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Spectrum monitoring techniques in the radionavigation-satellite service frequency bands

SM Series
Spectrum management

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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 SM.2454-0

Spectrum monitoring techniques in the radionavigation-satellite service frequency bands

(2019)

Overview

Hundreds of millions of people around the world use satellite navigation systems. This radionavigation-satellite service (RNSS) is the key for many applications like navigation and time-signalling. Governments, industry, and private people use the services in their daily life and in safety-critical scenarios. For these services to function, high reliability, availability and accuracy of these signals are needed.

Different radionavigation systems (from space to Earth) exist. They are either designed for global (GNSS – Global Navigation Satellite System) or regional coverage. They all have a common susceptibility to radiofrequency interference (RFI) because, relative to terrestrial-based transmitters, the received signal power on Earth is very low. Technical measures are taken to allow good signal separation from receiver noise. On the other hand, interference or excessive noise can lead to a loss of signal availability over a broad area. Such RFI can come from transmitters operating in the RNSS bands and/or in adjacent or nearby bands.

Operators of navigation satellite systems are concerned about interference to the reception of the RNSS signals and the use of illegal jammers. The International Committee on Global Navigation Satellite Systems (ICG) established the Interference Detection and Mitigation (IDM) Task Force to develop a strategy supporting mechanisms to detect and mitigate sources of electromagnetic interference. Reports of the IDM Task Force members from the European Union, China, United States of America and Russia expressed concern about the issues of interference and gave examples of negative interference impact.

Of particular concern was the increased availability and use of illegal GNSS jammers, which leads to failures in receivers. Such jammers are publicly offered for sale via the Internet and are easy to use for the consumer. Due to the low signal strength of RNSS signals on Earth, the affected area of a relatively low power jammer can be quite large.

This Report describes spectrum monitoring techniques for the RNSS frequency bands which are independent of operation of the actual RNSS systems. The purpose of the monitoring is to assess the conditions of RNSS signals reception. The techniques outlined in this Report can be used to monitor the wanted signals, detect and localize interferers, and even support studies of propagation related effects.

TABLE OF CONTENTS

Page

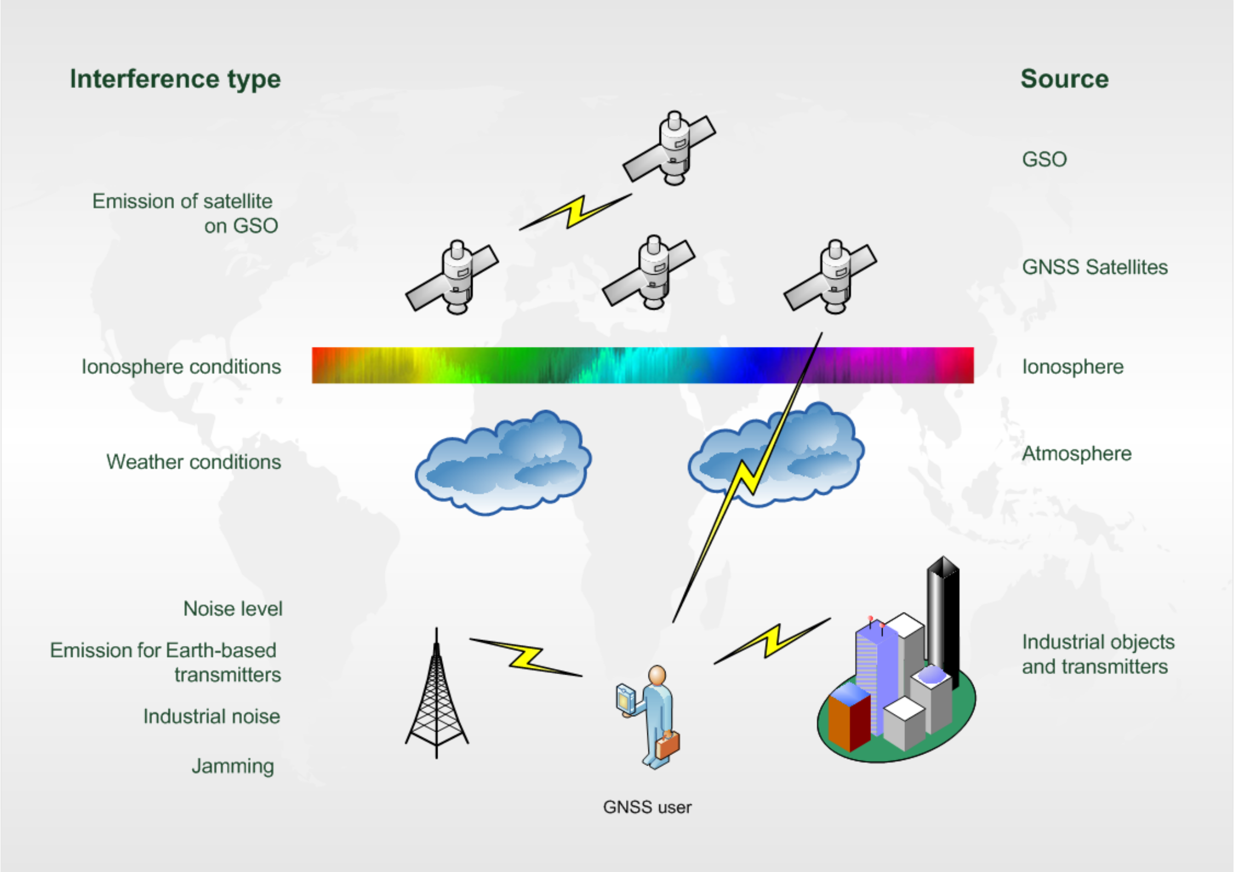
Introduction

This Report describes spectrum monitoring methods in the frequency bands used for radionavigation satellite service (RNSS).

Receivers for radionavigation services, like the global navigation satellite systems, are operated at very low signal levels, which makes them very susceptible to interference and noise. This leads to a reduction of the equipment’s timing accuracy, which ultimately leads to the device reporting incorrect position information. Due to the widespread use of these receivers, e.g. for aeronautical radionavigation, or frequency reference of radio transmitters, interference in these bands can have severe consequences. Spectrum monitoring can help protect the RNSS spectrum by detecting unwanted terrestrial emissions that may result in RNSS signal jamming. Potential sources of such emissions in these frequency bands are shown in Fig. 1.

FIGURE 1

Potential sources of emissions and interference for RNSS signals



The techniques described in this Report are well suited for the low signal levels associated with satellite-based navigation services. Furthermore, methods are shown to simplify the visualization of complex monitoring data, thus aiding the evaluation of many measurement points. This allows for the monitoring of an entire RNSS frequency band, not only a single emission.

