International Telecommunication Union

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Recommendation ITU-R M.1787

(08/2009)

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

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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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

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 217/4 and ITU-R 288/4)

(2009)

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.

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;

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

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

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

e) 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,

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 9 should be used:

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 1 should be considered as part of this Recommendation.

NOTE 1 − 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. The signal frequency range is expressed in MHz.

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°. Each satellite transmits navigation signals in three frequency bands: L1 (1.6 GHz), L2 (1.2 GHz) and L3 (1.1 GHz). The satellites 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. 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. The carrier frequencies 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 1201.7430 MHz (lowest) to 1209.7800 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)	F_K^{L1} (MHz)	F_K^{L2} (MHz)	F_K^{L3} (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

TABLE 1 (*end*)

K (No. of carrier frequency)	F_K^{L1} (MHz)	F_K^{L2} (MHz)	F_K^{L3} (MHz)
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° of the phase) navigation signals shifted in phase by 90° (in quadrature) are transmitted at each carrier frequency. They are a standard accuracy (SA) signal and a high accuracy (HA) one.

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 triangulation. 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 is 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° longitude. The orbit inclination angle is 64.8°. The satellites are equally spaced by 45° 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

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.

5 Signal power and spectra

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

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 1M02G7X	10.2 1.02	15 15	−52 −42	11
L2	10M2G7X 1M02G7X	10.2 1.02	14 14	−53 −43	10
L3[(1)]	8M19G7X 8M19G7X	8.2 8.2	15 15	−52.1 −52.1	12

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

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.navcen.uscg.gov/gps/geninfo/. Information on GPS operating in the 1 215-1 300 MHz and 1 559-1 610 MHz bands is documented in the latest version of GPS interface specification document IS-GPS-200 with its latest revision notices. Current information on GPS operating in the 1 164-1 215 MHz band is documented in the latest version of GPS interface specification IS-GPS-705 with its latest revision notices. Information on the GPS space and control segments is available in the *GPS SPS Performance Standard*.

The baseline GPS satellite constellation nominally consists of a minimum of 24 operational satellites in six 55° 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 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. Two channels centred at 1 575.42 MHz (GPS L1 signal) and 1 227.6 MHz (GPS L2 signal). A third GPS channel centred at 1 176.45 MHz (GPS L5 signal) supports civil aviation applications.

The L1 channel is used to resolve a user's location to within 22 m. A second signal transmitted on both L1 and L2 channels, provide $P(Y)$-code receivers the necessary frequency diversity and wider bandwidth for increased range accuracy for Earth-to-space propagation delay resolution and for multipath suppression to increase the total accuracy by an order of magnitude. Any combination of two or more channels can be used to provide the necessary frequency diversity and wider bandwidth for increased range accuracy for Earth-to-space propagation delay resolution and redundancy. L1 and L5 civil signals provide this capability to civil aviation receivers, and L1, L2 and L5 signals also provide this capability to commercial-grade receivers.

2 System overview

GPS is a continuous space-based, all-weather radio system, for navigation, positioning and time-transfer 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 triangulation. 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.

GPS provides the Standard Positioning Service (SPS) for civil users.

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 satellites are placed in six orbital planes inclined 55° relative to the Equator. 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 for accurate timing, the processor to store navigation data, the pseudo-random noise (PRN) signal assembly for generating the ranging signal, and the L-band transmitting antenna. Although single frequency transmissions provide basic navigation, multiple frequency transmissions permit correction of ionospheric delays in signal propagation time.

3.2 Control segment

The control segment is comprised of a Master Control Station (MCS), ground antennas, and a network of monitor stations. 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, GPS receiver/processor, computer and input/output devices. 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, and 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 three signals. The signals include L1 C/A, L1 P(Y), and L1C. L1C has two components transmitted either in phase or in quadrature. When the L1C components are transmitted in quadrature, $L1C_P$ lags $L1C_D$ by 90° of phase. One L1C component, denoted $L1C_D$, is modulated by a data message, the other, denoted $L1C_P$, is dataless (i.e. a pilot only), and the components use different ranging codes. (The dataless component improves RNSS acquisition and tracking performance.)

