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REQUIRED GUARD BAND FOR THE PROTECTION OF THE RADIO NAVIGATION SATELLITE SERVICE IN THE 1559 - 1610 MHz BAND FROM INTERFERENCES PRODUCED BY FIXED SERVICE

This contribution has been developed and agreed in the framework of CEPT (Project Team 28 of Working Group Spectrum Engineering)

1 Issue

Document 8D/TEMP/124(Rev.1)- proposed elements for chapter 2, paragraph 2.4 of the draft report of CPM-99 to WRC 2000. In this proposal, an editorial note mentions that “Further studies are planned of the impact of FS on adjacent frequencies of RNSS receivers and on the reception of pseudolites”.

2 Introduction

The band 1559 - 1610 MHz is allocated on a primary basis to the Aeronautical Radio Navigation Service (ARNS), Radio Navigation Satellite Service (RNSS) in the space to earth direction and Fixed Service (FS) operating under RR S5.355 and S5.359. This document presents the results of a study on the required guard band to protect the Radio Navigation Satellite Service against harmful interference by the Fixed Service.

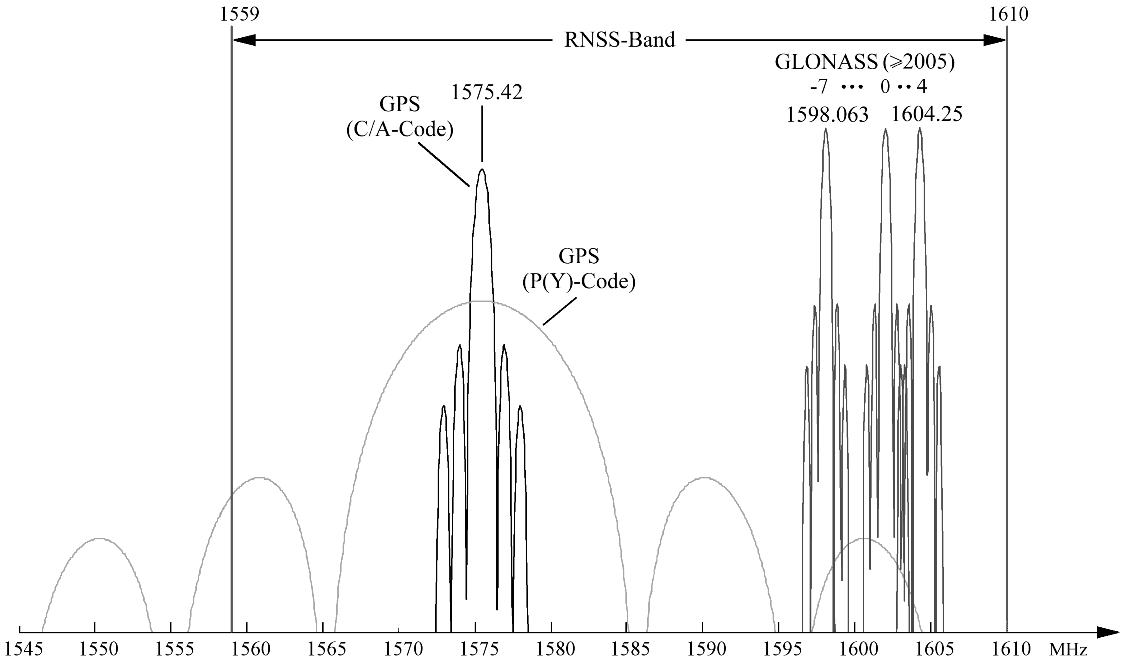

Fig. 1: Spectrum occupation in the RNSS-band

3 Background

For the determination of the required bandwidth for a guard band it is necessary to calculate how much interference power a satellite navigation receiver can tolerate if an interference signal with given properties is received. For this analysis it is assumed that a guard band is introduced that is centered around the center frequency of the satellite navigation signal f_{HF} and has a one-sided bandwidth Δf. The interference signal shall be a broadband signal at the edge of the guard band. The broad band interference signal is assumed to have a constant power density within the bandwidth B_I and a negligible power density outside (Fig. 2):

$$I(f) = \begin{cases} const \quad for \quad f_{HF} + \Delta f \le f \le f_{HF} + \Delta f + B_I \\ 0 \quad\quad otherwise \end{cases}$$ Eq. 1