Results of the measurements lead to conclusions on the level of electromagnetic background noise and presence of potentially harmful emissions in the frequency band at the exact location of the measurements.

The Report includes a general description of the methodology and a practical example.

1 Methodology for spectrum monitoring in the RNSS frequency bands

1.1 General description

The described method monitors the frequency spectrum, allowing the detection of the operating conditions and potential interference sources at a specific measurement location. The method considers that the reception level of RNSS signals on Earth is typically very low. Therefore, measurements are made to detect higher level signals which may be interference or high noise levels. The measurement does not only produce a single spectrum, but also indicates the direction in azimuth and (optionally) elevation of detected emissions. This results in a very large measurement data set. Nonetheless, techniques are used to reduce the measurement data to a few numbers, allowing a fast characterization of the monitoring result in the case that many measurements are to be examined.

The method is based on the use of a directional antenna. In some cases, an omnidirectional antenna may be used to complement the set of monitoring equipment and provide additional data. The measurement receiver system is typically controlled by a computer to reduce the time needed for data collection. During the measurement process, the directional antenna is used to assess the spectrum along several azimuth angles.

The method consists of the following major steps:

- obtain information about transmitting radio stations in the vicinity of the measurement location, when available;
- perform measurements, record spectra and calculate characteristic values;
- plot measurement results in diagrams;
- evaluate the results.

These steps are detailed in the following sections.

1.2 Analysis of information about transmitting radio stations in the vicinity

If possible obtain information about transmitting radio stations in the vicinity of the measurement location. The analysis of this information could help the measurement team to know if they may expect emissions from a certain direction or not.

1.3 Performing measurements, recording spectra, and calculating characteristic values

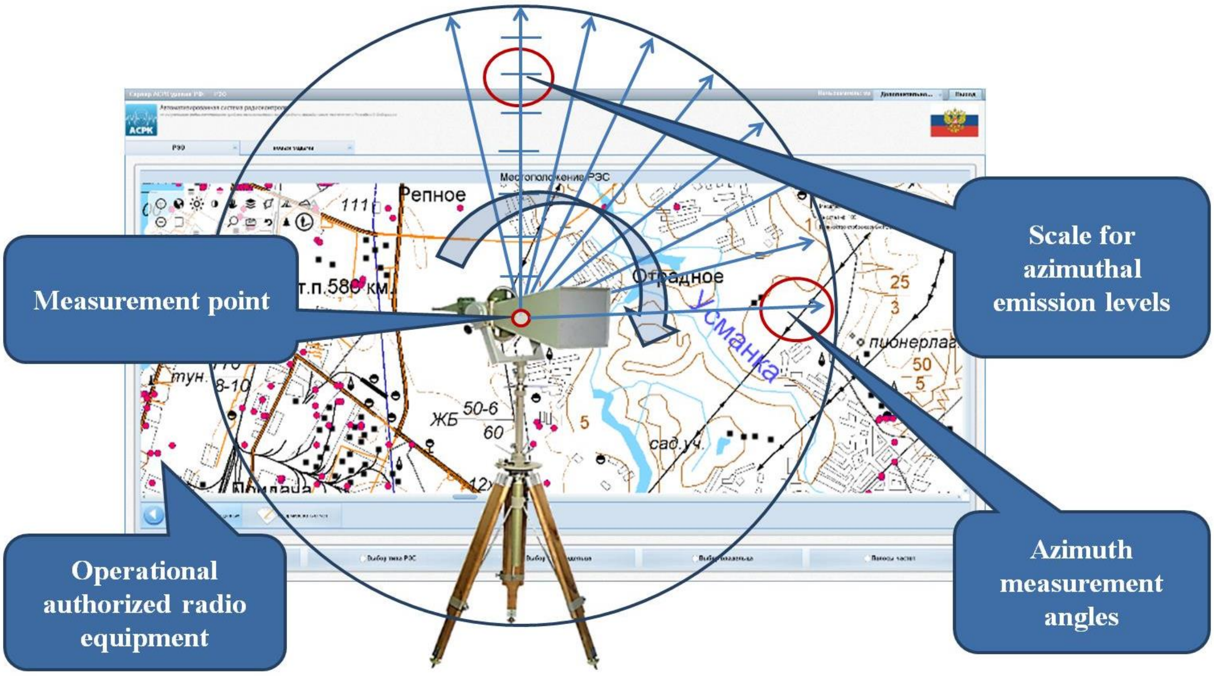
The measurements should be taken with a directional antenna mounted as shown in Fig. 2. In addition to the directional antenna, an omni-directional antenna may be used to verify the spectral measurement results by comparison.

On the measurement site, the spectrum is monitored in the chosen frequency band by rotating the directional antenna in steps by one full turn (see Fig. 2). On each step, the spectrum is recorded for further processing. The coordinates of the measurement location, the spectrum as seen on the directional antenna, time of measurement, azimuth and elevation angles of the directional antenna are all stored.

The angular resolution during this scanning-process depends on the desired spatial resolution and is limited by the antenna beam width. A typical choice is around 15 degrees.

FIGURE 2

Spatial scanning by directional antenna for measuring spectra and plotting diagrams of spatial distribution of emissions



The measurement results can be documented as shown in Table 1.

After all measurements are completed, each spectrum is characterized by three parameters (mean power, peak power and noise power) as described in the following paragraphs.

TABLE 1

Measurement conditions and measured data

№	**Measurement conditions**				**Measured data in the frequency band (directional antenna)**					
	Coordinates of measurement location	**Time of measurement**	**Measurement frequency band**	**Resolution bandwidth (RBW)**	**Azimuth**	**Elevation**	**Spectrum power level**	**Noise level power**	**Peak emission power**	**Average emission power**
	Longitude, latitude (degrees) and elevation above sea level (m)	Minute, hour, day, month, year	Minimum/ Maximum (MHz)	Hz	Degree	Degree	Set of values “frequency – power level” (data file)	dBm	dBm	dBm
1										
2										
…										
k										

1.3.1 Calculation of noise power

The noise power in the whole monitored frequency band is measured on the basis of methods specified in Recommendation ITU-R SM.1753 for each of the recorded spectra.

For calculation, the power spectrum samples are sorted in ascending order. Next, only the first 20% of samples above the minimum power level of that recording are selected and used for calculation of average value of the noise level:

$$P_n = 10log\left(\frac{1}{C}\sum_{i=1}^{C} 10^{\frac{P_i}{10}}\right) \tag{1}$$

where:

P_n: average noise power level, in dBm

C: number of elements in the first 20% of samples

P_i: value of i-th sample, in dBm.

