# ECC Report 340

Receiver selectivity performance of satellite Earth stations in the band 3800-4200 MHz

**approved 23 May 2022**

# 0 EXECUTIVE SUMMARY

ECC Decision (11)06 [7] establishes the regulatory framework for the deployment of MFCN in the 3.4-3.8 GHz range, and identifies the particularities associated to coexistence between MFCN and other services such as the fixed satellite service (FSS - space-to-Earth). According to this framework, co-existence between MFCN systems operating in the entire 3400-3800 MHz band and FSS in 3800-4200 MHz can be achieved through coordination between MFCN and FSS, on a case-by-case basis, since no single separation distance, guard band or signal strength limit can be established.

This Report provides information on the methods available to administrations and operators of FSS earth stations, to increase the selectivity of their earth stations by narrowing the frequency response of the receive chain, due to the operation of LNA/LNB over the entire band 3400-4200 MHz.

This Report discusses three techniques:

- Filtering in the radio-frequency (RF) domain, using external waveguide devices;
- Filtering in the RF domain using LNBs which incorporate the RF filtering stage in its circuit board;
- Filtering in the intermediate-frequency (IF) domain, using discrete devices in the inter-facility link (IFL).

For each technique the parameters required for its specification are illustrated, and examples of devices available in the market are given.

Section 4 discusses RF filtering using external waveguide filters. The introduction of RF filters has been shown to be an effective method to prevent LNBs from operating in a non-linear region and to reduce the magnitude of the necessary protection distances between an MFCN base station and a victim FSS earth station. The most relevant parameters of a filter specification are described, and some example of commercial products are presented.

Section 5 describes operational scenarios in which unwanted emissions originating from the non-linear behaviour of the LNB could appear, and how IF filtering can prevent those unwanted products from reaching the devices operating in intermediate frequency part of the earth station, which would further degrade the signal to noise ratio of the desired service. Additionally, the inclusion of an IF filter can, in some cases, be beneficial, especially when low-level interference passes through the LNB.

Section 6 provides an overview of new LNBs with integrated RF filtering stages and higher 1 dB compression point (P1 dBc). The availability of a new generation of LNBs could, when used in combination with external waveguide filters, further reduce the separation distance. The section provides also examples of current products in the market.

As noted in sections 4 and 6, it is possible to modify the radio-frequency selectivity of an FSS earth station by means of the following:

a) the addition of a waveguide band pass filter before the LNA/LNB;

a) the usage of an LNA/LNB with integrated RF bandpass filtering.

Both filtering solutions contribute to reduce the power incident to the Front-End of the LNA/LNB by rejecting unwanted frequencies, and thus contribute to maintain the device operating in its linear region. The characteristics of the filter installed could be considered during coexistence studies performed according to existing CEPT framework (ECC Report 254 [4]) and respond to the relevant conditions of Earth station on a case-by-case basis.

Based on the information of this Report, and establishing as reference a scenario in which the radio-frequency mitigation techniques described in this Report are not present, it is possible to conclude the following regarding the magnitude of the separation distance:

a) the use of highly selective RF filters, either as dedicated devices or embedded in the LNB housing, can contribute to reduce the required separation distance, by reducing the amount of unwanted power entering the LNB;

b) the combination of a highly-selective waveguide filter with a high IP1 dBc LNB device can further reduce this separation.

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## LIST OF ABBREVIATIONS

| Abbreviation | Explanation |
| --- | --- |
| **BEM** | Block Edge Masks |
| **BER** | Bit Error Rate |
| **BWA** | Broadband Wireless Access |
| **CEPT** | European Conference of Postal and Telecommunications Administrations |
| **DECT** | Digital Enhanced Cordless Telecommunications |
| **DNC** | Down-converter |
| **ECC** | Electronic Communications Committee |
| **ES** | Earth Station |
| **FE** | Front-End |
| **FSS** | Fixed Satellite Service |
| **G/T** | Gain over noise Temperature ratio |
| **IDU** | Indoor unit |
| **IF** | Intermediate Frequency |
| **IFL** | Inter-facility link |
| **IMT** | International Mobile Telecommunications |
| **LNA** | Low Noise Amplifier |
| **LNB** | Low Noise Block |
| **LNBF** | Low Noise Block converter with Feed |
| **LO** | Local Oscillator |
| **LRTC** | Least Restrictive Technical Conditions |
| **LTE** | Long Term Evolution |
| **MFCN** | Mobile/Fixed communication Networks |
| **ODU** | Outdoor unit |
| **OIP3** | 3rd intercept point |
| **OMT** | Orthomode transducer |
| **PLL** | Phase Lock Looped |
| **RF** | Radio Frequency |

# 1 INTRODUCTION

According to the CEPT framework, in place since 2007 [1], coexistence between MFCN systems operating in the entire 3400-3800 MHz band and FSS in 3400-4200 MHz can be achieved through coordination between MFCN and FSS, on a case-by-case basis, since no single separation distance, guard band or signal strength limit can be established.

The CEPT framework establishes that the services can be coordinated based on the same methodology used for coordination between BWA (later with IMT) and FSS since 2007, i.e. based on the separation distance. As part of the framework, a technical toolkit for administrations to consider coexistence with FSS based on the separation distance has been provided by the CEPT in ECC Report 254 [4]. The CEPT framework recognises the LNA/LNB blocking effect due to high power emissions (it is assumed that the LNA/LNB operate over the entire band 3400-4200 MHz), and suggests that filtering at the FSS earth station may improve operation of the LNA/LNB of the Earth Station in the frequency band 3800-4200 MHz.

Furthermore, the harmonised mitigation measure of separation distance is considered for the protection of FSS receivers: i) from the impact of regulated out of band emissions of MFCN systems above 3800 MHz and ii) in order to prevent overdrive of the LNA/LNB, which operates in the entire 3400-4200 MHz band.

The remainder of the Report is structured as follows:

- Scope of the Report (see section 2);
- Background (see section 3);
- Use of RF (radio frequency) filters to mitigate the impact of MFCN emissions on the operating band 3800 - 4200 MHz of the FSS service (see section 4);
- Use of IF (intermediate frequency) filters to mitigate the impact of MFCN emissions on the operating band 3800-4200 MHz of the satellite receiver (see section 5);
- Overview of existing architectures for integrating filtering into LNB blocks (see section 6);
- Conclusions (see section 7).

## 2 SCOPE OF THE REPORT

The scope of this Report is to study possible improvements of receiver selectivity performance (in particular LNA and LNB, including filtering) of satellite Earth stations operating in the frequency band 3800-4200 MHz, in order to facilitate coexistence with MFCNs operating in the adjacent band, considering that no single separation distance, guard band or signal strength limit can be established through coordination between MFCN and FSS.

# 3 BACKGROUND

This section provides the necessary background information regarding the existing CEPT regulatory framework for the evaluation of the coexistence between MFCN in the range 3400-3800 MHz and the FSS in the range 3800-4200 MHz. Furthermore, as it is necessary for the remainder of this Report, the concepts of receiver selectivity and radio frequency response of FSS earth stations are introduced.

## 3.1 DEFINITION OF RECEIVER SELECTIVITY AND RADIO FREQUENCY RESPONSE

Receiver selectivity, as defined in ECC Report 310 [2], is a measure of a receiver's ability to reject unwanted signals in adjacent frequency ranges.

The use of the term receiver may require disambiguation. In general terms (see ETSI EG 203-336 [32]), a "receiver" denotes the equipment responsible for signal reception. For example, in some contexts, the term "receiver" applies to the Earth station LNB while in others it refers to the Earth station's demodulator or signal reception equipment in the indoor unit (IDU). In the context of satellite communications, the term receiver is more frequently used to refer to the device at the end of the reception chain, the modem or set-top box.

Figure 1 presents the main subsystems composing an Earth station.

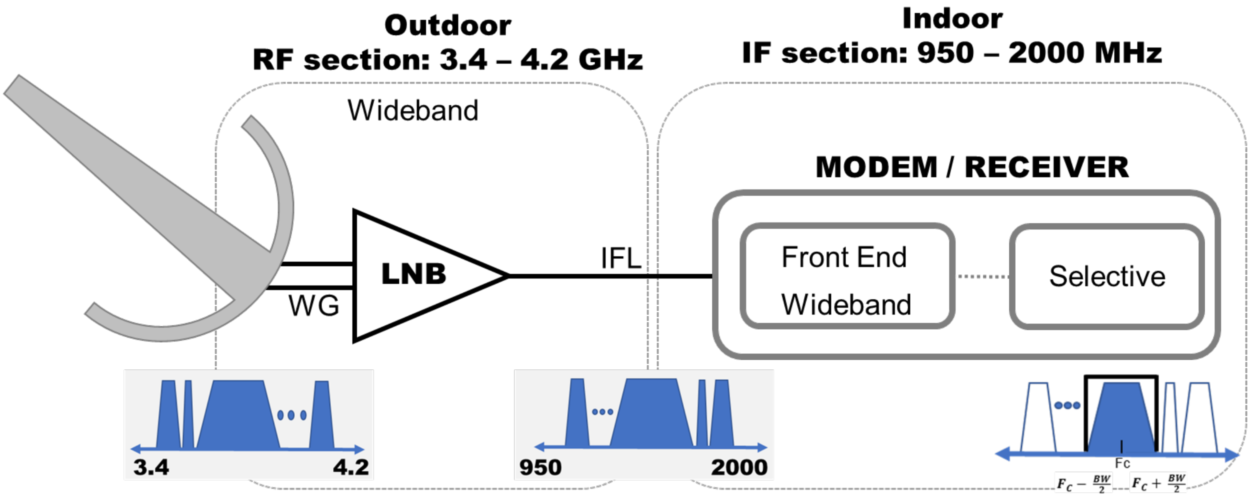


**Figure 1: Schematic of an FSS earth station, including the outdoor and indoor components and respective operating frequency ranges**

In Figure 1, the following parts can be identified:

- Outdoor unit (ODU): The ODU comprises an antenna and a Low Noise Block converter (LNB). The frequency down-conversion by the LNB enables transmission on a coaxial cable to the IDU. A frequency range that contains several modulated carriers is down-converted as one block. The most popular kind of antenna is a parabolic reflector antenna with offset feed. In that case the feed horn is often integrated with the LNB into one unit called Low Noise Block converter with Feed (LNBF);
- Indoor unit (IDU): The IDU demodulates one of the carriers, de-multiplexes the retrieved bit stream and decodes the digitally-modulated signal for delivery to a variety of devices. Common terms for the IDU are MODEM, set-top box or satellite receiver.

In the outdoor context, the LNB operates its front-end in the radio-frequency (RF) domain, while in the indoor context the receiver operates in the Intermediate Frequency (IF) domain. In both contexts, the Front-End is wideband, that is, its intended operating range in the corresponding domain is much wider than the bandwidth of the wanted carriers. Carrier selection and demodulation is performed by the modem or receiver equipment in the indoor unit. This happens in a second stage in the IDU receiver device, after the front-end. This stage is the only stage in the receive chain of the Earth station that can be characterised by having selectivity.

Considering the above, the receiver selectivity refers to the LNB device part of the ODU, in the context of this Report.

The Earth station selectivity is the multiplication of the frequency response, followed by integration (over the desired frequency range), of the equipment composing the ODU and the IDU.

This Report will present the frequency response of and performance characteristics the LNB in the ODU and study the devices available to modify the overall RF frequency response of the Earth station.

A discussion about the frequency response of RF devices is necessary because, as discussed in the introduction of this Report, in the CEPT framework for coordination via calculation of the required separation distance between MFCN and FSS services, emissions from the MFCN systems that can cause blocking (due to the operation of LNA/LNB over the entire band 3400-4200 MHz) should be considered, and may drive the Front-End of the ODU to a non-linear operating region and degrade the performance of the satellite service before it is down-converted and transmitted to the IDU. In a scenario where an Earth Station's LNB experiences blocking resulting from high power emissions, the introduction of a filter at the IF level will not reduce or eliminate the problem. Nevertheless, there are situations where the LNB is driven into its non-linear region and unwanted products are generated, or where direct interference in the IF path may occur, and where a reduction of the passband of the IDU front-end by means of IF filtering may reduce the level of those signals at the input of the receiver, thus improving reception.

## 3.2 INTERFERENCE MECHANISMS INVOLVED IN THE MFCN - FSS SHARING SCENARIO

When applying the harmonised mitigation measure of separation distance for the protection of FSS receivers in the band 3800-4200 MHz, two interference mechanisms are taken into account for the protection of FSS receivers (ECC Report 100 [3], ECC Report 254 [4] and ECC Report 203 [5]):

1. Interference from unwanted emissions. Unwanted emissions from MFCN stations operating in the 3400 - 3800 MHz band may generate interference into FSS reception in the 3800-4200 MHz band. The overall levels of the unwanted out-of-band emissions are regulated by in ECC Decision 11(06) [7] and EU Decision 2019/235 [8];

2. Service disruption due to saturation and non-linear behaviour of the LNBs.

   Typically, Earth station LNBs are designed to receive the entire 3400-4200 MHz band. The MFCN signals in the 3400-3800 MHz band therefore can saturate the amplifier stage in the LNB or bring it into non-linear operation thus blocking reception of signals.

   Moreover, as described in Report ITU-R S.2368 [9] emissions from MFCN systems will cause the LNBs in the FSS earth stations to produce unwanted signals in the form of intermodulation products. These products will act as additional interfering signals and further degrade the performance of the satellite service.

As noted in the CEPT framework, the above-mentioned interference mechanisms, combined with the characteristics of the sharing scenario on a case-by-case basis (e.g. relative antenna alignment between the interfering and interfered-with systems, propagation scenario and characteristics of the terrain, protection criteria, among others) allow the calculation of the required isolation (e.g. in MCL calculations) in order to guarantee coexistence of the services in bands adjacent to each other.