On the L2 carrier, GPS transmits three signals. The signals include L2 C/A, L2 P(Y), and L2C. L2C has two components which are time-multiplexed. One L2C component is modulated by a data message, the other is dataless, and the components use different ranging codes.

On the L5 carrier, GPS transmits a single signal, denoted L5. The L5 signal has two components transmitted in phase quadrature. One L5 component is modulated by a data message, the other is dataless, and the components use different ranging codes.

Tables 3, 4 and 5 list values for the key parameters of the GPS transmissions. 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 input of a receiver antenna located on the Earth’s surface.

Also included in the tables are digital signal processing parameters including the pseudo-random noise (PRN) code chipping rate and the navigation message data and symbol bit 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 two 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 3, 4 and 5 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. Transmitted signals are right-hand circularly polarized with the worst-case ellipticity shown in Tables 3, 4 and 5 for the angular range of ±14.3° from nadir.

6 GPS transmission parameters

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

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

$$BOC_{m,n}(f) = \frac{nT_{sw}}{m} \frac{sin\left(\frac{\pi f T_{sw}}{2}\right)^4}{\left(\frac{\pi f T_{sw}}{2}\right)^2} \frac{sin(n \pi f T_{sw})^2}{sin(\pi f T_{sw})^2}$$

where:

f: frequency (Hz)

T_{sw}: offset carrier's square-wave period (s); i.e. $1/(m \times 1.023)$ µs.

The BOC modulations used by GPS create additional phase transitions within each spreading PRN code chip period. The number of additional phase transitions is a function of m and n, as defined above, and is (m/n) times the PRN code chip rate.

6.1 GPS L1 transmission parameters

GPS operates several signals in the 1 559-1 610 MHz RNSS band. The signals include L1 C/A, L1C, and L1 P(Y). The L1C signal consists of two components. One component, $L1C_D$, is modulated by a data message and the other, $L1C_P$, is dataless. The key parameters of the GPS L1 transmissions are presented in Table 3.

$L1C_D$ uses a BOC(1,1) modulation. $L1C_P$ uses a modulation, referred to as 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 shown in Fig. 1 and given by:

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

FIGURE 1

PSD of L1C

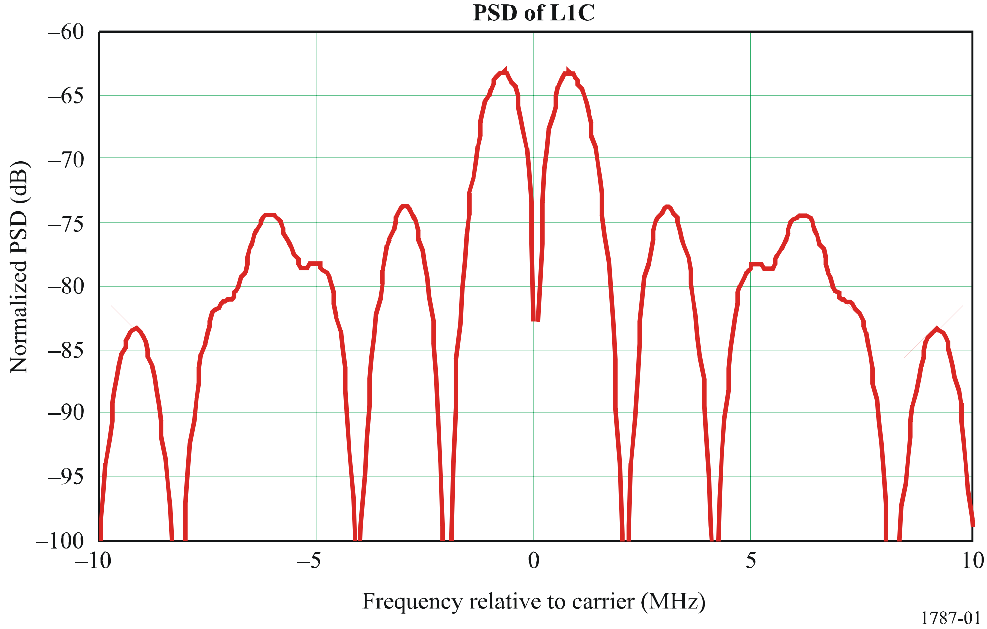

TABLE 3

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

Parameter (units)	Parameter value
Signal frequency range (MHz)	1 575.42 ± 12 (C/A, L1C$_D$, L1C$_P$ & P(Y))
PRN code chip rate (Mchip/s)	1.023 (C/A, L1C$_D$ & L1C$_P$) 10.23 (P(Y))
Navigation data bit/symbol rates (bit/s/Symbol/s)	50 bit/s/50 Symbol/s (C/A & P(Y)) 50 bit/s/100 Symbol/s (L1C$_D$)
Signal modulation method	BPSK-R(1) (C/A)| BPSK-R(10) (P(Y)) BOC(1,1) (L1C$_D$) MBOC (L1C$_P$) (See NOTE 3) (See NOTE 1)
Polarization	Right hand circular (RHCP)
Ellipticity (dB)	1.8 maximum
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)) (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). 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 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° elevation angle above the Earth's horizon viewed from the Earth's surface.

NOTE 3 – See the text of the section above this table for more details on MBOC.

6.2 GPS L2 transmission parameters

GPS operates several signals in the 1 215-1 300 MHz RNSS band. The signals include L2 C/A (rarely), L2C, and L2 P(Y). The civil L2C signal is a time-division multiplex of a navigation-data channel (simply called the data channel) and a dataless channel (also called a pilot channel). The key parameters of the GPS L2 transmissions are presented in Table 4.

TABLE 4

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

Parameter (units)	Parameter value
Signal frequency range (MHz)	1 227.6 ± 12 (C/A, L2C & P(Y))
PRN code chip rate (Mchip/s)	1.023 (C/A & L2C) 10.23 (P(Y))
Navigation data bit/symbol rates (bit/s/Symbol/s)	50 bit/s/50 Symbol/s (C/A & P(Y)) 25 bit/s/50 Symbol/s (L2C)
Signal modulation method	BPSK-R(1) (C/A & L2C) BPSK-R(10) (P(Y)) (See NOTE 1)
Polarization	Right hand circular (RHCP)
Ellipticity (dB)	3.2 maximum
Minimum received power level at the output of the reference antenna (dBW)	−164.5 (C/A & P(Y) −160.0 (L2C) (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). 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 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° elevation angle above the Earth's horizon viewed from the Earth's surface.

6.3 GPS L5 transmission parameters

GPS operates two navigation signals in the 1 164-1 215 MHz RNSS band. The signal components, L5I and L5Q, operate in quadrature and are transmitted at equal power. L5Q is dataless (also called a "pilot" channel). L5I, has navigation data providing timing, navigation, and positioning information. The key parameters of the GPS L5 transmissions are presented in Table 5.

TABLE 5

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

Parameter (units)	Parameter value
Signal frequency range (MHz)	1 176.45 ± 12
PRN code chip rate (Mchip/s)	10.23
Navigation data bit/symbol rates (bit/s/Symbol/s)	50 bit/s/100 Symbol/s (L5I)
Signal modulation method	BPSK-R(10) (See NOTE 1)
Polarization	Right hand circular (RHCP)
Ellipticity (dB)	2.4 maximum
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

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° elevation angle above the Earth's horizon viewed from the Earth's surface. The total received power for the combination of the L5I and L5Q quadrature signal is −154.9 dBW.

