International Telecommunication Union

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Radiocommunication Sector of ITU

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Radionavigation-satellite service applications for the 5 000-5 010 MHz and 5 010-5 030 MHz bands

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R M.2219

Radionavigation-satellite service applications for the 5 000-5 010 MHz and 5 010-5 030 MHz bands

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

(2011)

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Scope

A number of RNSS applications are planned for the 5 000-5 010 MHz and 5 010-5 030 MHz RNSS bands and this Report describes several of them for each band.

1 Background

This Report is intended to provide information on possible radionavigation-satellite service (RNSS) applications for the 5 000-5 010 MHz (Earth-to-space) and 5 010-5 030 MHz (space-to-Earth) RNSS bands. It is important to note that many of the applications contained in this Report are in the early stages of development. Further studies are required prior to implementation.

1.1 History of RNSS in the 5 000-5 030 MHz band

1.1.1 Regulatory aspects

Recent ITU-R activities relating to the RNSS bands in the 1 164-1 610 MHz range, including the number of systems and networks being considered under Resolution 609 (Rev.WRC-07) and the coordination discussions in those bands, indicate that because of the large number of satellite systems that have been filed to provide RNSS (most designed to transmit multiple signals), some frequencies in the RNSS allocations in this part of the spectrum are now at a point where little aggregate effective power flux-density (epfd) margin remains to accommodate additional signals. The 5 000-5 010 MHz (Earth-to-space) and 5 010-5 030 MHz (space-to-Earth) bands were allocated to the RNSS by WRC-2000 and confirmed by WRC-03. For the latter band, some technical and coordination requirements have been established in the ITU-R (e.g. RR Nos 5.328B and 5.443B) to facilitate compatible operation.

1.1.2 Development aspects

1.1.2.1 GPS

A few days after the 2007 World Radiocommunication Conference (WRC-07), the United States approved plans for the GPS Next Generation Operational Control System (OCX). The OCX requires use of the 5 010-5 030 MHz band for Telemetry and Command functions. For OCX, the United States is also filing for the 5 000-5 010 MHz band as a Telemetry and Command uplink band.

In May 2008, the United States approved plans for the next-generation Global Positioning System (GPS-III). GPS-III plans to use the 5 010-5 030 MHz band for Telemetry and Command functions for future GPS-III satellites. As of June 2009, the United States has formally submitted a satellite network filing to the ITU BR for RNSS use of the bands 5 000-5 010 MHz (Earth-to-space) and 5 010-5 030 MHz (space-to-Earth).

1.1.2.2 Galileo

Studies have been made by the European Space Agency (ESA) showing the advantages and the feasibility of a 5 GHz RNSS service added to the existing Galileo 1 GHz services.

1.2 Current RNSS development

1.2.1 Uplink band from 5 000 to 5 010 MHz

1.2.1.1 Galileo

The Galileo system includes in its architecture:

– a ground control segment providing system and satellite monitoring and control;

– a ground mission segment that uploads data for subsequent transmission to users of integrity messages via Galileo satellites. The key elements of this data, clock synchronization and orbit ephemeris, will be calculated from measurements made by a worldwide network of stations. Uplink to Galileo satellites is made through 5 GHz earth stations using the 5 000-5 010 MHz RNSS (Earth-to-space) allocation.

Table 1-1 of Recommendation ITU-R M.1906 provides characteristics of Galileo transmitting earth stations and characteristics of Galileo receiving space stations operating in the band 5 000-5 010 MHz.

1.2.1.2 Quasi-Zenith Satellite System

Operating in the 5 000-5 010 MHz band, the Quasi-Zenith Satellite System (QZSS) uplink feeder links will provide communications ranging, command, control and navigation message upload. The QZSS control stations are planned to be located in the Asia-Pacific Region.

1.2.1.3 GPS

Planned for operation in the 5 000-5 010 MHz band, GPS-III uplink feeder links will provide communications for system and satellite monitoring, commanding and control; updates of orbit ephemerides; and clock synchronization. See § 3.3.1.1 for more information on GPS 5 GHz uplinks.

1.2.1.4 Other RNSS satellite systems

This Report is intended to be updated as future RNSS systems are developed for the band 5 000-5 010 MHz.

1.2.2 Downlink band from 5 010 to 5 030 MHz

Compared with the environment around 1.2/1.5 GHz, the 5 GHz range offers a significantly lower level of potential interference that renders it attractive for critical applications. In addition, the impact of variation of ionospheric propagation conditions in this band is lower than in the other bands allocated to RNSS. This means that the availability of the high ranging accuracy provided by a "single frequency" receiver in the 5 GHz band is comparable to the ranging performance provided by a dual frequency receiver in the 1 GHz band.