Furthermore, regarding the interference mechanisms described above, this Report will discuss the following topics:

1. LNB blocking[1] caused by emissions in bands adjacent to the FSS service can be mitigated by the installation of radio-frequency (RF) filters, as indicated in ECC Report 100 [3].

[1] Also referred to as Receiver Blocking in ETSI EG 203 336 [32]

The main objective pursued by the installation of the filter is to limit the amount of interfering power at the input of the LNB's first amplification stage, which arises from emissions in the range 3400-3800 MHz, corresponding to the assigned block of an MFCN service.

Therefore, the first section of this Report will analyse the requirements associated to RF filters, in the context of MFCN and FSS service coexistence, when the services are deployed as indicated by ECC Decision 11(06) [7] and EU Decision 2019/235 [8].

2 The increase in selectivity in the front-end of a receiver to protect it from interference in IF frequencies, which could be experienced due to unwanted mixing products delivered by the LNB, or due to the down-conversion of MFCN signals when no RF filters are installed in the Earth station (see section 5).

3 The power levels at which non-linear behaviour in the FSS earth Station LNB such as gain compression, noise figure degradation and non-linear product generation- appears, can be modified by changes in the architecture of the LNB.

Section 6 will review how a modified LNA/LNB architectures result in devices that are more robust to the presence of high-power signals within their operating band.

### 3.3 REGULATORY BACKGROUND

Coexistence between MFCN operating in the entire band 3400-3800 MHz and FSS operating in the band 3400 - 4200 MHz is covered under the CEPT regulatory framework in place since 2007[2]. Initially, Broadband Wireless Access (BWA) systems were introduced and examined, followed by IMT systems. In all cases, the mitigation measure introduced and applied for the protection of FSS earth stations is similar: Separation distance computed on a case-by-case basis since no single separation distance, guard band or signal strength limit could be provided. In addition, mandatory baselines and Block Edge Masks (BEMs) were introduced and applied for the protection of FSS above 3800 MHz.

As shown in the CEPT framework, the legacy BWA and IMT systems licenced in the 3400-3800 MHz were considered to have similar technical characteristics and provisions for the protection of FSS in the band 3800 - 4200 MHz, as MFCN systems.

So, the CEPT regulatory framework, for the coexistence between MFCN at 3400-3800 MHz and FSS at 3800 - 4200 MHz, considers that:

- MFCN operate in the entire frequency band 3400-3800 MHz with specific technical conditions;
- FSS earth stations which are individually licensed or registered (where the locations, technical and operation characteristics are known) need to be protected;
- Coexistence between the MFCN base stations and the licensed FSS earth stations can be achieved through coordination between MFCN and FSS on a case-by-case basis, since no single separation distance, guard band or signal strength limit can be established;
- Coordination is based on the definition of separation distance between the two services (the same methodology as that which has been used for coordination between BWA and FSS), depending on the geographical deployment (e.g. tilt and clutter), on type of equipment, system specifications and protection criteria of both services in order to ensure compliance with the requisite protection criteria at FSS space-to-Earth downlink receivers operating in the 3400-4200 MHz band, according to ECC Report 254 [4];
- Studies on sharing between IMT and the fixed satellite service in the 3400-4200 MHz frequency band have been carried out by ITU-R (Report ITU-R M.2109 [34] and Report ITU-R S.2368 [9]);
- The regulated out of band emissions from MFCN transmitters above 3800 MHz are taken into account for the protection of FSS earth stations above 3800 MHz;

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[2] Since 2007, ECC Report 100 [3], ECC Report 203 [5], ECC Report 254 [4], ECC Report 281 [6], CEPT Report 49 [36], CEPT Report 67 [10] and ECC Decision 11 (06) [7] have been developed, together with Report ITU-R M.2109 [34], Report ITU-R S.2199 [37] and Report ITU-R S.2368 [9], which provide guidelines for the coexistence of the BWA/IMT/MFCN with other services in the bands considered and deal with the protection of FSS in the band 3400 to 4200 MHz.

- Due to the operation of LNA/LNB over the entire band 3400-4200 MHz, LNB overdrive and intermodulation products occur due to high power emissions, and filtering at the FSS ES may improve the operation of LNA/LNB (i.e. avoid non-linear behaviour).

Decision in [7], designate the 3400-3600 MHz and 3600-3800 MHz bands to MFCN.

CEPT administrations wishing to implement MFCN in the 3400-3800 MHz band should follow the least restrictive technical conditions (LRTC) suitable for MFCN ([7],[8]), and further described in ECC Report 281 [6] and CEPT Report 67 [10]. Some parts of these LRTCs are reproduced for convenience in Table 1.

**Table 1: Extract of the BEM In-Block and Additional Baseline power limits relevant to FSS earth station selectivity analysis in this Report**

| BEM Element | Frequency Range (MHz) | Non-AAS e.i.r.p limit dBm/(5 MHz) per antenna ($P_{max}$) | AAS TRP limit dBm/(5 MHz) per cell ($P_{max}$') |
|---|---|---|---|
| In-Block | 3400-3800 | 68 (Note 1) | 47 (Note 1) |
| Additional Baseline | 3800-3805 | Min($P_{max}$-40,21) | Min($P_{max}$'-40,16) |
| | 3805-3810 | Min($P_{max}$-43,15) | Min($P_{max}$'-43,12) |
| | 3810-3840 | Min($P_{max}$-43,13) | Min($P_{max}$'-43,1) |
| | Above 3840 | -2 | -14 |

Note: In a multi-sector base station, the radiated power limit applies to each one of the individual sectors.
Note: The transitional regions and the baseline power limits apply to the synchronised operation of MFCN networks as defined in ECC Report 281 [6].
Note: $P_{max}$ is the maximum mean carrier power in dBm for the base station measured as e.i.r.p. per carrier, interpreted as per antenna.
Note: $P_{max}$' is the maximum mean carrier power in dBm for the base station measured as TRP per carrier in a given cell.

Note 1: That the maximum BS in-block e.i.r.p. of ≤ 68 dBm/(5 MHz) and 47 dBm/(5 MHz ) are non-mandatory

# 4 USE OF RADIO FREQUENCY (RF) FILTERS TO MITIGATE THE IMPACT OF INTERFERENCE ON THE OPERATING BAND OF THE FSS SERVICE

## 4.1 RF FILTER SPECIFICATIONS

Filters are an effective mechanism to modify the frequency response of the FSS earth stations.

Filters can have one of five responses low-pass, high-pass, band-pass, band-stop (including notch filters), and all-pass. In the discussion that follows, the focus will be on band-pass filters, as it is the required response in the context of the coexistence of MFCN and FSS systems in adjacent bands. Note that high-pass filters could also be considered.

The response of a band-pass filter is composed of three regions:

- Upper and Lower rejection regions: characterised by high attenuation and designed to limit the contribution of signals from those regions into the load. These are the continuous ranges of frequencies that the filter is expected to stop/reject the emissions, with some minimum specified attenuation value;
- Passband region: characterised by low attenuation, and with a width equal to that of the desired signal bandwidth. It is the continuous set of frequencies which the filter is expected to let through without excessive attenuation or distortion;
- Transition bands: regions in between the passband and the rejection bands, in which the response of the filter is decreasing in attenuation, from the rejection levels (high) to the passband levels (low). Within this region, the filter's response does not meet neither the rejection nor the passband criteria. The width of the transition region is a critical design parameter and influences the characteristics of the transfer function and the methods used in the design of the filter.

The principal trade-off in filter design is between constraining the width of the transition bands and the filter order, which is the complexity of the filter and is related to the number of components or discernible structures required to implement a filter [11]. Figure 2 illustrates the main parameters required for the specification of a band pass filter.

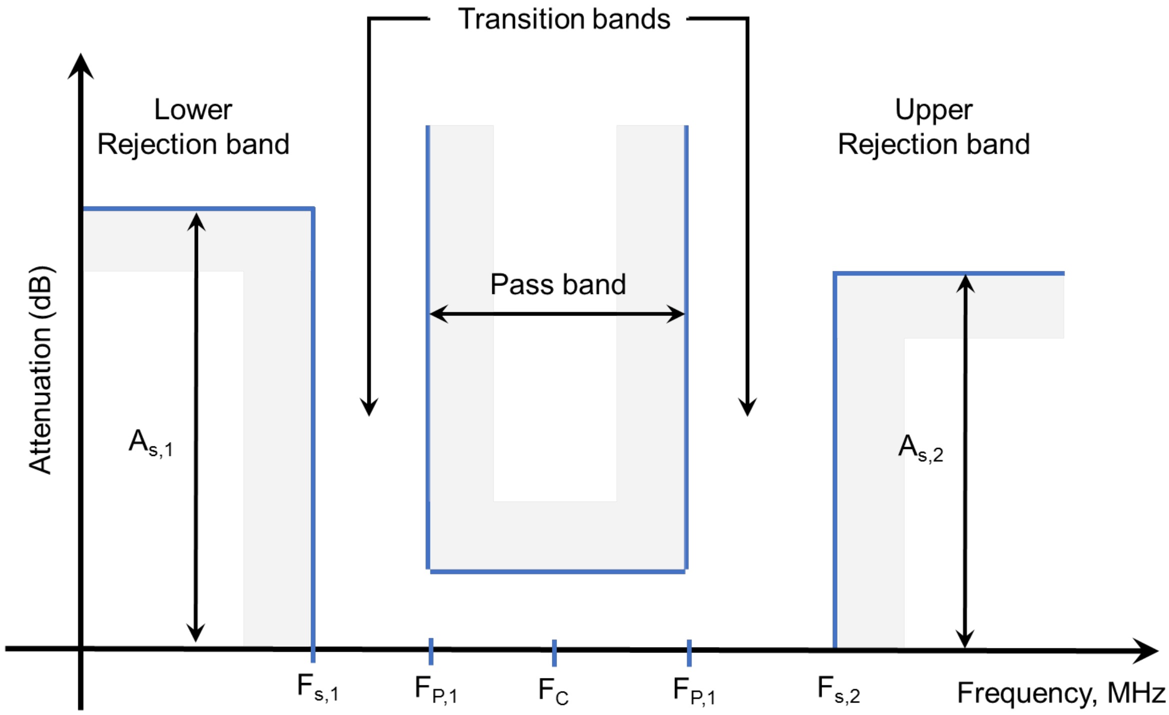


Figure 2: Basic parameters associated to the specification of a bandpass filter

The parameters are defined as follows:

- $A_{S,1}$, $A_{S,2}$: Attenuation (dB) associated to the stopbands or rejection bands;
- $F_{S,1}$, $F_{S,2}$: Cut-off frequencies (MHz) to transition out of and into the lower rejection and upper rejection bands, respectively;
- $F_{P,1}$, $F_{P,2}$ : the begin and end frequencies (MHz) of the filter's passband.

Other derivative parameters are listed below:

- Bandwidth: width of the passband;
- Shape factor: Sharpness of the frequency response;
- Ripple: peak to peak variation of the response within the passband (flatness of the signal as it passes through the passband). Passband and stopband ripple targets are required in the specification of a filter to indicate the limits beyond which the filter does not perform as desired.

Furthermore, other parameters not illustrated in Figure 2, but equally important and necessary when specifying as described below.

### 4.1.1 Insertion loss

The insertion loss (IL) is the amount of power lost as the signal traverses the filter. It can be formulated as

$$IL = -10\log_{10}\left(\frac{P_{Out}}{P_{In}}\right) \tag{1}$$

Where:

- $P_{out}$ and $P_{in}$ is the output and input power, respectively.

### 4.1.2 Phase and group delay

As with insertion loss, a filter response that has narrower transition band will usually also have larger group delay. Group delay has an impact on the performance of digital modulations, as it is linked to inter-symbol interference. In consequence, not only the service will be affected by the insertion loss penalty, but digital carriers may experience degraded BER resulting from a change in the overall group delay profile of the transmission path, which exceeds the equalisation capability of the demodulator.

Since group delay variation over frequency degrades any signal, it is desirable that the filter's contribution to the overall group delay of the transmission chain is low. Group delay specifications must be prepared considering the characteristics of the FSS modulations, including symbol rate ranges.

It must be noted that the equalizers on modern satellite receivers are able to compensate for some of the issues introduced by group delay but may not be able to accommodate large variations such as those present around the edges of the passband of filters exhibiting sharp selectivity.

When ripple can be traded-off in the design, elliptic-response filters allow for the fastest transition between a passband and a stopband, at the expense of a maximum ripple in both the passband and the rejection band.

### 4.1.3 Other filter parameters

Finally, there are other environmental parameters that affect filter performance. For example, changes in temperature will affect the components used to implement a filter and will cause drift in the frequency response. Temperature-induced drift is a critical factor to consider when high selectivity and steep transition bands are required in a filter response, as any shift on the cut-off frequencies of the rejection bands will result in additional interference into the system, an any shift (positive or negative) of the passband can result in undesired attenuation of the wanted signal.

For a more detailed discussion of RF filters, refer to [11]. Table 2 provides an example of the parameters required to fully specify a filter.

**Table 2: Example of a table for specification of an RF filter, including electrical and mechanical parameters**

| Electrical Specifications | Value |
|---|---|
| Passband limits | MHz |
| Insertion Loss within the passband | dB |
| Return Loss within passband | dB |
| Group delay variation +/- 0.5 MHz from any frequency within passband | ns |
| Rejection below $F_{S,1}$ | dB |
| Rejection below $F_{P,1}$ | dB |
| Rejection above $F_{P,2}$ | dB |
| Rejection above $F_{S,2}$ | dB |
| **Mechanical Specifications** | **Value** |
| Interfaces (waveguide, coaxial) | INPUT / OUTPUT |
| Maximum Dimensions (LxWxH). Length inclusive of flanges. Width and Height exclusive of flanges | cm / mm |
| Operating Temperature | degree C |

### 4.1.4 Filter response design tradeoffs

Once the performance requirements have been established, e.g. width of the reference bands and required rejection, a filter response can be selected.