Annex 3

Technical description and characteristics of the Galileo system

1 Introduction

The Galileo system consists of a constellation of 30 satellite positions (27 primary satellites and three in-orbit spares) with ten satellite positions in each of the three 56° inclined equally spaced orbital planes. Each satellite transmits the same four carrier frequencies for navigational signals. These navigational signals are modulated with a structured 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 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. Four initial channels are used for Galileo operations: each Galileo satellite transmits permanently four coherent, but independently usable RF signals on (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). A total of ten signals multiplexed and modulated onto three carriers are transmitted and split into different services. The three transmissions comprise components which can be mapped to provide the “positioning/navigation/timing” (PNT)-services in different configurations. A variety of receiver configurations will adopt one or several components tailored to the applications and specific user demands. All signal components (carriers, sub-carriers, ranging codes, data bit rates) are coherently derived from an on-board common atomic clock generator.

This frequency diversity and the wide bandwidth used by Galileo 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

Galileo 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 system operates on the principle of passive triangulation. The Galileo user equipment first measures the pseudo-ranges to four satellites, computes their positions, and synchronizes its clock to Galileo System Time by the use of the received ephemeris and clock correction parameters. It 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

“Safety of life”

The Galileo “safety-of-life service” is made available for critical applications in the aviation (from en-route navigation operations to precision approaches), rail and maritime domains.

Commercial

Galileo provides a commercial data dissemination service facilitating the development of professional applications and offering enhanced performance compared with the basic service, particularly in terms of service guarantee.

Mass market

Galileo provides an open, free basic service, mainly involving applications for the general public and services of general interest. This service addresses user communities comparable to those addressed by GPS SPS. It is interoperable with GPS.

Governmental

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

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 27 satellites (plus three spare satellites) operates in 14-hour orbits with a semi-major axis of about 30 000 km. The satellites are placed in three orbital planes inclined 56° relative to the Equator. There are ten satellites per plane.

3.2 Ground segment

The Galileo ground segment controls the entire Galileo constellation, monitoring of satellite health and up-loading data for subsequent broadcast to users. The key elements of this data, clock synchronization and orbit ephemeris, will be calculated from measurements made by a worldwide network of stations.

The ground segment provides the following functions:

– constellation management and satellite control;
– navigation and integrity processing and control;
– spacecraft housekeeping and performance monitoring (TTC);
– mission data uplinks.

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, Galileo receiver/processor, computer and input/output devices. It acquires and tracks the navigation signal from all satellites in view, converts them to pseudo-ranges and pseudo-range rates, and solves for three-dimensional position, velocity, and system time.

4 Galileo signal structure

The following provides a brief description of the Galileo signals available for use in navigation and timing applications.

a) Galileo E1

The Galileo E1 signal is centred on 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), the “Safety-of-Life” (SoL) and the Public Regulated Service (PRS), which all include a navigation message. The Galileo E1 carrier is modulated with a MBOC modulation for the OS and SoL service, and a cosine BOCcos (15,2.5) code for the PRS.

The BOC modulation is a measure to form the spectral shape (power spectral density distribution over frequency) 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 GPS C/A code chip rate of 1.023 Mchip/s.

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

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

where $2f_s$ $f_c = n$ $f_s = 15 \times 1.023$ MHz is the subcarrier frequency and $f_c = 2.5 \times 1.023$ MHz is the chip rate.

The MBOC modulation is such that the spectrum $G_{MBOC}(f)$ of the signal equates:

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

where:

$$G_{BOC(f_s,\, f_c)}(f) = f_c \left(\frac{\tan\left(\frac{\pi f}{s f_s}\right)\sin\left(\frac{\pi f}{f_c}\right)}{\pi f} \right)^2$$

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)

b) Galileo E6

The Galileo E6 signal is transmitted on a centre frequency of 1 278.75 MHz with a bandwidth of 40 MHz.

