International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R SA.2164

(09/2009)

Compatibility between the meteorological satellite and the fixed services in the band 7 850-7 900 MHz

SA Series

Space applications and meteorology

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Reports

(Also available online at http://www.itu.int/publ/R-REP/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	**Space applications and meteorology**
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management

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

Electronic Publication
Geneva, 2010

REPORT ITU-R SA.2164

Compatibility between the meteorological satellite and the fixed services in the band 7 850-7 900 MHz

(2009)

TABLE OF CONTENTS

Page

1 Introduction

World Radiocommunication Conference 2012 (WRC-12) Agenda item 1.24 considers the extension of the existing primary allocation to the meteorological-satellite service in the band 7 750-7 850 MHz to the band 7 850-7 900 MHz. Applications in the meteorological satellite service are limited to non-geostationary satellites transmitting in the space-to-Earth direction. Although the same service applications are affected as in the current allocation 7 750-7 850 MHz, and noting that meteorological systems already share this band successfully with the fixed service, this assessment covers all potential modes of operation and compatibility aspects for the potential extension to 7 850-7 900 MHz.

2 Background

Several polar orbiting meteorological satellite systems are currently using or planning to use the band 7 750-7 850 MHz. The main mode of operation is data transmission to a dedicated earth station in high latitudes, such as Svalbard on Spitsbergen, Norway. One of the systems operates in a multi-user mode transmitting meteorological data to a number of user stations, operated mainly by national weather services. Table 1 shows typical data of the 3 representative systems EUMETSAT polar-orbiting meteorological satellite system (Metop), United States National Polar-orbiting Operational Environmental Satellite System (NPOESS) and the second generation of polar-orbital meteorological satellites of China (FY-3).

The measurements and observations performed by those MetSat systems, provide data used in the areas of operational meteorology, climate monitoring, and detection of global climatic changes, having significantly improved operational meteorology, in particular the Numerical Weather Prediction (NWP).

Determined by the users of those data, namely the National Weather Services, next generation of these non-geostationary MetSat systems will have to provide continuity to the measurements and observations performed by the current systems. Furthermore, these future systems will have to perform additional measurements and observations of meteorological and climate parameters with higher resolution, resulting in much higher data rates and bandwidth as required today.

The necessary bandwidth for the downlink of the raw instrument data for future non-geostationary MetSat systems that fulfil those requirements for further enhanced data in the area of operational meteorology and climatology would be up to 150 MHz.

TABLE 1

Characteristics of some meteorological satellite system applications in the band 7 750-7 850 MHz

	Metop	**NPP**	**NPOESS**	**FY-3**
Carrier frequency (MHz)	7800	7812	7834	7775
Orbit height (km)	817	824	828	836
Maximum bandwidth (MHz)	63.0	30	30.8	45.0
Modulation scheme	QPSK	QPSK	SQPSK	QPSK
Satellite EIRP (dBW)	13.5	12.9	20.4	19.6
Earth station antenna diameter (m)	10.0	3.0	2.0	3.0
Earth station antenna gain (dBi)	55.2	44.9	41.7	45.2
Maximum PFD on surface of earth (dB(W/m^2 · 4 kHz))	–165.9	–162.9	–155.6	–158.1
Margin with respect to PFD limit (dB)	13.9	10.9	3.6	6.1

The desired extension of the MetSat allocation into the band 7 850-7 900 MHz would only affect the same radiocommunication services, namely the FIXED and MOBILE (except aeronautical mobile) service, like in the band 7 750-7 850 MHz where the METSAT service is already allocated on a co-primary basis limited to NGSO applications. Compatibility was already demonstrated in preparation for (WRC-97) where the allocation to the MetSat in the band 7 750-7 850 MHz was originally added to the table of allocations in Article 5 of the Radio Regulations (RR). Studies conducted prior to (WRC-97) concluded that more than 13 dB of margin were available to protect fixed service systems operating with worst case azimuths along the sub-satellite track. In particular the interference impact on the fixed and mobile service from the downlink of a polar-orbiting MetSat system like Post-EPS to its dedicated earth station is very limited as such an earth station is deployed at high northern (Svalbard, Spitsbergen) or southern latitudes (McMurdo, Troll, O'Higgens, Antarctica) in order to avoid blind orbits in which the stored instrument data of an entire orbit cannot be received.

For other applications such as the dissemination of data directly to the user (so-called direct read-out), for which the number of reception stations could be higher and which could be located anywhere, the sharing situation needs to be studied. Currently there are two systems (NPP and NPOESS of NOAA) planned for such type of operations which requires around 30 MHz of contiguous spectrum. For another system (Fengyun-3 or FY-3 from China), the dissemination of data is planned to be restricted mainly to the territory of China. The first satellite FY-3A was launched in 2008. The objective of this assessment is to provide a comprehensive overview of the impact all potential future meteorological system applications may have on fixed service installations.

3 Meteorological satellite system description

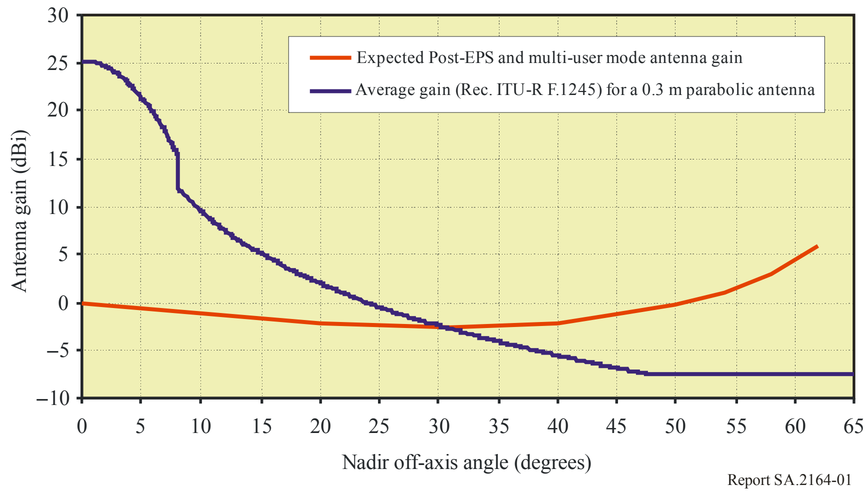
The next generation meteorological satellite system design such as Post-EPS will focus on wideband data dump transmissions into few main earth stations at high latitudes, such as Svalbard, Kiruna, Fairbanks, Troll, McMurdo and O'Higgens. The systems are expected to have bandwidth requirements up to 150 MHz. These high bandwidth requirements are primarily due to transmission of data from high resolution sensors and other instruments.

All currently operated and planned systems are deployed in non-geostationary orbits with typical orbital heights between 800 and 850 km and an inclination of around 98º and the same will apply for future systems. Earth stations in very high northern and southern latitudes are preferred in order to maximize contact time between the satellites and the earth stations. Transmissions are typically only affected when in line of sight of the corresponding earth station at elevation angles in excess of 5º. To date, two systems are planned to operate in a multi user mode with the transmitter continuously active. Power flux densities of systems using this frequency band for stored instrument data dump transmissions are typically significantly below the PFD limits but for the compatibility assessments, the satellites will be assumed to operate at the PFD limit. Antenna types are currently cardioid but for the higher data rates parabolic antennas may be needed. The most likely modulation technique for such high data rates is 8-PSK.

Figure 1 shows the assumed antenna gains for cardioid antennas based on currently implemented antennas as well as parabolic antennas likely to be used for future systems.

FIGURE 1

Meteorological satellite antenna gains assumed for simulations



Earth station receiving antenna diameters can in principle vary between 2 m for low data rate direct read-out reception in multi-user modes and 13 m for stored instrument data dump reception earth stations. Table 2 shows link budget examples for future meteorological satellite systems covering all potential operating modes and antenna types. For the stored instrument data dump reception station, the currently used antenna in Svalbard with a diameter of 10 m was selected.