For example, a Butterworth-type of response delivers flat passband response at the expense of selectivity, as a sharper transition between rejection and passband has immediate effect on the magnitude of the passband ripple. Passband ripple is an undesired side effect of a filter design response, as it will cause a degradation in performance of any signal present within the bandwidth where ripple is appreciable. In the specific case of satellite services, it will cause additional attenuation within the bandwidth of the satellite service that may not be present in other frequencies closer to the centre of the passband.

An alternative is a Chebyshev response, in which gain ripple is sacrificed at the expense of sharpness of the transition. In this case, the greater the ripple allowed, the faster the transition from the stopband to passband can be. Chebyshev responses are also called "equiripple". Equiripple in this context means that the maximum deviation from the desired gain response, due to ripple within the passband, will be kept under a design threshold.

## 4.2 EFFECTIVE FILTER REJECTION

The effective filter rejection is the measure of the total rejection provided by a filter, within the frequency range segments covered by the filter specification. It can be understood as the insertion loss computed within the rejection regions, outside the filter's passband, relative to the insertion loss experienced in the passband.

Considering the output - input relationship and the step-wise specification of the filter device, it is defined as:

$$Eff.Rej = \frac{P_{out,Tot}}{P_{in,Tot}} = \frac{\sum_{i=1}^{n} \mathrm{rej}_i.(\mathrm{PSD}_i \cdot \mathrm{BW}_i)}{\sum_{i=1}^{n} \mathrm{PSD}_i \cdot \mathrm{BW}_i} = \frac{1}{P_{in,Tot}} \cdot \sum_{i=1}^{n} \mathrm{rej}_i.(\mathrm{PSD}_i \cdot \mathrm{BW}_i) \tag{2}$$

With:

- i: section in the filter frequency response specification;
- $\mathrm{rej}_i$: rejection for step i;
- $\mathrm{BW}_i$: Bandwidth of step i;
- $\mathrm{PSD}_{i:}$ power spectral density for step i;
- $P_{out,Tot}$ , $P_{in,Tot,}$ : the total output and input power.

Note: under this definition, the value of effective rejection is in the range (0, 1]. In decibels, the effective rejection will be a negative number.

The effective filter rejection is useful to quantify the effect that a filter frequency response specification will have on the total input power into the earth station LNB. To be accurate, the calculations in equation (2) require a full description of the frequency response of the device.

## 4.3 FILTER RESPONSE IMPACT ON THE SYSTEM NOISE TEMPERATURE OF AN FSS EARTH STATION

Consider a simple Earth station model including a lossy network placed between the antenna and the LNB and ignoring the effects of reflected waves. In this case the system temperature obeys:

$$T_{SYS} = \frac{T_A}{L_F} + T_P(1 - L_F^{-1}) + T_{LNB} \tag{3}$$

Where:

- $T_A$ is the antenna noise temperature;
- $L_F$ is the loss of the passive network;
- $T_{LNB}$ is the equivalent noise temperature of the LNB;
- $T_P$ is the physical temperature of the lossy network.

The filter, if present in the FSS earth station, will take the place of the lossy network, and the insertion loss of the filter will be the driving parameter in the $L_F$ term of the equation (3).

The impact of the value of $L_F$ on the total system temperature is shown in Figure 3, for a 3.8 metre receive earth station with a clear sky antenna noise temperature of 40K[3], a filter with varying levels of insertion loss, and an LNB with an equivalent noise temperature of 30K. As illustrated in Figure 3, as the insertion loss increases, the Earth Station noise temperature increases and therefore the G/T ratio decreases. Thus, to mitigate the impact on the FSS, low attenuation within the passband is a key design objective for any filter.

[3] This value is typical of 3.8 m C band Earth stations, at an elevation angle of 45 degrees.

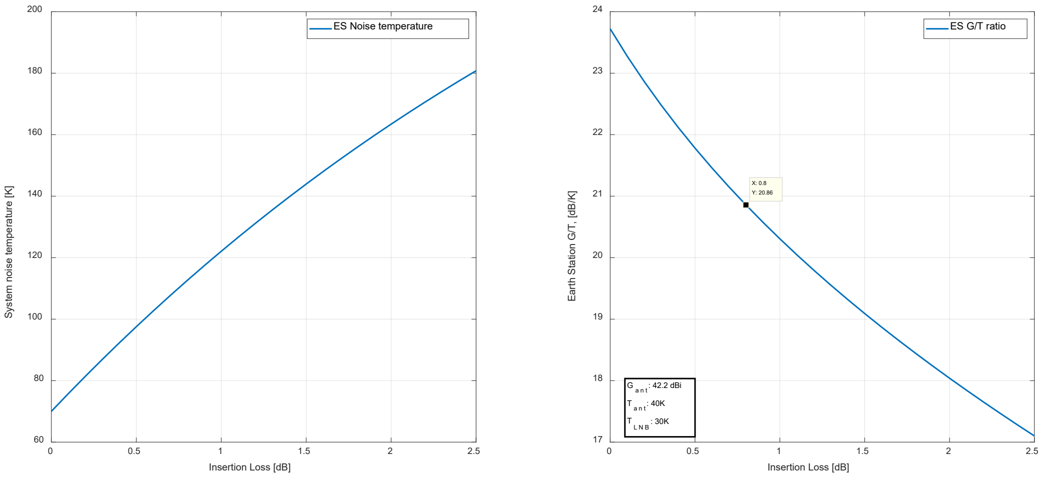


**Figure 3: Impact of filter insertion loss on the earth station system noise temperature and figure of merit (G/T). Frequency: 4 GHz. Earth Station diameter: 3.8m. Peak G/T is 23.7 dB/K**

The plot on the right in Figure 3 shows that a 0.8 dB insertion loss before the reference plane degrades the G/T by ~ 2.9 dB

As noted in section 4.1.4, the insertion loss variation within the passband depends on the selected filter response. Filter responses designed to have a narrow bandwidth in the transition region will present a higher insertion loss at the edge of the passband, compared to that at the centre of the passband. Therefore, services deployed near the edges of the passband will experience both a larger insertion loss and higher noise temperature.

## 4.4 THE ROLE OF FILTERS IN IMPROVING COEXISTENCE

After discussing the basic parameters associated to the frequency response of a filter, it is now possible to link the filter response and the effect it has on the coexistence between an MFCN system and an FSS earth station, by incorporating it in the principles of the operational guidelines in ECC Report 254 [4].

The selection of a filter that ensures adequate rejection of the MFCN signals must consider a combination of at least the following two factors:

- The rejection of the In-Block MFCN emissions profile within the LNB Front-End bandwidth (3400-3800 MHz) to protect LNB from saturation;
- The width of the transition region, between the maximum rejection and the passband region of the FSS service in 3800-4200 MHz or in parts of above 3800 MHz.

The design of the filter response (or the choosing of an existing filter) needs to take into account the amount of power that needs to be filtered and any possible available transition region to achieve the sought after rejection.

### 4.4.1 Rejection of MFCN In-Block emissions: Mitigating the LNB blocking problem

As described in ECC Report 254, in addition to the evaluation of the I/N allowance of FSS systems due to co-channel and out-of-band emissions from MFCN systems, overload of the FSS earth station low-noise amplifier (LNA) and low-noise block down-converter (LNB) should be considered. The main objective pursued when installing a filter in the receive chain of the earth station is to reject signals coming from the MFCN systems, in order to limit the amount of unwanted power at the input of the LNB's first amplification stage to guarantee that the LNB operates in the linear region.

The analysis consists of determining the amount of interfering power present at the input of the LNB, in the frequency range 3400-4200 MHz, after considering the rejection provided by the filter and quantified by means of the effective rejection.

$$P_{In,\ LNB} < P_{MAX,\ LNB} \quad (4)$$

Where:

- $P_{In,\ LNB}$ is the total input power into the LNB over its full operating band;
- $P_{MAX,\ LNB}$ is the linear operational power threshold of the FSS earth station LNB.

The total input power into the LNB is composed of the wanted signal component within the range 3800 - 4200 MHz range, and the interference component which will be more relevant in 3400-3800 MHz, and which will be attenuated by the filter's effective rejection.

$$P_{WANTED} + I_{MAX} + Eff.Rej_{dB} < P_{MAX,\ LNB} \quad (5)$$

Reorganising,

$$I_{MAX} < P_{MAX,\ LNB} - P_{WANTED} - Eff.Rej_{dB} \quad (6)$$

With:

- $I_{max}$ the maximum permitted interference power;
- $P_{MAX,LNB}$ is the linear operating threshold of the FSS earth station LNB;
- $P_{In}$ is the amount of power at the input of the LNB, and $_{wanted}$ the level of wanted signal power;
- $Eff.Rej_{dB}$ the effective rejection in decibels.

The value of $I_{MAX}$ determined by means of equation (6) can be used as input to the methods in ECC Report 254, annex 4 [4] to calculate a restriction or exclusion zone. As the benefits brought by the filter have been considered when defining the value of $I_{MAX}$, they do not need to be included in the definition of the coupling gain G of ECC Report 254.

For example, for a circular zone,

$$P_{MFCN\_e.i.r.p} + G_{PROP}(R_{BLOCK}) + G_{A,Rx} < I_{MAX} \quad (7)$$

With:

- $P_{MFCN}$ is the MFCN BS e.i.r.p. in units of dBm evaluated in the in-band range 3400-3800 MHz;
- $G_{PROP}(R_{BLOCK})$ is the propagation gain, which includes the dependency with distance;
- $G_{A,RX}$ is the FSS receive antenna gain, towards the MFCN transmitter.

Expanding the expression above using free space propagation loss and assuming full frequency overlap between services.

$$r_{(km)} \leq 10^{(-I_{MAX}+P_{MFCN}+G_{A,Rx(dB)}-32.4-20\log_{10}(F_{Rx(MHz)}))/20} = R_{Block} \quad (8)$$

It is important to recall that the validity of some of the models used in calculations, including the antenna gain envelope, is subject to the system operating in the far field condition, that is, on the distance being larger than $2D^2/\lambda$ where $\lambda$ is the wavelength and $D$ is the largest dimension of the antenna (often the diameter). The validity of the conclusions derived from these models cannot be assured for shorter distances and should be considered on a case-by-case basis (see Report ITU-R M.2109, annex E, section 1.2 [34])[4].

As indicated above, in addition to the LNB blocking phenomenon, out of band emissions from the MFCN will fall into the passband of the FSS service (3800-4200 MHz), causing an increase in the noise floor within the passband of the FSS earth station. The filter response (filter rejection) will not mitigate this effect, and in this case, other mitigation techniques might be needed such as separation distance of FSS ES and MFCN sites, to be determined on a case-by-case basis.

### 4.4.2 Estimation of the coexistence improvement

This section is aimed at providing an estimation of how much can a filter improve coexistence. Conversely, it also provides guidance on how to calculate an order of magnitude of the attenuation required in order to obtain a target improvement (measured, for example, in terms of separation distance reduction). Knowledge of the estimated required attenuation is useful for operators and national regulators to determine the best filtering to implement, depending on the physical separation of FSS ES and MFCN sites on a case-by-case basis.

The minimum rejection required to obtain this target improvement can be obtained by a combination of physical separation distance, relative alignment of the antennas (i.e. relative antenna gains of the victim and interfering stations towards one another), site shielding and additional filtering; other added sources of attenuation may also be possible.

In the paragraphs below, a rough estimation of the separation distance reduction is provided that would be achieved by adding a filter only. Operators and administrations may consider this in combination with ECC Report 254 [4] for a more complete picture of the coexistence environment.

Consider an ideal scenario in which out of band emissions from the MFCN systems do not play a role. Simplifying equation (8) above, in the absence of a filter and under free-space propagation conditions, a loss *L*o at a distance $d_0$ is required for operations. Under these circumstances, the relationship between $d_0$ and *L* is given by:

$$20\log_{10}(d_0) = Lo - 20\log_{10}(f) - c \tag{9}$$

Where:

- $d_0$ is the separation distance required without filtering;
- $f$ is the frequency;
- $c$ is a constant that depends only on the units of $d_0$ and $f$.

If a filter with effective rejection $A$ dB is now introduced, then it follows that the required attenuation *L* could be reduced by this amount. The distance after introducing the attenuation *A* is denoted $d_f$

$$20\log_{10}(d_f) = Lo - 20\log_{10}(f) - c - A = 20\log_{10}(d_0) - A \tag{10}$$

or equivalently

$$d_f = d_0 \cdot 10^{-A/20} \tag{11}$$

The reduction in separation distance, that is, the difference between $d_f$ and $d_0$, is given by

$$\Delta d = d_0 - d_f = d_0\left(1 - 10^{-A/20}\right) \tag{12}$$

Equation (12) links the target improvement in separation$\Delta d$ with the required attenuation to achieve it, $A$. Figure 4 illustrates this relation by providing 5 examples indicating the separation distances without filtering $d_0$. In

[4] A method for the estimation of the electrical field in the near field region of the antenna could be used in order to calculate the interference in the FSS receiver. For instance, a method for the estimation of the electrical field of an earth station in the near-field region was used in ECC Report 272 [38].

practice, an administration or operator will calculate the required separation distances without filtering $d_0$ following equation (8) and the methodology described in ECC Report 254 [4] (also reflected in section 4.4.1).

It can be seen that the required attenuation to achieve a certain target reduction is heavily dependent on the original situation, that is, on the original separation distance in the absence of additional attenuation $d_0$. Taking as an example $d_0$ = 10 km, it can be seen that the required attenuation increases with the target distance reduction; moderate reductions like 1 km require modest attenuations of around 1 dB, but the larger reductions that would allow placing both stations very close together require additional attenuations in excess of 50 dB. It should be remarked that higher attenuations put more stringent constraints on the filter design, as explained in the sections above.