1.2.2.1 Galileo

The Galileo Positioning System service link provides position, navigation and timing (PNT) to suitably equipped receivers.

The Galileo PNT service will provide downlinks in the 5 010-5 030 MHz band for the PNT requirements of all users. Downlinks for the 5 010-5 030 MHz band will be developed using current satellite technologies.

Galileo PNT offers two services: one with global coverage and one that makes use of spot beams, providing higher C/N_0 in specific areas.

1.2.2.2 QZSS

Operating in the 5 010-5 030 MHz band, the QZSS downlink feeder links will provide communications for system and satellite monitoring, ranging, and control. The QZSS control stations are planned to be located in the Asia-Pacific Region.

1.2.2.3 GPS

Planned for operation in the 5 010-5 030 MHz band, GPS-III downlink feeder links will provide communications for system and satellite monitoring, commanding and control; updates of orbit ephemerides; and clock synchronization. Plans are also being developed for GPS service links, providing position, navigation and timing (PNT) to properly equipped users. See § 3.3.2 for more information.

1.2.2.4 Other satellite systems

This Report is intended to be updated as future RNSS systems are developed for the band 5 010-5 030 MHz.

2 Considerations for 5 GHz RNSS signals

This section discusses some of the considerations of operating RNSS feeder uplinks in the band 5 000-5 010 MHz and feeder downlinks and user position, navigation and timing (PNT) service downlink signals in the band 5 010-5 030 MHz. The following two sections illustrate some design and implementation considerations for these signals in comparison with the operation of RNSS signals in the 1 164-1 610 MHz range.

2.1 RF environment at 5 GHz versus 1 GHz

The RF environment at 5 GHz presents increased rain, propagation and space losses relative to the environment at 1 GHz. Depending upon the specific system design, this can result in substantial increases in satellite requirements compared to 1 GHz RNSS designs, for example satellite power and mass. Also, receivers and transmitters operating at 5 GHz are more complex to design than those operating at 1 GHz. For example, the oscillator stability requirements for 5 GHz operations are more stringent than for 1 GHz. However, these challenges are offset by a corresponding set of design and implementation benefits available with 5 GHz operations. One important benefit of 5 GHz operation is that the RF environment offers reduced ionospheric delay and variation relative to the bands currently used for RNSS signals. This could significantly enhance the quality of navigation services for 5 GHz users. Another key benefit is that the smaller RF wavelength at 5 GHz facilitates the use of smaller antenna sizes for the same antenna gain. It also allows for the use of handheld multi-element antennas for multipath mitigation and interference mitigation in smaller form factors than for lower frequency RNSS applications. In addition to the benefits this represents for the RNSS Earth-based receivers and transmitters, it also facilitates the use of smaller Tracking and Command, communications and navigation antennas for the RNSS satellite payloads. While some of the necessary technology to support possible applications at 5 GHz does not currently exist, it is expected that the growth of commercial radio local area network equipment in higher frequency bands will facilitate its development.

2.2 Spectrum sharing environment at 5 GHz versus 1 GHz

For the PNT service links, the 5 010-5 030 MHz RNSS downlink band offers less spectral congestion than the RNSS bands in the 1 164-1 610 MHz range. A number of administrations have already filed for the provisioning of RNSS signals in that band. As shown in Fig. 1, both of the RNSS bands in 5 000-5 030 MHz share frequencies with a worldwide allocation for aeronautical radionavigation and aeronautical mobile-satellite (R) services, subject to agreement obtained under RR No. 9.21. However, no aeronautical systems are operating in this band.

Design of 5 GHz RNSS systems must take into account:

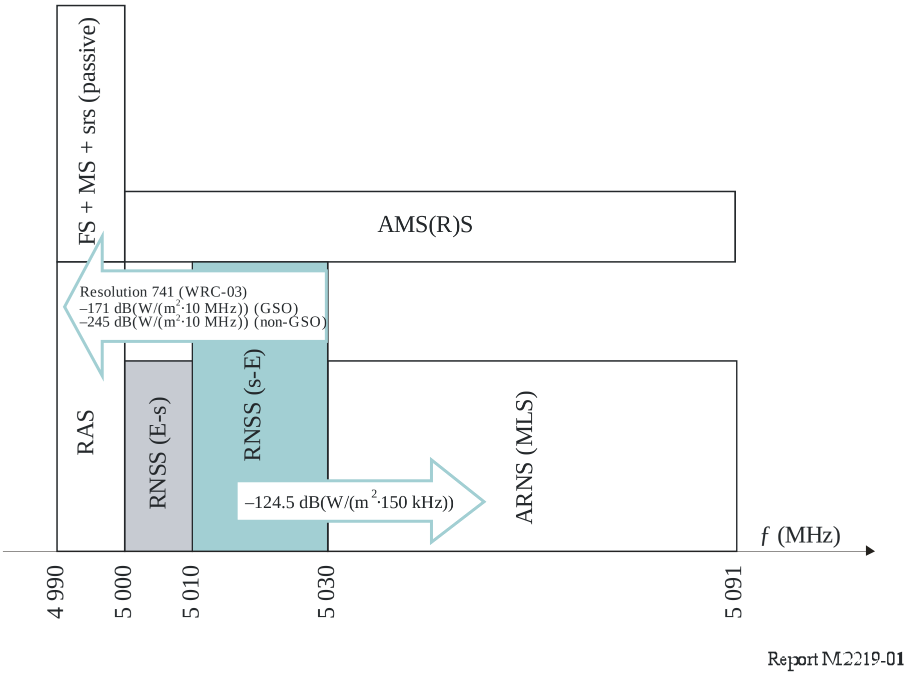
1) the ITU-R unwanted emissions requirements for compatibility with the radio astronomy service operating in 4 990-5 000 MHz;

2) the ITU-R unwanted emissions requirements for compatibility with the microwave landing systems (MLS) operating above 5 030 MHz; and

3) coordination between RNSS systems.

FIGURE 1

Spectrum sharing conditions of 5 GHz RNSS allocations



3 RNSS 5 GHz signal characteristics

3.1 Galileo

Two new services are anticipated that show advantages over present 1 GHz RNSS services. They are named Service with Precision and Robustness (SPR-C) and Regional Robust Service (RRS-C).

The signal modulation scheme is a Gaussian Minimum Shift Keying (GMSK) for both signals combined in quadrature. Table 1 shows the characteristics of both 5 GHz signals. Both 5 GHz GMSK signals are optimized for using the full 20 MHz bandwidth and allow spectral separation between the two services. GMSK signals are to be interpreted as an envelope of solutions in the sense that derived alternative signals with lower chip-rate and lower sub-carrier frequencies are included.

TABLE 1

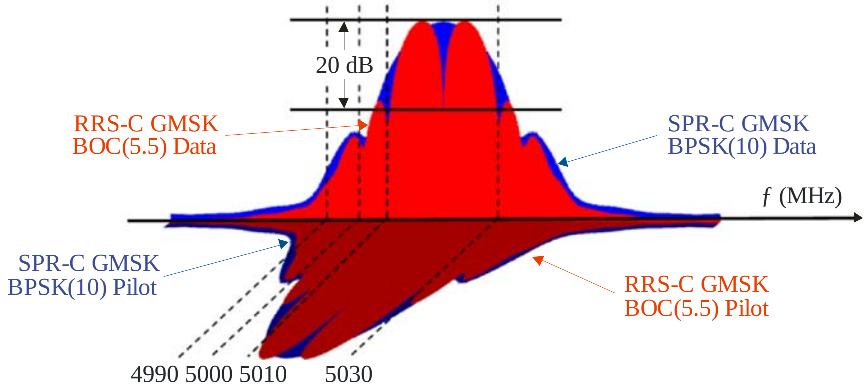
Galileo 5 GHz downlink signals

Frequency band	**5 010-5 030 MHz**			
Galileo service	**SPR**		**RRS**	
Channel	**Data**	**Pilot**	**Data**	**Pilot**
Signal type	BPSK(10)	BPSK(10)	BOC(5,5)	BOC(5,5)
Modulation	GMSK (BT_c = 0.3)	GMSK (BT_c = 0.3)	GMSK (BT_c = 0.3)	GMSK (BT_c = 0.3)
Data symbol rate	50 symbols/s	none	100 symbols/s	none
Maximum code length	51 150 chips	51 150 chips	random	random

The Galileo 5 GHz GMSK signal plan is presented in Fig. 2.

FIGURE 2

Galileo 5 GHz GMSK signal plan



3.2 QZSS

QZSS operates its feeder links in the bands 5 000-5 010 MHz and 5 010-5 030 MHz. The QZSS control stations for the first QZSS satellite are planned to be located in Okinawa.

