WHITE PAPER

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Technical Compatibility Challenges Between Fixed Satellite Service and 5G in C-band

Introduction

C-band Fixed Satellite Service (FSS) satellites have been providing services to businesses, governments and consumers for over 50 years and continue to be a critical enabler of socio-economic development around the world. Since their inception, governments, commercial enterprises, and users of all kinds – not to mention satellite operators – have invested billions of dollars in C-band satellites and ground infrastructure, and today there are about 200 geostationary satellites in orbit using C-band frequencies. With its propagation characteristics, and its resilience to rain fade, C-band spectrum is unique in its ability to provide robust multi-continental coverage.

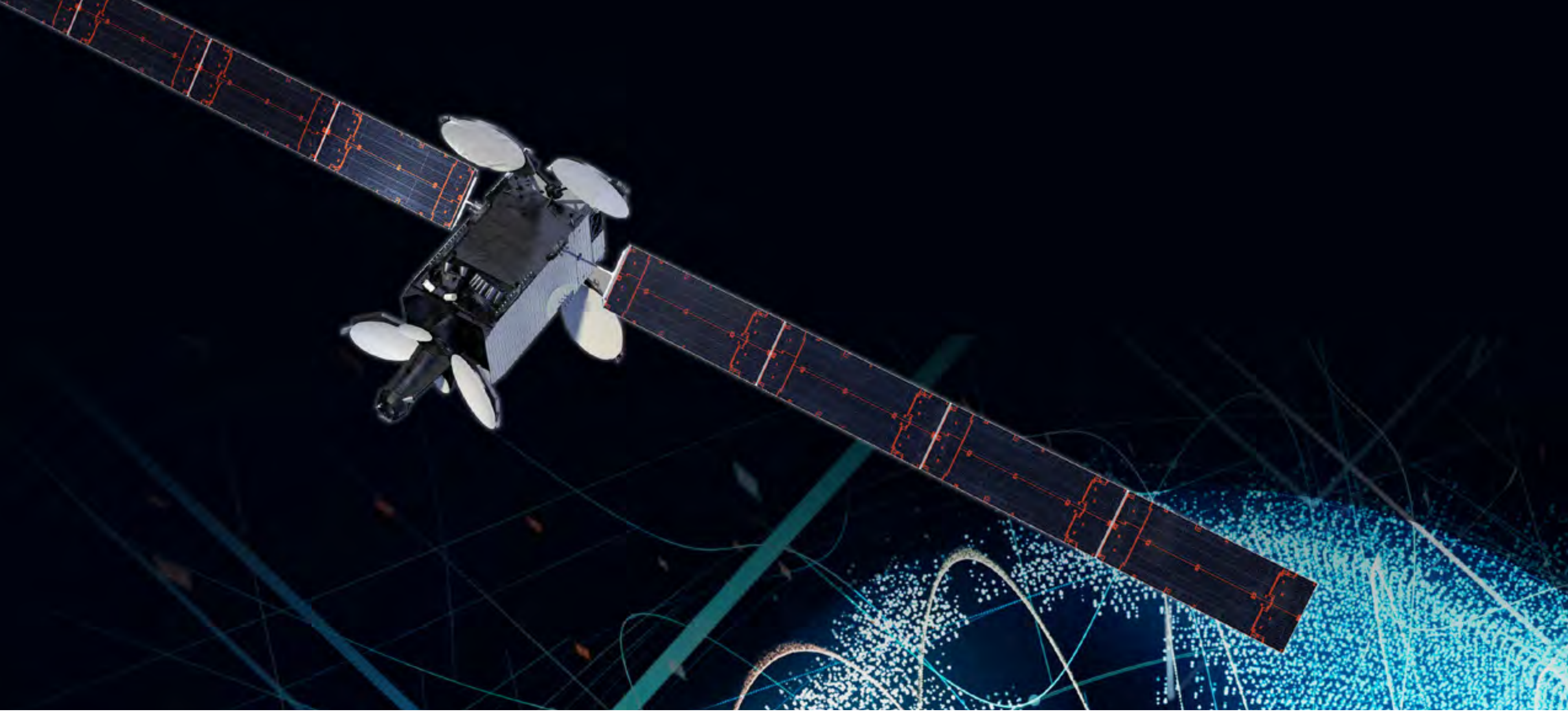
The mobile industry has expressed great interest in displacing satellite users from the C-band spectrum. With terrestrial 5G and with the latest technological advancements in mobile technology finally here, this interest in C-band has only intensified. Regulators now have to make tough decisions about how spectrum should be allocated, caught between the lure of 5G and its promises, and the importance of satellite services that they have relied upon – and continue to – for over 50 years. Regulators must balance all these technical and economic factors before making any decisions.