1.3.2 Calculation of peak power

The peak power in the whole monitored frequency band is calculated for each recorded spectrum by taking the maximum value of the power spectrum samples or by using suitable marker functions of the spectrum analyser/receiver:

$$P_{peak} = MAX(P_i),\ i=1,\ldots,N \tag{2}$$

where:

P_{peak}: peak emission power, in dBm

P_i: value of the i-th sample in dBm

N: total number of samples recorded.

1.3.3 Calculation of mean power

The mean power in the whole monitored frequency band is calculated for each recorded spectrum by averaging all power spectrum samples:

$$P_{mean} = 10log\left(\frac{1}{N}\sum_{i=1}^{N} 10^{\frac{P_i}{10}}\right) \tag{3}$$

where:

P_{mean}: mean emission power in the frequency band, dBm

N: number of spectrum samples

P_i: power of i-th measured spectrum sample, dBm.

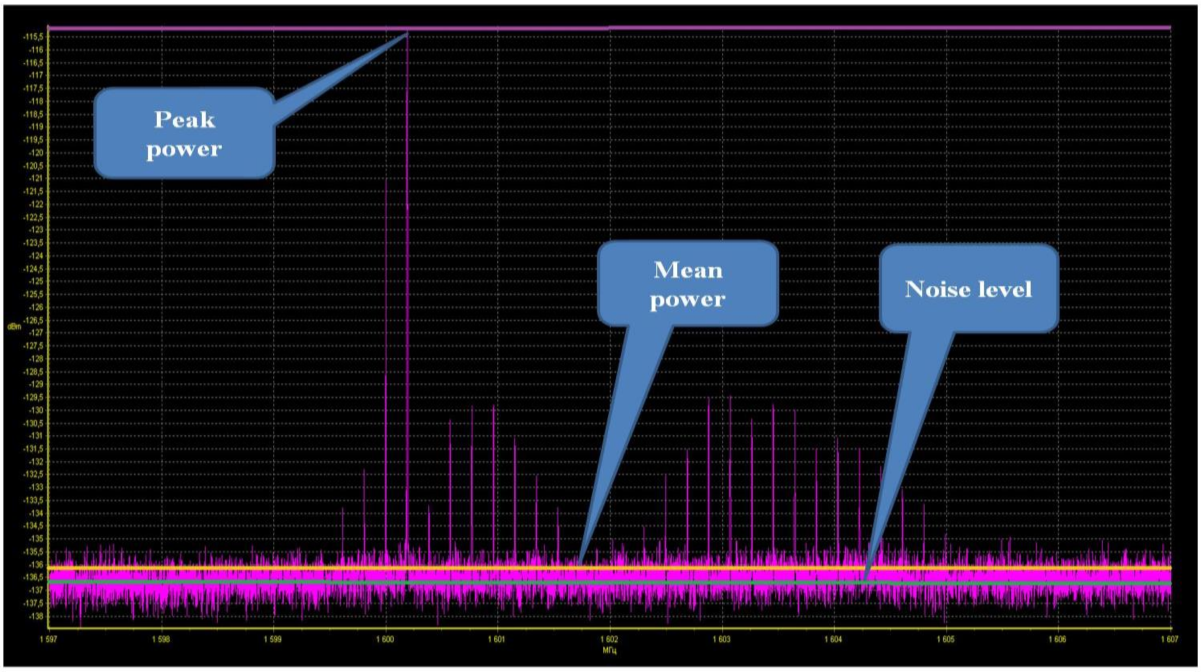
Figure 3 shows calculated integral characteristics of aggregate emissions in the monitored frequency band based on the set of spectrum power samples.

1.4 Plotting diagrams of spatial emission distribution and spectrum power arrival angles

For every recorded spectrum, a diagram is plotted, showing the recorded spectra along with the noise, peak and mean power levels calculated as described above and shown in Fig. 3.

FIGURE 3

Calculated integral characteristics of aggregate emissions in the monitored frequency band

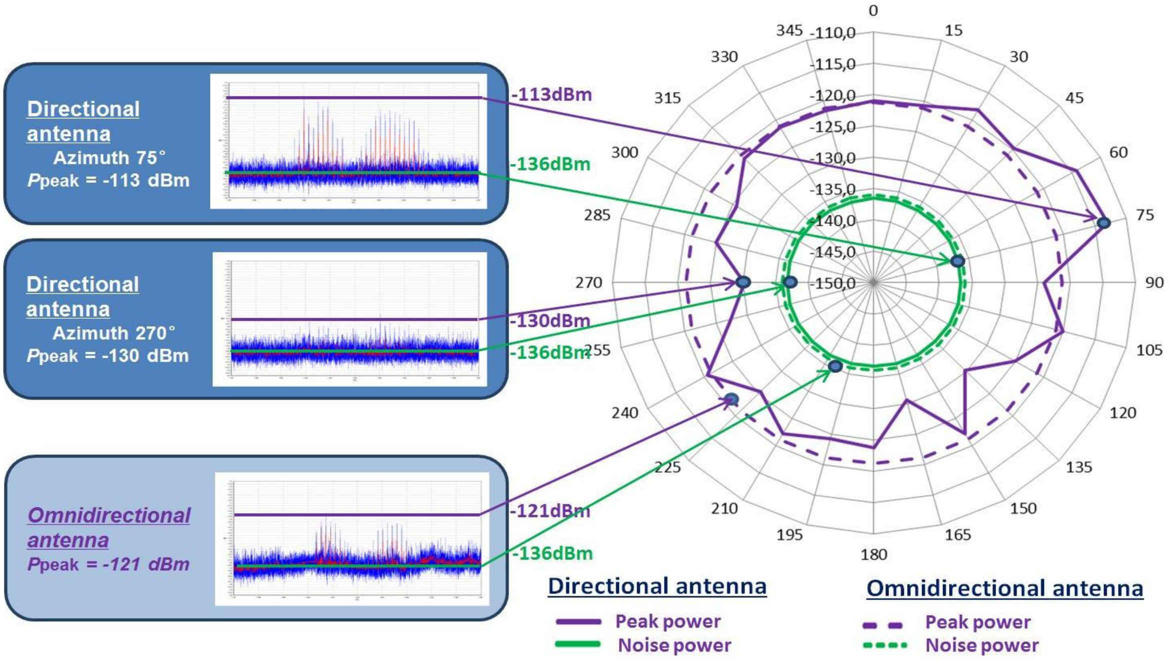


Using the three aggregate values as shown in §§ 1.3.1 to 1.3.3 from the directional and additional omnidirectional antenna, a circular diagram is constructed to represent the result of the azimuth scan. The centre of the diagram represents the measurement location. An example is shown in Fig. 4.

