 GHz and 1.2 GHz bands, high power amplifier for user link signal, and transmitting spot beam antenna to cover the Korean Peninsula and its adjacent area.

3.2 Ground segment

The ground segment consists of the following stations:
– 7 (at least) KASS Reference Stations (KRS),
– 2 KASS Processing Stations (KPS),
– 2 KASS Control Stations (KCS), and
– 3 KASS Uplink Stations (KUS).

The ground segment, KRS, KPS, KCS and KUS will be located in Korea. With 2 KPS, SBAS service within the service area will not be disrupted due to natural disaster and other effects. KUS is a facility to receive the KASS data transmitted from the space segment and transfer it to KPS through terrestrial communication link or satellite link. KRS receives GPS L1 (1 575.42 MHz) and L5 (1 176.45 MHz) signals from GPS satellites for monitoring GPS signals as well as for calculating and correcting for ionospheric delays in signal propagation time. KRS has the function to collect the basic data required for ranging of the KASS satellites position to create the ranging data (positioning data equivalent to that of GPS) in addition to KUS functions.

3.3 User segment

User segment (KASS receiver) in the air, on the ocean and on land, determines its geographical position using GPS constellations and the KASS signal. The KASS receiver acquires more accurate ranging and correction data.

4 KASS signal structure

RNSS signals for the KASS are compatible with the GPS L1 and L5 signals and modulated carriers with centre frequencies of 1 575.42 MHz with 24.0 MHz bandwidth and of 1 176.45 MHz with 24 MHz bandwidth, respectively. The transmitted sequence is the Modulo-2 addition of the navigation message at a rate of 500 Symbols/s and the 1 023 bit pseudo-random noise code. Finally, it is modulated using BPSK scheme with the chip rate of 1.023 Mchip/s. The modulation methods of the in-phase (I) and quadrature (Q) components of the signal are modulated depending on the choice of carrier frequency.

5 Signal power and spectra

The space segment of the KASS employs one spot beam antenna that radiates appropriate power level to the KASS users. The signals transmitted on the L1 and L5 carriers are right-hand circularly polarized. Characteristics of the KASS signals transmitted from the space segment are given in Table 30.

TABLE 30

Characteristics of the KASS signals

Carrier frequency (MHz)	Assigned bandwidth (MHz)	Maximum peak power (dBW)	Antenna gain (dBi, EOC)	Maximum e.i.r.p. (dBW, EOC)
1 575.42 (L1)	24.0	13.5	18.5	32.0
1 176.45 (L5)	24.0	14.0	18.5	32.5

Annex 12

Technical description and characteristics of a system for differential correction and monitoring (SDCM)

1 Introduction

SDCM is a space-based augmentation system for GLONASS global navigation system increasing accuracy and providing integrity for positioning of maritime, aeronautical, terrestrial and space navigation users for radio signals of standard accuracy.

2 System review

SDCM contains three geostationary satellites. Orbital positions of satellites and the corresponding satellite network names filed in the ITU are provided in Table 31.

TABLE 31

Satellite orbital positions and corresponding satellite networks

Satellite network	GSO orbital position
WSDRN-M	16 W
CSDRN-M	95 E
VSSRD-2M	167 E

All frequency assignments of satellite networks given in Table 31 are recorded in the MIFR in accordance with ITU Radio Regulations.

3 System configuration

SDCM consists of two segments: space segment and ground segment.

3.1 Space segment

Space segment contains of three satellites transmissions data to SDCM users through SBAS emissions.

3.2 Ground segment

Ground segment consists of SDCM control centre, ground systems transmitting SDCM data to users, network and payload control infrastructure, and receiving earth stations for measurement collections, distributed all over the world.

4 SDCM signal

WSDRN-M, CSDRN-M and VSSRD-2M satellite networks provide data to SDCM users transmitting SBAS message format CDMA signals at 1 575.42 MHz carrier frequency with a bandwidth of 24 MHz.

The transmitted sequence is the Modulo-2 addition of the navigation message at a rate of 500 Symbols/s and the 1 023 bit pseudo-random noise code. The carrier is modulated using a BPSK scheme with a chip rate of 1.023 Mchip/s. The SDCM symbol messages have a chip rate of 500 bits/s and synchronized with a period of 1 ms of C/A code.