1) 5 000-5 010 MHz band

Two Earth-to-space carriers are in operation for the first QZSS satellite. One is the command signal at 500 bit/s (including ranging) on a centre frequency of 5 004.5 MHz, and the other is the navigation message upload at 4 kbit/s on a centre frequency of 5 008.5 MHz.

The navigation message includes orbit ephemerides, clock error correction parameters, ionospheric delay correction and other differential error corrections. The messages for the L1-SAIF signal and the LEX signal require continuous and real-time updating to maintain the specified accuracy provided by these signals. Therefore, the QZSS feeder link's navigation message is to be operated on a continuous (24/7) basis.

2) 5 010-5 030 MHz band

The first QZSS satellite transmits a telemetry signal at 7.68 kbit/s (including ranging) on a centre frequency of 5 029.65 MHz.

3.3 GPS

The following sections on potential 5 GHz GPS signals describe additional useful capability for command and control, navigation, navigation-data or ranging.

3.3.1 GPS feeder link signals

GPS will have uplink and downlink feeder links in the 5 GHz bands. There is a requirement for transportable Master Control Stations (MCS). The necessary technical, regulatory and operational methods to facilitate such a system would be employed to ensure that the transportable nature of the ground station does not result in interference to other systems, including any necessary restrictions to ensure safe operation of aircraft if the MCS were to be deployed near an airport. GPS feeder uplink signals would be transmitted by these MCS and GPS feeder downlinks would be received by these MCS as described in the following two sections. Communications for feeder links may use filtered quadrature phase-shift keying (QPSK) or other bandwidth-efficient modulation.

3.3.1.1 GPS feeder uplinks

Planned for operation in the 5 000-5 010 MHz band, GPS feeder uplinks will provide communications for system and satellite monitoring, commanding and control; updates of orbit ephemerides; and clock synchronization. In particular, a 1.1 Mbit/s feeder uplink is being considered for future GPS satellites. The candidate centre frequency for this GPS feeder uplink is 5 000.605 MHz, subject to the constraints discussed under § 3.3.1 above.

3.3.1.2 GPS feeder downlinks

Planned for operation in the 5 010-5 030 MHz band, GPS feeder downlinks could provide communications for system and satellite monitoring, commanding and control; updates of orbit ephemerides; and clock synchronization. The current plans call for a 6.6 Mbit/s downlink Telemetry and Command signal centred at 5 013.63 MHz, to support future generation GPS satellites, subject to the constraints discussed under § 3.3.1 above.

3.3.2 GPS service downlink signals

The following potential GPS position, navigation and timing (PNT) service downlink signals for the band 5 010-5 030 MHz would complement the existing 1 GHz GPS PNT signals. The candidate centre frequency for these GPS service link signals is 5 019.861 MHz. Modulation techniques for 5 GHz GPS signals include BPSK, OQPSK and QPSK, as well as filtering and different shaping methods to satisfy system requirements subject to the constraints discussed under § 3.3.1 above.

GPS position, navigation and timing (PNT) service downlinks in the 5 010-5 030 MHz band can be developed under current satellite technologies. A simple link budget calculation can show that it is well within current satellite technology to provide RNSS PNT services to RNSS users employing assumed antennas with an idealized uniform 3 dBi gain over hemispherical coverage.

A downlink signal modulation, which meets 5 GHz service link requirements, is filtered staggered quadrature phase-shift-keying with a 10 Mbit/s pseudorandom spreading code (SQPSK(10)). The SQPSK signal could have a dataless component, to aid signal acquisition, in quadrature with a data component. The filtering would provide protection for services in other bands, while the filtered SQPSK(10) still provides good characteristics for PNT and transmit power and signal generation. The signal would be circularly polarized, but whether right- or left-handed is a design choice that could depend on the polarization of other signals in the band; viz., RNSS feeder links.

It is anticipated that receivers in the 5 010-5 030 MHz band will react to interference in a manner analogous to RNSS receivers using modernized PRN codes of PNT signals; e.g. GPS L1C, L2C, and L5, operating in the 1 164-1 300 MHz and 1 559-1 610 MHz bands, and studies for compatibility and sharing with non-RNSS services are expected to proceed along similar lines.

Compared to similar systems implemented at 1.5 GHz, RNSS systems developed for the 5 GHz band would experience as much as 10 dB increased free-space path loss, as well as increased water vapour, rainfall and foliage attenuation. Also, the technology for 5 GHz is currently more expensive than for other RNSS bands.