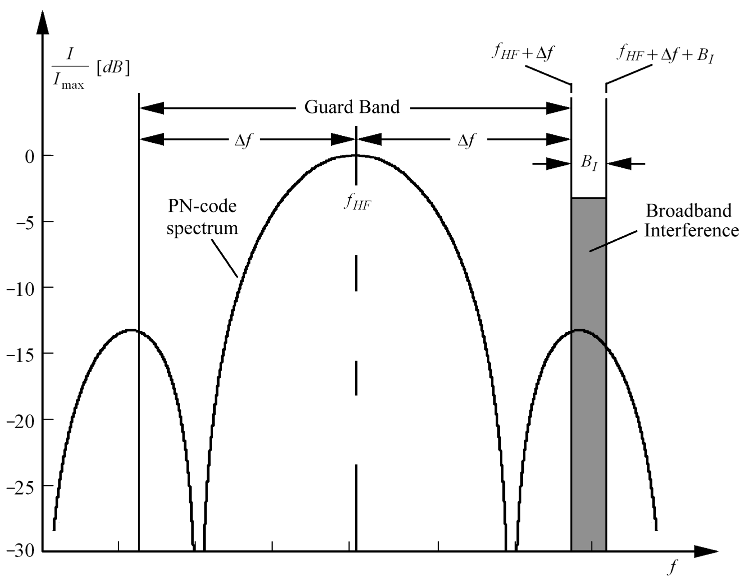

Fig. 2: Definition of the guard band

Interference signals received by the satellite navigation receiver received are attenuated by the so-called processing gain. If the frequency of the interference signal is not identical to the center frequency of the satellite navigation signal it is additionally attenuated by the pre-correlation filter. If the frequency range of the interference signal is outside the flat part of the mainlobe of the PN-Code spectrum, there is an additional attenuation due to the filtering effect of the correlation process.

To describe the maximum tolerable power (narrow band signals) or power density (broadband signals) for the interference signal an interference threshold can be indicated. For broadband signals it is common to indicate the maximum tolerable interference power density at center frequency of the satellite navigation signal in W/MHz units. To calculate the maximum tolerable power density of a broadband interference signal with arbitrary center frequency and bandwidth the so-called frequency dependent rejection (FDR) has to be introduced:

$$FDR = 10 \log \left[\frac{\int_{f_{HF}-0.5MHz}^{f_{HF}+0.5MHz} a(f) \cdot SINC^{2}\left[p\, T_C \left(f - f_{HF}\right)\right] \, df}{\int_{f_{HF}+\Delta f}^{f_{HF}+\Delta f+B_I} a(f) \cdot SINC^{2}\left[p\, T_C \left(f - f_{HF}\right)\right] \, df} \right] \qquad \text{Eq. 2}$$

With:

FDR:	Frequency Dependent Rejection in dB, i.e. attenuation of the interference signal under investigation, compared with a reference interference signal at the center frequency of the satellite navigation signal that has a bandwidth of 1 MHz
f:	frequency in MHz
f_{HF}:	center frequency of navigation signal in MHz (e.g. 1575.42 MHz for GPS-L1)
Δf:	one sided bandwidth of the guard band
B_I:	bandwidth of the interference signal
$f_{HF} + \Delta f$:	lower edge of interference frequency band
$f_{HF} + \Delta f + B_I$:	upper edge of interference frequency band
f_C:	code clock frequency of the satellite signal in MHz
T_C:	code chip duration $T_C = 1/f_C$ in µs
a(f):	frequency response of the pre-correlation filter, Butterworth filter of order 5, $\lvert a(f)\rvert = 1$ for in-band interference
SINC(x):	sin(x)/x-function

Eq. 2 holds for interference signals with a bandwidth B_I >>10 kHz, which is true for all cases analyzed in this paper. (For B_I << 10 kHz it is not sufficient to use the SINC-function as a model for the line spectrum of the PN-code).