To the extent that regulators allow 5G to use C-band for terrestrial services, it is critical that these regulators:

- Balance the needs of C-band satellite services and the realistic need of spectrum by mobile service providers; and
- Adopt appropriate technical measures to ensure that C-band FSS can continue to operate without interference.

This paper focuses on the technical challenges that arise when introducing 5G (or mobile service in general) to the downlink C-band spectrum in any part of the 3400-4200 MHz frequency range. This band is allocated on a global basis to the FSS and the Fixed Service (FS) on a primary basis. The band is also currently allocated to the Mobile Service (MS) on either a primary or secondary basis depending on the country.

The following sections provide guidance to administrations on the various critical elements that must be addressed prior to allowing terrestrial 5G mobile services to operate in the C-band spectrum.



Evolution of C-band FSS Services

C-band FSS has evolved to meet the communications needs of a diverse set of sectors and continues to be a vital component of the telecommunication infrastructure today and for the foreseeable future. Today C-band FSS provides a wide range of essential services including national and regional broadcasting, air navigation, meteorology, emergency response operations, mobile backhaul, and mission-critical VSAT communications.

There is a need to recognize that the intensity of C-band FSS deployments varies region to region, and country to country. These differences are based on many factors including the existing communications infrastructure in each country, geography, and climate. In countries with significant and nationwide deployment of terrestrial infrastructure, the majority of C-band FSS deployment is for business to business (B2B) service applications. For these countries C-band deployment is represented by relatively large and professionally installed earth stations at known locations. While in countries where the deployment of terrestrial infrastructure is more limited, or if the geography and climate pose challenges, the reliance on C-band FSS services is more profound and pervasive, and includes business to consumer (B2C) services in addition to B2B. For these countries, the B2C segment comprises a very significant number of smaller antennas, that are often self-installed, and are located at consumer households. In many locations these B2C earth stations provide the only means of reliable TV reception.

The licensing regimes for C-band earth stations also varies by country, but generally receive only C-band FSS earth stations have enjoyed a license-exempt regulatory framework that led to the proliferation of massive numbers of earth stations around the world. Generally, the satellite operator holds the necessary authorization and consumers are only required to install the earth station to obtain services, in a similar manner to owning a radio set at one's house.

The specific deployment of C-band FSS earth station is a critical factor that regulators will need to account for when analyzing if and how to allow 5G terrestrial services to operate in C-band spectrum.

5G Interference Mechanisms into FSS

FSS and 5G services co-frequency sharing in the same geographical area is neither feasible nor practical. Numerous studies[1] have shown this fact, and both satellite and terrestrial mobile stakeholders agree that this is true. Even when 5G and FSS operate in adjacent bands, interference to FSS receivers will occur unless mitigation techniques are implemented.

There are two main interference mechanisms between 5G operations and FSS receive earth stations:

- Saturation of the Low Noise Amplifier/Block-downconverter (LNA/LNB) of the satellite earth station
- Out of Band Emissions (OOBE) produced by 5G transmissions, which result in in-band interference from the perspective of the satellite earth stations

In the first mechanism, interference from the 5G signal occurs because there is an immense disparity in signal level between the terrestrially based 5G and the space-based satellite signal that will result in the saturation of the FSS receiver, commonly known as LNB or LNA. Satellite LNBs, which are designed to receive faint satellite signals transmitted from 36,000 km above the equator, are overwhelmed by the much higher terrestrially-based 5G transmissions. Coping with such disparity is not possible without RF filters.

In the second mechanism, OOBE from 5G signals leak into the adjacent satellite band resulting in direct interference that cannot be filtered out because it is co-frequency with the satellite signal. This OOBE interference is further exacerbated by the power disparity between the 5G and satellite signals.