The Galileo E6 signal provides a data dissemination channel for the Commercial Service (CS), a Public Regulated Service (PRS), both including a navigation message. The E6 carrier is modulated with a BPSK(5) code to provide the CS. The Galileo E6 carrier is also modulated with a BOCcos(10,5) code to provide the PRS (the spectrum for the Galileo E6 PRS follows the same equation as that of the E1 PRS signal above, but with $f_s = 10 \times 1.023$ MHz and $f_c = 5 \times 1.023$ MHz).

c) Galileo E5

The Galileo E5 signal is centred on a frequency of 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 is called the Galileo E5a signal, and provides a second signal (dual-frequency reception) for the open service (OS), including navigation data messages.

The side upper lobe of Galileo E5 is called the Galileo E5b signal, and provides both an Open Service (OS) and “Safety-of-Life” (SoL) service, including a navigation message with a sophisticated integrity information message.

The power spectral density of the AltBOC signal is given below:

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

where:

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

5 Signal power and spectra

The minimum receiver level on the surface of the Earth, for any elevation angle equal or above 10°, based on an ideally matched and isotropic 0 dBi receiver antenna, is −152 dBW for the E5, E6 and E1 signals.

6 Operating frequency

Galileo will transmit radionavigation signals in four different operating frequencies:

- Galileo E5a: 1 164-1 188 MHz.
- Galileo E5b: 1 195-1 219 MHz.
- Galileo E6: 1 260-1 300 MHz.
- Galileo E1: 1 559-1 594 MHz.

Annex 4

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

1 Introduction

The quasi-zenith satellite system (QZSS) consists of three satellite positions with one satellite position in each of three 45° inclined equally spaced orbital planes. 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). An experimental signal (LEX) will be added, centred at 1 278.75 MHz (LEX).

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 experimental signal having a higher data rate message.

The system operates on the principle of passive triangulation. 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 time-frame.

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 three satellites operates in 24-hour orbits with an apogee of 39 970 km and a perigee of 31 602 km. Each of the three satellites is placed in its own separate orbital plane inclined 45° relative to the Equator. The orbital planes are equally separated (i.e. phased 120 apart) and the satellites are phased such that there is always one satellite visible at a high elevation angle from Japan.

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 pseudo-random noise (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 LEX 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 are modulated with two different pseudo-random noise (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 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. 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 LEX signal is also bi-phase modulated (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 right-hand circularly polarized (RHCP) with ellipticity better than 1.2 dB for L1 and better than 2.2 dB for the L2, L5 and LEX signals. The user received signal powers (URPs) for angles of arrival to satellites larger than 10° are defined under the assumption of a 0 dBi RHCP receiver antenna.

The minimum guaranteed URP for L1, L2, L5 and LEX signals are described in Tables 6, 7 and 8.

6 Operating frequency

QZSS has an L1 signal operating in a segment of 1 559-1 610 MHz, an L2 signal and an LEX 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 L1-SAIF. *The parameters of L1C have not been finalized, so L1C values shown in Table 6 are subject to change.*

TABLE 6

QZSS transmissions in the 1 559-1 610 MHz band

Parameter (units)	Parameter value
Carrier frequency (MHz)	1 575.42
PRN code chip rate (Mchip/s)	1.023
Navigation data bit/symbol rates (bit/s/Symbol/s)	50 bit/s/50 Symbol/s (C/A) 250 bit/s/500 Symbol/s (L1-SAIF) 25 bit/s/50 Symbol/s (L1C)
Signal modulation method	BPSK-R(1) (C/A & L1-SAIF) BOC(1,1) (L1C) (See NOTE 1)
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 (L1-SAIF) (See NOTE 2)
RF transmitter filter 3 dB bandwidth (MHz)	32

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). 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 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.

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 LEX.

TABLE 7

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

Parameter (units)	RNSS parameter description
Carrier frequency (MHz)	1 227.6
PRN code chip rate (Mchip/s)	1.023 (L2C)
Navigation data bit/symbol rates (bit/s/Symbol/s)	25 bit/s/50 Symbol/s (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

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° or more above the Earth's horizon viewed from the Earth's surface.