The peak equivalent isotropically radiated power values of the SDCM L1 C/A signal are given in Table 32.

TABLE 32

SDCM L1 signal power values transmitted from satellites

Satellite network name	GSO orbital position	Peak equivalent isotropically radiated power (dBW) [1]
WSDRN-M	16 W	33.7
CSDRN-M	95 E	33.7
VSSRD-2M	167 E	33.7

[1] Peak e.i.r.p. value corresponds to beam-pointing shifted 7° northwards from the sub-satellite point.

4.1 SDCM carrier frequency

The frequency 1 575.42 MHz is the operational frequency of SDCM L1 C/A signal downlink as was noted above. Since the SDCM L1 C/A signal uses the same frequency as GPS, SDCM L1 C/A signal is differentiated from other GPS signals in the L1 range through the use of a unique PRN code. This is identical to the GPS system and its application of PRNs for each individual satellite. The PRN code is coordinated with the operator of the GPS system to insure compatibility with GPS and other GPS-like signal broadcasts.

4.2 SDCM signal basic parameters

SDCM transmits SBAS message format CDMA in L1 frequency band in space-to-Earth direction. The basic parameters of SDCM L1 C/A signal are provided in Table 33.

TABLE 33

Basic parameters of SDCM L1 C/A signal

Parameter	Parameter value
Signal frequency range (MHz)	1 575,42 ± 12
PRN code chip rate (Mchip/s)	1.023
Navigation data bit rates (bit/s)	250
Navigation data symbol rates (symbol/s)	500
Signal modulation method	BPSK-R(1) (see Note 1)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−158.5 (see Note 2)
RF transmitter filter −3 dB bandwidth (MHz)	24

Note 1: For GPS RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The minimum received power from SDCM is measured at the output of a 0 dBi right-hand circular polarized reference user receiving antenna (located near Earth's surface) at worst normal orientation when the satellite is above a 5-degree elevation angle above the horizontal plane.

Annex 13

Technical description and characteristics of the SES SBAS network

1　　　Introduction

SES currently supports two different SBAS systems, namely the Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay Service (EGNOS), which both provide GPS signal integrity data (detailing health status of received GPS signals), allowing use in safety critical applications.

The WAAS payload on-board the SES-15 satellite at 129°W will support RNSS services to the United States (US) Federal Aviation Administration (FAA) by providing a broadcast, which covers the US National Airspace System (NAS). The FAA provides this service because it improves the ability of GPS-enabled aircraft to make precision landings and provides additional safety of flight.

The EGNOS payloads on board the SES-5 and ASTRA-5B satellites, at 5°E and 31.5°E respectively, are similar to WAAS but broadcast signals that currently provide service coverage in the European Civil Aviation Conference (ECAC) Member States[3].

It should be mentioned that the satellite orbital locations as referred above are valid as per September 2017 and that satellites may be moved from time to time, depending on overall system requirements.

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[3]　The actual beam coverage is larger as it covers the visible landmasses.

2 System overview

The WAAS payload on-board SES-15 and the EGNOS payloads on-board SES-5 and ASTRA-5B operate service links in the RNSS bands 1 164-1 215 MHz and 1 559-1 610 MHz across the visible Earth in the same frequency range as the US GPS signals, L1 (in the 1 559-1 610 MHz band) and L5 (in the 1 164-1 215 MHz band), with feeder uplinks in the United States and Europe in frequency bands as described in Table 34 below.

The WAAS and EGNOS payloads will deliver data to WAAS and EGNOS-enabled GPS receivers. This information will then be used to correct errors in the measured GPS position, improving obtainable GPS position fix accuracy from 10 metres to around 1 metre. The primary feeder uplink station for the WAAS signal will be the SES South Mountain Earth station in Somis, CA, with a 'hot' backup located in Brewster, WA. For EGNOS, the feeder uplink stations for both SES-5 and ASTRA-5B are based in Betzdorf, Luxembourg and Redu, Belgium.

The ground stations apply forward error correction to the WAAS and EGNOS messages and time align them to the GPS broadcast sub-frame epoch and then uplink these messages to the navigation payloads which receive and rebroadcast the messages to the Earth's surface and aviation users in the covered national airspace systems.

The WAAS payload will also use a tracking beacon at 3 700.2 MHz.