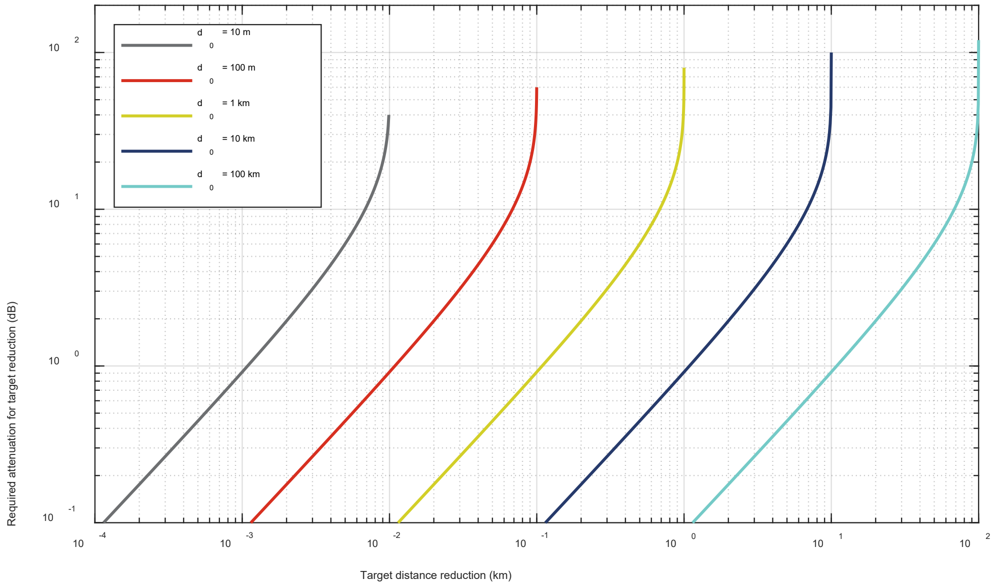


**Figure 4: Required extra attenuation to achieve a certain target reduction in separation distance, for different values of the original separation**

An alternative metric, independent of the original distance $d_0$, is the percentage separation reduction given by:

$$\%\Delta R = \frac{d_0 - d_f}{d_0} \cdot 100 = \left(1 - 10^{-A/20}\right) \cdot 100 \tag{13}$$

Table 3 provides some example calculations using this metric.

**Table 3: Example calculation of the reduction in separation distance of equations (12) and (13), for the ideal scenario**

| A (dB) | $d_0$ (km) | $d_0 - d_f$ (km) | $d_f$ (km) | $\%\Delta R$ |
|---|---|---|---|---|
| 60 | 10 | 9.99 | 0.01 | 99.90% |
| 40 | 10 | 9.9 | 0.1 | 99.00% |
| 20 | 10 | 9 | 1 | 90.00% |
| 6.0206 | 10 | 5 | 5 | 50.00% |
| 0.91515 | 10 | 1 | 9 | 10.00% |

Annex 1 presents examples of relative separation distance reduction when implementing a number of filters presented in section 4.5 of this Report.

## 4.5 AN OVERVIEW OF MICROWAVE FILTERS AVAILABLE IN THE MARKET TO FACILITATE COEXISTENCE OF MFCN AND FSS SERVICES

This section provides examples of commercially available filter devices that can be used on C-band FSS earth stations. These are provided as general examples and may or may not be immediately applicable to a coexistence scenario in CEPT countries. Operators of FSS earth stations should verify the allocations to the FSS from their respective Administrations.

### 4.5.1 ETL Systems

ETL Systems provides a variety of products for different passbands. For illustration purposes, two products are selected: F-WGC1-714044 with passband 3800-4200 MHz and 0.5 dB maximum insertion loss [12], and F-WGC1-714085 with passband in the 3820 to 4200 MHz range [13] and maximum 1.3 dB insertion loss.

**Table 4: Summary of parameters for ETL F-WGC1-714044 C band filter**

| Electrical Specifications | Value | Value |
|---|---|---|
| Product | F-WGC1-714044 | F-WGC1-714085 |
| Passband | 3800-4200 MHz | 3820-4200 MHz |
| Insertion Loss | from 3820 MHz to 4200 MHz : 0.5 dB maximum | 3820-3840 MHz: 1.3 dB maximum<br>3840-4200 MHz: 0.6 dB maximum |
| Return Loss within Passband | 18 dB minimum | 18 dB minimum |
| Group delay / Ripple (ns) | 17 / 12.5 | N.A. |
| Group delay variation (ns) | N/A | 2; Max at 3820-3830 MHz |
| Rejection | ≥ 50 dB @ 3750 MHz<br>≥ 80 dB @ 3400 MHz | 70 dB minimum < 3720 MHz<br>60 dB minimum in 3720-3800 MHz<br>30 dB minimum in 3800-3805 MHz<br>25 dB above 4230 MHz |
| **Mechanical Specifications** | **Value** | |
| Interfaces | CPR229G / CPR229F | |
| **Environmental Specifications** | **Value** | |
| Operating Temperature | -20 °C to +50°C | |


Figure 5: Sample of an FSS earth station with the ETL filter installed

### 4.5.2 Microwave Filter Company (MFC) C band filter solutions

The solutions provided by this manufacturer can be seen in their ”5G Mitigations” solution overview [14]. Two sample solutions highlighting different selectivity capabilities are described below.

#### *4.5.2.1 MFC 19524 multi-purpose receive C band filter assembly*

This is an example of a multi-purpose (WiMAX, Radar and Transmit band Reject Filters) C-band receive filter [15].

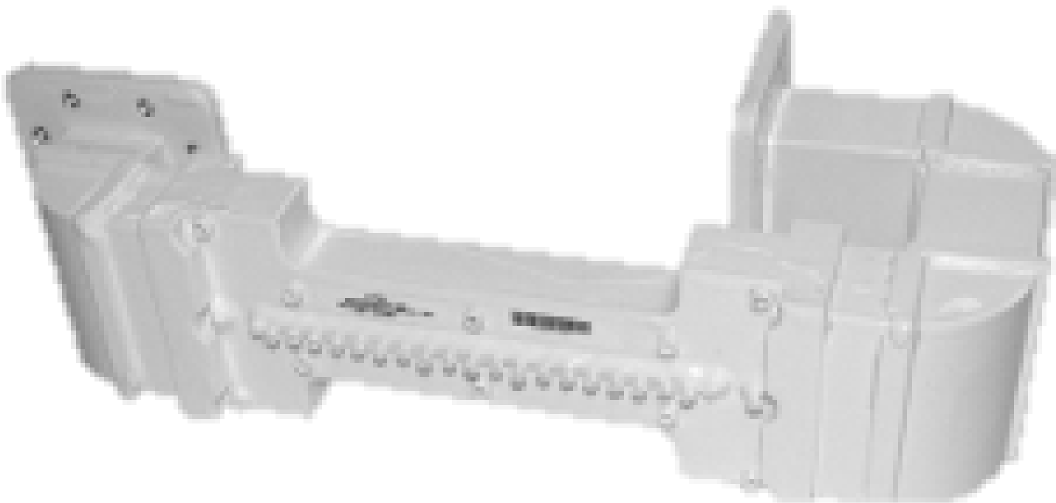

Figure 6: MFC 19524 C band filter

**Table 5: Summary of parameters for MFC 19524 multi-purpose C band filter**

| Electrical Specifications | Value |
|---|---|
| Passband | 3800-4200 MHz |
| Insertion Loss within passband | 0.3 dB typical (0.6 dB max) |
| Return Loss within passband | 19 dB Typical (VSWR 1.33:1) |
| Rejection below 3500 MHz | 70 dB minimum |
| Rejection below 3650 MHz | 45 dB minimum |
| Rejection above 4450 MHz | 50 dB minimum |
| Mechanical Specifications | Value |
| Interfaces | CPR229G |

#### *4.5.2.2 MFC 5G Mitigation series*

The MFC 20541 and 20523 [16] products have been designed to provide adequate rejection for the conditions of the US C band allocations for 5G services in the ranges 3820 to 4200 and 4000 to 4200 MHz.

**Table 6: Summary of parameters for MFC 5G mitigation series filter products**

| Electrical Specifications | Value | Value |
|---|---|---|
| Product | MFC 20541 (Red) | MFC 20523 (Blue) |
| Passband | 3820–4200 MHz | 4000–4200 MHz |
| Rejection | 3700-3720 MHz: 70 dB minimum<br>3720-3800 MHz: 60 dB minimum<br>3800-3805 MHz: 30 dB minimum<br>Above 4230 MHz: 25 dB minimum<br>5800-7075 MHz: 80 dB minimum | 3700-3900 MHz 70 dB minimum<br>3900-3980 MHz 60 dB minimum<br>3980-3985 MHz 30 dB minimum<br>Above 4230 MHz: 25 dB minimum |
| Insertion Loss within passband (3820-3825) | 1.4 dB max +/- 0.2 dB | |
| Insertion Loss within passband (3825-4200) | 1.2 dB max +/- 0.2 dB | |
| Return Loss | 20 dB min | |
| Group delay variation | 1.45 nSec typical | |
| Interfaces | CPR229G/ CPR229F | |

### 4.5.3 Alga Microwave Inc.

#### *4.5.3.1 C Band 5G Interference reject filters product family*

The Alga Microwave Inc. 5G filter products [17] have been developed specifically to mitigate the effects of 5G interference. The filters exhibit a sharp transition region, at the expense of increased ripple within the passband.


Figure 7: Alga Microwave Inc. 5G interference reject filter [17]

Table 7: Summary of parameters for Alga Microwave Inc. 5G rejection filters

| Electrical Specifications | Value | | | | |
|---|---|---|---|---|---|
| Product | Group 1 | Group 2 | Group 3 (Red) | Group 4 (J) | Group 5 (Blue or K) |
| Passband (MHz) | 3900-4200 | 3780-4200 | 3820-4200 | 4020-4200 | 4000-4200 |
| Insertion Loss | 1.3 dB max | | | | |
| Group delay variation | 1.45 nSec max | | | | |
| Rejection | 50 dB minimum at 3880 MHz | 60 dB minimum at 3760 MHz | 60 dB minimum at 3800 MHz | 60 dB at 4000 MHz | 70 dB below 3900<br>60 dB at 3980 MHz |
| Rejection in the upper band (>4230 MHZ) | 25 dB min at 4230 MHz | | | | |
| Return Loss | 19 dB | | | | |
| **Mechanical Specifications** | **Value** | | | | |
| Interfaces | | | | CPR-229 FLAT/ CPR-229 | |

As noted, it is critical to keep the insertion loss as low as possible in order to minimise service degradation due to a reduction in Earth station G/T.

### 4.5.4 Norsat International Inc

#### *4.5.4.1 BPF product family*

The Norsat BPF family [18] is composed of a series of filters, each with a different passband range but similar electrical and mechanical properties, designed to reject interference from 5G, Radar or other transmissions within the band of the FSS. The family is composed of seven products.

**Table 8: Summary of parameters for Norsat BPF family of filters. In all cases, the separation beween the 25 dB lower rejection band and the passband is 50 MHz**

| Electrical Specifications | | | | | | | |
|---|---|---|---|---|---|---|---|
| Insertion Loss within passband | 0.5 dB max. | | | | | | |
| Return Loss within passband | 16 dB minimum (VSWR 1.4:1) | | | | | | |
| Group Delay Variation within ± 0.5 MHz | 0.6 ns max. | | | | | | |
| Model | C-1 | C-2 | C-3 | C-4 | C-5 | C-6 | C-7 |
| Passband (MHz) | 3700-4200 | 3625-4200 | 3754-4200 | 3800-4200 | 3900-4200 | 4000-4200 | 4100-4200 |
| Lower rejection band: 25 dB (minimum) at | 3650 | 3575 | 3704 | 3750 | 3850 | 3950 | 4050 |
| Upper rejection band: 25 dB minimum at | 4250 MHz | | | | | | |
| Second upper rejection band: 60 dB minimum at | 4350 MHz | | | | | | |
| **Mechanical Specifications** | | | | | | | |
| Interfaces IN/OUT | CPR229G / CPR229F | | | | | | |
| **Environmental Specifications** | | | | | | | |
| Operating Temperature | -20 °C to +50°C | | | | | | |

### *4.5.4.2 EBPF product family*

The Norsat EBPF product family [19] consists of a series of devices optimised to have a sharp transition region at the expense of increased insertion loss.

The family is composed of six products, with different passband ranges, and similar electrical and mechanical parameters.

The EBPF-C4 filter has a passband suitable for the characteristics of EU Decision (3800-4200 MHz), exhibiting a sharp transition from the rejection to the passband region, with a 1.4 dB maximum insertion loss.

**Table 9: Summary of parameters for Norsat EBPF family of filters**

| Electrical Specifications | | | | | | |
|---|---|---|---|---|---|---|
| Insertion Loss within passband | 1.4 dB max. | | | | | |
| Return Loss within passband | 16 dB minimum (VSWR 1.4:1) | | | | | |
| Group Delay Variation within ± 0.5 MHz | 3.0 ns max. | | | | | |
| Model | C-1 | C-2 | C-3 | C-4 | C-5 | C-6 (Blue) |
| Passband (MHz) | 3700-4200 | 3625-4200 | 3754-4200 | 3800-4200 | 3900-4200 | 4000-4200 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Lower Rejection band: Rejection of 60 dB min. at (note 1) | 3682 | 3607 | 3736 | 3782 | 3882 | 3982 |
| Upper rejection band: Rejection of 25 dB min at | 4230 MHz | | | | | |
| **Mechanical Specifications** | | | | | | |
| Interfaces IN/OUT | CPR229G / CPR229F | | | | | |
| **Environmental Specifications** | | | | | | |
| Operating temperature | -20 °C to +50°C | | | | | |
| Note 1: In all cases, the separation between the 60 dB rejection band and the passband is 18 MHz | | | | | | |


**Figure 8: Norsat EBPF filter [20]**

For comparison, Figure 9 presents the insertion loss versus frequency response for two units: a member of the EBPF family, and one of the BPF family, for the same passband range. In this case, the responses are for the C-5 devices, with a passband between 3.9 and 4.2 GHz. According to the devices' specifications, the insertion loss in the passband is 1.4 dB for the EBPF-C5 versus 0.5 dB max for the BPF-C5. Rejection of 60 dB is achieved at 18 MHz from passband start in the EBPF-C5 versus 150 MHz in the BPF-C5. The upper rejection band is specified to have 25 dB 30 MHz from passband end on EBPF-C5 and at 50 MHz on the BPF-C5.

