RECOMMENDATION ITU-R SA.1030

TELECOMMUNICATION REQUIREMENTS OF SATELLITE SYSTEMS FOR GEODESY AND GEODYNAMICS

(Question ITU-R 143/7)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that satellite systems for geodesy and geodynamics have unique telecommunication requirements;

b) that these requirements affect assignments and other regulatory matters,

recommends

1. that the requirements and characteristics described in Annex 1 should to be taken into account in connection with frequency assignments and other regulatory matters concerning satellites systems for geodesy and geodynamics, and their interaction with services other than the Earth exploration-satellite service or the space research service.

ANNEX 1

Telecommunication requirements and characteristics of satellite systems for geodesy and geodynamics

1. Introduction

This Recommendation applies to satellite systems in which one or more satellites are linked to earth stations and/or to each other by means of high-precision range and range-rate measurements, using radio waves.

There are other satellite systems which contribute to the advancement of geodesy and geodynamics:

– range measurements by pulsed laser;

– VLBI measurements on deep-space probes and celestial sources (see Recommendations on deep-space research);

– ocean altimetry using satellite-borne radar (see Recommendations on spaceborne active remote sensing);

– microwave radiometry for determining the composition of the troposphere and so correcting propagation effects on other measurements (see Recommendations on spaceborne passive remote sensing).

These various techniques are often jointly operated, with different equipments on board the same spacecraft and with earth stations colocated, that is to say close to each other and close to a geodetic fiducial point.

2. Telecommunication requirements for range and range-rate measurements

2.1 General

Space telecommunication systems for geodesy and geodynamics are generally required to perform three functions:

– high-precision orbit determination,

– high-precision positioning of points on the Earth's surface, and

– rapid data distribution (preferably, this function is performed by the system itself).

The first and second functions are closely linked. In order to position points in a geocentric reference system, it must be possible to predict or restore the satellite orbit in that reference system with a degree of accuracy comparable to that required for the positioning. Consequently, the orbit determination system used for the tracking of geodetic satellites must have better accuracy than that which is generally required for application satellites. Such an orbit determination system typically uses a fairly large number of earth stations (e.g. 10-50) distributed geographically so as to ensure continuous tracking of the satellite(s) which should always be visible from two or more stations. This network may be used also for geodetic applications, i.e. to determine parameters relating to the Earth's rotation, the geocentric coordinates of stations and the base lines linking pairs of stations.

The second function (precise absolute and relative point positioning) is generally performed with transportable ground stations or networks to be established temporarily in areas of geographical interest, sometimes in clusters of more than 20 stations within a limited region.

With respect to the third function, certain geodetic and satellite orbital parameters must be covered within a relatively short time (approximately one day). It may also be necessary to distribute *in situ* data gathered locally and orbit prediction data generated at a central facility.

2.2 Measurement telecommunications

Determination of the relative positions of earth stations and satellites or of their variation in relation to the movement of the spacecraft can be based on the measurement of:

– range,

– range rate,

– range difference (e.g. from two satellites to one earth station),

– range difference rate,

– double differential range (e.g. from each of two satellites to each of two earth stations),

– double differential range rate.

Classifying of measurement telecommunications may also be based on the number and direction of the links:

– one-way space-to-Earth,

– one-way Earth-to-space,

– one-way space-to-space (satellite-to-satellite tracking),

– two-way between earth stations and satellites,

– two-way between satellites.

2.3 Data transmission

The measurement systems listed above provide their results at one end of the system. In the case where these data are not extracted at the point where they are needed for further processing or dissemination, they have to be transmitted back to the other end of the system. Furthermore, processing the raw data might entail the addition of auxiliary data available at the other end of the link, for example:

– data on propagation conditions measured in the vicinity of the earth stations (atmospheric pressure, temperature, humidity), and added to the uplink signal;

– ephemeris data of the satellites, information on the state of the ionosphere, etc., to be distributed to the earth stations.

Three types of information can be transferred within the system:

– measurement signals,

– measurement results,

– auxiliary data.

The latter two could be multiplexed with the measurement signal or use separate links for retransmission.

3. Preferred frequency bands

3.1 RF spectrum constraints due to propagation characteristics

The usable frequency bands are limited by the characteristics of the media through which the signals pass.

– The troposphere causes both absorption loss and signal delay. Although tropospheric delay causes errors which exceed the accuracy goals of satellite geodesy and which have to be corrected in the parameter recovery process, it is not a criterion for the choice of preferred frequencies. Absorption loss significantly affects link budgets only above about 20 GHz.

– The ionosphere causes negligible absorption above about 100 MHz. The lower limit of usable frequencies is determined by the phase shift and group delay of the signals used for measurement.

Range measurement errors due to the ionosphere depend on the total electron content (TEC), which generally varies according to latitude, time, season and solar activity within a range as broad as from 1.4×10^{16} to 70×10^{16} el/m^2 and beyond that range in some regions. The direct correction of measurement errors by means of models is not very accurate owing to the great variability of the ionosphere.