TABLE 34

WAAS and EGNOS feeder link bands for the L1 and L5 signals

Satellite	L1 feeder link (MHz)	L5 feeder link (MHz)
SES-15 (WAAS)	6 628.27-6 650.27	6 679.42-6 701.42
SES-5 (EGNOS)	5 840.42-5 860.42	5 778.795-5 829.795
ASTRA-5B (EGNOS)	5 823.420-5 847.420	5 725.197-5 778.393

3 System configuration

3.1 Space segment

The Navigation Payload is a simple loop back or 'bent pipe' type transponder which receives the uplinked WAAS or EGNOS message on pair of fixed frequency channels in the FSS uplink band, which are filtered and translated to the 1 559-1 610 MHz band (for the L1 signal) and the 1 164-1 215 MHz band (for the L5 signal). Amplifiers and dedicated transmit antennae transmit the RNSS signals to the Earth providing coverage over the desired airspaces.

3.2 Ground segment

The associated SBAS ground infrastructure that receives the RNSS signals and computes the appropriate correction data is provided by the relevant SBAS operator before being incorporated into the uplinked signal.

4 WAAS and EGNOS payload signal structure

The WAAS and EGNOS augmentation messages are broadcast co-frequency with the GPS L1 and L5 signals. The aviation community determines the signal structure for the SBAS messages. The

SBAS messages are in the same basic format and structure, as the GPS navigational signal transmitted on these frequencies by the GPS satellites. They use a GPS format and structure since they are intended to be received by the suitably equipped user receivers like a GPS message.

The common signal structure includes a GPS 'C/A code' with the incorporated WAAS Message and a GPS-like civil code. The system is designed so that either or both of the GPS C/A and P(Y) code signals can be incorporated on the uplinks and therefore be transmitted on the L1 and L5 downlinks.

The transmitted L1 and L5 signal levels from the WAAS and EGNOS payloads on-board the SES space stations are listed in Table 35.

TABLE 35

**Signal strength for the L1 and L5 signals from the WAAS and EGNOS
payloads on-board the SES satellites**

Peak equivalent isotropically radiated power (dBW) [1]	L1	L5
SES-15 (WAAS)	35.5	34.7
SES-5 (EGNOS)	35.7	36.6
ASTRA-5B (EGNOS)	35.7	36.6

[1]   Peak power is at the nadir point of the transmit coverage.

5   SES SBAS payloads operating frequencies

The relationship between the corresponding uplink and downlink centre frequencies for the SES WAAS and EGNOS payloads are shown in Table 36.

TABLE 36

WAAS and EGNOS centre frequencies for L1 and L5

Satellite	L1 uplink (MHz)	L1 downlink (MHz)	L5 uplink (MHz)	L5 downlink (MHz)
SES-15 (WAAS)	6 639.27	1 575.42	6 690.42	1 176.45
SES-5 (EGNOS)	5 850.42	1 575.42	5 804.295	1 191.795
ASTRA-5B (EGNOS)	5 835.42	1 575.42	5 751.795	1 191.795

Since they use the same frequencies as GPS, the SES WAAS and EGNOS payload signals are differentiated from the regular GPS L1 and L5 signals through the use of a unique PRN code. This scheme is identical to the GPS system and its application of PRNs for each individual satellite. The PRN code is coordinated with the operator of the GPS system to insure compatibility with GPS and other GPS-like signal broadcasts.

6   Command and telemetry spectrum

The SES-15 WAAS payload at 129°W and the SES-5 and ASTRA-5B EGNOS payloads at 5°E and 31.5°E respectively, are all hosted navigation payloads on-board the SES satellites and its command and telemetry functions are integrated with the spacecraft's TT&C systems.

The SES-15 WAAS payload does however operate a vertically polarized tracking beacon at 3 700.2 MHz.

7 Transmission parameters

The SES-15 WAAS payload at 129 °W and the SES-5 and ASTRA-5B EGNOS payloads at 5°E and 31.5°E respectively, transmit space-to-Earth RNSS navigation signals in two bands, which are provided in Tables 37 and 38 below, representing the two RNSS bands in which the SES hosted payloads transmit navigation signals.

7.1 L1 signal transmission parameters

The key parameters of the L1 signal transmissions are presented in Table 37.

