5G mmWave

26 GHz mmWave Unwanted Emissions Study

mmWIS-IIS-TN-00000000001
## Revision-Index

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<th>Date</th>
<th>Authorized by</th>
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<th>Author</th>
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<td>01.01</td>
<td>14.06.19</td>
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<td>first released version</td>
<td>R. Wansch, A. Hofmann, T. Heyn</td>
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<td></td>
<td>Update: Added new 3GPP specified out-of-band emission of RAN#84 Plenary in June</td>
<td>R. Wansch, A. Hofmann, T. Heyn</td>
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1 Executive Summary

The ITU is currently performing compatibility studies for use of mmWave IMT equipment in the 26 GHz band (24.25 GHz to 27.50 GHz) in advance of a potential identification of the 26 GHz band for IMT at WRC-19. Users of the nearby spectrum at 23.6 – 24.0 GHz have raised concerns regarding potentially high levels of unwanted emissions interfering with the 23.6 – 24.0 GHz Earth Exploration Satellite Service (ESS) band which is extensively used for very sensitive passive sensing applications.

This study revisits the current unwanted emission (UWE) levels for the 23.6 – 24.0 GHz EESS band as defined by the various stake holders (3GPP, ITU, EC, esa/EUMETSAT, and WMO) as can be seen below in Table 1-1. Then, filter requirements are derived as one possible way to fulfil the different unwanted emission levels, to the extent not otherwise satisfied by power amplifier design alone. A short overview of possible antenna architectures is given to derive area requirements for these filters.

The study seeks to evaluate achievable performance with currently available filter technology with respect to various unwanted emission requirements and determine whether any Guard Band might be required beyond the current 250 MHz band between 24.00 and 24.25 GHz (which is outside the 26 GHz band).

The current definitions of the different required unwanted emission level limits for 5G services in the 26 GHz mmWave band (US: 24.25 GHz – 27.50 GHz) vary quite heavily. Table 1-1 summarizes the different required unwanted emission level limits. As can be seen they vary between -20 dBW/200 MHz for 3GPP standards and -55 dBW/200 MHz which is proposed by the World Meteorological Organization (WMO). The European Commission recently published the decision 2019/784 [12] to define the harmonization in exactly this band for terrestrial systems in Europe.

Throughout this study, a baseline is used of the 5G NR FR2 base stations which meets the 3GPP 5G stated requirements of unwanted emission levels below -20 dBW/200MHz through the power amplifier design and the defined guard band contained within the 5G NR Channel Bandwidth without additional filtering on the power amplifier output(s). To the extent that equipment providers’ power amplifier implementations have actual emissions below this limit, that will reduce the rejection needed to be achieved by any additional filtering.
Table 1-1: Summary of unwanted emission level requirements as proposed from the different institutions

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>BS</td>
<td>-20.0</td>
<td>-20.0</td>
<td>-23.8</td>
<td>-42.0</td>
<td>-54.2</td>
<td>-55.0</td>
</tr>
<tr>
<td>UE</td>
<td>-20.0</td>
<td>-20.0</td>
<td>-20.0</td>
<td>-38.0</td>
<td>-50.4</td>
<td>-51.0</td>
</tr>
</tbody>
</table>

ESA/EUMETSAT has stated that levels higher than -54.2 dBW/200 MHz for BS and higher than -50.4 dBW/200 MHz for UEs cause problems to their systems [8]. The World Meteorological Organization (WMO) has also stated levels in the same range -55 dBW/200 MHz and -51 dBW/200 MHz respectively.

In order to be able to achieve these unwanted emissions levels, filters could be added.

To derive possible filter solutions, first principal antenna architectures which may be used by IMT are introduced to get an estimation of the available space for filters. For calculating the needed filter rejection levels, the currently defined unwanted emission levels as specified by 3GPP (IMT) of -20 dBW/200 MHz are used as a starting point, and then compared with selected unwanted emission levels as proposed by other organizations.