An even more specialized diagram to represent a hemisphere sweep with the directional antenna is shown in § 3. This allows an analysis of signals from terrestrial and space sources.

FIGURE 4

Construction of an azimuthal diagram based on the spectrum recordings at one measurement point



1.5 Result evaluation

The values and diagrams obtained from the measurements can be used to check the availability of unwanted emissions. The azimuth scan can also provide a direction towards those emissions.

Especially unwanted or interfering emissions can be identified by setting suitable threshold values regarding the peak values or an unexpected rise of noise power.

The differences between peak, mean and noise power can be normalized for easier comparison and categorization of signals. It can aid in the discovery of a potential interference signal.

2 Monitoring equipment requirements

2.1 General requirements

The operating frequency range of the measurement equipment should cover the appropriate RNSS frequency band. Table 2 shows frequency allocations for the RNSS services – GLONASS (L1, L2, L3), GPS (L1, L2, L5), Galileo (E1, E5, E6), BeiDou (B1, B2, B3).

TABLE 2

Frequency bands allocated to radionavigation satellite service

No	Frequency band (MHz)
L1, E1, B1	1 559-1 610
L2, E6, B3	1 215-1 300
L3, L5, E5, B2	1 164-1 215

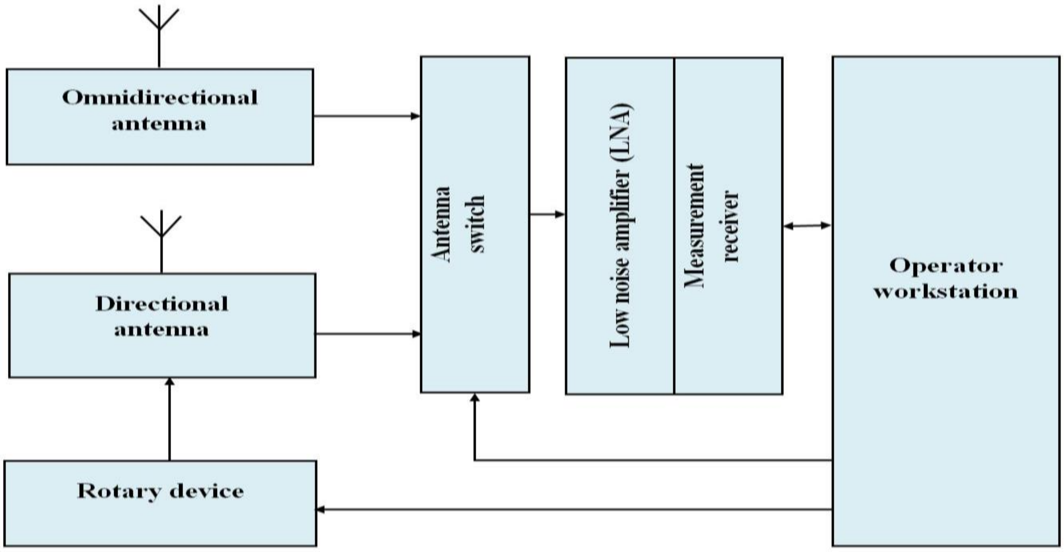
The monitoring equipment is comprised of the following elements:

- directional measurement antenna, mounted on tripod with a rotary table;
- omnidirectional antenna (optional);
- antenna switch;
- low noise amplifier (optional);
- bandpass filter (optional);
- measurement receiver or spectrum analyser;
- navigation receiver for recording measurement coordinates;
- computer with remote control interface.

Figure 5 shows a block diagram of the equipment.

FIGURE 5

Block diagram of measurement equipment



Information regarding permissible interference levels can be derived from Recommendations ITU-R M.1902, ITU-R M.1093 and ITU-R M.1905. This leads to:

- receiver sensitivity in 1 kHz bandwidth should be −115... −119 dBm;
- receiver noise in 1 Hz bandwidth (DANL) should be −155... −160 dBm.

2.2 Requirements to the measurement equipment

Equipment requirements are based on the experience of using in RNSS frequency bands, and the requirements specified in Recommendation ITU R SM.1753. Real-time spectrum analysers were used because in contrast to sweeping analysers, they allow detection, display, and recording of short duration, pulsed events.

The following antenna types are used:

- Directional: Horn antenna or parabolic antenna for azimuth scanning, if terrestrial sources are of interest;
- Directional: Parabolic antenna, for azimuth and elevation scanning, if signals from air and space sources are of interest;
- Omnidirectional: dipole or biconical antenna for the overview scan (auxiliary equipment).

If possible, the polarization of the measuring antennas should be matched to the polarization of the protected RNSS system. If parabolic antennas with feeders are used, the direction of polarization is changed due to the reflector: typically, RNSS are Right Hand Circular Polarized (RHCP). This changes to a Left handed circular polarization (LHCP), when the wave is guided from the reflector to the dish.

3 Practical example of monitoring in the RNSS bands

This example demonstrates monitoring at a specific measurement location throughout the frequency range 1 597-1 607 MHz. It demonstrates the measurement setup and the procedures for recording and evaluating the measurement data, including plotting and interpretation of the resulting diagrams. The RNSS system of interest is GLONASS.

3.1 Measuring equipment for monitoring GLONASS frequency band

The following set of equipment was used for measurements:

1 Spectrum analyser:
  - GLONASS L1 frequency band 1 597-1 607 MHz,
  - resolution bandwidth (RBW) – 1 kHz,
  - detector type – averaging,
  - number of spectrum averages – 100.

2 Measurement horn antenna:
  - polarization – linear vertical,
  - antenna height – 2.85 m,
  - elevation angle – 0°,
  - antenna azimuth – 0° to 360° with 15° step.

3 Measurement parabolic antenna, diameter – 2 m.

4 Omnidirectional antenna for comparison:
  - polarization – linear vertical,
  - antenna height – 2.85 m.

3.2 Measurement point

The selected measurement point was in a town with low and medium-height buildings.

3.3 Analysis of frequency assignments

According to the frequency plan and the frequency assignments database, no active terrestrial transmitters in the RNSS frequency bands were expected.