For the pre-correlation filter for GPS and ENSS-1 a Butterworth filter of order 5 is used, which is very common. According to ITU-R M.1088 ([3]) the bandwidth of the precorrelation filter shall be $1.7 \cdot f_C$ (e.g. 17 MHz in the case the GPS P(Y)-code). GLONASS uses for every single satellite channel different center frequencies. Therefore, a GLONASS receiver usually has a common IF-filter for all channels in front of the A/D converter. Some receivers have additionally a digital pre-correlation filters for every single channel, others do not. Here we assume a combination of HF- and IF-filter according to [5] as a common pre-correlation filter for all channels with $a(f) = a_{tot} = a_{HF} + a_{IF}$ (Fig. 4).

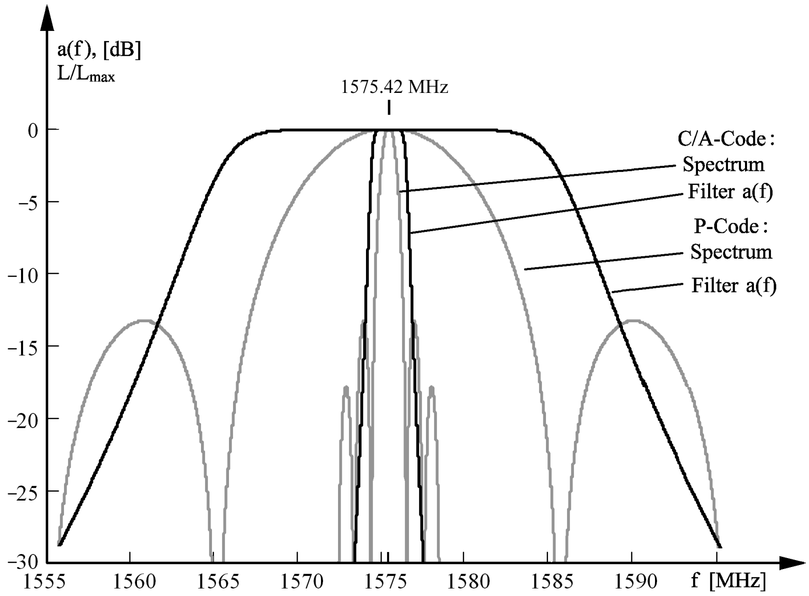

Fig. 3: Pre-correlation filter characteristics for GPS

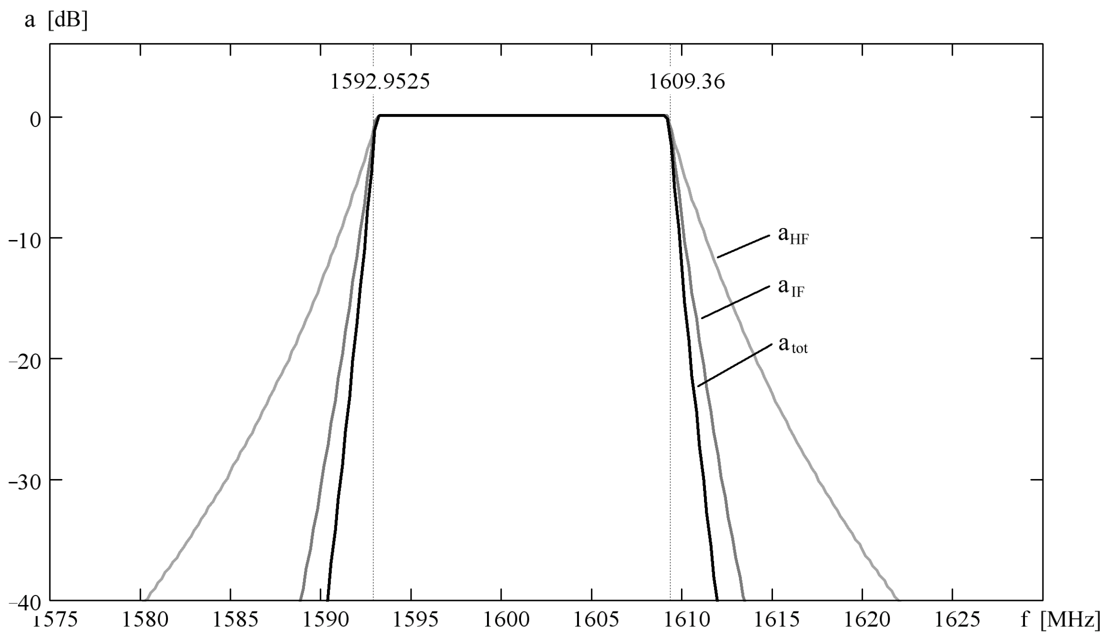

Fig. 4: HF- and IF-filter characteristics of a GLONASS receiver ([5])

The power of a transmitted interference signal is attenuated by the frequency dependent rejection and the free space loss. For a given protection bandwidth Δf the corresponding FDR can be calculated. The remaining necessary attenuation to damp the received interference signal below the interference threshold I_{th} of the receiver has to be provided by the free space loss. Once the required free space loss is determined, the minimum required separation distance can then calculated as follows:

$$d_{\min}(\Delta f) = \frac{l}{4p} \cdot 10^{\frac{EIRP + G_r - I_{th} - FDR(\Delta f)}{20}} \qquad \text{Eq. 3}$$

With:

d_{min}: minimum required distance in m

EIRP: equivalent isotropically radiated power density of the interference source

in dBW/bandwidth
G_r: gain of the receive antenna in direction of the interference source in dB (e.g. –4.5 dB for incident below 5° elevation angle)
I_{th}: interference threshold of the satellite navigation receiver in dBW/MHz

In the complementary case, when the separation distance d_{min} is given and the required protection bandwidth Δf shall be calculated, this cannot be done analytically. But it is possible to determine the required protection bandwidth from a graphical representation of the required separation distance versus protection bandwidth (Fig. 6) which was calculated as mentioned above.

4 Characteristics of Fixed Service Transmitter

Tab. 1 summarizes characteristics of typical Fixed services transmitter which was used for the analysis ([1], [2]).

Tab. 1: Characteristics of German Army Communication Equipment

Frequency range:	1400 MHz to 1660 MHz *
Transmit Power:	1.25 W ≈ 1 dBW
Transmit Antenna Gain: Half Power Beamwidth:	22 dB 6.8°
EIRP:	23 dBW = 200 W
Worst Case Scenario	Bandwidth = 0.6 MHz => EIRP = 23 dBW/0.6 MHz

* In Germany the frequency range 1575.42 MHz +/-14 MHz is excluded from the Fixed Service operation for the protection of GPS.