Many current antenna solutions are based on flat panel arrays with a 8x8 architecture to achieve the minimum required performance for base stations (BS). It is worth noting that filtering at each antenna element places certain physical limitations on the used filter technology. Other design choices (especially on architectural and amplifier levels) are available to the equipment manufacturer which may help to overcome size limits. For example, driving the power amplifiers within a more linear portion of their characteristic curve to avoid spectral regrowth; this approach reduces the requirements on the filtering itself and filters may even be placed between the amplifier and the modem. Additionally, optimized antenna architectures with a lower number of amplifiers (with possible reductions in steering angle ranges) can be further studied as means for possible reductions in unwanted emissions.

Mobile User Equipment (UE) with its compact form factor places additional constraints on the filter design due to size limitations. Evaluation of various
filter technologies for use in mobile UE devices may be further studied in a future report.

This document discusses different filter technologies and explains that there are already viable solutions on the market at affordable prices. The most promising solutions are based on SMT Microstrip or PolyStrata® technologies. The PolyStrata® filter examined in this report was designed as is described below to meet a 20 dB filter rejection, and could be modified to achieve greater filter rejection. These technologies also offer small filter sizes that can be implemented in the base station and the user equipment at a reasonable cost.

The performance requirements for the filters are high, especially the desire for minimal insertion loss (i.e., loss of signal power occurring in the transmission band of a device (e.g., filter)). Achieving the minimal insertion loss within the passband while at the same time achieving the desired level of attenuation or filter rejection at the lower edge of the 26 GHz band leads to a few possible filter approaches.

The cost of such filters can be in the order of $1.00 to $2.00 and therefore are already quite inexpensive.
A summary of the salient parameters is provided in the following table:

*Table 1-2: Summary of filter parameters*

<table>
<thead>
<tr>
<th>Technology</th>
<th>SMT microstrip</th>
<th>PolyStrata®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insertion loss</td>
<td>3dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>Guard band to achieve proposed UWE levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT [-20 dBW/200 MHz]</td>
<td>0 MHz (No filter required)</td>
<td>0 MHz (No filter required)</td>
</tr>
<tr>
<td>EC [-42 dBW/200 MHz TRP]</td>
<td>500 MHz</td>
<td>0 MHz (Note 1)</td>
</tr>
<tr>
<td>WMO [-55 dBW/200 MHz]</td>
<td>1000 MHz</td>
<td>Under study (Note 2)</td>
</tr>
<tr>
<td>Required Lower Edge of Operating Band Edge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT [-20 dBW/200 MHz]</td>
<td>24.25 GHz</td>
<td>24.25 GHz</td>
</tr>
<tr>
<td>EC [-42 dBW/200 MHz TRP]</td>
<td>24.75 GHz</td>
<td>24.25 GHz, (Note 1)</td>
</tr>
<tr>
<td>WMO [-55 dBW/200 MHz]</td>
<td>25.25 GHz</td>
<td>Under study, (Note 2)</td>
</tr>
<tr>
<td>Available Bandwidth for IMT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMT [-20 dBW/200 MHz]</td>
<td>3.25 GHz</td>
<td>3.25 GHz</td>
</tr>
<tr>
<td>EC [-42 dBW/200 MHz TRP]</td>
<td>2.75 GHz</td>
<td>3.25 GHz, (Note 1)</td>
</tr>
<tr>
<td>WMO [-55 dBW/200 MHz]</td>
<td>2.25 GHz</td>
<td>Under study, (Note 2)</td>
</tr>
<tr>
<td>Size [mm³]</td>
<td>4 x 1,6 x 1,6</td>
<td>3 x 4 x 1</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>High</td>
<td>High¹</td>
</tr>
<tr>
<td>Manufacturing stability</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Estimated cost</td>
<td>1-2 $</td>
<td>1-2 $</td>
</tr>
</tbody>
</table>

*Note 1:* As detailed in Chapter 11, the 3GPP 5G specification provides for three different IMT BS types, with medium range and local area BS producing 7 dB lower nominal levels of unwanted emissions into 23.6 – 24.0 GHz than wide area BS. The Guard-Band under the EC standard is 0 MHz for the case of medium range BS and local BS. For wide range BS, the Guard Band under the EC standard using the specific PolyStrata® filter examined is about 200 MHz, but this can also be as low as 0 MHz with PolyStrata® filters designed to satisfy the EC standard – See Note 2.