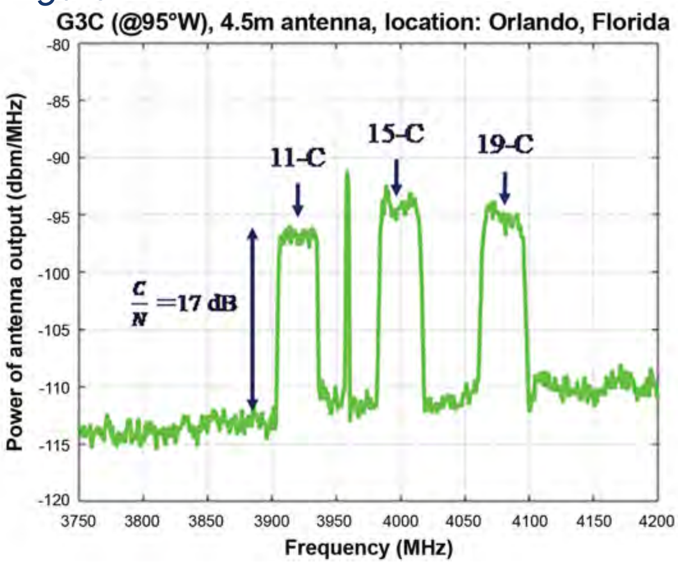
Tests have shown that either of these interference mechanisms can result in complete loss of the FSS signal. In the following sections, we discuss these interference mechanisms and how to deal with them in greater detail.

1. See ITU-R Recommendations S.2368 and M.2109 and ECC reports 100 and 254.

Saturation of the Satellite Receiver (LNB or LNA)

The downlink FSS C-band signal travels more than 36,000 km from a satellite in the geostationary arc to the Earth resulting in a signal level that is disproportionately weaker than that of a terrestrially based 5G base station.

Figure 1



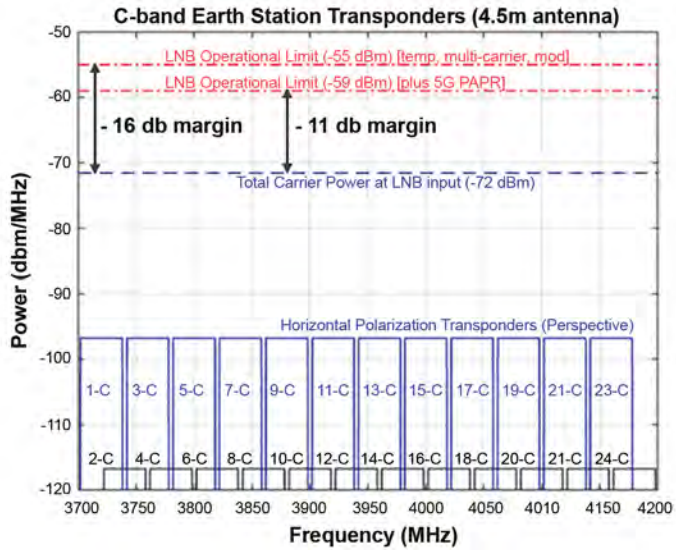
For example, Figure 1 shows a measured receive C-band signal at the output of a 4.5m antenna receiving from the Intelsat Galaxy 3C satellite.[2] The total carrier power for the 11-C transponder over 30 MHz bandwidth is -83 dBm[3] and the C/N level is a robust 17 dB.

For a fully loaded satellite with 12 transponders in one polarization the total carrier power will be approximately -72 dBm. This aggregate power level is well within the performance capabilities of typical LNAs or LNBs.

To ensure proper reception of a FSS signal, earth station equipment is designed to detect signals with relatively low carrier power levels by employing sensitive LNBs. As shown in Figure 2 the operational limit of typical FSS earth station LNB is -55 dBm, which provides a 16 dB margin from the typical total carrier power of -72 dBm.