TABLE 2

Link budget examples for future meteorological satellite systems operating around 7.8 GHz

	System A	**System B**	**System C**
Carrier frequency (MHz)	7 825	7 825	7 825
Orbit height (km)	830	830	830
Maximum bandwidth (MHz)	150	150	150
Minimum elevation angle (degrees)	5	5	5
Modulation scheme	8-PSK	QPSK	8-PSK
Satellite RF power in dBW (dBW)	23.0	24.8	3.8
Satellite antenna type	cardioid	cardioid	parabolic
Maximum satellite antenna gain (dBi)	6.0	6.0	25.2
Satellite EIRP (dBW)	29.0	30.8	29.0
Distance satellite – Earth station for 5° (km)	2 848	2 848	2 848
Free space propagation loss (dB)	179.4	179.4	179.4
Rain margin for 99.9% availability (dB)	2.2	2.2	2.2
Short term downlink loss (dB)	181.6	181.6	181.6
Earth station antenna diameter (m)	10.0	2.2	4.0
Earth station antenna gain (dBi)	55.3	42.1	47.3
Short term signal power level at receiver input (dBW)	–97.4	–108.7	–105.3
Receiver system temperature (K)	180	180	180
Maximum PFD on surface of earth (dB(W/m^2 · 4 kHz))	–152.0	–152.0	–152.0
Margin with respect to PFD limit (dB)	0.0	0.0	0.0
Receiver noise power density (dBW/Hz)	–206.0	–206.0	–206.0
Signal to noise density ratio (C/N_0) – Short-term (dB/Hz)	108.7	97.3	100.8
Required E_b/N_0 (with coding gain if applicable) (dB)	13.0	7.5	13.0
System margin – Short-term (dB)	9.2	5.1	1.2

4 Fixed service system assumptions

Recommendation ITU-R F.758 contains relevant information on fixed service characteristics in the band 7 850-7 900 MHz. Annex 1 of that Recommendation provides information on basic considerations in the development of sharing criteria, and Tables 12 and 13 of Annex 2 provide characteristics of typical FS systems in this band. Table 44 of Recommendation ITU-R F.758 specifies minimum antenna gains. Table 3 contains the relevant system characteristics extracted from Annex 2 of Recommendation ITU-R F.758. The methods for analysing interference between non-geostationary satellites and the FS are described in Recommendation ITU-R F.1108. This Recommendation makes also reference to related Recommendations ITU-R F.1094, ITU-R F.1668 and ITU-R F.1703, which have been taken into account.

TABLE 3

FS system parameters for frequency sharing around 7.8 GHz

Frequency band (GHz)	7.1-8.5			7.725-8.275
Modulation	64-QAM			128-QAM
Capacity (Mbit/s)	45	90	135	155
Channel spacing (MHz)	10	20	30	29.65
Antenna gain range (dBi)	37-49	37-49	37-49	37-45
Feeder/multiplexer loss (minimum) (dB)	0	0	0	Tx:4.6 Rx:4.8
Antenna type	Dish	Dish	Dish	Dish
Maximum Tx output power (dBW)	+3	+3	+3	+3
E.i.r.p. range (dBW)	40-52	40-52	40-52	40-43.4
Mean e.i.r.p. density range (dBW/MHz)	30-42	27-39	25-37	25.3-28.7
Receiver IF bandwidth (MHz)	10	20	30	28
Receiver noise figure (dB)	3	3	3	2
Receiver thermal noise (dBW)	–131	–128	–126	–128

A 49 dBi antenna gain can be achieved with a diameter of approximately 4.8 m, whereas around 3.0 m is required to achieve 45 dBi. It is recognized that 4.8 m antennas are rarely used but that many FS systems operate with antenna sizes of typically 1.2 m and 2.4 m with corresponding gains of 37 and 40 dBi.

In addition to radio-relay systems, some countries may also operate electronic news gathering (ENG) systems in the 7 750-7 900 MHz band. Antennas of such systems are typically smaller than those of radio-relay systems, which increase the visibility duration. On the other hand, acceptable interference levels are higher, providing a countering effect. Overall, the sharing situation is not expected to be significantly different to that for radio-relay systems.

5 Interference assessment to fixed service receivers

In order to protect the FS systems, the following power flux-density limits at the earth's surface have been included in Article 21.16 of the RR for the band 7 750-7 850 MHz:

–152 dB(W/m^2/4 kHz) for angles of arrival (δ) between 0 and 5°above the horizontal plane;

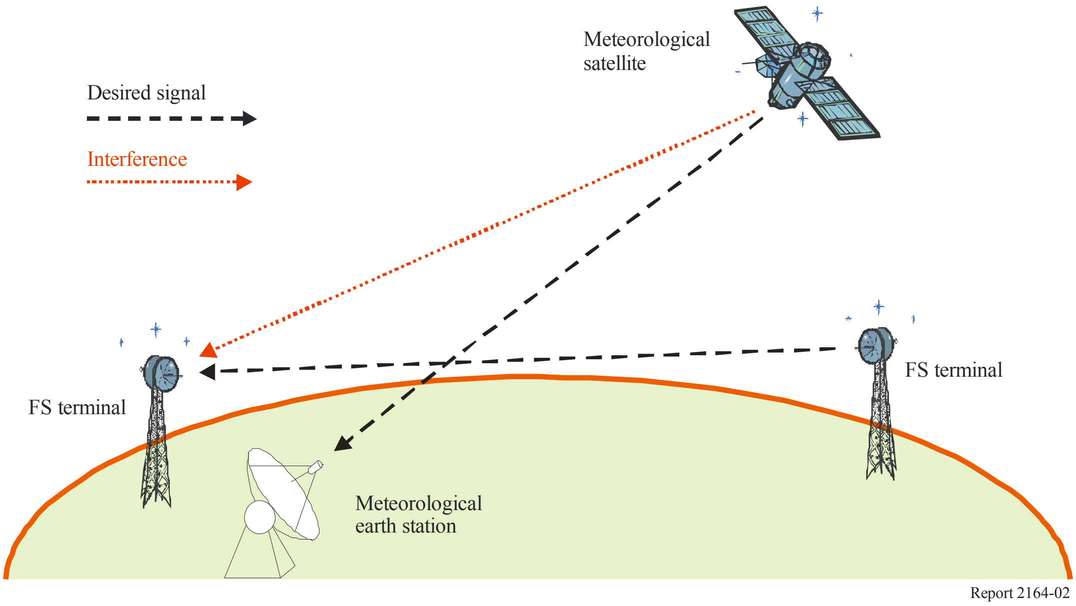
–152 dB + 0.5 (δ-5) (W/m^2/4 kHz) for angles of arrival between 5° and 25°;

–142 dB(W/m^2/4 kHz) for angles of arrival between 25° and 90°.

This section will investigate whether these limits provide also sufficient protection for the planned extension. The assessment is based on Table 3 containing the extracted relevant information from Recommendation ITU-R F.758. The simulation method of Recommendation ITU-R F.1108 is applied to determine the Fractional Degradation in Performance (FDP) of FS systems. Recommendation ITU-R F.1094 recommends a maximum allowable performance degradation of 10% for the FS. Based on a typical receiver noise density of –165 dB(W/4 kHz) this results in a maximum permissible FDP level of –181 dB(W/kHz). Figure 2 illustrates the geometrical constellation:

FIGURE 2

Potential interference constellation for fixed and meteorological satellite services



The basic equation for calculation of interference into an FS receiver is given by:

$$P_{ir} = P_d + G_{SAT-\varphi 1} - l_s - l_p + G_{FS-\varphi 2}$$

where:

P_{ir} :	interference power density received by FS station (kHz)
Pd :	power density transmitted by satellite (kHz)
$GSAT\text{-}\varphi 1$:	antenna gain of satellite towards FS station
ls :	space loss between satellite and FS station
lp :	polarization discrimination
$GFS\text{-}\varphi 2$:	antenna gain of FS station towards satellite.

For the meteorological satellites, the characteristics as contained in Table 2 have been used. Transmissions to corresponding earth station are affected when the elevation angle is above 5°. A polarization discrimination of 3 dB has been taken into account as FS systems transmit typically in linear polarization whereas space services apply circular polarization.