*Note 2:* The example PolyStrata® filter examined in this analysis was designed to provide 20 dB of rejection in the stop band at 24.0 GHz. With small adjustments, a PolyStrata® filter could be designed for greater stop band rejection, reducing, or possibly eliminating any additional guard band required to meet the WMO unwanted emission limit.
CONCLUSION

As can be seen in previous Table 1-2 possible filter technologies are already available on the market for a reasonable price. With these filters in combination with appropriate designs for the antenna architecture and the related amplifiers all unwanted emission levels can be met.

The 3GPP/IMT proposed unwanted emission protection levels of -20 dBW/200 MHz does not require any additional filtering which allows the entire band of 3.25 GHz from 24.25 – 27.5 GHz to be used for IMT.

The SMT microstrip filter can be used to decrease the additional guard band requirements for the requirements beyond the 3GPP/IMT but it cannot eliminate the need for some additional guard band.

The PolyStrata® filter examined can achieve the EC proposed 5G unwanted emission TRP limit of -42 dBW/200 MHz in the 23.6 – 24.0 GHz band while allowing the entire band of 3.25 GHz from 24.25-27.5 GHz to be used for IMT for medium range BS and local area BS. In addition, with small design adjustments to this PolyStrata® filter design, the same EC unwanted emission can be achieved while allowing the entire band of 3.25 GHz from 24.25-27.5 GHz to be used for IMT for all 5G BS types.

The PolyStrata® filter examined also achieves any unwanted emission levels less stringent than -42 dBW/200 MHz while also allowing the entire band of 3.25 GHz from 24.25-27.5 GHz to be used for IMT for all 5G BS types. Other commercially viable filters may be designed and manufactured to achieve different proposed unwanted emission protection levels similarly.
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11.4.1 CEPT ECC Decision
11.4.2 ESA-EUMETSAT-EUMETNET Comment

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3 Introduction

3.1 Scope of Study

This study analyses ways to mitigate potential interference between proposed 5G IMT networks operating in the 24.25 - 27.50 GHz frequency band and currently in use satellite frequencies for passive earth exploration satellite service (EESS) meteorological earth observations in the mmWave-band at 23.6 – 24.0 GHz.

3.2 Acronyms

3GPP 3rd Generation Partnership Project
5G 5th Generation
AAS Active Antenna Systems
ACLR Adjacent Channel Leakage power Ratio
BPF Band Pass Filter
BS Base Station
BWP Bandwidth Part
CA Carrier Aggregation
CEPT European Conference of Postal and Telecommunications administrations
CPW Coplanar Waveguide
CR Change Request
CSRR Coupled Split Ring Resonator
ECC Electronic Communications Committee
EESS Earth Exploration Satellite Service
EIRP Equivalent Isotropic Radiated Power
ERC European Radiocommunications Committee
ESA European Space Agency
FR Frequency Range
FSL Free Space Loss
IC Integrated Circuit
IIS Institut für Integrierte Schaltungen
IMT International Mobile Telecommunications
ISS Inter-Satellite Service
ITU International Telecommunication Union
LRTC Least Restrictive Technical Conditions
3.3 Definitions

**Guard Band**: Any required operating offset from lower/upper end of 26 GHz band to achieve UWE limits

**Unwanted Emission**: Combination of out-of-band and spurious emissions

3.4 Applicable and Referenced Documents


[3] ID1.3: 3GPP TSG-RAN WG4 Meeting #84, R4-1714048
[4] ID1.3: 3GPP TSG-RAN WG4 Meeting #85, R4-1712718
[5] ID1.3: 3GPP TSG-RAN WG4 Meeting #85, R4-1713636
[18] Corry Micronics datasheet: CMIBPF-23G-2G
[20] Ming Dong ; Dongya Shen ; Chaojun Ma ; Xiupu Zhang, “A cascaded six order bandpass siw filter using electric and magnetic couplings technology”, 2017 Sixth Asia-Pacific Conference on Antennas and Propagation (APCAP), 2017
[21] Qing Liu ; Dong-Fang Zhou ; De-Wei Zhang ; Yi Zhang, „A Miniaturized Quasi-Elliptic BPF with High Selectivity Based on Combining CPWs and
CSRR in a Single Dual-Mode SIW Cavity”, 2018 International Conference on Microwave and Millimeter Wave Technology (ICMMT), 2018


