RECOMMENDATION ITU-R M.1088

CONSIDERATIONS FOR SHARING WITH SYSTEMS OF OTHER SERVICES OPERATING IN THE BANDS ALLOCATED TO THE RADIONAVIGATION-SATELLITE SERVICE

(Question ITU-R 83/8)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that the Global Positioning System (GPS) provides worldwide precision navigation information in three dimensions to air, land and sea-based stations;

b) that the bands 1 215-1 240 MHz and 1 559-1 610 MHz are allocated on a primary basis respectively to the radiolocation and radionavigation-satellite services and to the aeronautical radionavigation and radionavigation-satellite services in all three Regions;

c) that many administrations additionally allocate the 1 215-1 240 MHz band on a primary basis to the fixed, mobile and radionavigation services, and the 1 559-1 610 MHz band on a primary basis to the fixed service;

d) that any properly equipped earth station may receive navigation information from the GPS on a worldwide basis;

e) that because the GPS provides a radionavigation function, it is recognized as performing a safety service and thus requires special measures to ensure its freedom from harmful interference,

recommends

1. that the characteristics and system description of Annexes 1 and 2 be used in assessing sharing with the GPS.

ANNEX 1

GPS receiver characteristics (for typical, low-cost air-navigation receivers)

*L*1 carrier frequency:	1 575.42 MHz
*L*2 carrier frequency:	1 227.6 MHz
P code chip rate:	10.23 Mbit/s
C/*A* code chip rate:	1.023 Mbit/s
Navigation data rate:	50 bit/s
Undetected bit-error rate:	10^{-5}
Minimum received power level (*L*2, *P*):	–136 dBm
Minimum received power level (*L*1, *P*):	–133 dBm
Minimum received power level (*L*1, *C*/*A*):	–130 dBm
Preamplifier limiting level:	–40 dBm
Preamplifier burnout level:	30 dBm, ave. 40 dBm, peak
Overload recovery time:	1 s
RF 3-dB filter bandwidth:	± 17 MHz

RF 45-dB filter bandwidth:	± 50 MHz
Isolation between *L*1 and *L*2:	40 dB
Receiver noise figure:	3 dB
Normal acquisition I/S margin (*L*1, *C*/*A*):	24 dB
State 5 tracking I/S margin (*L*1, *C*/*A*):	31 dB
State 5 tracking I/S margin (*L*1, *P*):	41 dB

ANNEX 2

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

1. GPS system

1.1 Introduction

The Global Positioning System (GPS) will consist of 24 satellite positions with four satellite positions in each of six 55° inclined equally spaced orbital planes. Each satellite will transmit the same two 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 will provide accurate position determination in three dimensions anywhere on or near the surface of the Earth.

1.1.1 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 were selected for GPS operations: 1 575.42 MHz (*L*1) and 1 227.6 MHz (*L*2). The *L*1 channel will be used to resolve a user's location to within 150 m. A second signal transmitted on both *L*1 and *L*2 channels, provides 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. Telemetry and maintenance signals from United States based control facilities to the satellite and return will be accommodated in the allocated telemetry band in the United States of America.

GPS will provide a worldwide navigation service. The requirement for navigation safety (refer to Radio Regulation No. 953) demanded by such a service underscores the critical importance that other radio services not cause harmful interference to GPS receivers.

1.2 System overview

GPS is a space-based, all-weather, continuous radionavigation, positioning and time-transfer system which will provide 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. It then determines the three-dimensional user position in a Cartesian Earth-centred, Earth-fixed (ECEF) 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. 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.

GPS provides two navigation accuracy levels: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). For the PPS, the 95 percentile horizontal, vertical and time accuracies are 18 m, 30 m and 170 ns, respectively. The corresponding SPS accuracies are 100 m, 166 m and 330 ns. The velocity accuracy derived from PPS is almost entirely dependent on receiver design and user dynamics, but a 95 percentile accuracy of 0.2 m/s per axis can be typically achieved.