Recommendation ITU-R F.1245 contains antenna patterns to be used for interference assessments involving time varying constellations, which is the case for non-geostationary satellites. Antenna patterns for FS terminals as well as meteorological earth stations have been based on the following equations:

For $D/\lambda > 100$:

$$G_{(\varphi)} = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for } 0 \le \varphi < \varphi_m$$

$$G_{(\varphi)} = 2 + 15 \log \left(\frac{D}{\lambda}\right) \qquad \text{for } \varphi_m \le \varphi < \max(\varphi_m, 12.02\left(\frac{D}{\lambda}\right)^{-0.6})$$

$$G_{(\varphi)} = 29 - 25 \log \varphi \qquad \text{for } \max(\varphi_m,\ 12.02\left(\frac{D}{\lambda}\right)^{-0.6}) \le \varphi < 48°$$

$$G_{(\varphi)} = -13 \qquad \text{for } 48° \le \varphi < 180°$$

$$\varphi_m = 20\frac{\lambda}{D}\sqrt{G_{max} - 2 - 15\log\left(\frac{D}{\lambda}\right)}$$

where:

D : antenna diameter

λ : wavelength

φ : off-axis angle of the antenna (degrees).

For $D/\lambda < 100$:

$$G_{(\varphi)} = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for } 0 \le \varphi < \varphi_m$$

$$G_{(\varphi)} = 39 - 5 \log \left(\frac{D}{\lambda}\right) - 25 \log \varphi \qquad \text{for } \varphi_m \le \varphi < 48°$$

$$G_{(\varphi)} = -3 - 5 \log \left(\frac{D}{\lambda}\right) \qquad \text{for } 48° \le \varphi < 180°$$

Several FS locations in northern Europe have been considered, amongst them Frankfurt, Helsinki, London, Moscow, Murmansk, Paris, Rome, St. Petersburg, Svalbard and Vienna. Locations in southern Europe are less affected as the visibility of polar-orbiting satellites decreases with lower latitudes.

Regarding FS antenna elevations, a mean value of zero degrees has been used for most simulations. A comparative assessment was made for elevation angles between 0° and 5°. For the dish size of FS antennas, diameters of 1.2 m, 2.4 m, 3.0 m and 4.8 m have been considered. For most simulations, a conservative value of 3.0 m has been used, although it is recognized that most deployed FS antennas have diameters of 1.2 m or 2.4 m.

The analysis was performed using the Radio Frequency Interference Assessment Tool (RFIAT). Satellites were placed in circular orbits at 830 km with an inclination of 98°. A total simulation time of 100 days was initially selected for all cases but was repeated with 365 days for those cases where the fluctuations became very high. Unfortunately, the simulation time for 365 days comes close to 24 h for a single case so that only a limited number of cases could be simulated over this duration. In principle over a simulation time period of 365 days, all simulated curves would be smooth without fluctuations. Calculations were carried out in 5 s intervals. For every location considered, azimuth angles from 0 to 360° in steps of 5° have been considered. Every single simulation is therefore based on 21 to 450 million samples.

The program calculates the interference statistics based on the following equation for the FDP:

$$FDP = \sum_{I_i = \min}^{\max} \frac{I_i \cdot t_i}{N_T}$$

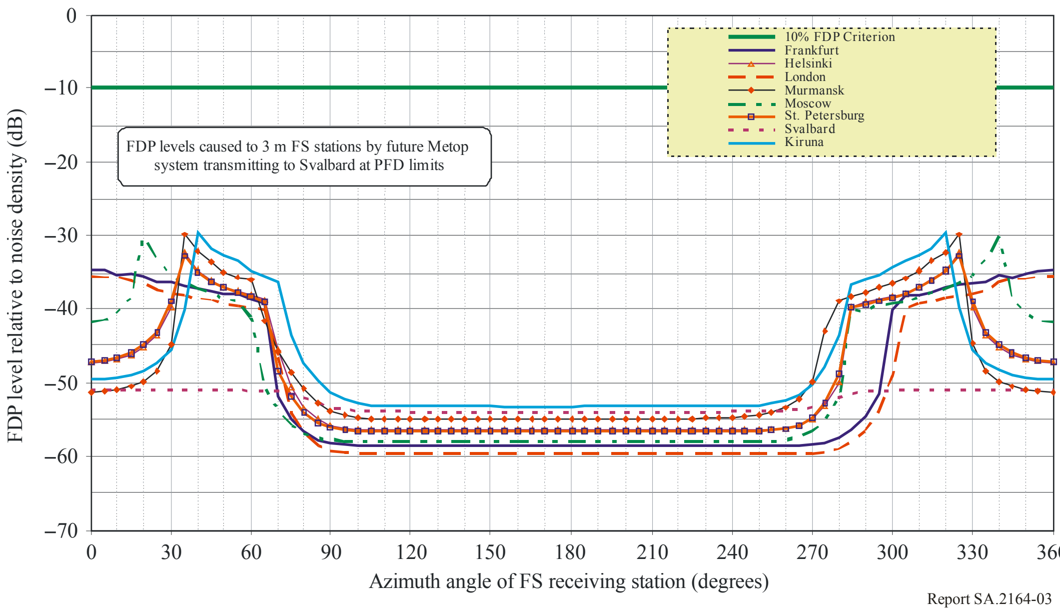
where:

- I_i: interference power density level
- t_i: fractional period of time that interference power density equals I_i
- N_T: noise power level of FS station per kHz (–171 dB(W/kHz)).

The acceptable limit of 10% is shown as the equivalent –10 dB line relative to the noise power density. Figure 3 shows the FDP for several FS locations where the meteorological satellite would hypothetically transmit at the PFD limit with a cardioid antenna to a corresponding earth station in Svalbard (System A). Frankfurt, Helsinki, London, Moscow, Murmansk, St. Petersburg and Svalbard have been selected as potential FS locations with 3 m dishes. It can be seen that around 20 dB of margin are available for hypothetical transmissions at the PFD limit. Considering that in practice these types of missions are usually operated around 10 dB below the PFD limit, the margins would be even 10 dB higher.

FIGURE 3

FDP levels for meteorological satellites transmitting to Svalbard with cardioid antennas



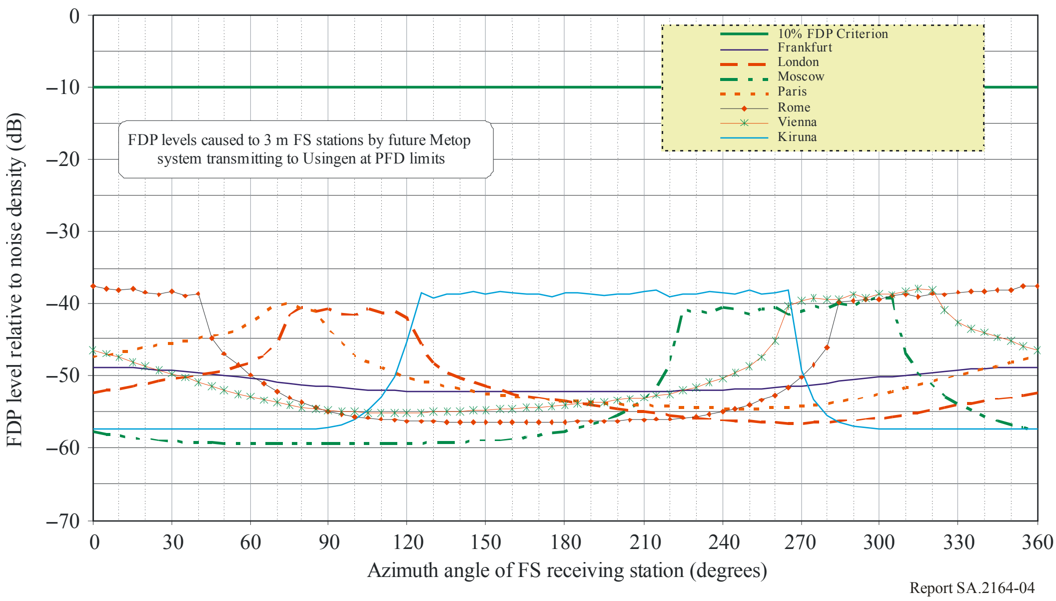
Report SA.2164-03

Figure 4 shows the FDP for several FS locations where the meteorological satellite would hypothetically transmit at the PFD limit to a corresponding earth station in Usingen (in the middle of Germany). Such a situation is currently not foreseen because of limited orbit coverage but could hypothetically occur if a second earth station is deployed for back-up purposes. Also in this case the practical PFD can be expected around 10 dB below the PFD limit. In such a case, mid latitude FS locations are more affected than high latitude locations so that Frankfurt, London, Moscow, Paris, Rome and Vienna have been selected as potential FS locations with 3 m dishes. Also in this case around 30 dB of margin are generally available, not taking into account the 10 dB of additional margin when operating at PFD levels realistically 10 dB below the PFD limit.