Offsetting these drawbacks, there are some benefits to a 5 GHz implementation. The primary benefit is that the shorter wavelength makes the use of higher gain antennas and antenna arrays possible within a given antenna footprint. In fact, since the wavelength is about 30% of other RNSS bands, the diameter, physical aperture, and weight of antennas with the same gain patterns as a similar antenna in the 1.5 GHz range is reduced by roughly factors of 0.3, $(0.3)^2 = 0.09$, and $(0.3)^3 = 0.027$ respectively. This may lend itself to applications for which size and weight are strong system constraints for both user equipment and satellite payloads. This, in turn, may enable the use of adaptive antennas with the capability to increase received signal power or put nulls on RFI sources or both. Such capabilities are useful since unwanted emissions from other services could interfere with RNSS signals at short range. Such antennas however may not be suitable for all applications. In addition, since such an antenna consists of a number of antenna elements, receiver front-ends and beam-forming/steering electronics, the receiver architecture becomes complex. Another benefit to a 5 GHz implementation is the potential for improved position and timing accuracy. This is due to the reduced variability in ionospheric propagation delay.

As noted in § 2 above, no studies have concluded on how 5 GHz service links would work in the presence of RNSS feeder downlinks. Further study could include such techniques as orthogonal circular polarizations, modulations with low cross-correlation properties, and incorporating more link margin for RFI from feeder downlinks. Also, the compatibility of simultaneous feeder downlink and service link signals from different RNSS systems needs to be considered.

3.3.2.1 New GNSS acquisition assistance signal

One possible signal, which could aid in rapid acquisition of GNSS data, would be to transmit a global assistance message having a rate of 5-50 kbit/s (i.e. 100-1 000 times faster than current GPS signals). Considerations discussed in section 2 above, as well as regulatory issues, would need to be considered.

Data messages could include the following content and features:

1) Timing information (similar to the NIST WWVB transmit signal);

2) Provide assisted-GPS globally to users, even when cell phone coverage is unavailable;

3) Faster clock and ephemeris download (e.g. 100-1 000 times faster than existing means with global coverage);

4) Transmit precise timing information for acquisition assistance (as is done in cell phones);

5) Other aid to users. It is envisioned that these signals would provide enhanced navigation services. One benefit of these enhanced navigation services would be better signal acquisition performance resulting in substantially shorter time-to-first-fix. These signals may require more signal power than currently envisioned for future GPS.

3.3.2.2 New navigation signals

New 5 GHz GPS navigation signals could support a variety of applications, though cost-benefit studies have not been completed. Data-plus-Pilot signal structure is expected to be selected over a purely dataless signal. A 5 GHz signal using the same modulation as used for the GPS L1C signal is being explored as well as a new signal design. In any case, sufficiently narrow signals will be used to work in the available spectrum, and fit within the constraints indicated in § 3.3.1 above. Further details will be provided as signal details are developed.

3.3.2.2.1 New SQPSK navigation signal design

A downlink signal modulation, which meets 5 GHz service link requirements, is filtered staggered quadrature phase-shift-keying with a 10 Mbit/s pseudorandom spreading code (SQPSK(10)). The SQPSK signal could have a dataless component, to aid signal acquisition, in quadrature with a data component. The filtering would provide protection for services in other bands, while the filtered SQPSK(10) still provides good characteristics for PNT and transmit power and signal generation. The signal would be circularly polarized, but whether right- or left-handed is a design choice that could depend on the polarization of other signals in the band; viz., RNSS feeder links.

3.3.2.2.2 L1C-like signal design

The L1C-like signal design maximizes interoperability with other modernized signals. Although front-end RF signal processing would take place in the 5 GHz band, digital signal processing would be essentially the same as used in the 1.6 GHz band. It remains to be determined whether performance in the 5 GHz band would be comparable to expected performance in the 1.6 GHz band.

The 5 GHz L1C-like signal has:

1) Data: BOC(1,1);

2) Pilot: TMBOC(6,1,4/33): BOC(1,1) for 29 out of 33 chips, and BOC(6,1) for 4 of 33 chips.

While the signal features and performance would be limited to those of the current L1C design in this case, this design maximizes interoperability with other modernized signals and their signal processing.

3.4 Other satellite systems

This Report will be updated as future RNSS systems are developed for the bands 5 000-5 010 MHz and 5 010-5 030 MHz.