TABLE 8

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

Parameter (units)	RNSS parameter description
Carrier frequency (MHz)	1 278.75
PRN code chip rate (Mchip/s)	5.115 (LEX)
Navigation data bit/symbol rates (bit/s/Symbol/s)	2 kbit/s/250 Symbol/s (LEX)
Signal modulation method	BPSK-R(5) (LEX) (See NOTE 1)
Polarization and ellipticity (dB)	RHCP; maximum 2.2
Minimum received power level at input of antenna (dBW)	−155.7 total power (See NOTE 2)
RF transmitter filter 3 dB bandwidth (MHz)	56

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° or more above the Earth's horizon viewed from the Earth's surface.

8.3 QZSS L5 transmission parameters

QZSS will operate two navigation signals 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.

TABLE 9

QZSS transmissions in the 1 164-1 215 MHz band

Parameter (units)	RNSS parameter description
Carrier frequency (MHz)	1 176.45
PRN code chip rate (Mchip/s)	10.23
Navigation data bit/symbol rates (bit/s/Symbol/s)	50 bit/s/100 Symbol/s (L5I)
Signal modulation method	BPSK-R(10) (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) (See NOTE 2)
RF transmitter filter 3 dB bandwidth (MHz)	38.0

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° or more above the Earth's horizon viewed from the Earth's surface.

Annex 5

Technical description and characteristics of the MTSAT 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.

MTSAT (Multi-functional Transport Satellite) Satellite-based Augmentation System (MSAS) is an SBAS defined as "a wide coverage augmentation system in which the user receives augmentation information from a satellite-based transmitter". The MSAS plays the role of the RNSS function in the MTSAT.

MSAS utilizes two MTSATs to enhance the system reliability and robustness. Each MTSAT transmits one carrier frequency for GPS augmentation signals (RNSS signals). These signals include following information; ranging, GPS satellite status, basic differential correction (GPS satellite ephemeris and clock corrections) and precise differential correction (ionospheric corrections).

1.1 Frequency requirements

The frequency requirements for MSAS are based upon GPS L1 channel centred 1 575.42 MHz.

The requirement for the aeronautical navigation "safety" underscores the critical importance that other radio services not cause harmful interference to the air navigation users.

MTSAT RNSS function requires feeder-link frequency in uplink from ground earth stations (GES) to satellites, and that such use is not sufficiently protected from other FSS signals.

2 System overview

MTSAT performs MSAS space segment and broadcasts GPS augmentation information to suitably equipped users especially for the civil aviation "safety" operation.

MSAS 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 MCS using GPS data received at the Ground Monitoring Station (GMS) on real time base.

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 is a navigation payload of MTSAT and re-transmits RNSS signals generated by the ground earth station (GES). The constellation of two MTSATs operates at two geostationary orbits out of 135 E, 140 E or 145 E. MTSAT is a three-axis stabilized vehicle. The major elements of its navigation payload are receiving antenna for feeder-link signal uplinked from the ground stations, frequency down converter from 14 GHz band to 1.5 GHz band, high power amplifier for service link signal, and transmitting antenna whose shaped-beam gain pattern radiates near-uniform power to users.

3.2 Ground segments

The ground segments consist of two MCS, four ground monitoring stations (GMS), two monitor and ranging stations (MRS) and network communication subsystem (NCS). MCS is the core of MSAS and located at aeronautical satellite centres in Hitachi-ohta and Kobe. By building two stations, disruption of service due to failure of the equipment, natural disaster and effects of weather can be avoided. GMS is a facility to receive MSAS data transmitted from MTSAT and transfer it to MCSs through NCS. It receives GPS L1 and L2 (1 227.6 MHz) signals from GPS and they are used for monitoring GPS signals as well as for estimating the ionospheric delay. It is positioned in four locations, namely Sapporo, Tokyo, Fukuoka and Naha. MRS has the function to collect the basic data required for ranging of the MTSAT position to create the ranging data (positioning data equivalent to that of GPS) in addition to GMS functions. MRS is established in two locations at the eastern and southern edge of the MTSAT footprint, namely in Hawaii and in Canberra, Australia, in order to obtain high-precision orbit ranging by securing long base lines.