TABLE 37

L1 signal transmissions in the 1 559-1 610 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	$1\ 575.42 \pm 11$
PRN code chip rate (Mchip/s)	1.023
Navigation data bit rates (bit/s)	250
Navigation data symbol rates (symbol/s)	500
Signal modulation method	BPSK-R(1) (see Note 1)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−158.5 (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	24.0

Notes to Table 37:

Note 1: For RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The minimum received power is measured at the output of a 3 dBi linearly polarized reference user receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5-degree elevation angle or more above the horizontal plane.

7.2 L5 signal transmission parameters

The key parameters of the L5 signal transmissions are presented in Table 38.

TABLE 38

L5 signal transmissions in the 1 164-1 215 MHz band

Parameter	Parameter value
Signal frequency range (MHz)	1 176.45 ± 11
PRN code chip rate (Mchip/s)	10.23
Navigation data bit rates (bit/s)	250
Navigation data symbol rates (symbol/s)	500
Signal modulation method	BPSK-R(10) (see Note 1)
Polarization	RHCP
Ellipticity (dB)	2.0 maximum
Minimum received power level at the output of the reference antenna (dBW)	−157.9 (see Note 2)
RF transmitter filter 3 dB bandwidth (MHz)	24.0

Notes to Table 38:

Note 1: For RNSS parameters, BPSK-R(n) denotes a binary phase shift keying modulation using rectangular chips with a chipping rate of $n \times 1.023$ (Mchip/s).

Note 2: The minimum received power is measured at the output of a 3 dBi linearly polarized user reference receiving antenna (located near ground) at worst normal orientation when the satellite is above a 5-degree elevation angle or more above the horizontal plane.

Annex 14

Technical description and characteristics of the Eutelsat SBAS Network

1   Introduction

Eutelsat will operate the next generation of the European Geostationary Navigation Overlay Service (EGNOS). The payload will be hosted on the future EUTELSAT 5 West B (E5WB) satellite with a launch due for end of 2018. E5WB will provide space capacity to ensure a better accuracy and reliability of positioning information for RNSS systems.

2   System configuration

The Eutelsat network consists of one satellite in geostationary orbit at 5° W and two ground stations.

2.1   Space segment

E5WB will use two transponders of 24 MHz bandwidth to process the uplink RNSS signal generated by the ground segment. The Eutelsat E5WB satellite receives the uplinked SBAS signals on fixed frequency channels within the 5 850-6 700 MHz frequency range. The signals are filtered and translated to two frequency ranges: the L1 signal (centred on 1 575.42 MHz) and the L5 signal

(centred on 1 176.45 MHz). The RNSS signals are transmitted to the Earth through a Global beam antenna providing coverage over the visible Earth's surface. The antenna has a maximum isotropic gain of 20 dBi and a pointing accuracy of approximately 0.2 degrees.

2.2 Ground segment

The associated SBAS ground infrastructure that receives the RNSS signals and computes the appropriate correction data is provided by the relevant SBAS operator before being incorporated into the uplinked signal. Parameters of the 9-metre antenna for feeder links in the 5 850-6 700 MHz frequency range are described in Table 39.

TABLE 39

Ground stations antenna parameters

Antenna diameter (metre)	Beamwidth (degree)	Maximum isotropic gain (dBi)	Antenna radiation pattern
9	0.39	53	29-25 log

2.3 User segment

The user segment is composed of a multitude of various terminals capable of receiving and computing data from GPS, Galileo and other RNSS constellations in combination with EGNOS data to achieve more accurate ranging and corrections.

3 Transmissions characteristics

The transmission characteristics of the L1 and L5 transmitted navigation signals are shown in Table 40.

TABLE 40

Transmission characteristics

Carrier frequency	Assigned bandwidth (MHz)	Polarization	Maximum peak power (dBW)	Antenna gain (dBi)
1 575.42 MHz (L1 signal)	24	RHCP	17	20
1 176.45 MHz (L5 signal)	24	RHCP	17	20

The SBAS messages are in the same basic format and structure as the GPS navigation signal transmitted on these frequencies by the GPS satellites. They are composed of a C/A code with the incorporated SBAS message and a P(Y) code signal which can both be incorporated on the uplinks and therefore be transmitted as L1 and L5 downlink signals in the 1 559 to 1 610 MHz and 1 164 to 1 215 MHz bands, respectively.