Figure 5 shows the FDP for several FS locations where the meteorological satellite would hypothetically transmit at the PFD limits to a corresponding earth station in Fucino (Italy). Such a situation could occur if an administration wishes to deploy its own national system like the FY-3 system in China, although FY-3 transmits also to Svalbard. For such a case again Frankfurt, London, Moscow, Paris, Rome and Vienna have been selected as potential FS locations with 3 m dishes. Also in this case around 30 dB of margin are available, again not taking into account the 10 dB of additional margin due to realistically 10 dB lower PFD levels.

FIGURE 4

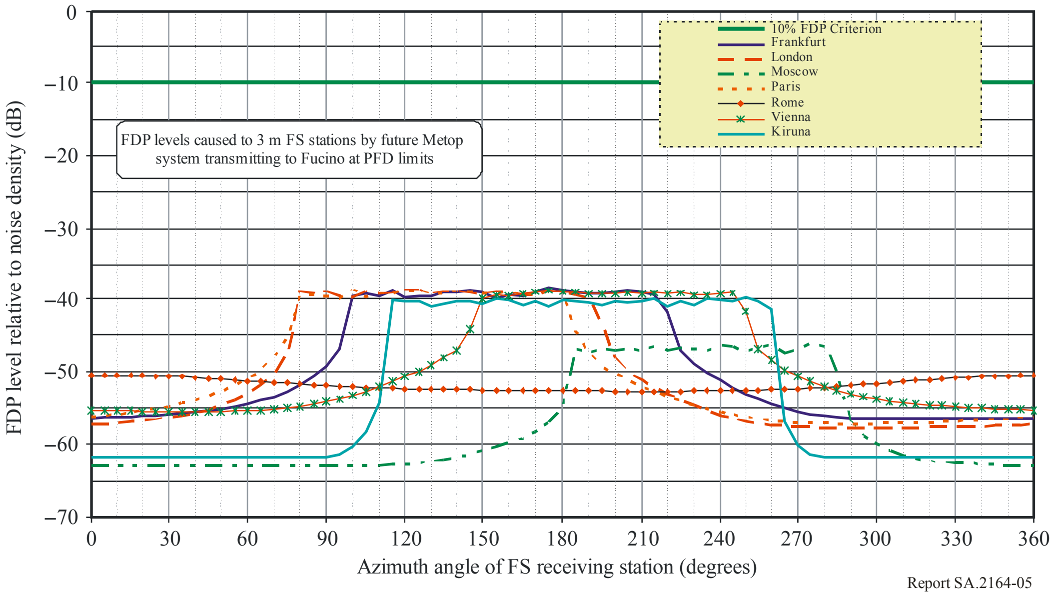
FDP levels for meteorological satellites transmitting to Usingen with cardioid antennas



Report SA.2164-04

FIGURE 5

FDP levels for meteorological satellites transmitting to Fucino with cardioid antennas

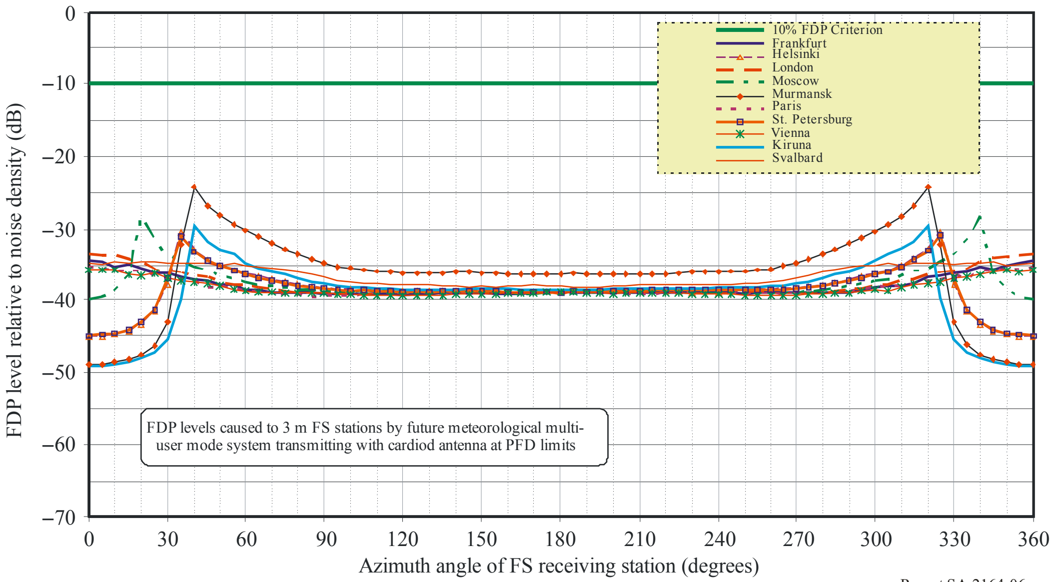


Report SA.2164-05

Figure 6 shows the FDP for several FS locations where the meteorological satellite would continuously transmit in a multi-user direct read-out mode at the PFD limit (System B). In reality, these types of missions are actually operated close to the PFD limit to allow for support of several smaller user stations of national weather services. Frankfurt, Helsinki, London, Moscow, Murmansk, Paris, St. Petersburg and Vienna have been selected as potential FS locations with 3 m dishes. This is basically the worst case situation that can occur in practice. It can be seen that around 18 dB of margin are still available.

FIGURE 6

FDP levels for meteorological satellites transmitting continuously with cardioid antennas



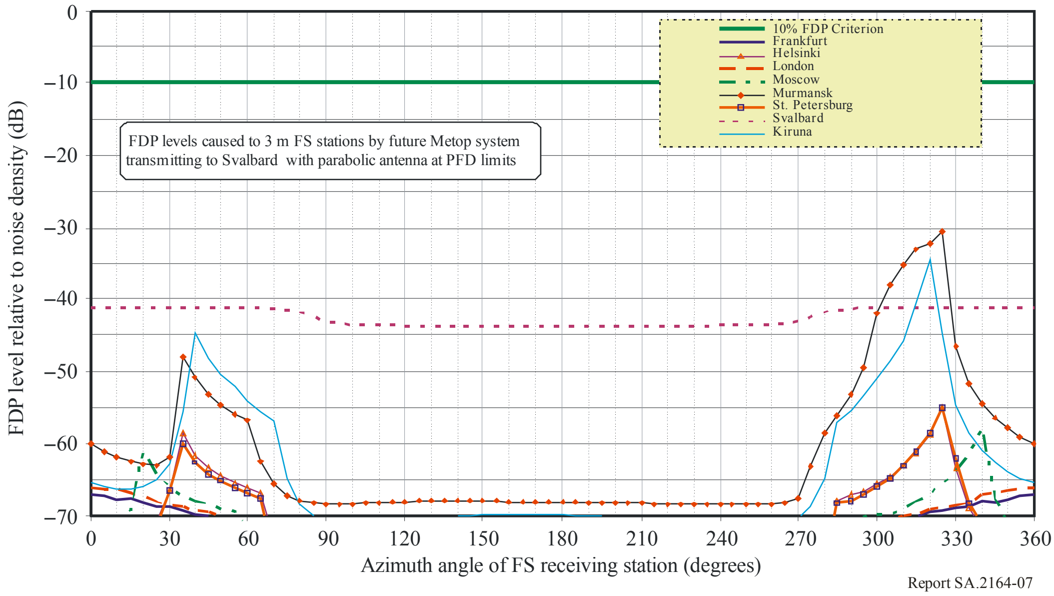
Report SA.2164-06

Figure 7 shows the FDP for several FS locations where the meteorological satellite would hypothetically transmit via a parabolic antenna (System C) at the PFD limit to a corresponding earth station in Svalbard. Such a case becomes attractive if QPSK or 8-PSK is not sufficient any longer to transmit the required high data rates within the envisaged 150 MHz. Operation close to the PFD limit may then occur. The same FS locations as for System A transmitting to Svalbard have been assumed. In this case around 20 dB of margin are available with respect to operation at the PFD limits.