3.3 User segment

User segment (SBAS airborne receiver) determines the aircraft position using GPS constellations and SBAS signal. The SBAS airborne receiver acquires the ranging and correction data, and applies these data to determine the integrity and improve the accuracy of the derived position.

4 MSAS signal structure

RNSS signals for MSAS are compatible with the GPS L1 and modulated carriers with a centre frequency of 1 575.42 MHz and 2.2 MHz bandwidth. 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. It shall then be BPSK-modulated onto the carrier at a rate of 1.023 Mchip/s.

5 Signal power and spectra

MTSAT employ a shaped-beam antenna that radiates near-uniform power to MSAS users. Transmitted signals are right-hand circularly polarized. Characteristics of MSAS signal transmitted from MTSAT satellites are given in Table 10.

TABLE 10

Characteristics of MSAS signals

Carrier frequency (MHz)	Type of emission	Assigned bandwidth (MHz)	Maximum peak power (dBW)	Maximum power density (dB(W/kHz))	Antenna gain (dBi)
1 575.42	2M20G1D	2.2	13.0	−17.3	20.0
	2M20G7D	2.2	16.0	−14.3	

6 Operating frequency

MSAS space segment operated in GPS L1 frequency at centre carrier frequency of 1 575.42 MHz with 2.2 MHz bandwidth, in a segment of the 1 559-1 610 MHz band allocated to the radionavigation-satellite service.

7 Telemetry functions

There is no need for MSAS to operate telemetry signals in 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz and 5 010-5 030 MHz.

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 Space Based Augmentation System (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 fixed-satellite service (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° 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 11. The transmit signal level decreases by approximately 3 dB from the peak, at the satellite nadir point, to edge of coverage at 8.75° boresight angle. The other LM-RPS networks can be expected to perform in a similar fashion.

TABLE 11

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 12.

TABLE 12

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

Parameter (units)	Parameter value
Signal frequency range (MHz)	1 575.42 ± 12
PRN code chip rate (Mchip/s)	1.023
Navigation data bit/symbol rates (bit/s/Symbol/s)	250 bit/s/500 Symbol/s
Signal modulation method	BPSK-R(1) (See NOTE 1)
Polarization	Right hand circular
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

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° 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 13.

TABLE 13

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

Parameter (units)	Parameter value
Signal frequency range (MHz)	1 176.45 ± 12
PRN code chip rate (Mchip/s)	10.23
Navigation data bit/symbol rates (bit/s/Symbol/s)	250 bit/s/500 Symbol/s
Signal modulation method	BPSK-R(10) (See NOTE 1)
Polarization	Right hand circular
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

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° 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 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. The system provides accurate position determination in three dimensions 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. Three initial channels are used for the COMPASS operations: 1 575.42 MHz, 1 191.795 MHz, and 1 268.52 MHz. 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.

Telemetry and maintenance signals are accommodated in an allocated telemetry band.

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 triangulation. 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. 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 inclined approximately 55° relative to the Equator and the orbit height is about 21 500 km. There are nine satellites per plane. The three inclined GSO satellites are placed in the orbital planes inclined approximately 55° relative to the Equator and the crossing longitude is about 118° E. The geostationary satellites and the constellation have the same RNSS payloads.

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 MCS at Beijing, 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 navigation and timing applications.

4.1 COMPASS signals in the frequency band 1 559-1 610 MHz

COMPASS operates two signals in the 1 559-1 610 MHz RNSS band. The two signals are centred on 1 575.42 MHz.

The B1 signal uses a BOC(14,2) modulation. The B1 signal is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream. The B1 signal consists of two components in phase quadrature. One component, $B1_D$, is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream and the other component, $B1_P$, is dataless.

The B1-C signal consists of two components in phase quadrature. One component, B1-C_D, is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream and the other component, B1-C_P, is dataless.