In comparison, a 5G base station transmits at significantly higher power levels with an EIRP as high as 65 dBm/MHz.[4] Calculating the level of 5G signal that will be received at an FSS earth station is

Figure 2

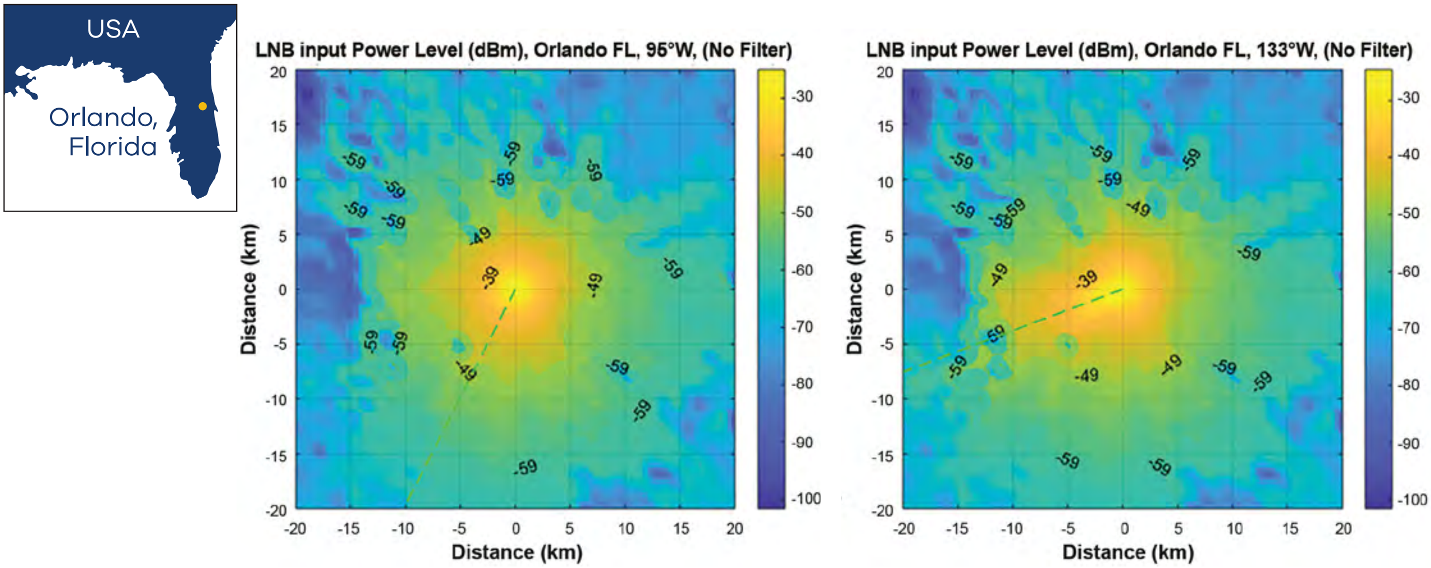


dependent on many factors. Key factors include the distance between the base station and the earth station, the gain of the FSS earth station antenna in the direction of 5G base station, the gain of the 5G base station antenna in the direction of the earth station, clutter loss, blockage, etc. As an example, the power at the input of the LNB of a 4.5m earth station located in Orlando, Florida, at -81.373°W longitude/ 28.477°N latitude, pointed at the Galaxy 3C or Galaxy 15 satellite at 95°W or 133°W, was calculated. The analysis assumed the base station and the earth station are both at 10m height and that the International Mobile Telecommunications (IMT)[5] base station is transmitting at 65 dBm/MHz EIRP over 100 MHz towards the earth station. The analysis used the irregular terrain model (ITM) for path loss.[6] The elevation angle of the earth station is 54 degrees towards 95°W or 25 degrees towards 133°W.

Figure 3 (on following page) shows the result of the analysis for the 95°W and 133°W orbital locations respectively, where the location of the earth station is depicted as the center location (x=0, y=0) and the dashed green line represents the pointing direction of the earth station towards the satellite. Assuming an earth station LNB threshold of -59 dBm, this illustrates the 5G base station needs to be more than 18km away in order to avoid saturating the earth station LNB for the worst-case location. At lower elevation angles the separation distance is larger in the direction that the earth station is pointing towards. This demonstrates that separation distances are large and impractical and thus mitigation techniques, are required.

2. https://www.intelsat.com/global-network/satellite-network
3. Specifically, -98 dBm/MHz + 10*log10(30) equals -83 dBm
4. Reference the FCC order paragraph 335 or §27.50
5. In this document, IMT and 5G are used interchangeably
6. The ITM model for path loss used a 1% reliability and 50% confidence. The model does not consider clutter, multipath, or near-field effects. This model is also known as the Longley-Rice.