Figure 8 shows the FDP for several FS locations where the meteorological satellite would transmit at the PFD limit via a parabolic antenna to a corresponding earth station in Usingen. The same FS locations as for System A transmitting to Usingen have been assumed. Also in this case at least 25 dB of margin would be available.

FIGURE 7

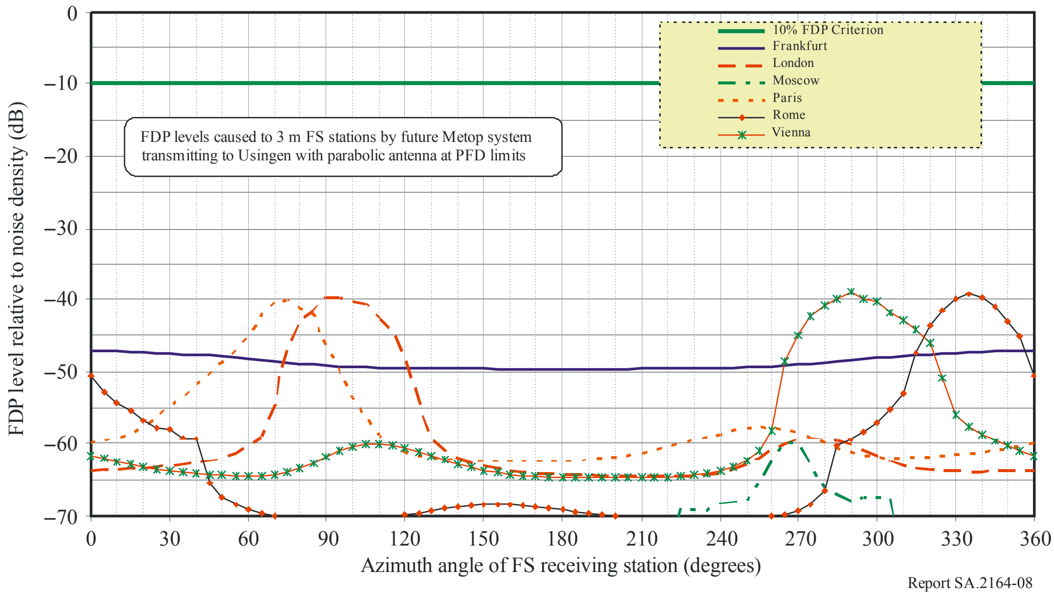
FDP levels for meteorological satellites transmitting to Svalbard with parabolic antennas



Report SA.2164-07

FIGURE 8

FDP levels for meteorological satellites transmitting to Usingen with parabolic antennas

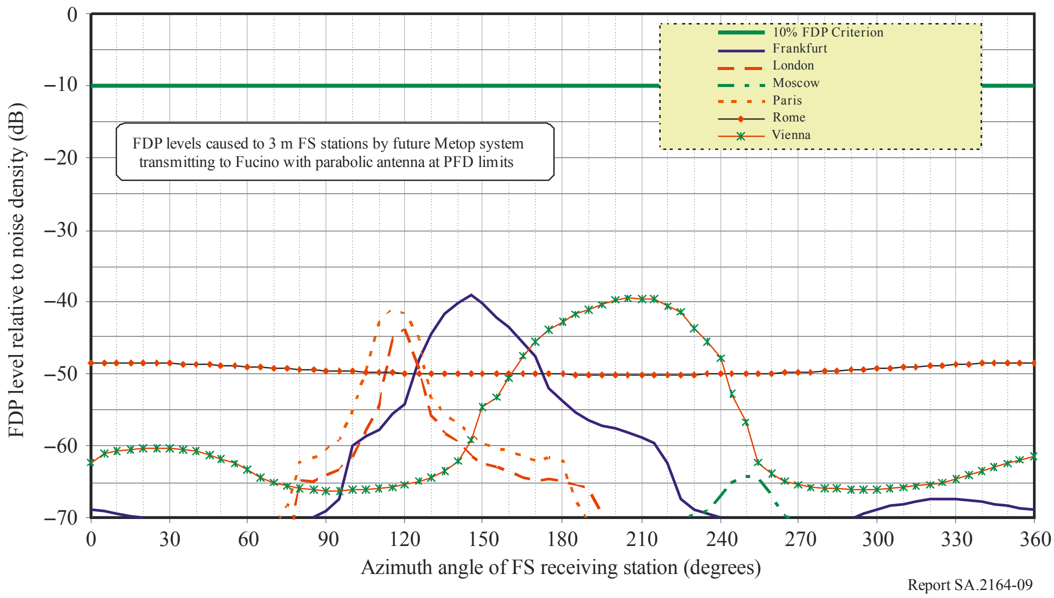


Report SA.2164-08

Figure 9 shows the FDP for several FS locations where the meteorological satellite would transmit at the PFD limit via a parabolic antenna to a corresponding earth station in Fucino. The same FS locations as for System A transmitting to Fucino have been assumed. Here also at least 25 dB of margin would be available.

FIGURE 9

FDP levels for meteorological satellites transmitting to Fucino with parabolic antennas



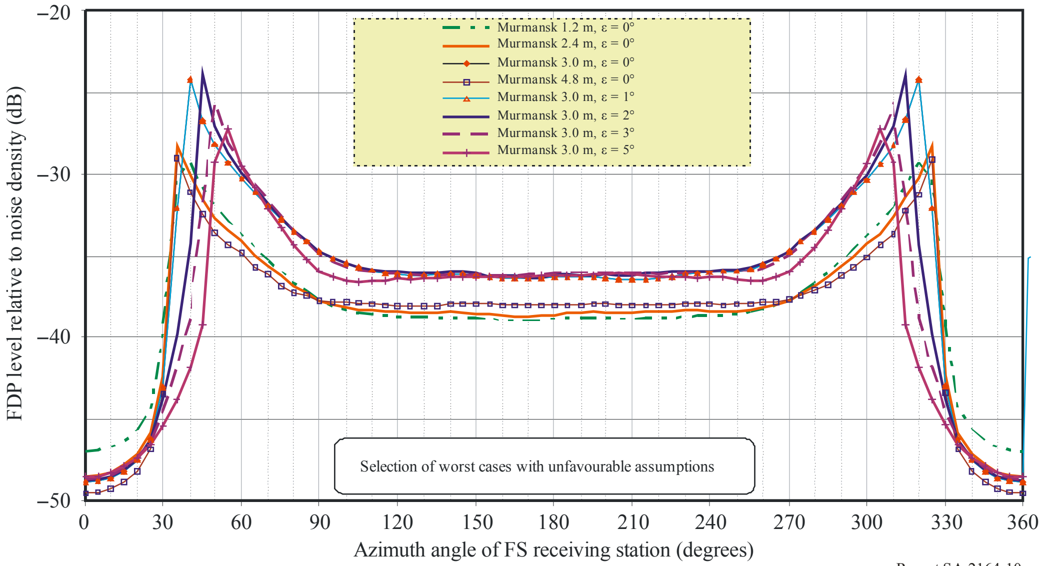
Report SA.2164-09

All above simulations have been conducted assuming likely deployment of FS systems based on conservative 3 m antennas with maximum gain as specified in Recommendation ITU-R F.758. It is recognized that in practice most FS stations have different antenna diameters. Commonly used dish sizes are 1.2 m and 2.4 m. In addition, Recommendation ITU-R F.758 specifies also the potential use of antennas up to 4.8 m. These 4 antenna diameters have been used for further assessments. Elevation angles were assumed with a mean value of zero degrees but may in some cases also vary up to a few degrees so that also elevation angles of 1°, 2°, 3° and 5° were considered. The most unfavourable location of Murmansk found in the above simulations has been used to assess a worst case FS deployment as shown in Fig. 10. System B (continuously transmitting in a multi-user direct read-out mode at the PFD limit) was selected as the worst meteorological satellite system for the very worst case identified. It can be seen that increasing antenna diameters result mainly in higher fluctuations around a mean level. Regarding varying FS elevation angles, the FDP may increase up to 4 dB for angles between 1° and 2° where 1° over a distance of 20 km would correspond to an altitude difference of 350 m.