B1-C_D uses a BOC(1,1) modulation. B1-C_P uses a MBOC modulation. 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 B1-C components is given by:

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

4.2 COMPASS signals in the frequency band 1 164-1 300 MHz

COMPASS operates four signals in the 1 164-1 300 MHz RNSS band. The signals include B2, B3 and B3-A.

The COMPASS B2 signal is centred on a frequency of 1 191.795 MHz and is generated with an AltBOC modulation of side-band sub-carrier rate of 15.345 MHz. The power spectral density of the AltBOC signal is given below:

$$G(f) = \frac{1}{2\pi^2 f^2 T_c} \frac{\cos^2(\pi f T_c)}{\cos^2(\pi f T_c / n)} \left[\cos^2\left(\pi f \frac{T_{sc}}{2}\right) - \cos\left(\pi f \frac{T_{sc}}{2}\right) - 2\cos\left(\pi f \frac{T_{sc}}{2}\right)\cos\left(\pi f \frac{T_{sc}}{4}\right) + 2 \right]$$

With $T_{sc} = \frac{1}{f_{sc}} \cdot f_{sc}$ is the subcarrier frequency, f_c the chip rate, T_c chip period and T_{sc} the period of the subcarrier.

The B2 signal consists of two components in phase quadrature. One component, $B2_D$, is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream and the other, $B2_P$, is dataless.

The B3 signal is centred on 1 268.52 MHz. The carrier is QPSK modulated with a pseudo-random noise (PRN) code having a chip rate of 10.23 Mchip/s (in I channel or Q channel), which is Modulo-2 added to a 500 bit/s binary navigation data stream prior to modulation.

The B3-A signal is also centred on 1 268.52 MHz, and uses a BOC(15,2.5) modulation. The B3-A signal consists of two components in phase quadrature. One component, B3-A_D, is modulated with a 50 bit/s/100 Symbol/s binary navigation data stream and the other, B3-A_P, is dataless.

5 Signal power and spectra

The minimum received power level on the surface of the Earth, for any elevation angle equal or more than 5°, based on an ideally matched and isotropic 0 dBi receiver antenna are as follows:

B1 signal:	−153.4 dBW for MEO network,	−155.2 dBW for GSO/IGSO network.
B1-C signal:	−156.4 dBW for MEO network,	−158.2 dBW for GSO/IGSO network.
B2 signal:	−153 dBW for MEO network,	−154.8 dBW for GSO/IGSO network.
B3/B3-A signal:	−156.5 dBW for MEO network,	−158.3 dBW for GSO/IGSO network.

Annex 8

Technical description and characteristics of the Inmarsat navigation networks

1 Introduction

The Inmarsat navigation transponder networks consist of eight RNSS payload satellites in geostationary orbit for the provision of space capacity to SBAS systems. Five 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. The information below is correct as of September 2008.

The satellite orbital locations, expected from February 2009, are as shown in Table 14. 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 14

Satellite orbital longitudes

Satellite	Orbital position
3F1	64° E
3F2	15.5° W
3F3	178° E
3F4	54° W
3F5	25° E
4F1	143.5° E
4F2	25° E
4F3	98° W

1.1 System overview

Currently Inmarsat provides two Inm-3 navigation payloads for Space-Based Augmentation Systems (SBAS), namely for the European Geostationary Navigation Overlay Service (EGNOS).

In the current EGNOS, the European Space Agency (ESA) is utilizing two Inm-3 navigation transponders over Atlantic Ocean Region East (AOR-E) at 15.5° W (satellite 3F2) and Indian West Ocean Region (IND-W) at 25° E (satellite 3F5).

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

Not applicable − Inmarsat provides space capacity for SBAS only.

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 15. 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° off-axis angle.

TABLE 15

Nominal* 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-3F4	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

* As per Inmarsat ITU filings.

NOTE 1 − 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 16, each satellite receives the uplinked SBAS signal in the C-Band and downlinks the navigation signal in the L-Band.

TABLE 16

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

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 17 provides further related information.

TABLE 17

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 18 provides further related information.

TABLE 18

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	