Figure 3: LNB Input Power Versus Distance with No Filter (Orlando, FL)



OOBE Interference

The strong 5G signal level inherently leads to OOBE that will also negatively impact the ability to receive C-band FSS signals in adjacent spectrum. To a large extent it is incumbent upon the 5G provider to implement mitigation techniques when deploying its network to sufficiently manage the aggregate OOBE to acceptable levels to allow C-band FSS operations in adjacent bands to continue to operate in an interference-free manner (see Table 1 on following page). However, most of these mitigation techniques require the 5G provider to know the location of the earth station described in Evolution of C-band FSS Services section on page 3, and this is rarely available.

Mitigation Technique

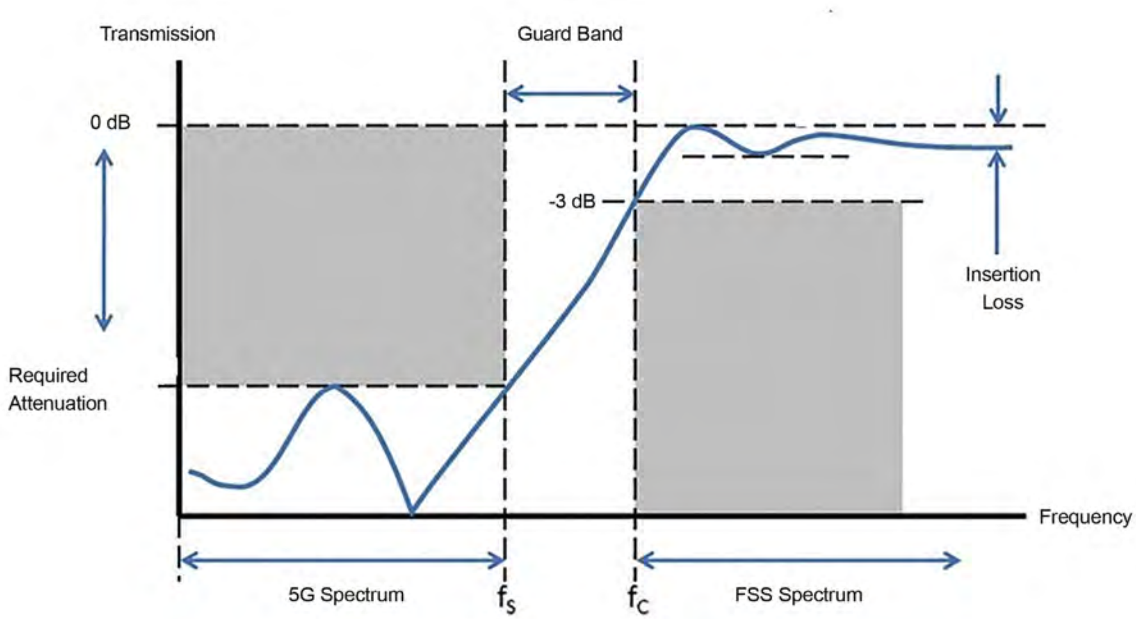
As described above, the 5G signal power at the input of an FSS earth station LNB can easily saturate the LNB and wipe-out the satellite signal. The best solution to mitigate the 5G interference is to insert a RF waveguide filter between the output of the antenna and the input of the LNB. This will filter out to a great extent the unwanted 5G signal from saturating the LNB.[7]

Figure 4 shows a waveguide filter (left picture), and an actual installed waveguide filter on an active C-band earth station that was used for actual over-the-air 5G testing (right picture).

Figure 4

7. It should be noted that filters are a not a cure for all cases, for example filters will not work if the 5G base station is transmitting directly into the bore sight (or close to it) of the FSS earth station. In these cases, when the location of earth stations are known, it is necessary to adopt a pfd limit from the 5G transmitter at the earth station that will enable the filter to work.

Figure 5



As shown in Figure 5, for the filter to operate properly it is necessary to have a guard band between the edge of the 5G transmission and the FSS transmission to provide the waveguide filter the necessary bandwidth to reject the 5G interference at the earth station. The width of the guard band will depend on several factors and these are addressed on the following page.