Figure 11 considers all the above worst case constellations for cumulative interference received from all 3 meteorological satellite systems. It can be seen that even with a combination of very unfavourable assumptions, around 11 dB of margin would still be available.

FIGURE 10

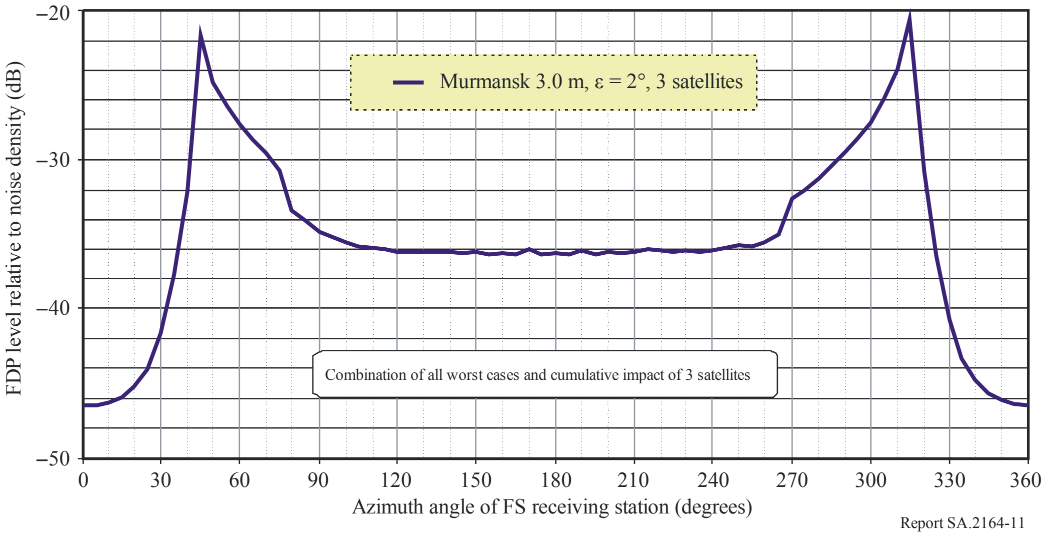
FDP levels as a function of FS antenna diameters and elevation angles



Report SA.2164-10

FIGURE 11

Cumulative FDP levels for 3 satellites and a combination of all worst case constellations



Report SA.2164-11

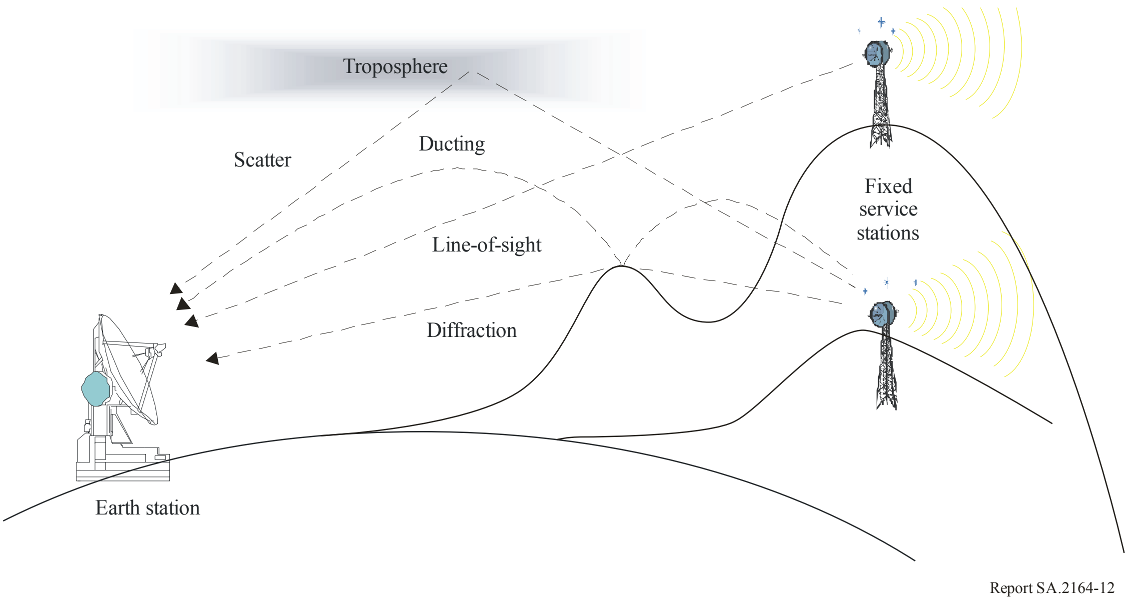
6 Interference assessment to meteorological earth station receivers

A transmitting terrestrial station of the fixed or mobile service may cause interference to a receiving meteorological earth station if the separation distance between existing fixed service stations and the selected location for a meteorological earth station is not sufficient. This distance is a function of several parameters and will have to be selected such that the received interfering signal from the terrestrial station is reduced sufficiently to meet the performance objectives of the meteorological earth station.

In addition to the free space loss, interfering signals are typically attenuated due to atmospheric effects, path obstacles, vegetation and diffraction due to the Earth's curvature. However, besides direct paths and propagation by diffraction, there exist additional propagation mechanisms, such as troposcatter and layer refraction (ducting), which can cause significant interference to meteorological earth stations. Figure 12 provides an overview of the associated propagation mechanisms.

FIGURE 12

Illustration of propagation mechanisms



The separation distance is also a function of the antenna azimuth and will decrease with the offset to the pointing direction. Off-pointing of the FS antennas will have a major effect on the separation distance.

Earth station diameters for the meteorological satellite service at frequencies around 7.8 GHz range typically between 3 and 10 m for stored instrument data dump systems and 2 m for multi-user direct read-out systems. Future higher data rates may also require larger antenna diameters. Short-term protection criteria for the meteorological satellite service have been assumed with –126 dB(W/10 MHz) for 0.0125% of time as contained in Recommendation ITU-R SA.1026.

In basically all international coordination procedures, actually required separation distances are calculated by means of Recommendation ITU-R P.452. This Recommendation addresses long-term effects such as propagation by diffraction (Recommendation ITU-R P.526) or tropo-scattering as well as short-term propagation effects such as reflection, refraction, ducting and hydrometeor scattering. The underlying mathematical models are quite complex and can only be addressed at a broad level in this contribution. The key equation for the required basic transmission loss is given by:

$$L_b(p) = P_t + G_t + G_r - P_r(p) \qquad \text{dB}$$

where:

p : maximum percentage of time for which the permissible interference power may be exceeded

$L_b(p)$: minimum required loss (dB) for p% of the time; this value must be exceeded by the predicted path loss for all but p% of the time

P_t : maximum available transmitting power level (dBW) in the reference bandwidth at the terminals of the antenna of a transmitting terrestrial station or earth station

P_r (p) : permissible interference power of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than p% of the time at the terminals of the antenna of a receiving terrestrial station or earth station that may be subject to interference, where the interfering emission originates from a single source

G_t : gain (dB relative to isotropic) of the antenna of the transmitting terrestrial station or earth station. For a transmitting earth station, this is the antenna gain towards the physical horizon on a given azimuth; for a transmitting terrestrial station, the maximum main beam axis antenna gain is to be used

G_r : gain (dB relative to isotropic) of the antenna of the receiving terrestrial or earth station that may be subject to interference. For a receiving earth station, this is the gain towards the physical horizon on a given azimuth; for a receiving terrestrial station, the maximum main beam axis antenna gain is to be used.

For each mode of propagation, it is necessary to determine the predicted path loss which is based on a number of propagation mechanisms. Interference to a MetSat earth station may arise through a range of propagation mechanisms whose individual dominance depends on climate, radio frequency, time percentage, distance and path topography. The propagation mechanisms that are considered in this study are primarily diffraction (including vegetation losses) and tropospheric scatter.

The calculations in this assessment are based on a mean latitude of 60° but no significant differences were found for latitudes between 45° and 75°.

The required separation distance is to a major extent a function of the actual transmitter and receiver antenna gains. For the FS antenna, the following 3 cases have been considered:

Firstly, the extremely unlikely case of the FS antenna pointing exactly towards the meteorological earth station antenna, secondly an offset of 1° and thirdly an off-set of 5°.