3.4 Performing measurements, recording spectra, and calculating characteristic values

On the measurement site, the spectrum was analised by a scan of azimuths using the horn antenna (‘azimuth scan’). In addition, measurements were performed using an omni-directional antenna. Finally, a scan of the hemisphere was done using the parabolic antenna (‘elevation scan’). Afterwards, the characteristic values (see §§ 1.3.1 to 1.3.3) were calculated. The monitored frequency range is the GLONASS L1 band (1 597-1 607 MHz)

3.4.1 Values recorded in the azimuth plane

The results from the azimuth scan are shown in Table 3 and further summarized in Table 4. The results from the omnidirectional antenna are shown in Table 5. The data from both Tables were combined into Fig. 4.

TABLE 3

Characteristics for spectra observed using directional antenna

Azimuth (degree)	Peak emission power (dBm)	Mean emission power (dBm)	Noise power (dBm)
0	−121.0	−136.1	−136.5
15	−120.7	−136.0	−136.6
30	−118.1	−136.1	−136.6
45	−119.7	−135.8	−136.6
60	−114.2	−136.1	−136.6
75	−113.0	−136.2	−136.7
90	−124.0	−136.3	−136.7
105	−120.0	−136.1	−136.7
120	−125.1	−136.2	−136.7
135	−130.2	−136.2	−136.7
150	−115.0	−136.2	−136.7
165	−130.6	−136.2	−136.7
180	−123.7	−136.1	−136.7
195	−124.3	−136.2	−136.7
210	−122.2	−136.3	−136.7
225	−125.4	−136.6	−136.7
240	−120.5	−136.6	−136.7
255	−127.3	−136.6	−136.7
270	−130.2	−136.6	−136.7
285	−125.0	−136.5	−136.7
300	−125.7	−136.3	−136.7
315	−121.9	−136.0	−136.6
330	−121.4	−135.9	−136.6
345	−121.6	−136.2	−136.7

TABLE 4

Maximum, minimum and mean values of power obtained during the measurements

Type of power	Peak emission power (dBm)	Mean emission power (dBm)	Noise power (dBm)
Mean value	−120.1	−136.2	−136.7
Maximum value	−113.0	−135.8	−136.5
Minimum value	−130.6	−136.6	−136.7

TABLE 5

Characteristics for spectra observed using omnidirectional antenna

Parameter	Measured value (dBm)
Peak signal power in the band	−118.7
Mean power in the band	−130.5
Noise power	−134.4
Receiver noise power	−136.4

3.4.2 Values recorded in the elevation / hemisphere scan

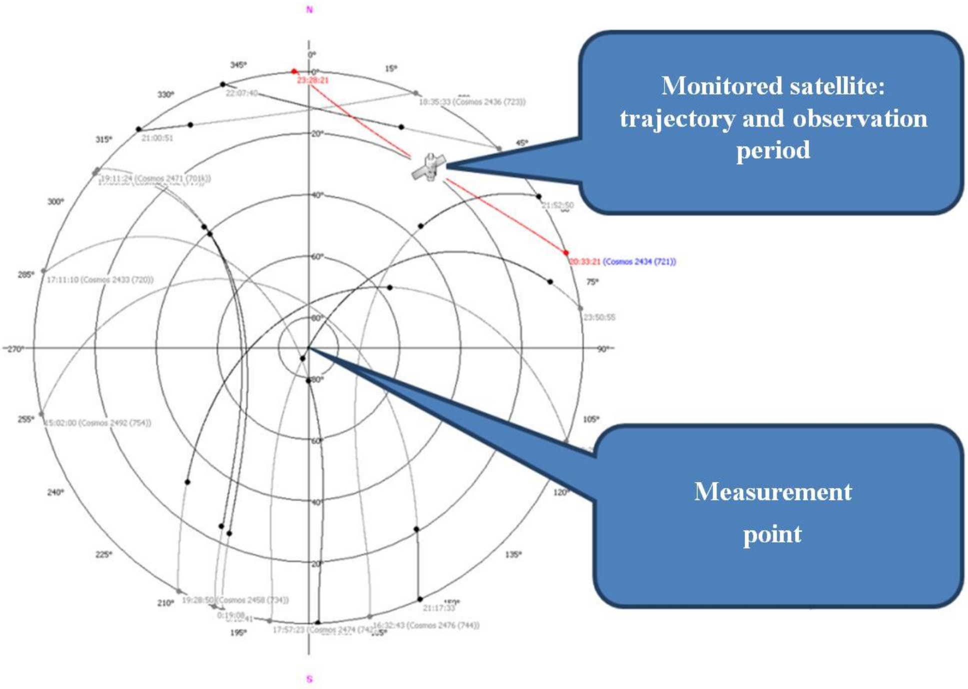
Measurement results from the parabolic antenna are well suited to analyse signals from terrestrial, aeronautical, and space emission sources. If analysis of the entire hemisphere is wanted, many more recordings and antenna angles are needed.

During the measurement process, the GLONASS satellite Cosmos-2434 (721) was tracked using its trajectory data for the period of radio visibility, and the satellite's resulting trajectory is shown in red in Fig. 6. All other GLONASS satellites are marked in black. The points represent where the satellites came in and out of visibility at the measurement location.

Additionally, Fig. 6 shows trajectories of all GLONASS satellites with radio visibility during the measurements, using azimuth/elevation coordinate system centred at the measurement location. The black points represent the beginning and end of the satellites radio visibility during the measurement time.

FIGURE 6

Trajectories of the GLONASS satellites during measurements



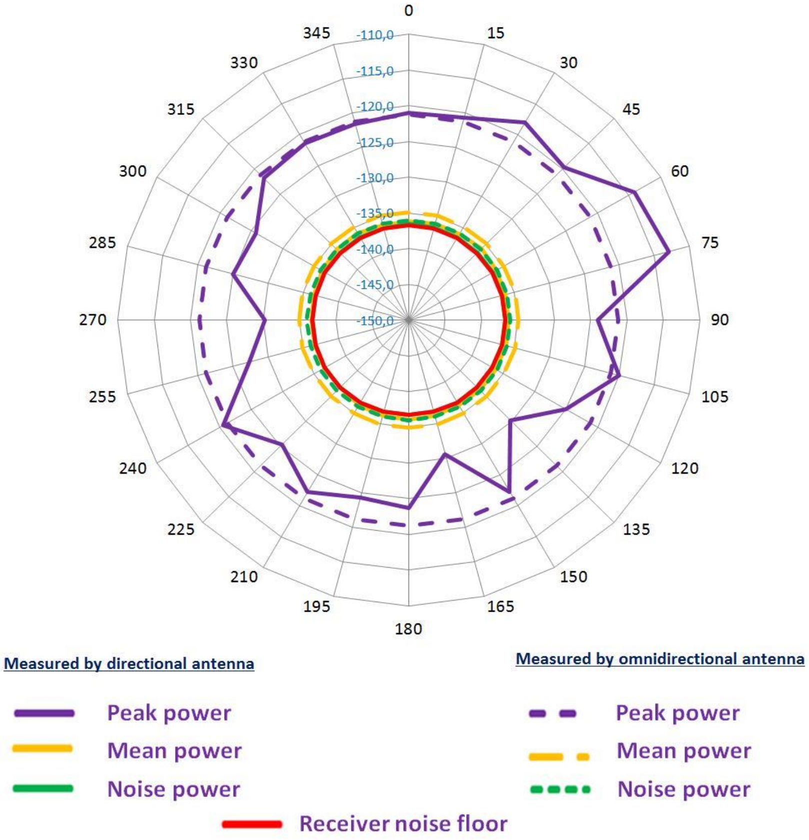
3.5 Plotting of diagrams and result analysis