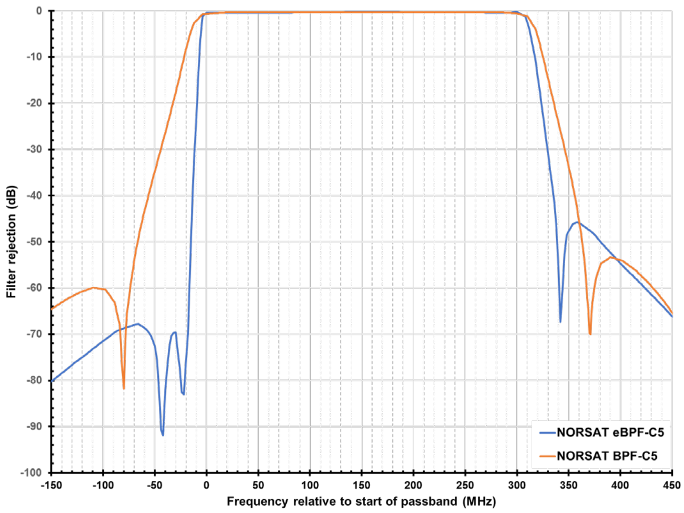


**Figure 9: Comparison of the frequency response of two filter devices with equal passband range: BPF versus EBPF. Note the difference in the slope of the transition regions**

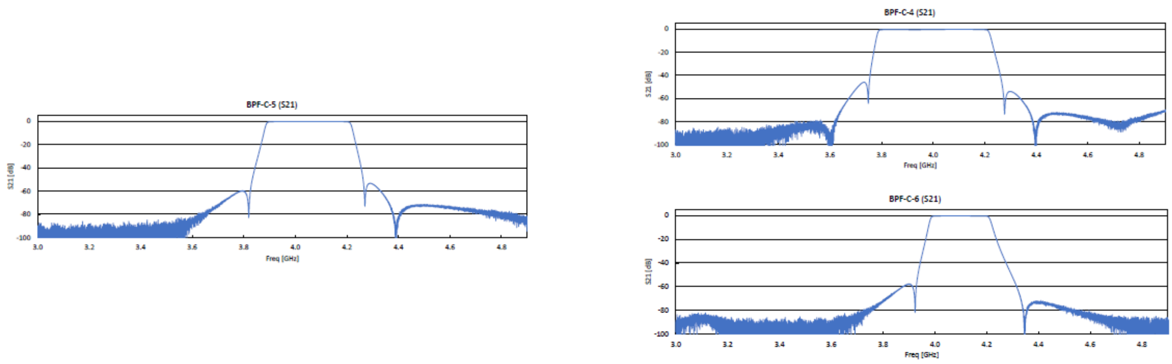


**Figure 10: Norsat EBPF filter performance graphs**

### 4.5.5 AsiaSat BPF-3800S

The AsiaSat BPF-3800S is part of a family of bandpass filters [20].

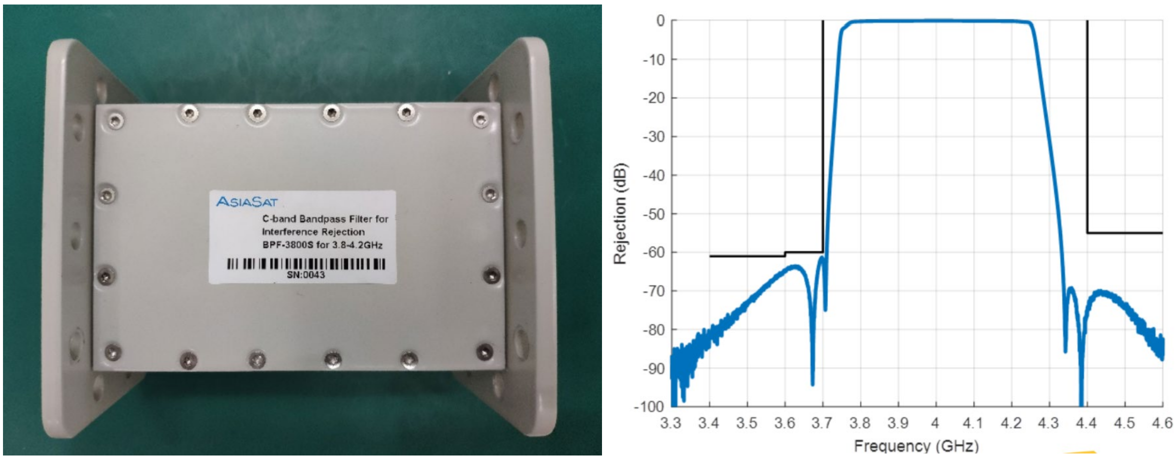


**Figure 11: AsiaSat BPF-3800S filter and typical frequency response**

**Table 10: Summary of performance parameters for AsiaSat BPF-3800S**

| Electrical Specifications | Value |
|---|---|
| Passband | 3800-4200 MHz |
| Insertion Loss from 3820 MHz to 4200 MHz | 0.45 dB maximum |
| Return Loss within passband | 16 dB minimum |
| Rejection below 3600 MHz | >61 dB minimum |
| Rejection between 3600-3700 MHz | >60 dB minimum |
| Rejection between 4400-4800 MHz | >55 dB minimum |
| **Mechanical Specifications** | **Value** |
| Interfaces | WR229G / WR229F |
| **Environmental Specifications** | **Value** |
| Operating Temperature | -40 °C to +60°C |

### 4.5.6 XMW Microwave filter products

#### *4.5.6.1 BPF-4000-400, BPF-4050-300*

**Table 11: Summary of performance parameters for BPF-4000-400, BPF-4050-300 [21], [22]**

| Electrical Specifications | Value | |
|---|---|---|
| Product | BPF-4000-400 (BPF C-4) | BPF-4050-300 (BPF C-5) |
| Passband | 3800-4200 MHz | 3900–4200 MHz |
| Centre Frequency | 4000 MHz | 4050 MHz |
| Insertion Loss in band | 0.5 dB maximum | 0.5 dB maximum |
| Return Loss in band | 15 dB minimum | 15 dB minimum |
| Rejection | 25 dB min @ CF ± 250 MHz<br>60 dB min @ CF ± 300 MHz<br>70 dB min @ CF ± 350 MHz | 25 dB min @ CF ± 200 MHz<br>60 dB min @ CF ± 300 MHz<br>70 dB min @ CF ± 350 MHz |
| **Mechanical Specifications** | **Value** | |
| Interfaces | CPR229G / CPR229F | |

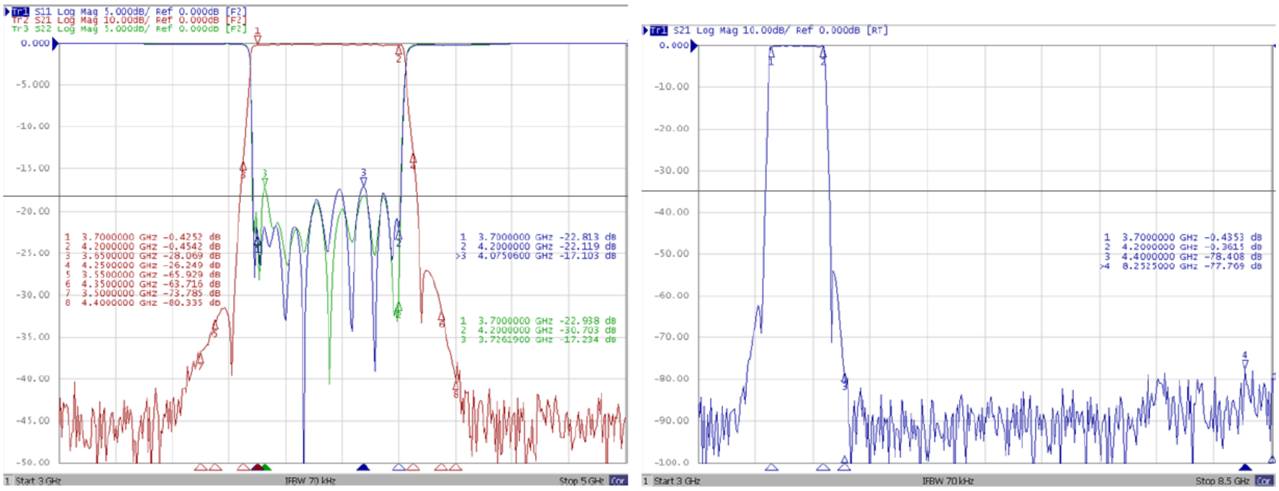


**Figure 12: XMW BPF-4000-400, BPF-4050-300 filter response: near in band and near out-of-band graphs**


**Figure 13: XMW BPF-4000-400 product**

### *4.5.6.2* BPF-CX-4050-300

The CX family of products provides a sharper selectivity, with a narrower transition bandwidth compared to the PFC-C products.

**Table 12: Summary of performance parameters for BPF-CX-4050-300 [23]**

| Electrical Specifications | Value |
|---|---|
| Passband | 3900-4200 MHz |
| Centre Frequency | 4050 MHz |

| | |
|---|---|
| Insertion Loss in band | 1.4 dB maximum |
| Return Loss in band | 18 dB minimum |
| Rejection | 60 dB minimum @ 3880 MHz<br>25 dB minimum @ 4230 MHz<br>60 dB minimum @ 4250 MHz |
| Interfaces | CPR229G / CPR229F |

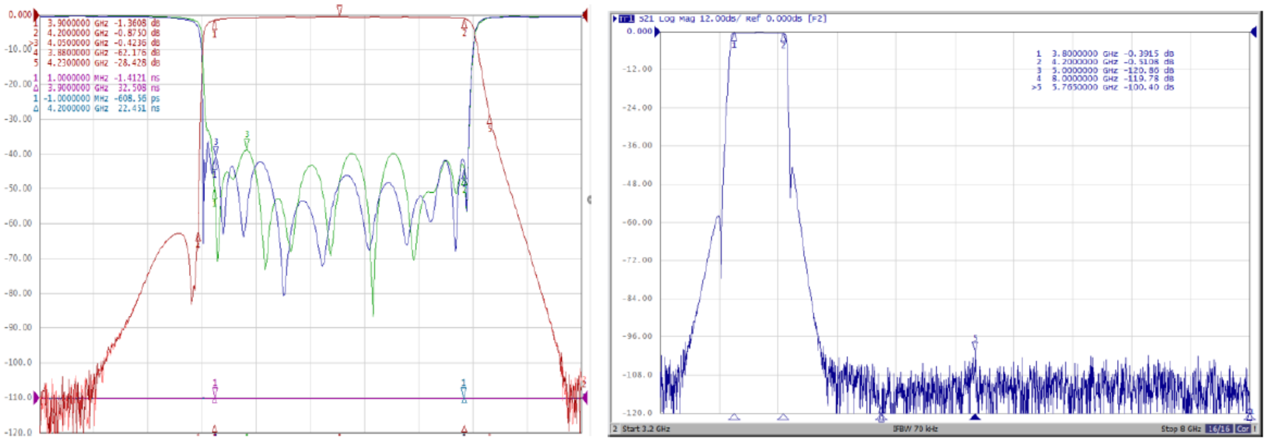

**Figure 14: XMW BPF-CX-4050-300 filter response: near in band and near out-of-band performance graphs**

**Figure 15: XMW BPF-CX-4050-300 filter**

### 4.5.7 AV-Comm Standalone Waveguide Filter products

AV-Comm provides a series of products designed to offer interference mitigation to C-band earth stations, for different sources of interference (5G, WiMAX) [24]. The products are available with different passband configurations.

**Table 13: Summary of performance parameters for selected AV-Comm products**

| Electrical Specifications | | |
|---|---|---|
| Insertion Loss within passband | 0.5 dB maximum | |
| Return Loss within passband | 14.9 dB minimum (VSWR 1.44:1 ) | |
| Model | F6012 | F6013 |
| Passband (MHz) | 3800–4200 | 3900–4200 |
| 25 dB minimum at<br>60 dB minimum at<br>70 dB minimum at | 3750 / 4250 MHz<br>3650 / 4350 MHz<br>3580 / 4420 MHz | 3850 / 4250 MHz<br>3750 / 4350 MHz<br>3680 / 4420 MHz |
| Lower rejection band:<br>Rejection of 60 dB minimum at | 3650 MHz | 3750 MHz |
| Upper rejection band:<br>Rejection of 25 dB minimum at | 4250 MHz | |
| Weight (kg) | 2 | |


**Figure 16: AV-Comm waveguide filter product**

### 4.5.8 Summary of filter performance

Table 14 summarises the key parameters for each of the filters described in the previous section. The sample compared considers units with values of passband between 3800 and 4200 MHz. Table 14 provides the maximum and minimum insertion loss for each filter, which varies between a maximum of 1.3 dB and a minimum of 0.2 dB, return loss, which varies between 14 dB and 20 dB, effective rejection, and width of the transition band. Figure 17 presents a visual comparison of the performance in the transition region, for three cases, illustrating the differences in the response in the transition region. Referring to Figure 17, filter A exhibits a sharp response, allowing for a narrower guard-band than the other two.