1.3. System description

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.

1.3.1 Space Segment

The Space Segment comprises the GPS satellites, which function as “celestial” reference points, emitting precisely time-encoded navigation signals from space. As currently planned, the operational constellation of 24 satellites will operate in 12 h orbits with a semi-major axis of about 26 600 km. The satellites will be placed in six orbital planes inclined 55° relative to the Equator. There will be four satellites per plane. The satellites will be optimally phased to provide visibility of at least five satellites to the users at 5° above the horizon.

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 two 1.2/1.6 GHz band frequencies to users on or near the surface of the Earth. The dual-frequency transmission is to permit correction of ionospheric delays in signal propagation time.

1.3.2 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) at Colorado Springs, Colorado (United States of America), where all data processing is performed, and five widely separated monitor stations at Ascension Island, Diego Garcia, Kwajalein, Colorado Springs and Hawaii. Co-located with three of the monitor stations are the upload ground antennas for satellite maintenance.

The monitor stations passively track all satellites in view and accumulate ranging and Doppler data. These data are processed at the MCS for calculation of the satellite’s ephemerides, clock drifts, and propagation delay and then used to generate upload messages. At least three times per day 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.

1.3.3 User Segment

The User Segment is the collection of all user sets and their support equipment. The user set typically consists of an antenna, GPS 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 and Doppler frequency shifts, converts them to pseudo-ranges and pseudo-range rates, and solves for three-dimensional position, velocity, and system time. User equipment will range from relatively simple, light-weight manpack receivers to sophisticated receivers which are integrated with other navigation sensors or systems for accurate performance in highy dynamic environments.

1.4 GPS signal structure

The GPS navigational signal transmitted from the satellites consists of two modulated carriers: *L*1 at centre frequency of 1 575.42 MHz (154 f_0) and *L*2 at centre frequency of 1 227.6 MHz (120 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.

The *L*1 signal is modulated with both a precision (*P*) and a coarse/acquisition (*C/A*) pseudo-random noise (PRN) code, each of which is modulo-2 added to a 50 bit/s binary navigation data stream prior to phase modulation. The *P* code is a long binary pseudo-random sequence of zeros and ones with a clock rate of 10.23 MHz and a period of exactly one week. Every Saturday/Sunday midnight, it restarts, serving as a running indicator of time of the week in the space vehicle. The *C/A* code is a short code, having a clock rate of 1.023 MHz and a period of exactly 1 ms.

The *L*2 signal is bi-phase modulated with either the *P* or *C/A* code, as selected by ground command. The same 50 bit/s data stream is modulo-2 added to the code prior to phase modulation as is done on the *L*1 signal. During normal operations, the *P* code will be transmitted on *L*2.

The operation of bi-phase modulation onto the carrier maps the binary PRN code sequences into sequences of plus and minus ones, and turns the modulo-2 addition into multiplication. Thus, the *L*1 and *L*2 signals transmitted by the satellite can be described as a function of time.

The functions of the 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 pair of *P* and *C/A* codes they transmit, and

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

The 50 bit/s data stream provides the navigation message which is formatted in five subframes of 6 s in length. Each subframe, consisting of ten 30-bit words starts with a telemetry word (TLM) and the *C/A* to *P* code handover word (HOW). The latter permits the *C/A* to *P* transfer to be made at the termination of any 6 s subframe. The first three subframes contain the clock correction and ephemeris data of the particular satellite being tracked. These messages are normally valid for a 4 h period.

Subframes 4 and 5 contain the almanac information that defines the less precise ephemerides of all the satellites in the constellation, as well as satellite health status, special messages, offset of GPS time from Universal Time Coordination (UTC), etc. There are 25 pages of data each for subframes 4 and 6 and they are transmitted on a rotating page basis. It therefore takes 6 s to receive one page and 2.5 min to receive all 25 data pages.