3.5.1 Diagrams and result interpretation of the azimuth scan

Figure 7 combines the data of Table 3 and Table 4 into a single diagram.

FIGURE 7

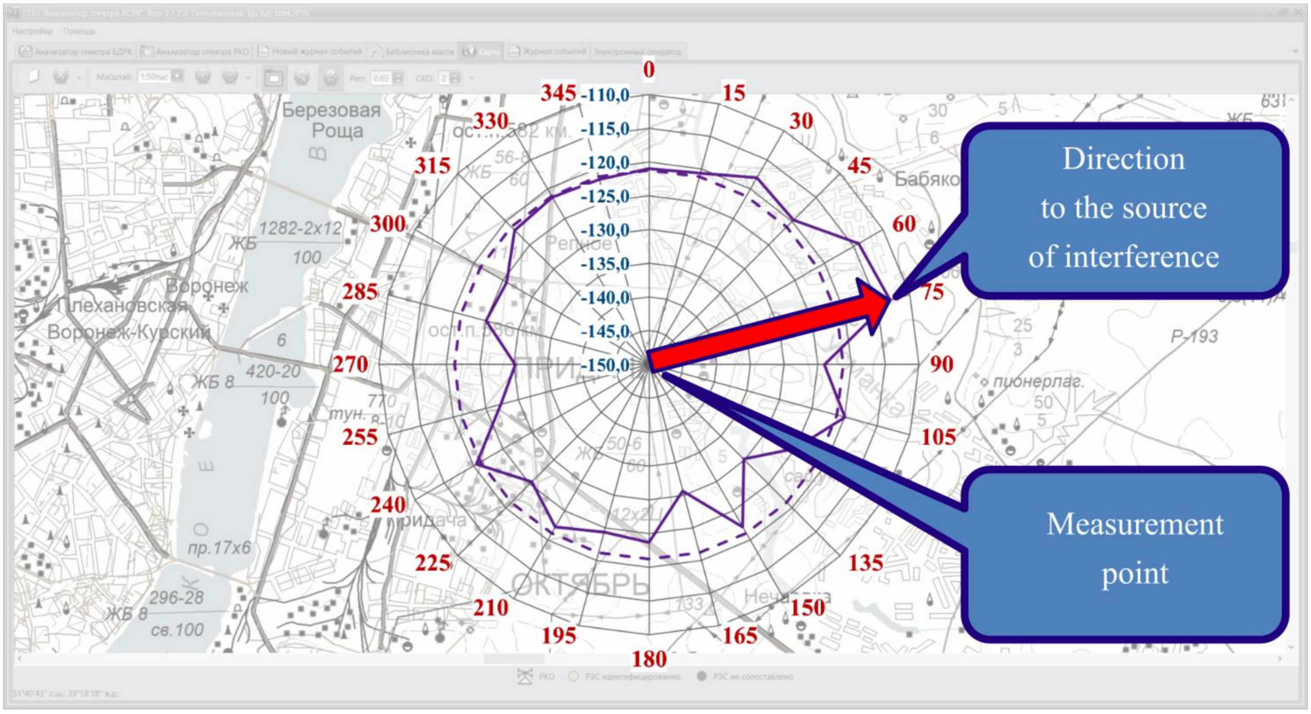
Combined diagram of azimuth scan results



The Figure shows a distinct peak in the direction of 60°-75° degree. Figure 8 shows the diagram overlaid on a digital map which clearly shows the presence, and directions of the sources of emissions and interference. The directions to the sources of emissions and interference are identified by maxima in the data.

FIGURE 8

Results on a digital map indicate the direction to potential source of interference



Since no active transmission was expected in the direction of 60° - 75°, that spectrum recording is inspected in more detail. Figure 9 shows the L1 frequency band spectrum at the measurement location in the direction of the peak level. The peak level is approximately 17 dB above the mean level.

FIGURE 9

Spectrum of the GLONASS L1 frequency band (directional antenna, azimuth angle 75°)