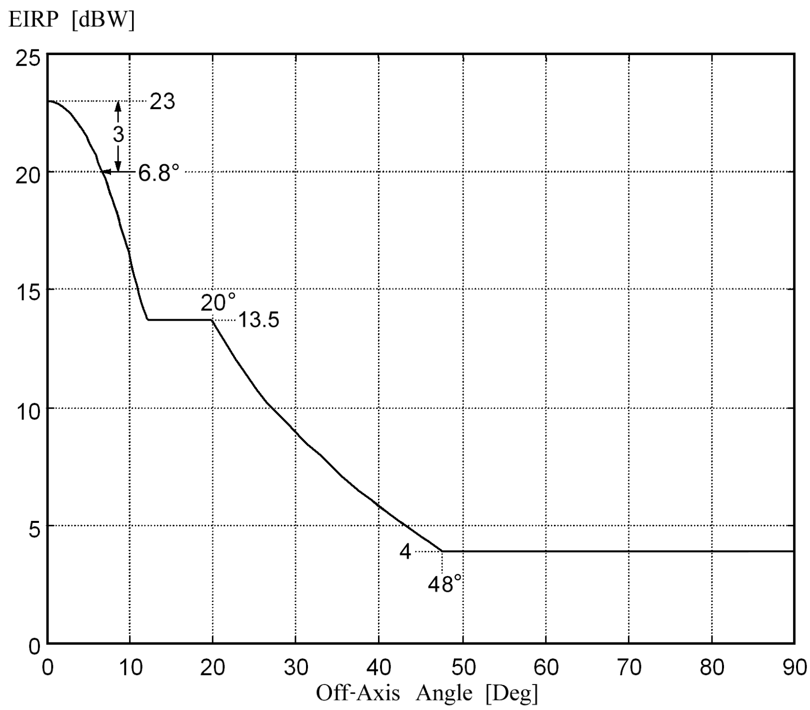

Fig. 5: Typical plot of EIRP vs. off-axis angle

5 Scenarios

The following analysis is based on a typical FS transmitter being used in Germany. An incident interference signal with an elevation angle below 5° is assumed. This corresponds to an antenna gain of -4.5 dB towards interference source. The required protection bandwidth is determined from a plot of the required separation distance versus protection bandwidth which has been calculated as mentioned above (section 2). Fig. 6 shows such a plot for the case of GPS.

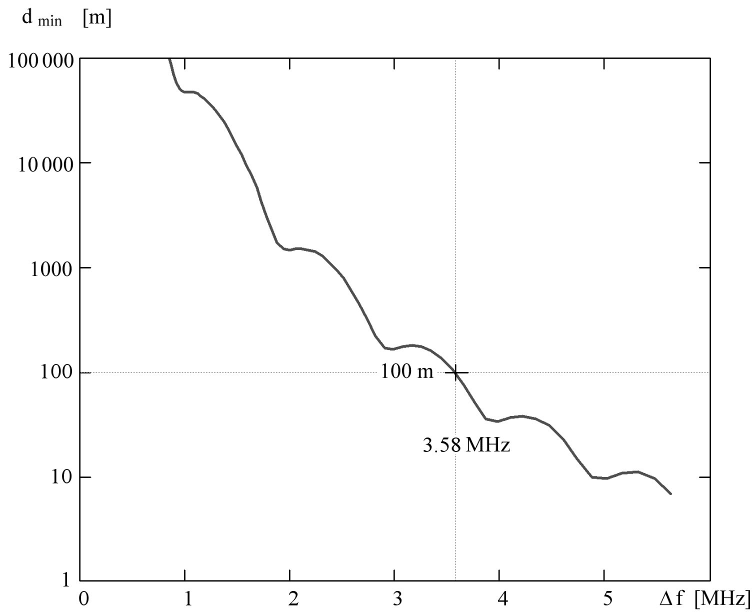

Fig. 6: Required separation distance versus protection bandwidth for GPS C/A-code

5.1 Interference to GPS

The assumptions for the analysis of the interference to GPS L1 are provided in Tab. 2.

Tab. 2: Assumptions for the analysis of interference to GPS L1:

Signal frequency:	1575.42 MHz
Code clock frequency C/A-code:	1.023 MHz
Code clock frequency P(Y)-code:	10.23 MHz
Pre-correlation filter C/A-Code:	5 th order Butterworth Filter with bandwidth: 1.7 MHz (C/A-Code)
Pre-correlation filter P(Y)-Code	5 th order Butterworth Filter with bandwidth: 17 MHz (according to [3])
Interference EIRP:	23 dBW/0.6 MHz
Interference threshold I_{th} C/A-code:	-146.5 dBW/MHz for acquisition (according to ICAO Draft GNSS SARPs same threshold for P(Y) as for C/A code *)
Interference threshold I_{th} P(Y)-code:	-146.5 dBW/MHz for acquisition **)

* In the ICAO Draft GNSS SARPs the interference threshold for tracking (precision approach) is -140.5 dBW/MHz. For acquisition the threshold is 6 dB less i.d. -146.5 dBW/MHz.