5G terrestrial operators have a number of tools at their disposal to manage and reduce the aggregate OOBE from base stations and user equipment to acceptable levels. Table 1 shows some of the tools available for the MNO to reduce the OOBE levels, it is noted that number 3, 4 and 5 all require that the earth stations locations are known. These mitigation techniques can be deployed by the MNO across their entire network, in specific areas or on a case-by-case basis to ensure the interference will not impact the C-band FSS operations.

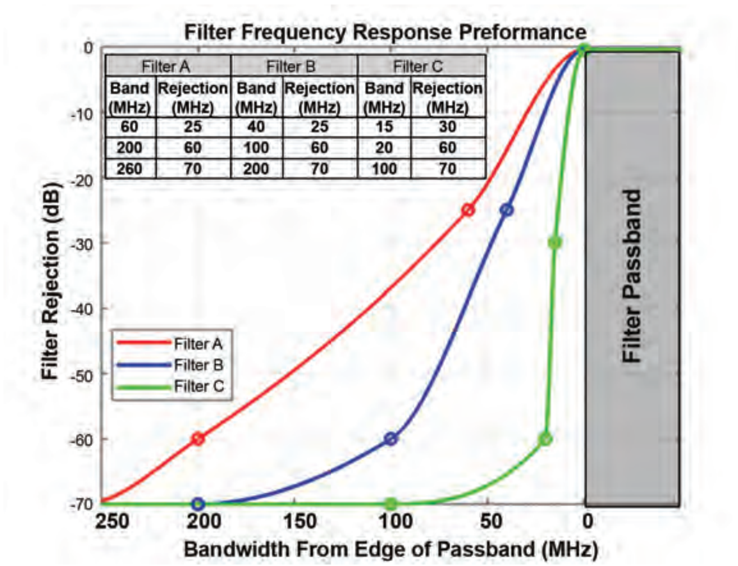
Table 1

Means Available to 5G Operators to Manage OOBE	
1	Use lower transmit power levels for the base station and user equipment.
2	Install better transmit OOBE mask.
3	Use Multiple-Input Multiple-Output (MIMO) technology to null the radiation pattern in the direction of earth stations.
4	Deploy microcells near FSS earth stations which have lower transmit powers.
5	Force user equipment to roam to non-C-Band frequencies near FSS earth stations.

Impact of Filter Performance on Separation Distance

Today, 5G is in the early stages of implementation with deployment occurring mainly in urban/suburban areas. In the long term, however, 5G deployment is expected to be deployed more broadly. The 5G EIRP levels are expected to be high with the use of advanced phased array active antenna systems (AAS), to provide services in rural locations and penetrate buildings. 5G base stations are also expected to be deployed widely in different locations to maximize both capacity and coverage. Hence, in order to protect FSS earth station antennas from 5G interference it is imperative to build a bandpass filter with good filter rejection capability, preferably greater than 60 dB. A fundamental trade-off exists between the frequency response of the bandpass filter and the spectrum gap between the 5G and FSS. Figure 6 illustrates an example using three generic filters.

Figure 6: Frequency Response for Filter A, Filter B, and Filter C



Filter A, Filter B, and Filter C achieve 60 dB rejection at 200 MHz, 100 MHz, and 20 MHz from the edge of the passband respectively. These filters represent a composite average of many types of filters that are available in the marketplace today. Filter C is the gold standard bandpass filter and requires the least amount of spectrum to transition from passband to stopband of 60 dB rejection. Filter A, on the other hand, requires 200 MHz to achieve 60 dB rejection–an order of magnitude of more bandwidth. To maximize the efficient use of spectrum for terrestrial and satellite systems, it is important to design a bandpass filter with minimum frequency separation specification between the IMT and FSS. The frequency response of the filter is the most important parameter for IMT FSS co-existence. However, the bandpass filter must also exhibit good performance for the insertion loss, return loss, and group delay.