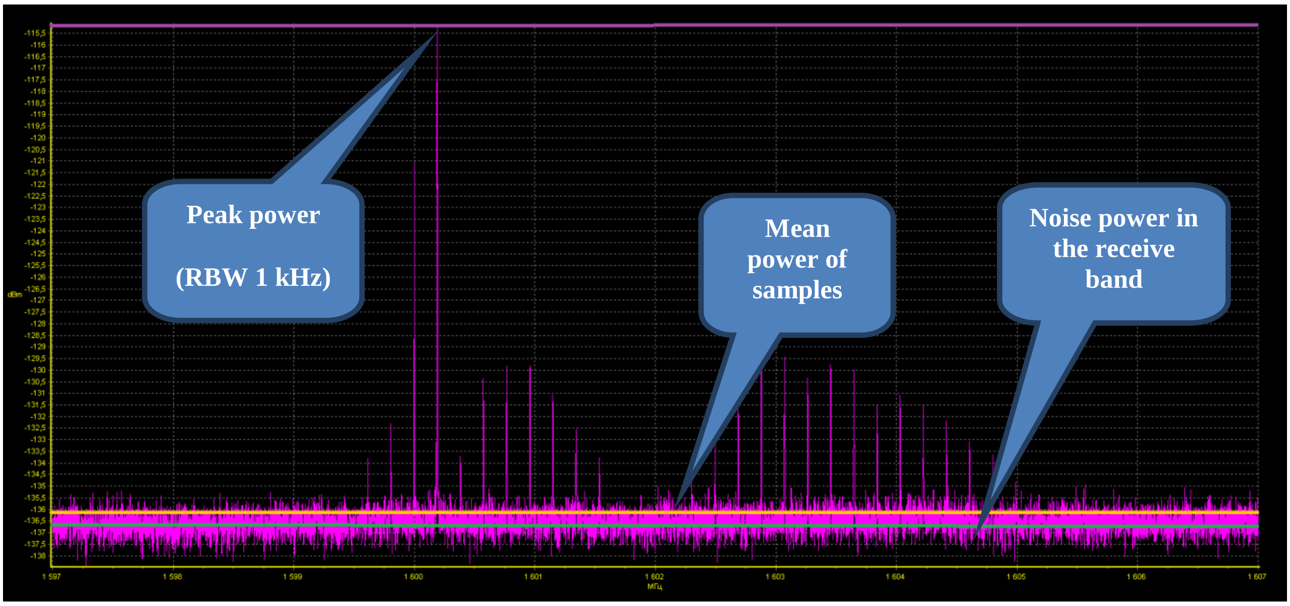
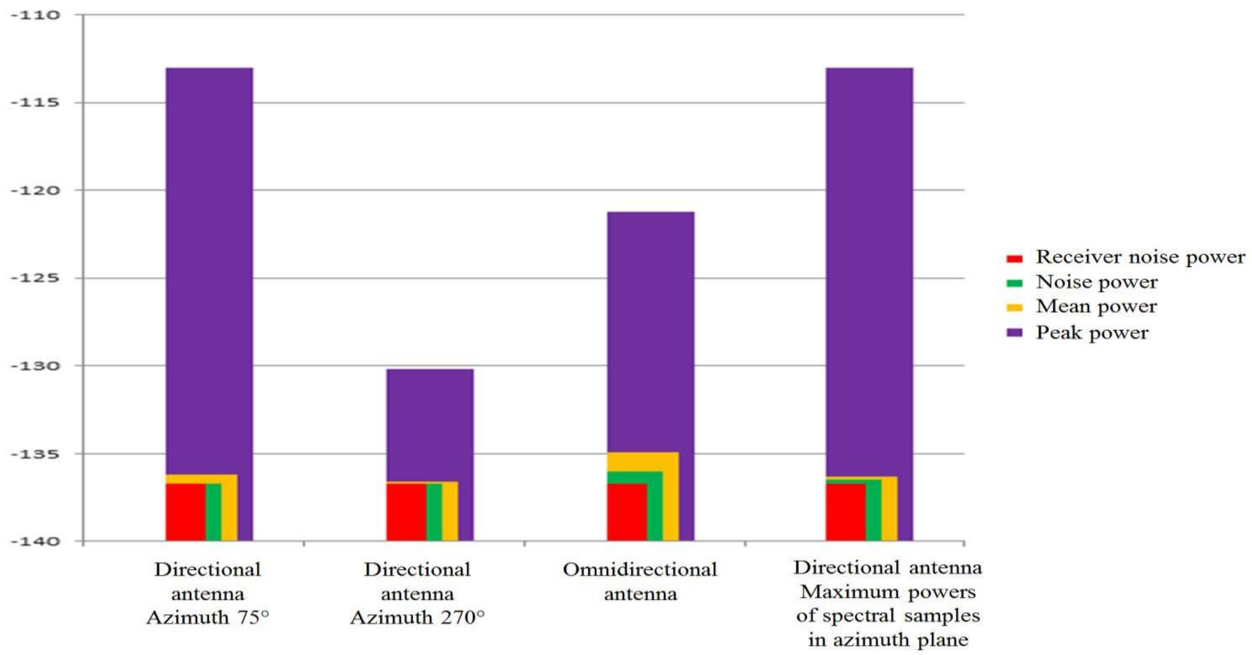


Figure 9 shows the results of spectral measurements for the directional and non-directional antenna.

FIGURE 10

Summary of characteristic receive levels in the GLONASS L1 frequency band

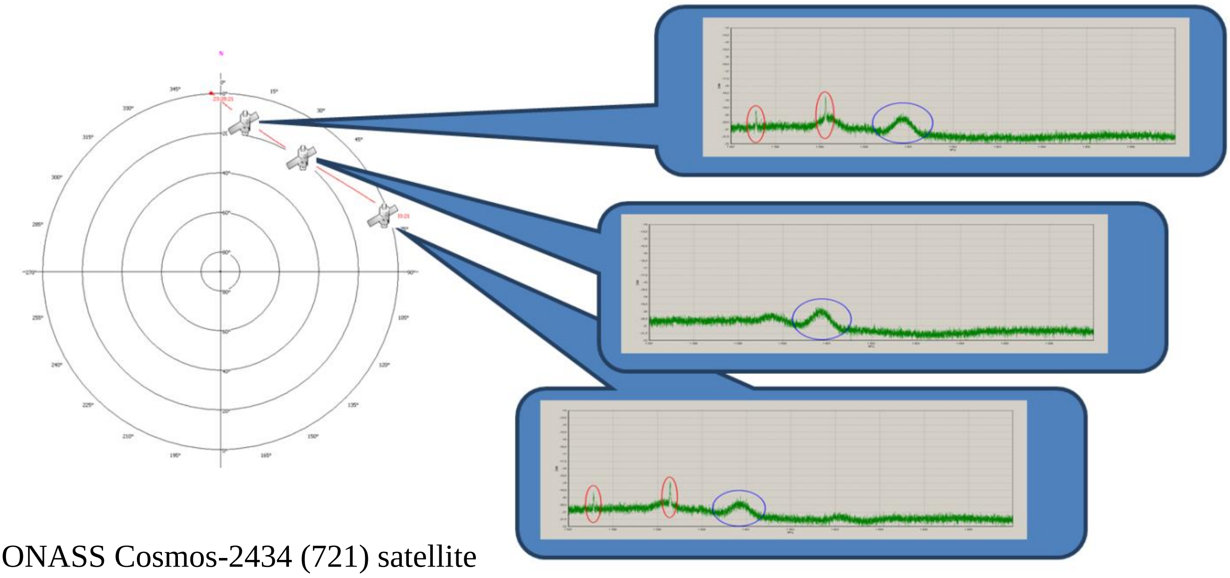


3.5.2 Diagrams and result interpretation of the hemisphere scan

Figure 11 shows spectra in the frequency band 1 597 to 1 607 MHz (GLONASS L1) for three azimuth angles to the GLONASS satellite. The signal from the monitored GLONASS satellite in the plotted spectra is marked by a blue circle. Figure 11 also shows the spectra of interference emissions (marked with red circles) received at small elevation angles.