For a 3 m FS terminal, the antenna gain specified in Recommendation ITU-R F.699 has been used for determining the antenna gain contour. It is defined by the following equations applicable to cases where the ratio between the antenna diameter and the wavelength is less than or equal to 100. This is the case for 1.2 m, 2.4 m and 3.0 m antennas:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for } 0 \le \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad \text{for } \varphi_m \le \varphi < 100\,\lambda/D$$

$$G(\varphi) = 52 - 10\log\frac{D}{\lambda} - 25\log\varphi \qquad \text{for } 100\,\lambda/D \le \varphi < 48°$$

$$G(\varphi) = -10 - 10\log\frac{D}{\lambda} \qquad \text{for } 48° \le \varphi \le 180°$$

In cases where the ratio between the antenna diameter and the wavelength is greater than 100, which is the case for the 4.8 m antenna, the following equation was used:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \quad \text{for} \quad 0 \leq \varphi < \varphi_m$$

$$G(\varphi) = G_1 \quad \text{for} \quad \varphi_m \leq \varphi < \max(\varphi_m, \varphi_r)$$

$$G(\varphi) = 32 - 25 \log \varphi \quad \text{for} \quad \max(\varphi_m, \varphi_r) \leq \varphi < 48°$$

$$G(\varphi) = -10 \quad \text{for} \quad 48° \leq \varphi \leq 180°$$

where:

G_{max} : maximum antenna gain (dBi)

$G(\varphi)$: gain (dBi) relative to an isotropic antenna

φ : off-axis angle (degrees)

D : antenna diameter (m)

λ : wavelength (m)

G_1 : gain of the first side lobe: 2 + 15 log (D/λ).

$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1} \quad \text{degrees}$$

$$\varphi_r = 15.85\,(D/\lambda)^{-0.6} \quad \text{degrees}$$

Several different situations have been considered ranging from a combination of many adverse effects up to a favourable constellation, with a number of typical cases in-between.

The worst but extremely unlikely constellation is based on direct pointing of the FS antenna towards the meteorological earth station, maximum power density, lowest elevation (5°) of the meteorological earth station pointing in the direction of the FS station and no obstacle higher than 20 m over a distance of 50 km from a 10 m meteorological earth station, and 10 m at a distance of 20 m for 2 m earth stations assuming some local shielding. The reason for this difference is that small user stations of national weather services are often deployed in urban areas which offer good shielding or which can easily be surrounded by a fence or wall of about 10 m if needed.

Large meteorological earth stations will usually be found in areas which offer good site shielding through hills and vegetation. Vegetation attenuation guidelines for woodland can be found in Recommendation ITU-R P.833. Around 8 GHz, the attenuation is about 1.5 dB/m and it has been assumed that around 0.1% of a line of sight path is obstructed with trees, bushes, rocks or buildings. Horizon contours with hills up to several hundred metres are commonly found around a meteorological earth station site. Except for the worst case, obstacles between 50 m and 200 m above the antenna centre point have been assumed at a distance of 5 km.

For FS terminals, an effective antenna height of 50 m above ground was assumed. Tables 4 and 5 contain detailed information on all key assumptions made for the calculation of the derived separation distances for 10 m stored instrument data dump reception stations and 2 m direct read-out user stations, respectively.

The assessment takes also into account the low probability of the meteorological earth station pointing with high antenna gains towards the FS location. This is particularly important for any worst case constellations as the interference percentage would be unrealistically overestimated. A correction factor based on the following equation for the upper bound of the probability has been used:

$$p = \frac{1 - \cos \delta}{1 - \cos 85°}$$

where δ is the off-pointing angle towards the FS location starting at the minimum elevation angle of 5°. This equation is based on the area of a partial sphere above the earth station determined by all elevation angles above 5° which is given by 2·π·r·(1-cos(85°)) and the area of a cone cutting through this sphere with a cone opening angle determined by the separation angle between the axis of the meteorological satellite antenna and the FS location. The area for this cone intersecting with the sphere is given by 2·π·r·(1-cos(δ)). The consequential impact is that the percentage allowed for the interference excess can be increased by this correction factor. While this has no impact on free space loss and diffraction loss calculations, it does have an impact on those components of the Recommendation ITU-R P.452 model which depend on time statistics, such as troposcatter and layer ducting.

Figure 13 shows the achieved transmission loss relative to the required transmission loss for 10 m meteorological stored instrument data dump reception earth stations and a worst case 4.8 m fixed service point-to-point radio relay stations operating at the maximum EIRP density of 42 dB(W/MHz). The required worst case separation distance would be around 50 km. In practice, it is recognized that FS stations operate at significantly lower EIRP levels. Assuming more typical EIRP densities of 27, 33, 35 and 39 dB(W/MHz) for 1.2 m, 2.4 m, 3.0 m and 4.8 m dish sizes and a 90 Mbit/s 64-QAM system, respectively, would result in worst case separation distances, without any shielding, of 23, 27, 30 and 40 km, respectively. In all other cases, the first line-of-sight obstacle determines basically the required separation distance.

TABLE 4

Key characteristics for 10 m meteorological stored instrument data dump earth stations and FS radio relay stations

	worst case	typical case	favourable case	FS antenna off pointing	obstacle (hill, building)	forest or bushland
Radio frequency (MHz)	7825	7825	7825	7825	7825	7825
Permissible interference level for met. station (dB(W/MHz))	-135.0	-135.0	-135.0	-135.0	-135.0	-135.0
Met. antenna off-pointing angle to FS station (deg.)	5.0	10.0	48.0	10.0	10.0	10.0
Met. antenna gain towards FS station (dBi)	11.5	4.0	-13.0	4.0	4.0	4.0
Met. antenna centre point above terrain level (m)	12.0	12.0	12.0	12.0	12.0	12.0
Height of nearest obstacle above terrain level (m)	20.0	100.0	150.0	100.0	200.0	50.0
Distance to nearest obstacle along earth surface (m)	50000	5000	5000	5000	5000	5000
Average vegetation attenuation rate (dB/km)	1.5	1.5	1.5	1.5	1.5	1.5
FS station max. EIRP density towards horizon (dB(W/MHz))	42.0	42.0	42.0	42.0	42.0	42.0
FS station maximum antenna gain (dBi)	49.3	49.3	49.3	49.3	49.3	49.3
FS off-pointing gain reduction (0, 1, 5 deg.) (dB)	0.0	17.3	24.8	24.8	17.3	17.3
FS effective antenna height above terrain level (m)	50.0	50.0	50.0	50.0	50.0	50.0

TABLE 5

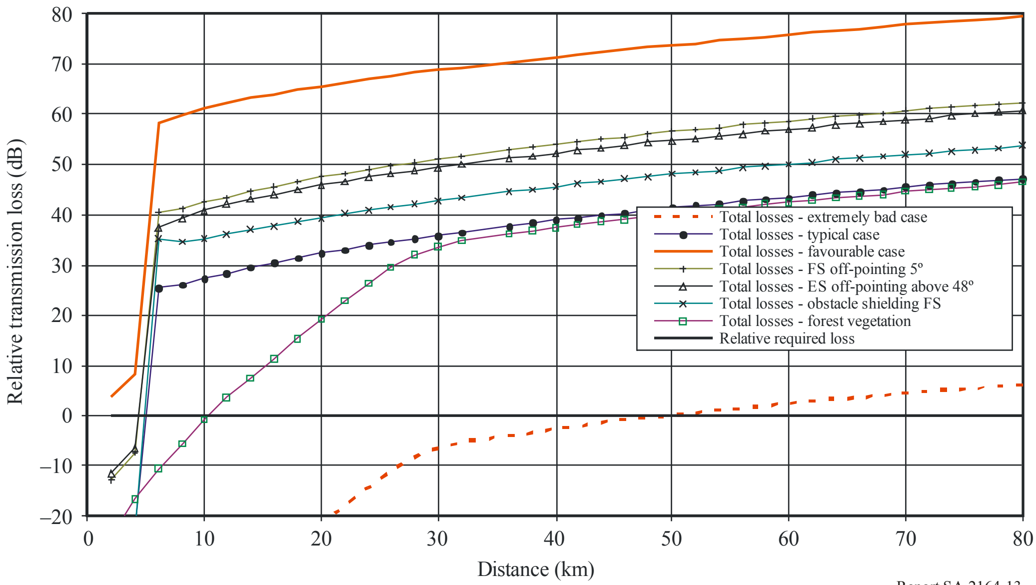
Key characteristics for 2 m meteorological direct read-out user stations and FS radio relay stations