1.5 Signal power and spectra

The GPS satellites employ a shaped-beam antenna that radiates near-uniform power to system users. Transmitted signals are right-hand circularly polarized with the ellipticity for *L*1 no worse than 0.7 dB and for the *L*2 no worse than 2.0 dB for the angular range of ±14.3° from boresight. For satellite elevation angle ≥ 5°, the minimum guaranteed power is specified as –133 dBm for the *L*1 *P* code component and –130 dBm for the *L*1 *C/A* code component. The corresponding *L*2 power level carrying only *P* code is at least –136 dBm. The actual power received from the satellites is currently 4-5 dB higher than the specified values.

2. Operating frequency

Primary operation (*L*1) is in a segment of band 9 allocated to the radionavigation-satellite service.

3. Telemetry functions

The GPS is a passive system. There is no need for a navigational uplink. Therefore, spectrum is conserved by placing telemetry and housekeeping functions in bands allocated for such use.

4. Receiver characteristics

Different GPS receiver configurations are suitable for different applications having various levels of host vehicles dynamics and interference environments. The typical characteristics of an inexpensive, unsophisticated receiver are given in Annex 1.

Typical GPS user equipment is comprised of four principal components: antenna, receiver/processor, computer, and the CDU (control and display unit). The antenna in most cases is a relatively simple element providing hemispheric coverage of both *L*1 and *L*2 frequencies. This omnidirectional antenna will have no need for pointing to receive all visible satellite signals, but it will also not have much capability to discriminate spatially against interference.

The RF front end of the receiver typically consists of a bandpass filter, a preamplifier, and a multi-state down-converter. The bandpass filter is to provide rejection of out-of-band signals. To prevent high-power interference from damaging the receiver, the preamplifier/filter assembly will also have a diode limiter.

After amplification and down-conversion to a convenient IF, the receiver then generates and attempts to match the incoming code pattern for a particular satellite. The process is called correlation or code despreading. After code despreading, the receiver bandwidth is reduced whereas any interference signal will be spread by the locally generated replica code. The normal acquisition is to synchronize to the *C*/*A* signal and then transfer to *P*. This is the most vulnerable operating state of the receiver (state 1) to outside interference because it has not yet locked onto the code.

Once the code is acquired, the alignment or synchronization of the incoming signal and the locally generated replica is maintained by both the code and carrier tracking loops. With the carrier and code loops in lock, the receiver can demodulate the data, measure the pseudo-range and pseudo-range rate. This operating state of the receiver (state 5) can be maintained if the interference signal level is 41 dB higher than either *L*1 *P* or *L2 P* signal, and 31 dB higher than *L*1 *C*/*A* signal. Most receiver designs convert their correlator outputs into digital form and perform their tracking loops plus other receiver control logic with software.

5. Interference thresholds

The GPS receiver is susceptible to two forms of interference. The first interference mechanism affects the high-level limiter diode in the RF front end. The diode will saturate and prevent burnout of the following receiver stages when the peak RF power level at the receiver input equals or exceeds –40 dBm, causing a temporary loss of signal. If the average RF power at the receiver input exceeds 1 W or peak RF power exceeds 10 W, the high-level clipper diode may fail because of burnout.

The second interference mechanism affects the detection process of the GPS receiver. When the interference adds noise to the receiver it affects the acquisition and tracking performance by reducing the signal-to-noise ratio in the detection circuitry or in the tracking loops. The maximum interference level tracking performance can tolerate without significantly increasing its acquisition time is 24 dB above the *L*1 *C*/*A* signal level. By comparing this interference level to the specified minimum received *L*1 *C*/*A* signal power, the interference threshold for normal acquisition is determined to be –106 dBm. At levels above this, acquisition time becomes degraded. Similarly, the interference thresholds for state 5 operation are –92 dBm for the *L*1 *P* and –99 dBm for the *L*1 *C*/*A* signal.