In order to reduce measurement errors caused by inadequate knowledge of the ionosphere, it is necessary either to use fairly high frequencies or to merge the measurement data obtained simultaneously at a number of coherent frequencies.

For a mean TEC value of 20×10^{16} el/m^2, the gross error and residual error after correction by the combination of dual-frequency measurements are given in Table 1 for a vertical path completely traversing the ionosphere.

For an oblique path inclined at 30° in relation to the ground horizontal, the values in Table 1 should be multiplied by 1.8. At elevation angles less than 20° at 400 MHz or less than 10° at 2 000 MHz, the differential curve of the rays causes a rapid increase in residual errors.

As shown in Table 1, the combination of dual-frequency measurements considerably reduces the ionospheric error. However, if in dual-frequency systems these frequencies are not sufficiently spaced in the radio spectrum, the non-ionospheric errors grow by a factor which is, for example, between 1.2 and 1.6 for the pair 150/400 MHz and attains 3.4 for the pair 1 227/1 575 MHz.

One major conclusion that can be drawn from the above considerations is that single-frequency measurement systems are generally inadequate for high-accuracy satellite geodesy and geodynamics missions. Measurement systems for such missions require at least two frequency bands sufficiently spaced in the radio spectrum.

TABLE 1

Ionospheric error over a vertical path for TEC = 20 × 10^{16} él/m^2

Frequencies		Path measurement error		
Main frequency (MHz)	Auxiliary frequency (MHz)	Gross error at main frequency	Residual error	
			Phase delay	Group delay
400	150	50 m	0.24 m	0.48 m
2 000	400	2 m	0.42 cm	0.83 cm
1 575	1 227	3.2 m	0.15 cm	0.30 cm
8 000	2 000	12.5 cm	0.005 cm	0.01 cm

3.2 *Necessary bandwidth*

3.2.1 *Necessary bandwidth for Doppler effect measurements*

Owing to the Doppler shift, the received frequency differs from the emitted frequency by a quantity $+\Delta f$ or $-\Delta f$ depending upon whether the slant range is decreasing or increasing.

$$\Delta f = \frac{v}{\lambda} \quad \text{for one-way measurements,}$$

$$\Delta f = \frac{2v}{\lambda} \quad \text{for two-way measurements,}$$

v being the rate and λ the wavelength.

Table 2 gives the necessary bandwidth $2\Delta f$ for $v = 9$ km/s.

TABLE 2

Necessary bandwidth for measuring the Doppler effect corresponding to a range rate of 9 km/s

f (MHz)		150	400	2 000	8 000
λ (m)		2	0.75	0.15	0.0375
$2\Delta f$ (kHz)	One-way measurements	9	24	120	480
	Two-way measurements	18	48	240	960

3.2.2 *Necessary bandwidth for ranging*

Radio ranging consists of measuring the propagation phase or group delay of signals between the spacecraft and the earth station. However, the measurement is generally not taken on the carrier because of the ambiguity of $n\lambda$ (one-way) or $n\lambda/2$ (two-way). In order to remove the ambiguity, measurements are taken on signals which modulate the carrier.

Two main types of modulation are used. In one case, the phase delay of several sinusoidal signals or tones, modulating the carrier simultaneously or sequentially, is measured. The lowest frequency tone is used to remove the ambiguity, while the highest determines the range resolution. Highest modulating frequencies are typically about 1-10 MHz. However, this technique has the disadvantage of concentrating RF energy on spectrum lines and therefore its use may be difficult in some of the bands shared with services requiring protection defined in terms of spectral power-density limits.

In the other case, the group delay of a pseudo-noise code, modulated on the carrier, is measured. Here the energy is spread over a band of some 1-10 MHz.

In both cases, after modulation of the carrier, the RF bandwidth is between about 2-20 MHz. Larger bandwidths might be used in the future.

The Doppler frequency shift (see Table 2) must be added to these values.

3.2.3 Necessary bandwidth for data transmission

The data rate of the auxiliary data is in the region of some tens of bit/s. This information may be multiplexed with ranging signals.

3.3 Usable frequency bands

Telecommunication systems for satellite geodesy and geodynamics are relevant to the space research service and to the earth exploration-satellite service. Furthermore, some systems operated by the radionavigation-satellite service can also be exploited for geodesy or geodynamics.

Table 3 shows some of the frequency bands currently used or envisaged for satellite geodesy and geodynamics applications.

TABLE 3

Frequency bands currently used or envisaged in satellite telecommunication systems for geodesy and geodynamics

Frequency band (MHz)	Direction	Allocation
401-403	Earth-to-space	Earth exploration satellite
1 215-1 260	Space-to-Earth	Radionavigation satellite
1 559-1 610	Space-to-Earth	Radionavigation satellite
2 025-2 110	Earth-to-space	Space research and earth exploration satellite
2 200-2 290	Space-to-Earth	Space research and earth exploration satellite
7 190-7 235	Earth-to-space	Space research
8 025-8 400	Space-to-Earth	Earth exploration satellite
8 450-8 500	Space-to-Earth	Space research

Note 1 – For geodesy and geodynamics purposes the bands allocated to the radionavigation-satellite service should only be for reception.