Table 14: Summary of bandpass filter performance parameters

| Model | Passband (MHz) | Insertion Loss (min/max) (dB) | Return Loss (dB) | Effective rejection up to passband start | Attenuation of first lower rejection region | Lower rejection region end frequency | Transition region width (MHz) |
|---|---|---|---|---|---|---|---|
| ETL F-WGC1-714044 | 3800-4200 | N.A / 0.5 | 18 min | -33.7 | -50 | 3750 | 50 |
| ETL F-WGC1-714085 | 3820-4200 | 1.3 / 0.6 | 18 min | | -60 | 3720 | 80 |
| ALGA Group 3 | 3820-4200 | 0.25 / 1.3 | 20 | -70 | -60 | 3800 | 20 |
| ALGA Group 4 (J) | 4020-4200 | N.A / 1.3 | 19 | - | 60 | 4000 | - |
| ALGA Group 5 (K) | 4000-4200 | N.A / 1.3 | 20 | - | 70 | 3900 | - |
| Norsat BPF-C-4 | 3800-4200 | N.A / 0.5 | 16 | -30.8 | -30.8 | 3750 | 50 |
| Norsat EBPF-C-4 | 3800-4200 | N.A / 1.4 | 16 | -42.7 | -60 | 3782 | 18 |
| AsiaSat BPF-3800S | 3800-4200 | N.A / 0.45 | 16 | -35.8 | -60 | 3700 | 100 |
| AV-Comm F6012 | 3800-4200 | N.A / 0.5 | - | - | -25 | 3750 | 50 |
| AV-Comm F6013 | 3900-4200 | N.A / 0.5 | - | - | -25 | 3850 | 50 |
| MFC 19524 | 3800-4200 | N.A / 0.6 | 17 | -26.6 | -45 | 3650 | 150 |
| MFC 20541 | 3820-4200 | 1.2 / 1.4 | 20 | - | -30 | 3800 | 20 |
| MFC 20523 | 4000-4200 | 1.2 / 1.4 | 20 | - | -30 | 3980 | 20 |
| XMW BPF 4000-400 | 3800-4200 | 0.5 | 15 | - | -25 | 3750 | 50 |
| XMW BPF 4000-300 | 3900-4200 | 0.5 | 15 | - | -25 | 3850 | 50 |
| XMW BPF CX-4050-300 | 3900-4200 | 1.4 | 18 | - | -60 | 3880 | 20 |

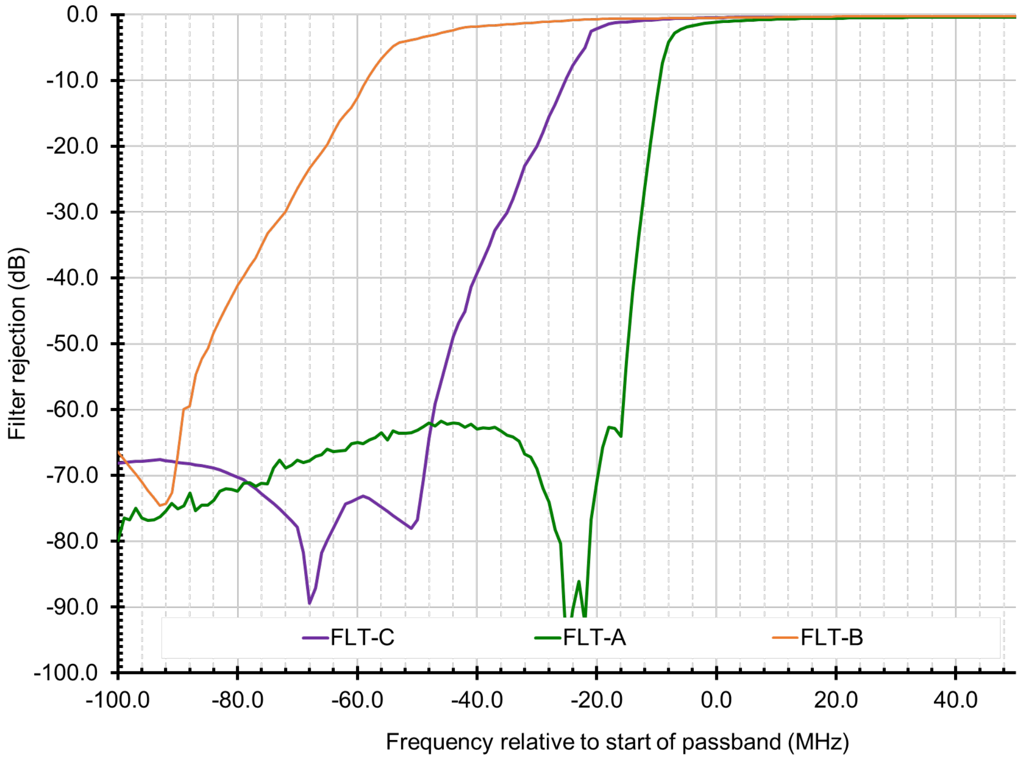


**Figure 17: Illustration of filter response in the transition region**

As noted in previous sections of this Report, selecting a filter with the correct effective rejection for the scenario analysed is critical to ensure that, given an MFCN emissions profile and the calculated separation distance, the input power into the FSS LNB does not exceed the linear operating threshold of the earth station LNB.

The method of adding an additional filter between the LNA/LNB and feeder has proved to be an effective way to avoid LNA/LNB overdrive and to ensure the operation of services. Depending on the type of Earth station, one or two filters will be required.

# 5 USE OF INTERMEDIATE FREQUENCY (IF) FILTERS TO MITIGATE THE IMPACT OF INTERFERENCE ON THE OPERATING BAND OF THE SATELLITE RECEIVER

Under nominal operating conditions, the input levels into the LNB will not result in the generation of unwanted effects such as gain compression, spectral distortion of the wanted signal or unwanted mixing products. In addition, the output dynamic range of the satellite LNB and the input dynamic range of the satellite receiver are defined in such a way that in typical installations the input level into the receiver will not cause receiver overload issues due to wanted signal levels. The typical input range of a receiver is between -65 dBm and -25 dBm per FSS carrier.

## 5.1 POTENTIAL INTERFERENCE ARISING FROM MFCN EMISSIONS AND SCENARIOS WHERE IF FILTERING CAN PROVIDE RELIEF

### 5.1.1 Interference due to reciprocal mixing

In the presence of a high-power interferer, even in absence of a wanted signal, unwanted mixing products resulting from the combination of the high-level unwanted input signal and the LNB Local oscillator, will appear and will be passed through to the output of the LNB. This phenomenon is known as "reciprocal mixing". These unwanted products will be delivered to the satellite receiver and could cause interference when they fall over the wanted signal frequency range.

The role of the filter in these cases is identical to that mentioned in the RF case: to remove any unwanted signals that would be picked up by the wideband satellite receiver. As in the case of RF filters, signals outside the passband of the filter will be rejected, while any signal falling in the passband will be let through. Therefore, it may still be possible that unwanted mixing products falling near to the desired signal, will not be attenuated by the filter. For example, given an LO and RF wanted signal frequencies of 5.15 GHz and 3.6 GHz respectively, mixing products of the type *a**LO-*b**RF with *a* and *b* equal to (1,1), (3,4) or (4,6), could still make it through to the FSS receiver.

### 5.1.2 Interference due to signal leakage

Moreover, and depending on quality of the of the connection between the LNB and the receiver, for devices operating in the 950-1450 MHz IF range, it could be possible to experience interference coming from terrestrial networks. These cases arise from poor shielding of the inter-facility cabling or poor connectors which act as antennas and allow L band emissions (such as those coming from DECT, LTE or MFCN systems in the 900 - 1500 MHz range) to leak into the input of the satellite receiver.

### 5.1.3 Direct interference into the IF path from MFCN emissions

For the mid-band range MFCN deployments (3400 to 3800 MHz), direct interference due to leakage of RF into the IF path of the FSS receiver is not possible. However, in absence of an RF filter on the FSS earth station, it is possible to experience a condition in which the MFCN signal is received by the FSS earth station, down-converted and delivered to the receiver.

Noting that a typical C-band LNB converts the RF input frequency range 3400-4200 MHz to the IF output frequency range 950-1750 MHz, and that the input frequency range of a receiver often covers a wider range (such as 950-2050 MHz [25], [26]), consider the following example. Assume an FSS installation without an RF filter and in a condition such that the input signals into the LNB (composed of MFCN and FSS signals) will be delivered to the modem without additional degradation[5], which will now operate outside of its specified input level range. In consequence, reception of FSS signals is degraded or even prevented.

In such a situation, a high pass filter between LNB and modem can provide mitigation.

[5] In this example, the aggregate input level into the LNB is not enough to drive it into blocking or generate non-linear mixing.

In addition, there are cases in which the LNB produces unwanted intermodulation products of the second order, which appear at frequencies above 1800 MHz and thus do give rise to interference but contribute to the aggregate power level at the input of the receiver. Receiver overload can be prevented by inserting an IF a low pass filter between LNB and receiver.

A band pass filter at IF between LNB and modem, with its passband identical to the band still used by satellite carriers, can prevent both effects.

In the context of Earth Station LNB overload, which happens at the RF input, the use of IF filters will not provide any mitigation. In a situation where the LNB is driven into non-linear operations (experiencing what is known as LNB blocking), the receiver will not be able to demodulate the wanted signal not only because of the presence of unwanted mixing products out of the LNB, but mainly due to issues arising from an unintelligible wanted signal.

## 5.2 EXAMPLE OF IF FILTERS AVAILABLE IN THE MARKET

Table 15 presents a sample of band-pass and low-pass filters, which can provide relief in the situations described in the previous section.

**Table 15: Sample IF filters in the market and parameters**

| Manufacturer | AV-Comm | | | | ETL |
|---|---|---|---|---|---|
| Model | F-4002 | F-4004 | F-4006 | F-4008 | FBPL1-7002 |
| Passband (MHz) | 950-1530 | 950-1450 | 1000-1350 | 950-1250 | 950-1450 |
| Stop-band (MHz) | 1610-1830 | 1530-1750 | 1385-1750 | 1330-1550 | Low cut-off: 690 MHz<br>High cut-off: 1820 MHz |
| Rejection | > 45 dB | | | | > 35 dB |
| Filter type | Low Pass | | | | Band pass |
| Connector type | F | | | | F |

# 6 OVERVIEW OF NEW ARCHITECTURES FOR INTEGRATING FILTERING INTO LNB BLOCKS

In this section reviews the architecture of an LNB and the key parameters that can be improved to increase the LNB's RF selectivity.

The basic block diagram of an LNB is shown in Figure 18.

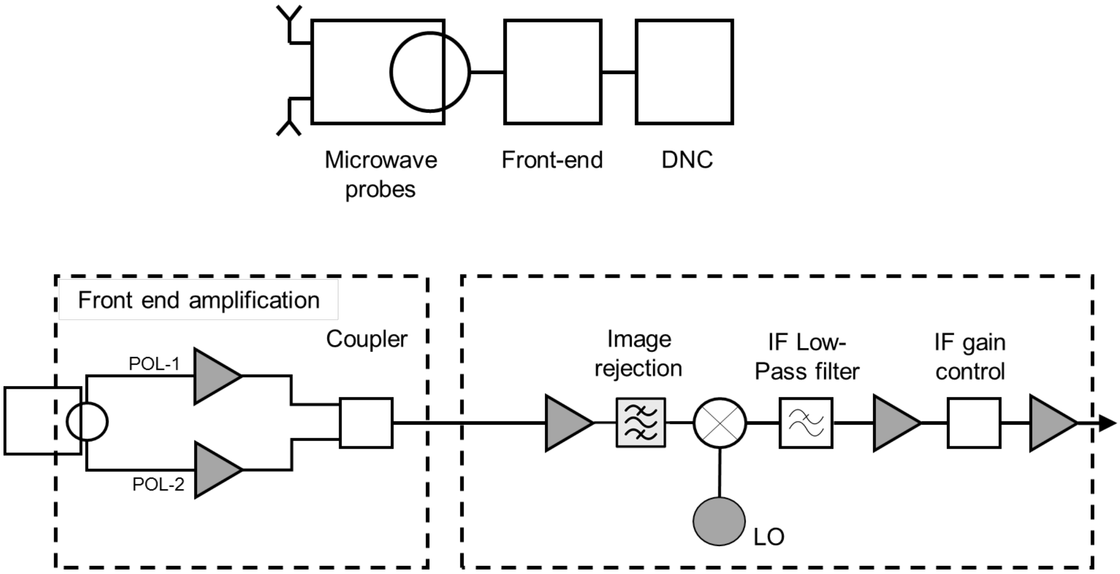


**Figure 18: LNB high-level block diagram**

The basic LNB is composed of three blocks: a Probe or Microwave section, which incorporates all the microwave components of the receiving chain and which may include the antenna feed in the case of LNBF devices, and is responsible for adapting the impedance from the wireless to the wired medium, the Front-end block (FE), which provides low noise amplification and ensures sensitivity of the LNB, and the down-converter (DNC) which translates in frequency and provides additional amplification capabilities of the IF signal.

The FE is the core block that dictates the noise performance of the device. From this perspective, its critical performance parameters are the noise figure and gain. The FE could have two independent first-stages, one per polarisation, or a single first stage, where an OMT has provided initial polarisation selectivity.

In a classical LNB architecture, the selectivity is driven by the response of the Front-End and dictated by the response of the amplifiers. There are no filtering stages associated to this architecture, which makes the Front-End wide-band.

As discussed in this Report, the LNB will block when the total input power level exceeds a threshold that can be approximated by:

$$\text{Input blocking threshold} = \text{Output 1 dBc} - \text{Gain}_{LNB} \qquad (14)$$

ECC Report 100 [3], ECC Report 254 [4] and Report ITU-R S.2368 [9] reference value of LNB input blocking thresholds of -60 dBm.

However, an LNB will start to exhibit unwanted intermodulation products and highly non-linear behaviour when driven with a signal with level approximately 5 dB below the input blocking threshold [9].