Figure 7, alternatively, shows the separation distance versus spectrum gap between IMT and FSS for the three generic filters in Figure 6. For each filter the required distance separation is provided in order to avoid LNA/LNB saturation assuming the 5G EIRP is 50 dBm/MHz or 65 dBm/MHz.[8]

Figure 7: Separation Distance as a Function of Filter Performance

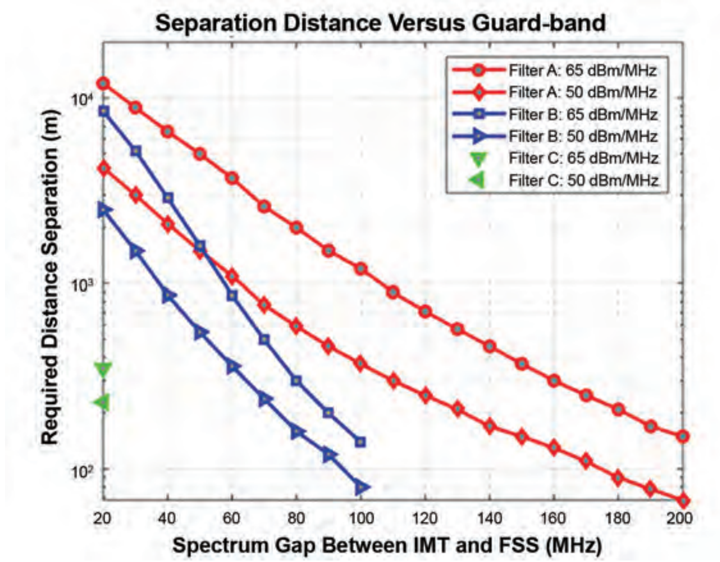


Table 2 summarizes the required distance for the different filters and EIRP levels when the spectrum separation between IMT and FSS is 20 MHz. It is evident that Filter C has more than an order of magnitude lower separation distance compared to Filter A or Filter B. For 5G operators the high separation distance incurred using Filter A or Filter B essentially precludes 5G deployment in the area.

Table 2: Separation Distance at 20 MHz Guard Band for Different Filter Types and EIRP Levels

Filter Type	EIRP: 50 dBm/MHz	EIRP: 65 dBm/MHz
Filter A	4,195 m	11,987 m
Filter B	2,497 m	8,490 m
Filter C	230 m	350 m

8. Additional assumptions: ITM model for pathloss; earth station elevation angle: 23 deg; 5G out-of-band emission: -20 dBm/MHz; LNB saturation threshold: -59 dBm; 4.5m earth station antenna; and IMT pointing directly at earth station.

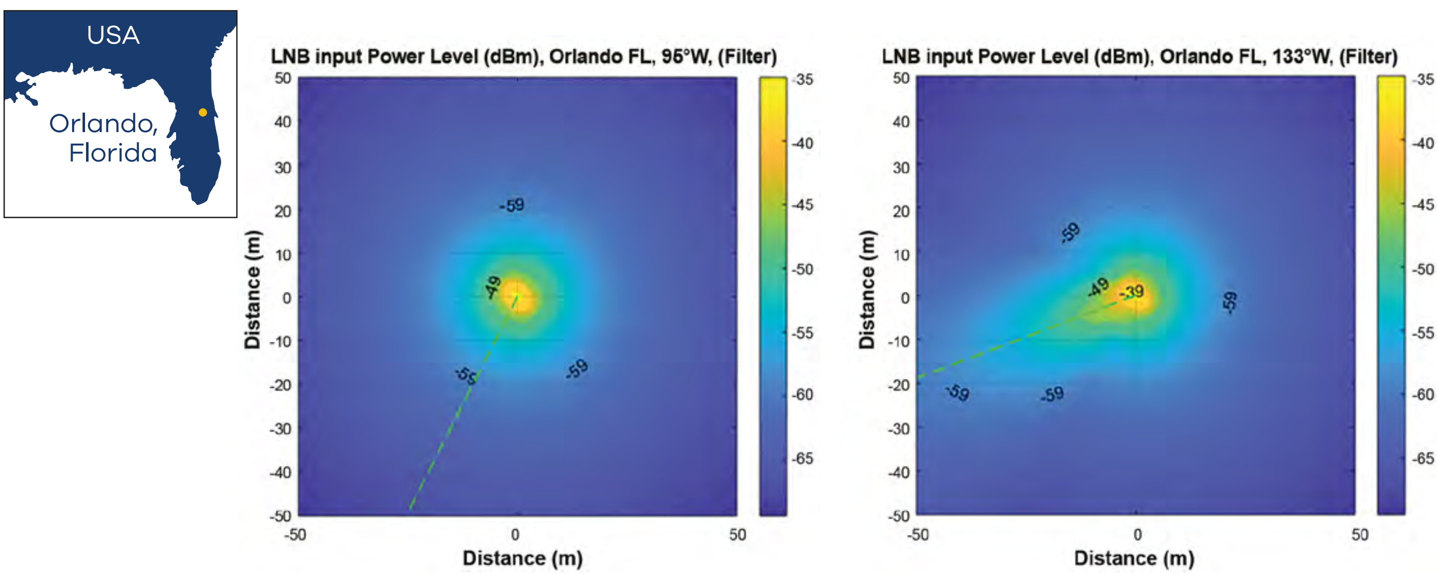
Table 3 summarizes the required bandwidth between 5G and FSS if the separation distance is the same as that needed for Filter C; namely: 230m separation distance for 50 dBm/MHz, and 350m separation distance for 65 dBm/MHz. The table shows that required bandwidth for Filter A is more than six times the required bandwidth for Filter C. Because spectrum is so highly valued, the large required bandwidth for Filter A and Filter B may not be acceptable to spectrum regulators.