[25] Nuvotronics filter addendum to 3GPP TSG-RAN WG4 #79, Tdoc R4-164226, PolyStrata filter implementation example_rev2.doc


4 Summary of Regulatory Documents

The following table shows the summary of all required unwanted emission levels as proposed by the different institutions. As can be seen, there is a large variety between -20.0 dBW/200 MHz and -55.0 dBW/200 MHz. These values will later be used to determine any filter and Guard Band requirements. A detailed explanation for these required unwanted emission levels can be found in chapter 11.

Table 4-1: Summary of emission levels as proposed from the different institutions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BS</strong></td>
<td>-20.0</td>
<td>-20.0</td>
<td>-23.8</td>
<td>-42.0</td>
<td>-54.2</td>
<td>-55.0</td>
</tr>
<tr>
<td></td>
<td>-37.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UE</strong></td>
<td>-20.0</td>
<td>-20.0</td>
<td>-20.0</td>
<td>-38.0</td>
<td>-50.4</td>
<td>-51.0</td>
</tr>
<tr>
<td></td>
<td>-37.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5 Signal Properties of 5G IMT mmWave Communications

5.1 Operation bands

The frequency range of FR2 is divided into the following 4 operating bands:

Table 5-1: Operating bands in FR2

<table>
<thead>
<tr>
<th>Operating Band</th>
<th>Uplink (UL) operating band</th>
<th>Downlink (DL) operating band</th>
<th>Duplex Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BS receive</td>
<td>BS transmit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UE transmit</td>
<td>UE receive</td>
<td></td>
</tr>
<tr>
<td>n257</td>
<td>26500 MHz - 29500 MHz</td>
<td>26500 MHz - 29500 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>n258</td>
<td>24250 MHz – 27500 MHz</td>
<td>24250 MHz – 27500 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>n260</td>
<td>37000 MHz – 40000 MHz</td>
<td>37000 MHz – 40000 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>n261</td>
<td>27500 MHz – 28350 MHz</td>
<td>27500 MHz – 28350 MHz</td>
<td>TDD</td>
</tr>
</tbody>
</table>

However, as listed in the table above, all operating bands use the same frequency range for uplink and downlink. **In this study only the operating band n258 is analyzed.** An analysis of unwanted emissions in other FR2 bands and potential interference with other services may be studied in a future report.

5.2 Channel bandwidth

The UE channel bandwidth supports a single NR RF carrier in the uplink or downlink at the UE. From a BS perspective, different UE channel bandwidths may be supported within the same spectrum for transmitting to and receiving from UEs connected to the BS. Transmission of multiple carriers to the same UE (CA) or multiple carriers to different UEs within the BS channel bandwidth can be supported.

From a UE perspective, the UE is configured with one or more BWP / carriers, each with its own UE channel bandwidth. The UE does not need to be aware of the BS channel bandwidth or how the BS allocates bandwidth to different UEs.

The placement of the UE channel bandwidth for each UE carrier is flexible but can only be completely within the BS channel bandwidth.

The relationship between the channel bandwidth, the Guard Band and the transmission bandwidth configuration is shown in Figure 5-1.
The maximum transmission bandwidth configuration $N_{RB}$ for each UE channel bandwidth and subcarrier spacing (SCS) is specified in Table 5-2.

### Table 5-2: Maximum transmission bandwidth configuration

<table>
<thead>
<tr>
<th>SCS (kHz)</th>
<th>50 MHz $N_{RB}$</th>
<th>100 MHz $N_{RB}$</th>
<th>200 MHz $N_{RB}$</th>
<th>400 MHz $N_{RB}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>66</td>
<td>132</td>
<td>264</td>
<td>N.A.</td>
</tr>
<tr>
<td>120</td>
<td>32</td>
<td>66</td>
<td>132</td>
<td>264</td>
</tr>
</tbody>
</table>

The minimum Guard Band for each UE channel bandwidth and SCS is specified in Table 5-3.