FIGURE 11

Spectra in GLONASS L1 frequency band 1 597-1 607 MHz for three azimuth angles to the GLONASS satellite



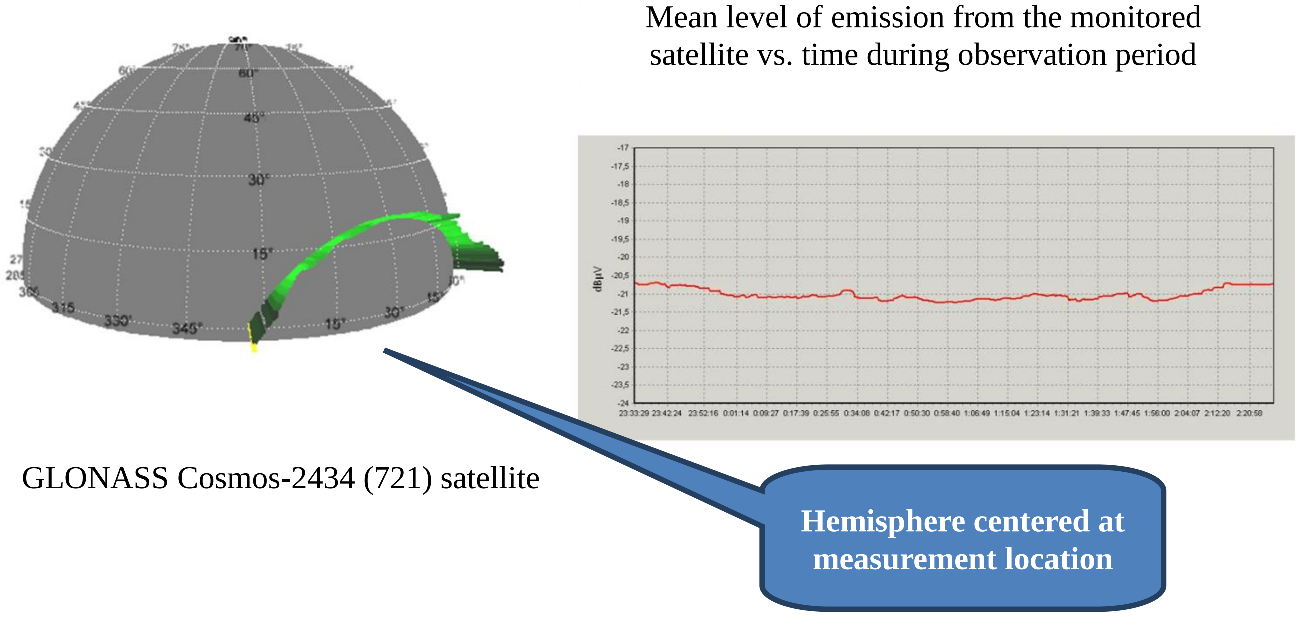
GLONASS Cosmos-2434 (721) satellite

Figure 12 represents a combination of recorded mean values in the direction of the monitored satellite in two coordinate systems:

- 3D hemisphere diagram with "azimuth/elevation/emission level" coordinates. Emission levels are shown in green colour. The hemisphere is centred at the measurement point;
- 2D diagram with "emission level in the band vs time during observation period", where each time value corresponds to certain azimuth and elevation angle towards the monitored satellite.

FIGURE 12

Combination of emission mean values in the frequency band 1 597-1 607 MHz (GLONASS L1)



Mean level of emission from the monitored satellite vs. time during observation period

GLONASS Cosmos-2434 (721) satellite

Hemisphere centered at measurement location

The increased levels in the diagrams above indicate possible sources of interference, maybe due to an increase in the level of background noise with the parabolic antenna pointed towards horizon.

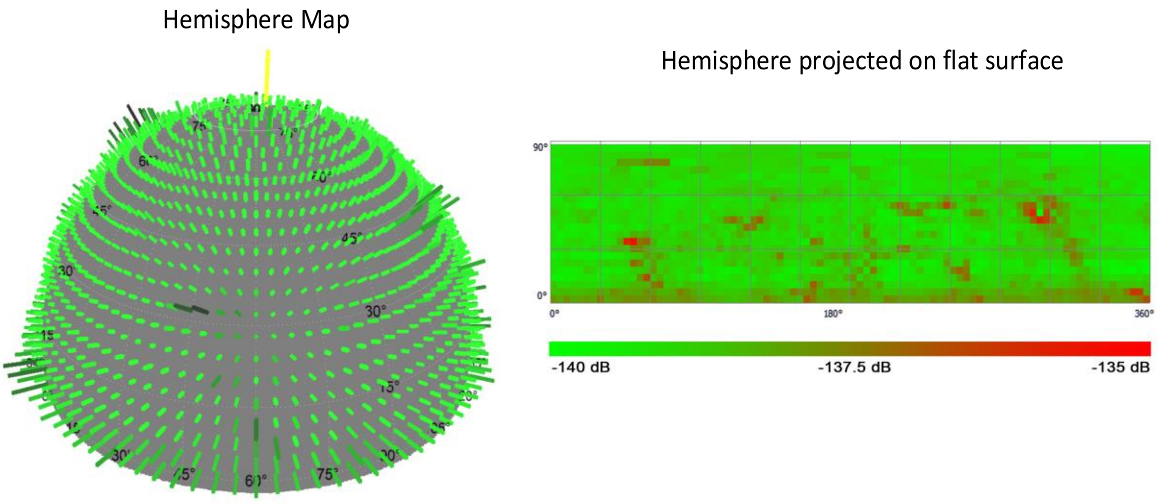
Figure 13 shows a 3D-diagram of the mean levels in the frequency band 1 597-1 607 MHz measured using the parabolic antenna. The results are shown in two ways:

- 3D hemisphere diagram with “azimuth/elevation/emission level” coordinates; the length of the green arrows indicates the power level measured by the spectrum analyser. The hemisphere is centred at the measurement location.
- 3D diagram in the plane “azimuth/elevation/emission level”, where the spherical coordinates are mapped onto a flat surface; the levels are mapped to a colour-scale (intensive red colour indicates maximum emission values, lower intensity of green colour indicates minimum values).

The diagrams for mean emissions levels in the given frequency band show high emissions levels arrived from airspace or outer space with certain azimuth and elevation angles during the measurement period.

FIGURE 13

Maximum receive levels in L1 frequency band, measured over the whole hemisphere



Hemisphere Map

Hemisphere projected on flat surface