Table 3: Size of Guard Band as a Function of Filter Type and 5G Base Station EIRP

Filter Type	5G Base Station EIRP: 50 dBm/MHz	5G Base Station EIRP: 65 dBm/MHz
Filter A	125 MHz	155 MHz
Filter B	70 MHz	75 MHz
Filter C	20 MHz	20 MHz

As an example of the benefits of employing a filter, the same analysis described on page 5, the power at the input of the LNB of a 4.5m earth station antenna located in Orlando, Florida pointed at Galaxy 3C or Galaxy 15 satellite at 95°W or 133°W, respectively was performed. Figure 8 shows the results with Filter C installed between the antenna feed and LNB. In contrast to the no filter case shown in Figure 3, with the filter the separation distance needed between the 5G base station and the earth station is between 20m to 50m depending on the location of the 5G base station. This is about a three orders of magnitude improvement in the required separation distance compared to Figure 3.

Figure 8: LNB Input Power Versus Distance with Filter C (Orlando, FL)



As a policy matter, the 5G and FSS spectrum must be defined in advance of deployment of 5G, which also includes technical rules including the required frequency separation between the two services. Additionally, as shown above it is important to note that frequency separation cannot be dissociated from the filter characteristics. The bandpass filter to mitigate interference must meet key performance specifications, namely: filter rejection, passband-to-stopband bandwidth, insertion loss, return loss, and group delay. However, the most important bandpass filter performance is the frequency response for 5G FSS co-existence.

Importance of Earth Station Registration

Knowing the locations of the FSS earth stations can facilitate the adoption of technical and regulatory rules for the deployment of 5G terrestrial services, while ensuring protection of critical C-band FSS operations. The information acquired from earth station registration provides administrations with a clear picture of the status quo and allows an administration to balance the needs of existing and future C-band satellite services and the realistic need of C-band spectrum by mobile service providers. Additionally, this will lead to more precise and targeted sharing solutions that work in their particular circumstance. Therefore, it is critical that each administration undertake a process to register all receive only C-band FSS earth station operating in their countries.

Conclusion

Prior to allowing terrestrial mobile services in any segment of the 3400-4200 MHz band range, it is necessary that technical rules are adopted to ensure C-band FSS operations are protected. The specific mitigation techniques required will be based on various factors, including the extent to which C-band earth stations are deployed in a country or region, whether the earth station locations are known or not known, and the operational parameters of the mobile service and its planned deployment. Therefore, it is incumbent upon each regulator to carefully analyze the use of C-band spectrum in their own country and establish and implement mitigation techniques to ensure current and future C-band FSS services can continue to operate and thrive. It is equally important to involve stakeholders and incumbents in such assessment to ensure all relevant inputs are taken into consideration.

About Intelsat

As the foundational architects of satellite technology, Intelsat operates the largest, most advanced satellite fleet and connectivity infrastructure in the world. We apply our unparalleled expertise and global scale to reliably and seamlessly connect people, devices and networks in even the most challenging and remote locations. Transformation happens when businesses, governments and communities build a ubiquitous connected future through Intelsat's next-generation global network and simplified managed services.

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