	worst case	typical case	favourable case	FS antenna off pointing	obstacle (hill, building)	forest or bushland
Radio frequency (MHz)	7825	7825	7825	7825	7825	7825
Permissible interference level for met. station (dB(W/MHz))	-135.0	-135.0	-135.0	-135.0	-135.0	-135.0
Met. antenna off-pointing angle to FS station (deg.)	5.0	10.0	48.0	10.0	10.0	10.0
Met. antenna gain towards FS station (dBi)	11.5	4.0	-13.0	4.0	4.0	4.0
Met. antenna centre point above terrain level (m)	3.0	3.0	3.0	3.0	3.0	3.0
Height of nearest obstacle above terrain level (m)	10.0	15.0	20.0	15.0	50.0	50.0
Distance to nearest obstacle along earth surface (m)	10	10	10	10	1000	100000
Average vegetation attenuation rate (dB/km)	0.2	0.2	0.2	0.2	0.2	1.5
FS station max. EIRP density towards horizon (dB(W/MHz))	42.0	42.0	42.0	42.0	42.0	42.0
FS station maximum antenna gain (dBi)	45.2	45.2	45.2	45.2	45.2	45.2
FS off-pointing gain reduction (0, 1, 5 deg.) (dB)	0.0	13.2	20.7	20.7	13.2	13.2
FS effective antenna height above terrain level (m)	50.0	50.0	50.0	50.0	50.0	50.0

Figure 14 shows the achieved transmission loss relative to the required transmission loss for 2 m meteorological direct-read-out user stations and a worst case 4.8 m fixed service point-to-point radio relay stations operating at the maximum EIRP density of 42 dB(W/MHz). The required worst case separation distance would be around 42 km. For more typical EIRP densities of 27, 33, 35 and 39 dB(W/MHz), worst case separation distances, without any shielding, of 8, 16, 20 and 31 km, would be required, respectively. In typical cases, a separation distance of less than 2 km is expected to be required.

FIGURE 13

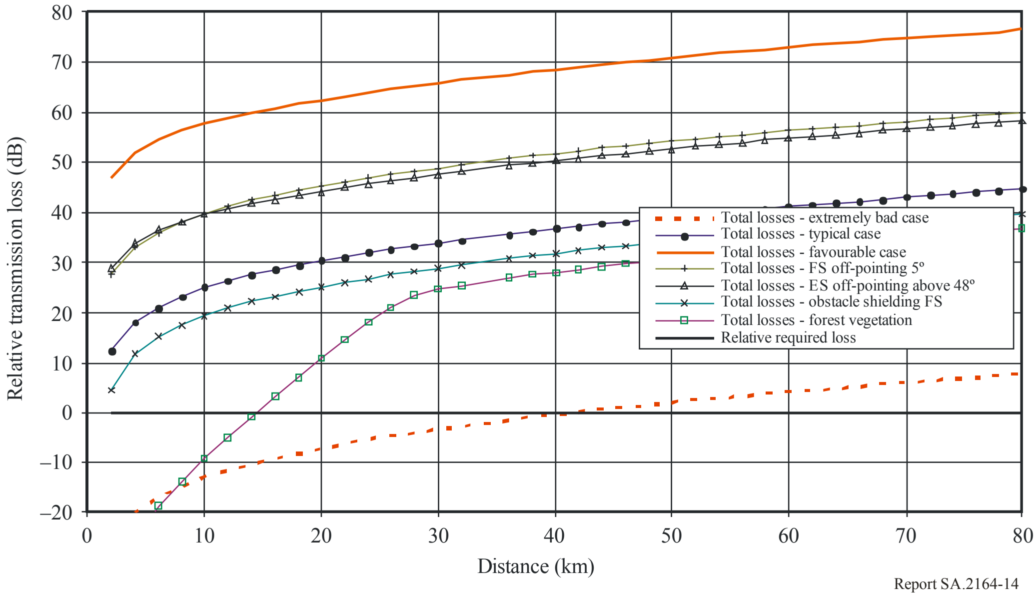
Separation distances for a 10 m meteorological stored instrument data dump earth station and FS radio relay stations



Report SA.2164-13

FIGURE 14

Separation distances for 2 m meteorological direct read-out user stations and FS radio relay stations



7 Technical summary and discussion

7.1 Potential of interference into fixed service receivers

A number of representative European FS station locations have been investigated with respect to potential interference caused by low earth orbiting meteorological satellites transmitting to a corresponding 10 m stored instrument data dump reception earth station in Svalbard or 2 m direct read-out user stations operated by national weather services.

Currently deployed meteorological satellite systems do not operate at the PFD limit but the power density levels for emissions of the satellites have been hypothetically increased for the simulations for operation at the PFD limit applicable in the band 7 750-7 850 MHz.

Worst cases will occur for FS locations at high latitudes, not only because of shorter separation distances to Svalbard but also due to increasing visibility and therefore longer satellite contact times. Even for satellites transmitting continuously to serve user stations of national weather services, the impact on FS stations will generally reduce with decreasing latitudes so that FS locations in higher latitudes will determine practically the degree of compatibility.

Minimum margins with respect to the FDP criterion range typically between 25 and 30 dB. In worst case locations (e.g. Murmansk), margins of 18 dB were available for 3 m FS antenna dishes and a mean elevation angle of 0°. Varying antenna diameters had an insignificant impact on the results. Worst case elevation angles between 1° and 2° resulted in a margin reduction of up to 4 dB, leaving a net margin in the worst case of 14 dB. Cumulative interference from 3 satellite systems operating at the PFD limit resulted in a net margin of still 11 dB with respect to the FDP criterion.

7.2 Potential of interference into meteorological earth station receivers

Separation distances between transmitting FS stations and receiving MetSat earth stations can vary significantly. For 10 m stored instrument data dump reception earth stations with worst case assumptions based on hypothetical maximum FS EIRP densities of 42 dB(W/MHz), direct pointing of the FS antenna towards the MetSat earth station, pointing of the MetSat earth station with a minimum separation of 5° and line-of-sight interference, a maximum separation distance of around 50 km would be required. This separation is mainly required by troposcatter propagation. More typical but still unfavourable/pessimistic assumptions would result in separation distances between 20 km and 40 km. Typical constellations require separation distances determined basically be the first line-of-sight obstacle. In more favourable constellations, a few km will generally be sufficient.

For 2 m meteorological direct read-out user stations with worst case assumptions based on hypothetical maximum FS EIRP densities of 42 dB(W/MHz), direct pointing of the FS antenna towards the MetSat earth station, pointing of the MetSat station with a minimum separation of 5° and line-of-sight interference, a maximum separation distance of around 42 km would be required. More typical, but still unfavourable/pessimistic assumptions, would result in separation distances between 8 km and 31 km. Typical constellations require separation distances of a few kilometres and more favourable constellation may not require any separation beyond the local shielding.

Sharing with potential ENG systems operating in this band will also be feasible considering that antennas of such systems are typically smaller than those of radio-relay systems. This increases the visibility duration but on the other hand, received interference levels are lower, providing a countering effect. Overall, the sharing situation will be very similar as compared to radio-relay systems.

8 Conclusions

Sharing between fixed service receivers and non-geostationary meteorological satellite systems is feasible without any constraints and the PFD limit in the band 7 750-7 850 MHz is adequate to protect the fixed service.

A combination of the worst case FS location, worst FS elevation angle, worst FS antenna diameter and cumulative impact of 3 meteorological satellites transmitting simultaneously at the PFD limit resulted in a remaining margin of 11 dB with respect to the FDP criterion.

Separation distances between transmitting FS stations and receiving meteorological antennas can extend up to around 50 km for very worst case constellations and are mainly caused by tropospheric scatter propagation.

Separation distances for typical constellations are on the order of 5-20 km and generally determined by the first obstacle in the line-of-sight transmission path.

The potential extension band 7 850-7 900 MHz can be shared under exactly the same conditions as the current allocation in the band 7 750-7 850 MHz.