** Here it is assumed that a codeless tracking receiver e.g. as would be applied for Wide Area Augmentation Systems (WAAS, EGNOS) will have a pre-correlation filter suitable for the P-code (17 MHz bandwidth) and will have to acquire the C/A-code before it can track the P(Y) code. For this reason for the P(Y)-code receiver the same interference threshold is assumed as for the C/A-code receiver.

Tab. 3 shows the band from which typical FS transmitters should be excluded, assuming various separation distances between the FS transmitter and a GPS C/A-Code RNSS receiver for different off-axis angles between Fixed Service transmitter and RNSS receiver.

Tab. 3: Protection of GPS L1 C/A-Code receivers from FS interference:

Separation distance d_{min} with an off-axis angle of 0°	30 m	100 m	1000 m	10 km
Separation distance d_{min} with an off-axis angle of 20°	10 m	33 m	330 m	3.33 km
Required protection bandwidth Δf	4.48 MHz	3.58 MHz	2.44 MHz	1.58 MHz
Required guard band: 1575.42 MHz ± Δf	1570.94 to 1579.90 MHz	1571.84 to 1579.00 MHz	1572.98 to 1577.86 MHz	1573.84 to 1577.00 MHz
Protection of RNSS-band 1559 to 1610 MHz	sufficient	sufficient	sufficient	sufficient

Tab. 4 shows results for a GPS receiver using the P(Y)-Code for codeless tracking to measure ionospheric delay. This type of receiver is used for certain precise navigation and position determination applications and is planned for use in the GNSS RIMS (Ranging and Integrity Monitoring Stations) of EGNOS (the European Geostationary Navigation Overlay Service). The required guard band limits outside the RNSS-band (1559 MHz - 1610 MHz) are printed in bold type.

Tab. 4: Protection of GPS L1 P(Y)-code codeless-tracking receivers from FS interference:

Separation distance d_{min} with an off-axis angle of 0°	30 m	100 m	1000 m	10 km
Separation distance d_{min} with an off-axis angle of 20°	10 m	33 m	330 m	3.33 km
Required protection bandwidth Δf	47.2 MHz	37.6 MHz	21.2 MHz	17.2 MHz
Required guard band: 1575.42 MHz ± Δf	**1528.20** to **1622.62** MHz	**1537.82** to **1613.02** MHz	**1554.22** to 1596.62 MHz	**1558.22** to 1592.26 MHz
Protection of RNSS-band 1559 to 1610 MHz	not sufficient	not sufficient	not sufficient	not sufficient

5.2 Interference to GLONASS

The assumptions for the analysis of the interference to GLONASS L1 are provided in Tab. 5.

Tab. 5: Assumptions for the analysis of interference to GLONASS

Signal frequency:	1598.063 MHz (channel -7) for the lower edge and 1604.250 MHz (channel 4) for the upper edge of the guard band
Code clock frequency C/A-code:	0.511 MHz
Code clock frequency P-code:	5.11 MHz
Pre-correlation filter:	combination of HF and IF-filter according to [5] (same filter for C/A- and P-code receiver)
Interference EIRP:	23 dBW/0.6 MHz
Interference threshold I_{th} C/A-code:	-152 dBW/MHz for acquisition (according to ICAO Draft GNSS SARPs *)
Interference threshold I_{th} P-code:	-152 dBW/MHz for acquisition (according to ICAO Draft GNSS SARPs **)

* In the ICAO Draft GNSS SARPs the interference threshold for tracking (precision approach) -146 dBW/MHz is. For acquisition the threshold is 6 dB less i.d. -152 dBW/MHz.
** Here it is assumed that a civilian P-code receiver will have to acquire the C/A-code before it can track the P code. For this reason for the P-code receiver the same interference threshold is assumed as for the C/A-code receiver.