### Table 5-3: Minimum Guard Band and transmission bandwidth configuration

<table>
<thead>
<tr>
<th>SCS (kHz)</th>
<th>50 MHz</th>
<th>100 MHz</th>
<th>200 MHz</th>
<th>400 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>1210</td>
<td>2450</td>
<td>4930</td>
<td>N.A.</td>
</tr>
<tr>
<td>120</td>
<td>1900</td>
<td>2420</td>
<td>4900</td>
<td>9860</td>
</tr>
</tbody>
</table>

However, in FR2 an additional SCS of 240 kHz exists.

The minimum Guard Band of receiving BS SCS 240 kHz SS/PBCH block for each UE channel bandwidth is specified in Table 5-4.
Table 5-4: Minimum Guard Band (kHz) of SCS 240 kHz SS/PBCH block

<table>
<thead>
<tr>
<th>SCS (kHz)</th>
<th>100 MHz</th>
<th>200 MHz</th>
<th>400 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>3800</td>
<td>7720</td>
<td>15560</td>
</tr>
</tbody>
</table>

The number of RBs configured in any channel bandwidth shall ensure that the minimum Guard Band specified in this clause is met.

Figure 5-2: UE PRB utilization

5.3 Channel arrangements

Table 5-5: Channel raster to resource element mapping

<table>
<thead>
<tr>
<th>Resource element index k</th>
<th>N_RB mod 2 = 0</th>
<th>N_RB mod 2 = 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical resource block number N_PRB</td>
<td>( \left\lfloor \frac{N_{RB}}{2} \right\rfloor )</td>
<td>( \left\lfloor \frac{N_{RB}}{2} \right\rfloor )</td>
</tr>
</tbody>
</table>

5.4 Summary of Relevant Requirements

The Guard Bands as defined within 3GPP depend on the different bandwidths as defined. If higher bandwidths like 200 MHz are used an additional Guard Band of 7.7 MHz can be added to the filter Guard Band. This does not have too much of an impact on the filters needed as proposed later. Therefore, we ignore these additional 7.7 MHz as they only relax the filter performance by a small portion.
6 Considerations on Antenna Design

The following chapter will give a short description how a base station antenna may be implemented. It assumes that full beamforming is mandatory and dedicated phase-shifting front-end chips will be used.

**Antenna Layout**

To maximize the coverage area we assume that full beam-steering in the elevation plane of the antenna is necessary. Additionally, we assume that no polarization tracking is implemented to minimize the number of components. To cover the complete hemisphere of such an antenna a distance between the elements of no more than $\lambda/2$ at the highest frequency is needed.

\[ \lambda/2(@27.5 \text{ GHz}) = 5.45 \text{ mm} \]

The following Figure 6-1 shows a principal layout of such an antenna for a base station. The dimensions are calculated for an element distance of 5.5 mm.

![Figure 6-1: Layout and dimensions of 8x8 array antenna](image)

To drive the individual antenna elements integrated phase shifter / amplifier solutions are needed. E.g., Anokiwave provides such solutions and shall serve as an example.

A suitable chip is the Anokiwave 24/26 GHz Silicon 5G Tx/Rx Quad Core IC AWMF-0139. It is a chipset serving 4 antenna elements with a maximum output power of 14 dBmW, a noise figure of 5.5 dB, 6 bit phase and 5 bit amplitude control. We assume that the 14 dBmW are per output, so a total output power of 20 dBmW is achieved. Power consumption is 1.3 W for the receivers and between 1.8 W and 2.5 W for the transmitters. So, the total power consumption of such an antenna will be about 21 W for the receiving
stages and between 29 W and 40 W for the transmitters, added up between 50 W and 61 W. The total transmitted power without integrating the antenna gain will then be 32 dBmW.