To compute the input linear operating threshold, when the output 3rd intercept point (OIP3), LNB gain and Carrier to Intermodulation ratio (C/IM) objective are known, use equation (15)[6]:

$$\text{Input linear operating threshold} = \text{OIP3} - (\text{C/IM})/2 - \text{Gain}_{\text{LNB}} \quad (15)$$

## 6.1 MODIFICATIONS TO THE LNB ARCHITECTURE TO INCREASE RF SELECTIVITY

Based on the previous discussion, one mechanism available to LNB designers to mitigate the impact of high-level interferers on the behaviour of the LNB is to increase the 1 dB gain compression point (P1dBc) and/or reduce the effective gain of the device. Wideband amplifiers with low gain and P1dBc are common in the context of large Earth Station operations, in which Low Noise Amplifiers (LNAs) are expected to be operating in conjunction with high gain antennas (see for example [27]). This design change does not modify the architecture from the classical design of Figure 18.

Another mechanism used to reduce the sensitivity of the LNB to interfering signals, is to narrow its operating bandwidth by means of the addition of a filtering stage after the Front-End. Such devices have already been proposed [29]. In this case, the basic block diagram is modified as illustrated by Figure 19.

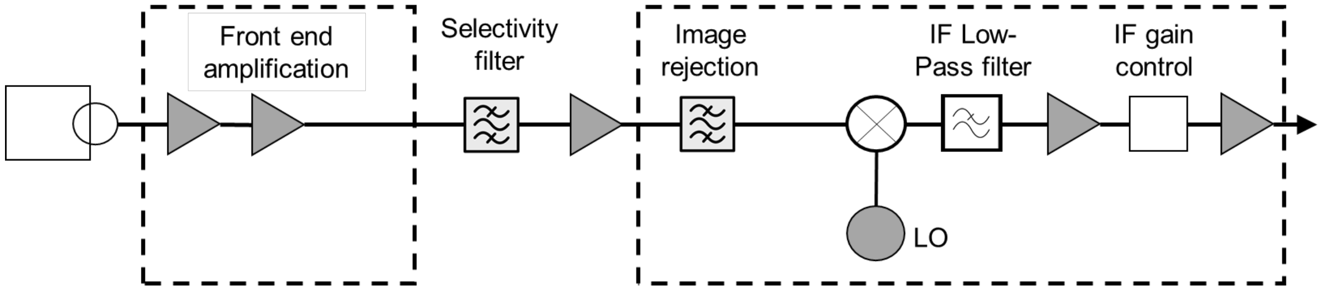


**Figure 19: Modified LNB architecture. Increased selectivity by means of an additional filtering stage after the second amplification stage**

With this modified architecture the filter has additional capabilities to restrict the incoming interfering RF signals. However, due to the limited amount of real estate available in the LNB circuit boards to accommodate the filtering stages, the characteristics of the achievable frequency response of the filter is relatively limited.

In addition to an RF filtering stage, the LNB requires a more robust mixer able to operate without introducing undesired mixing products in the presence of high-power input signals.

## 6.2 AN OVERVIEW OF INTEGRATED FILTER / LNB DEVICES AVAILABLE IN THE MARKET

This section provides examples of commercially available integrated filter-LNA/LNB devices that can be used as a replacement of existing LNA/LNB of C-band FSS earth stations. These are provided as a general example and may or may not be immediately applicable to a coexistence scenario in CEPT countries.

### 6.2.1 Swedish Microwave AB, model C-PLL 5.30 C

The Swedish Microwave family of Single Band PLL LNBs [29] incorporates filtering for mitigation of interference. Model C-PLL 5.30 C incorporates a filter with a passband between 3800 and 4200 MHz and a very robust P1dBc (-45 dBm).

[6] It is common practice to estimate the value of OIP3 as OP1dB + 10 dB, when OIP3 is not known. Combining the expressions, the linear operating threshold can be estimated as OP1dB+10 dB - (C/I)/2 - $\text{Gain}_{\text{LNB}}$. Assuming a C/IM target of 30 dB, the threshold can be approximated as OP1dB - 5 dB - $\text{Gain}_{\text{LNB}}$

Table 16: Swedish Microwave AB, model C-PLL 5.30 C specifications

| Electrical Specifications | Value |
|---|---|
| Noise figure | 0.69 dB / 50 K typical |
| Passband | 3800-4200 MHz |
| Local Oscillator (LO frequency | 5.3 GHz |
| Intermediate Frequency (IF) frequency | 1500-1100 MHz |
| Flatness (full band) | +/- 2 dB |
| Rejection below 3500 MHz | >40 dB |
| Rejection at 3650 MHz | 30 dB |
| Rejection above 5000 MHz | >40 dB |
| Gain | 60 dB typical 55 dB min. |
| Output 1 dB compression point | +15 dBm min. |
| **Mechanical Specifications** | **Value** |
| Interfaces | Input WG CPR229G<br>Output F-connector / N-connector |
| **Environmental Specifications** | **Value** |
| Operating Temperature | -40 °C to +80°C |

As shown in Table 16, the difference in rejection at 3500 and 3650 MHz is only 10 dB. This hints at a low slope of the transfer in the transition region into the passband. The width of the transition region from >40 dB to passband is 300 MHz, and 150 MHz to transition from 30 dB rejection to passband.

Based on the technical specification, the IP1dB can be computed as

$$\text{Input 1 dBc point} = \text{Output 1 dBc} - \text{Gain}_{LNB} = +15 - 60\text{ dB} = -45\text{ dBm} \qquad (16)$$

### 6.2.2 Norsat PLL 3200-BPF

The Norsat PLL 3200-BPF [30] is a family of integrated filter + LNB products, available for different configurations of passband range.

According to the manufacturer, the following features make the 3200-BPF LNB series capable to withstand the effects induced by high power interfering signals:

- The introduction of additional RF filtering stages after the Front-End second LNA to reduce the effective passband of the device;
- The introduction of a more robust mixer, able to work at higher input levels, without generating mixing products.

The performance parameters are listed in Table 17. The introduction of the band pass filters has an impact on the overall noise figure of the device.

**Table 17: Norsat 3200-BPF specifications**

| Electrical Specifications | | | | | | | |
|---|---|---|---|---|---|---|---|
| Noise temperature | 60K max | | | | | | |
| Gain | 60 dB typical 55 dB miniumum. | | | | | | |
| Output 1 dB compression point | +9 dBm miniumum | | | | | | |
| LO frequency | 5.150 GHz | | | | | | |
| | **Opt.1** | **Opt.2** | **Opt.3** | **Opt.4** | **Opt.5** | **Opt.6** | **Opt.7** |
| Passband | 3700-4200 | 3625-4200 | 3754-4200 | 3800-4200 | 3900-4200 | 4000-4200 | 4100-4200 |
| IF frequency | 950-1450 | 950-1525 | 950-1396 | 950-1350 | 950-1250 | 950-1150 | 950-1050 |
| Rejection range | <3600 | <3525 | <3654 | <3700 | <3800 | <3900 | <4000 |
| **Mechanical Specifications** | | | | | | | |
| Interfaces | Input | CPR229G waveguide grooved | | Output | F-Connector (75 Ohm) | N-Connector (50 Ohm) | |
| **Environmental Specifications** | | | | | | | |
| Operating Temperature | - 40 to + 60°C | | | | | | |

As shown in Table 17, there is a 100 MHz separation between the end of the lower rejection band and the start of the passband. The rejection capabilities of the filter are comparable to those of the BPF family. Wherever possible, the manufacturer advises to combine an external filter with the modified LNB, for maximum rejection capabilities [28].

Regarding the input P1dBc, and based on the technical specification [30]:

$$\text{Input P1dBc point} = \text{Output 1 dBc} - \text{Gain}_{LNB} = +9 - 60\text{ dB} = -51\text{ dBm} \quad (17)$$

Thus, this device is more robust in the presence of interference, by a combination of a modified input saturating threshold and the ability to reject interference signals.

The LNB with Integrated filtering includes band-pass filters after the first amplifier stage, a mixer that can withstand higher power and IF filtering. The filter can successfully mitigate the intermodulation affects with interference up to about -25 dBm.

Figure 20 provides an example with a combination of an external filter and LNB with integrated filter. The following graph shows measured rejection of the Norsat 3200-sBPF-1 LNB (LNB with integrated 5G filter), the eBPF-C-1 (5G waveguide BPF) and the combination of the BPF and the LNB with integrated filter.

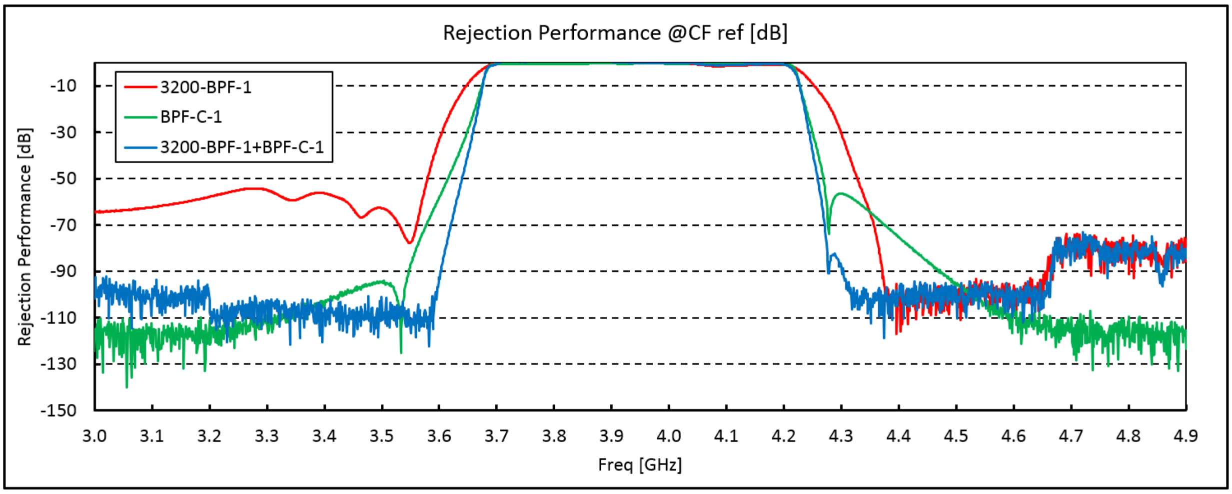


**Figure 20: Norsat combination of an external filter and LNB with integrated filter performance graphs**

### 6.2.3 Av-Comm C Bandpass Filtered LNB PLL

The AV-Comm family of filtered PLL LNBs [31] provides a single polarisation solution with C Band input range of 3.8-4.2 GHz and with 5 kHz Phase Lock Looped (PLL) stability.

The family contains products with various passband configurations, as shown on Table 18.

**Table 18: AV-Comm family of filtered LNB products with PLL**

| | Electrical Specifications | | | |
|---|---|---|---|---|
| Noise temperature | 25 K | | | |
| Gain | 65 dB | | | |
| LO frequency | 5150 GHz | | | |
| LO stability | +/- 5 kHz | | | |
| | **L1510** | **L1512** | **L1507** | **L1508** |
| Passband | 3625-4200 | 3700-4200 | 3800-4200 | 3900-4200 |
| | **Mechanical Specifications** | | | |
| Interfaces | Input | CPR229 waveguide | Output | F-Connector (75 Ohm) |

In addition, products with passband filter and PLL stability of +/-300 kHz are offered: L1516 with a passband of 3700-4200 MHz, L1517 with passband 3625-4200MHz, L1522 with a passband of 3800-4200 MHz and L1521 with passband 3900-4200 MHz.

The manufacturer does not provide information on P1dBc, IP3 or insertion loss.

## 6.3 BENEFITS OF THE MODIFIED LNB ARCHITECTURE FOR COEXISTENCE SCENARIO OF MFCN-FSS SERVICES

Based on the performance parameters and characteristics of the new devices, it is apparent that the capabilities of the integrated filtering stage, while beneficial, does not match the rejection and selectivity characteristic of stand-alone filter devices. Although the stop band rejection values may be similar, the width of the transition region is markedly different. Therefore, manufacturers recommend combining these new LNBs with external RF filters to ensure adequate protection [28].

Considering that the modified architectures introduce a filtering stage, the principles to incorporate the improvements into the process to calculate protection distances follow the same guidelines as those presented in Annex 1.

It is important to remark that the combined features of enhanced selectivity and robustness in the presence of interfering signals are beneficial. However, they do not contribute to improving the performance of satellite services within the passband.

# 7 CONCLUSIONS

This Report studied devices useful to restrict the frequency response and increase selectivity on the receive chain of an Earth station operating in the frequency band 3800-4200 MHz and using wideband LNA/LNBs operating in the 3400-4200 MHz. As noted in the scope of the report, restricting the frequency response of the Earth station devices could contribute to improve coexistence with MFCNs operating in the adjacent band, by potentially reducing the physical separation between FSS ES and MFCN sites. The report provided a brief review of various products available in the market including microwave filter products, IF filter products and integrated Filter and LNB devices, all of which contribute to improving the selectivity of an Earth station in the presence of emissions from MFCN systems in the adjacent band 3400-3800 MHz and its resilience to interfering signals.

As noted in sections 4 and 6, it is possible to modify the radio-frequency selectivity of an FSS earth station by means of the following:

- the addition of a pre-LNA/LNB waveguide band pass filter;
- the usage of an LNA/LNB with integrated bandpass filtering.

Both filtering solutions reduce the power incident to the Front-End of the LNA/LNB by rejecting unwanted frequencies, and thus contribute to maintain the device operating in its linear region.

Furthermore, section 5 discussed cases and conditions under which the use of IF filters improves the operational conditions of the receiver in the Earth station IDU. Although IF filters cannot mitigate the problem of LNB blocking because of their location in the receive chain of the Earth station, they can remove unwanted signals that may interfere with the signals presented to the receiver Front-End.

However, it is important to note that the filtering techniques studied in the report do not contribute to mitigate the potential interference caused by unwanted emissions falling within the FSS ES receiving band 3800 - 4200 MHz. Emissions falling into the FSS ES receiving band, taking into account the technical and operational characteristics of both FSS ES and MFCN could determine the separation distance required.