Tab. 6 shows results for a GLONASS SAS ("C/A-Code") receiver, which is more susceptible to interference from adjacent-band FS emissions because GLONASS receivers must receive signals from different satellites at different frequencies. The pre-correlation filter in the GLONASS receiver therefore has a much wider bandwidth.

Tab. 6: Protection of GLONASS L1 SAS-Code receivers from FS interference:

Separation distance d_{min} with an off-axis angle of 0°	30 m	100 m	1000 m	10 km
Separation distance d_{min} with an off-axis angle of 20°	10 m	33 m	330 m	3.33 km
Required protection bandwidth Δf	7.55 MHz	6.74 MHz	5.3 MHz	3.92 MHz
Required guard band for channels –7 to +4 1598.063 - Δf to 1604.25 + Δf	1590.51 to **1611.8** MHz	1591.32 to **1610.99** MHz	1592.76 to 1609.55 MHz	1594.14 to 1608.17 MHz
Protection of RNSS-band 1559 to 1610 MHz	not sufficient	not sufficient	sufficient	sufficient

Tab. 7 shows results for a GLONASS PAS ("P-Code") receiver, which is also susceptible to interference from adjacent-band FS emissions because of its wide bandwidth.

Tab. 7: Protection of GLONASS L1 PAS-Code receivers from FS interference:

Separation distance d_{min} with an off-axis angle of 0°	30 m	100 m	1000 m	10 km
Separation distance d_{min} with an off-axis angle of 20°	10 m	33 m	330 m	3.33 km
Required protection bandwidth Δf	9.0	8.3	6.6	4.47
Required guard band for channels –7 to +4 1598.063 - Δf to 1604.25 + Δf	1589.06 to **1615.25** MHz	1589.76 to **1612.55** MHz	1591.46 to **1610.85** MHz	1593.59 to 1608.72 MHz
Protection of RNSS-band 1559 to 1610 MHz	not sufficient	not sufficient	not sufficient	sufficient

6 Summary and Conclusion

The required protection bandwidths for the operation of the Radionavigation Satellite Systems GPS and GLONASS from harmful interferences produced by Fixed Service transmitters have been determined with parameters of a typical Fixed Service Station. This analysis shows that under worst case conditions a removal of the Fixed Service from the band (1559 to 1610 MHz) would protect the signals of GPS C/A-code sufficiently (Fig. 1). But removal of Fixed Service from a part of the band below 1559 MHz and above 1610 MHz would additionally be necessary to protect the signals of GPS, L1, P(Y)-code for codeless tracking, GLONASS L1, SAS- and PAS-code.

Considering the required guard band needed to protect RNSS and the fact that there will be future GNSS applications which would be implement in some part of the band 1559-1610 MHz, the sharing of the band 1559-1610 MHz between RNSS and FS is not recommended.

7 Reference Documents

[1] „Compatibility study between Mobile Satellite Service in the 1610 – 1626.5 MHz band and Fixed Service operating under RR 730“, ERC Report 29, Brussels, June 1994,

[2] Siemens Data Sheet for “Radio Relay System FM1000”)

[3] ITU-R M.1088, „Considerations for sharing with systems of other services in the bands allocated to the radionavigation-satellite service“

[4] ITU 8D/172-E, October 1998

[5] „Proposals for Modification of Doc. SE(98) Temp 105, Report on sharing studies between unwanted emissions of MSS mobile earth stations, operating in the band 1610 - 1626.5 MHz and the radionavigation by satellite service receiver operating in the band 1559 - 1610 MHz“, Russian federation, Doc. SE28(98)-147, Oslo, September 1998