As noted in this Report, a reduction of the power levels at the input to the LNA/LNB may be necessary, in certain cases, to prevent the device from operating in a non-linear region. Radio-frequency filters, be them discrete or integrated into the LNA/LNB, should be designed considering the characteristics of the emissions of the MFCN in the 3400-3800 MHz range, the technical and operational characteristics of the earth station and taking into account the impact of the chosen filter response on the passband. Taking this into consideration, this Report describes the trade-offs that exist between the design parameters of a filter and its performance (e.g. required rejection, gain versus frequency response, width of transition region). Even though restricting the frequency response and receiver selectivity contributes to improve the coexistence with MFCN operating in the adjacent band, it should be noted that there is an impact on receiver performance (due to the noted degradation in Earth station G/T) and there could be an impact on the FSS earth station operator in terms of implementing/upgrading equipment.

Current integrated LNB filter devices are limited in terms of potential selectivity values, compared to external filters. Given the limited space available in the LNB housing and circuit board, the selectivity achievable by these integrated devices does not reach the same levels as that possible with a dedicated filter. From the perspective of minimising a separation distance requirement, it appears preferable to either utilise an external filter or to combine an external filter with a modified architecture LNB (see for instance [28]). The use of these new LNB devices alone will not necessarily permit a larger reduction of separation distance, compared to that which would be obtained using a discrete RF filter device of larger selectivity.

Filters are one technique to prevent LNB devices from operating in a non-linear region. To provide additional protection from non-linear operations, LNA or LNB devices with a higher input compression point (IP 1dBc), for example, with values of -45 dBm instead of -60 dBm, could be used to further ensure that operations in the presence of MFCN emissions will not result in the generation of unwanted mixing products in the LNA/LNB itself.

To summarise, based on the information of this Report, and establishing as reference a scenario in which the radio-frequency mitigation techniques described in the report are not present (i.e. no filters used), it is possible to conclude the following regarding the magnitude of the separation distance:

- the use of highly selective RF filters, either as dedicated devices or embedded in the LNB housing, can contribute to reduce the required separation distance, by reducing the amount of unwanted power entering the LNB;
- the combination of a highly-selective filter design with a high IP1dBc LNB device further reduces this separation.

A quantification of the amount of reduction achievable by the introduction of one or more devices is out of the scope of this document. Administrations should refer to ECC Report 254 [4], which provides two approaches to establish protection requirements, and incorporate the principles of effective rejection discussed in this Report to the necessary calculations.

# ANNEX 1: EXAMPLE INPUTS PARAMETERS AND RESULTING COEXISTENCE IMPROVEMENT IN THE CONTEXT OF ECC REPORT 254

This annex provides an example that illustrates how the procedures described in ECC Report 254 [4], can be used in the context of the determination of the size of circular exclusion or protection zones. In this example, the focus is on the determination of the relative distance $R_{BLOCK}$ that prevents LNB blocking on a victim FSS earth station. This example does not contain all technical elements required to be considered as a sharing study, with its main goal being to illustrate the relative reduction of separation distance when implementing some of the mitigation measures presented in this Report.

The example will consider the frequency response of various filters available in the market with a 3800 - 4200 MHz passband, to compute the integrated rejection, as opposed to the effective rejection developed from a specification. The integrated rejection is evaluated as the integral of the rejection response of the device within the range 3400-3800 MHz.

Furthermore, the analysis presented below will consider a single interfering source for illustration purposes.

## A1.1 OUTLINE OF THE CALCULATION PROCESS

In this numerical example, the procedure in ECC Report 254 [4], discussed in section 4.4.1, is used. Recalling equations (6) and (7) from section 4.4.1:

$$P_{MFCN\_e.i.r.p} + G_{Prop}(D) + G_{A,Rx} + Eff.Rej_{dB} + P_{WANTED} < P_{MAX,\ LNB} \quad (18)$$

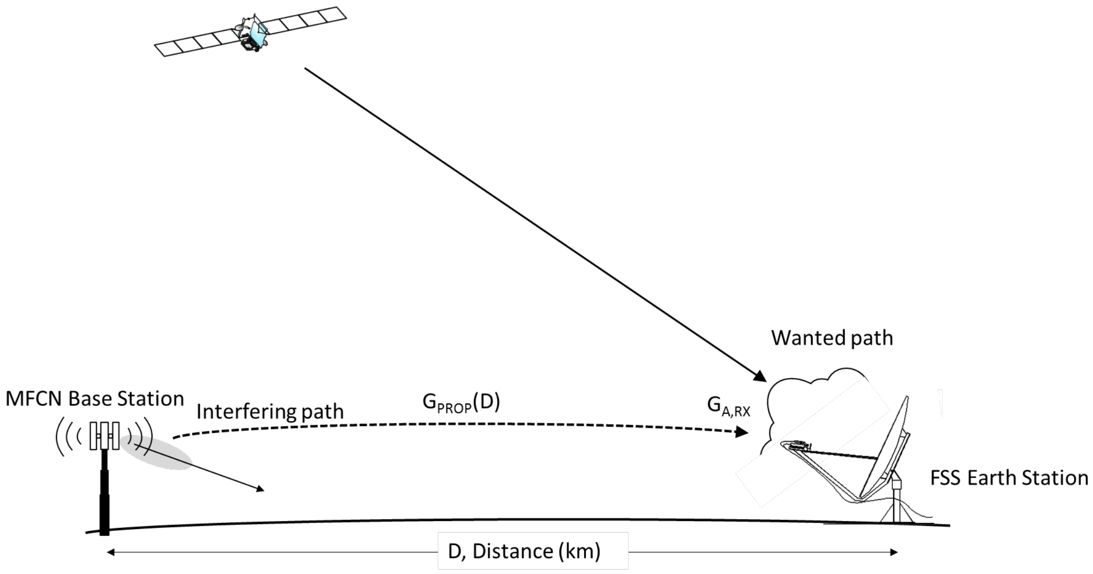


Figure 21: Geometry of the Interferer - Victim path

Defining $G_{PROP}(R_{BLOCK\ MIN})$ as the value that sets the above expression to zero, the following is obtained:

$$G_{PROP}(R_{BLOCK\ MIN}) = P_{MAX,\ LNB} - P_{WANTED} - (P_{MFCN\_e.i.r.p} + G_{A,Rx} + Eff.Rej_{dB}) \quad (19)$$

The objective of this illustrative analysis is to determine the value of $R_{BLOCK\ MIN}$ that guarantees protection of the LNB from blocking. The process is iterative in nature, as it may not be possible to invert directly the propagation model to solve for $R_{BLOCK}$.

In this example, to evaluate the propagation loss as a function of distance, the following path general models are used:

- Macro Rural Line-of-sight propagation model presented in Report ITU-R M.2135-1 [33];
- Free Space Path Loss.

## A1.2 SUMMARY OF INPUTS REQUIRED

Considering that the expression to use to compute the distance $R_{BLOCK}$ is:

$$G_{PROP}(R_e) = P_{MAX,\ LNB} - \{P_{WANTED} + (P_{MFCN} + G_{A,Rx} + Eff.Rej_{dB})\} \quad (20)$$

Table 19 presents the inputs taken as assumptions for this analysis. It is important to note that these values are taken as examples and in no way cover all deployment scenarios. Consequently, any modification of these assumptions could impact the results presented in the section A1.4.

**Table 19: Reference radiation pattern of earth station antennas in the fixed-satellite service for use in coordination and interference assessment in the frequency range from 2 to 31 GHz**

| Variable | Description | Value |
|---|---|---|
| $P_{MAX,\ LNB}$ | LNB operating threshold | -60 dBm |
| $P_{WANTED}$ | FSS power levels at the input of the earth station | -68.9 dBm |
| $P_{MFCN}$ | MFCN power level at the source, over the range 3400-3800 MHz | 86.3 dBm |
| $G_{A,Rx}$ | from Recommendation ITU-R S.465 [35] | |
| $Eff.Rej_{dB}$ | To be computed for each filter | See A1.3 |

## A1.3 CALCULATION OF THE INTEGRATED FILTER REJECTION AND FILTER INSERTION LOSS WITHIN THE FSS PASSBAND

The following filters were considered in this example (also presented under section 4.5 of the Report):

- Norsat BPF-C4;
- AsiaSat BPF-3800S;
- Alga Microwave C-Band 5G Filter (Red);
- A1 Microwave PB2183WB C-Band Satcom Receiver Protection Filter;
- ETL C band Waveguide Band Pass Filter F-WGC1-714044.

## A1.4 COMPUTATION OF THE MINIMUM SEPARATION GIVEN A SINGLE INTERFERING SOURCE. CASE 1: NO FILTER INSTALLED

As noted in section A1.1, the expression to analyse is (in dB)

$$G_{PROP}(R_{BLOCK\ MIN}) = P_{MAX,LNB} - \{P_{WANTED} + (P_{MFCN} + G_{A,Rx} + Eff.Rej_{dB})\} \quad (21)$$

In absence of a filter, the rejection $Eff.Rej_{dB}$ evaluates to 0 dB.

Taking into account the above list of assumptions considered for this illustrative analysis, the minimum separation distance, for the combinations of (propagation loss, Antenna gain) can be evaluated by solving for the distance $R_{BLOCK\ MIN}$ that returns the desired attenuation value.

Four Interferer-Victim alignment angles will be considered to evaluate $G_{A,Rx}$: 10, 20, 30 and 40 degrees. In the following tables in section A1.5, the resulting distance[7] reduction (in %) for each of the cases is then calculated, based on the reference situation without filtering.

[7] Far field distance.

## A1.5 EXAMPLE COMPUTATION OF THE RELATIVE REDUCTION OF THE MINIMUM SEPARATION GIVEN A SINGLE INTERFERING SOURCE. CASE 2: FILTER INSTALLED IN THE FSS EARTH STATION

Table 20: Norsat BPF-C4

| | | Reduction in required separation distance (%) | | | |
|---|---|---|---|---|---|
| Model | Antenna type | $G_{A,Rx}$ @ 10 deg. = 7 dBi | $G_{A,Rx}$ @ 20 deg. = -0.5 dBi | $G_{A,Rx}$ @ 30 deg. = -4.9 dBi | $G_{A,Rx}$ @ 40 deg. = -8.1 dBi |
| Free Space | Non-AAS | 95.5% | 95.5% | 95.5% | 95.6% |
| | AAS | 95.5% | 95.5% | 95.5% | 95.5% |
| Report ITU-R M.2135 [33] Rural macro cell (LoS) | Non-AAS | 78.7% | 80% | 81.7% | 83.2% |
| | AAS | 78.8% | 80.2% | 82.5% | 84.2% |

Table 21: AsiaSat BPF-3800S

| | | Reduction in required separation distance (%) | | | |
|---|---|---|---|---|---|
| Model | Antenna type | $G_{A,Rx}$ @ 10 deg. = 7 dBi | $G_{A,Rx}$ @ 20 deg. = -0.5 dBi | $G_{A,Rx}$ @ 30 deg. = -4.9 dBi | $G_{A,Rx}$ @ 40 deg. = -8.1 dBi |
| Free Space | Non-AAS | 87.5% | 87.5% | 87.5% | 87.5% |
| | AAS | 87.5% | 87.5% | 87.5% | 87.5% |
| Report ITU-R M.2135 [34] Rural macro cell (LoS) | Non-AAS | 64.4% | 64.5% | 64.2% | 65.3% |
| | AAS | 64.6% | 64.5% | 64.9% | 66.3% |

Table 22: Alga Microwave C Band 5G Filter (Red)

| | | Reduction in required separation distance (%) | | | |
|---|---|---|---|---|---|
| Model | Antenna type | $G_{A,Rx}$ @ 10 deg. = 7 dBi | $G_{A,Rx}$ @ 20 deg. = -0.5 dBi | $G_{A,Rx}$ @ 30 deg. = -4.9 dBi | $G_{A,Rx}$ @ 40 deg. = -8.1 dBi |
| Free Space | Non-AAS | 99.9% | 99.7% | 99.5% | 99.3% |
| | AAS | 99.9% | 99.7% | 99.5% | 99.3% |
| Report ITU-R M.2135 [33] Rural macro cell (LoS) | Non-AAS | 98.3% | 97.4% | 96.7% | 96.0% |
| | AAS | 98.2% | 97.3% | 96.5% | 95.8% |

**Table 23: A1 Microwave PB2183WB C-Band Satcom Receiver Protection Filter**

| | | Reduction in required separation distance (%) | | | |
|---|---|---|---|---|---|
| **Model** | **Antenna type** | **$G_{A,Rx}$ @ 10 deg. = 7 dBi** | **$G_{A,Rx}$ @ 20 deg. = -0.5 dBi** | **$G_{A,Rx}$ @ 30 deg. = -4.9 dBi** | **$G_{A,Rx}$ @ 40 deg. = -8.1 dBi** |
| Free Space | Non-AAS | 90.5% | 90.5% | 90.5% | 90.4% |
| | AAS | 90.4% | 90.5% | 90.5% | 90.5% |
| Report ITU-R M.2135 [33] Rural macro cell (LoS) | Non-AAS | 69.0% | 69.0% | 69.2% | 71.3% |
| | AAS | 69.0% | 69.3% | 70.2% | 71.6% |

**Table 24: ETL C band Waveguide Band Pass Filter**

| | | Reduction in required separation distance (%) | | | |
|---|---|---|---|---|---|
| **Model** | **Antenna type** | **$G_{A,Rx}$ @ 10 deg. = 7 dBi** | **$G_{A,Rx}$ @ 20 deg. = -0.5 dBi** | **$G_{A,Rx}$ @ 30 deg. = -4.9 dBi** | **$G_{A,Rx}$ @ 40 deg. = -8.1 dBi** |
| Free Space | Non-AAS | 94.4% | 94.4% | 94.5% | 94.5% |
| | AAS | 94.4% | 94.4% | 94.4% | 94.4% |
| Report ITU-R M.2135 [33] Rural macro cell (LoS) | Non-AAS | 76.2% | 76.8% | 78.3% | 80.2% |
| | AAS | 76.5% | 77.5% | 78.9% | 81.1% |

## ANNEX 2: LIST OF REFERENCES


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