![Diagram](attachment:diagram.png)

**Figure 6-2: Block diagram of 4-channel phase-shifter / amplifier chip Anokiwave AWMF-0139**

To implement these kinds of chips together with a filter, the following figure shall serve as a principal approach. It does not consider additional peripheral elements. It also assumes that the chip together with the filter can be implemented on the same PCB-side.

![Diagram](attachment:diagram.png)

**Figure 6-3: Placement of quad phase shifter / amplifier chip together with filters within a 2x2 antenna subelement**

Such a 2x2 sub-element will have a dimension of 11 x 11 mm². The chip has a size of 3.6 x 3.6 mm². For an easy implementation a PCB-mountable filter of a maximum size of 3 x 5 mm² is mandatory.

For the array integration all supply voltages, the command lines and the feed network need to be implemented in additional layers in the PCB. We assume that for such an antenna at least 10 layers. A first stack-up is shown in Figure 6-4. If additional functions need to be implemented the number of layers may increase.
The constraints as pointed out before are based on the most dense implementation of the antenna. There may also be additional solutions where the number of amplifiers is reduced as one amplifier may feed a number (say four) of antenna elements. Then, either external phase-shifters and attenuators or a sub-grouping of antenna elements has to be implemented. The first approach leads to more external components and a lower integration level of the phase shifting circuitry. The latter leads to reduced scanning properties of the antenna array. Both approaches lead to a reduction of the number of filters by a factor of four and increased available area for the filters.

Figure 6-4: Stack-up of an example PCB covering the following functions: antenna layer, ground layers, feed network layer, power layers, control line layer and assembly layer
7 Determination of Filter Requirements

Based on the emission levels as defined in Table 4-1 we calculate the corresponding filter rejection levels to fulfil the different requirements. This is assuming that the 5G unwanted emission levels are anyway achieved by design of the active hardware used in 5G mmWave technologies. Therefore, we also do not take into account all the calculations regarding EIRP, TRP etc. as the proposed emission levels already include some statistical modelling of the unwanted emissions. In essence, all the UWE levels are based on TRP\(^2\).

For clarification, the definitions of EIRP and TRP shall be shortly described. Totally Radiated Power – TRP is a measure for the integrated power in a volume around the transmitter. It sums up all the power on a sphere’s surface around the transmitting device. The following formula displays this:

\[
TRP = \frac{1}{4\pi} \int_0^{2\pi} \int_0^\pi P(\theta, \varphi) \sin(\theta) \, d\theta \, d\varphi
\]

Where

\[
P(\theta, \varphi) = P_{Tx} G(\theta, \varphi)
\]

In essence TRP should be the product of Transmit Power \(P_{Tx}\) and the efficiency \(\eta\) of the antenna:

\[
TRP = \eta P_{Tx}
\]

Equivalent Isotropically Radiated Power EIRP is a calculative measure to determine the radiated power of an antenna in a certain direction (main-beam) direction and therefore displays the space-filtering properties of an antenna.

\[
EIRP = P_{Tx} G_{\text{max}}
\]

As gain and directivity are also connected via the efficiency, we can say:

\[
EIRP = TRP \, D_{\text{max}}
\]

The required filter rejection is a simple difference between the 5G requirements and the individual requirements from the other institutions.

\[
a_{\text{filter}}(23.6 - 24\text{GHz}) = \text{unwanted emission level (5G)} - \text{required unwanted emission level (other institutions)}
\]

As can be seen in the following Table 7-1 the filter rejection required to achieve the most stringent proposed EESS protection levels can be as high as 31 – 35 dB at a distance of 250 MHz from 26 GHz band edges. This clearly leads to a very sharp filter performance which is challenging to achieve in order to meet the most stringent proposed EESS protection levels.

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\(^2\) It is based on TRP as it assumed that the BS points below horizon and that in a worst case scenario all the power transmitted is somehow scattered and contributing to interference (but not being directed towards a certain direction).
### Table 7-1: Required filter rejection levels in 24 GHz EESS bands based on different required unwanted emission levels in these bands

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BS</strong></td>
<td>-20.0</td>
<td>-20.0</td>
<td>-23.8</td>
<td>-42.0</td>
<td>-54.2</td>
<td>-55.0</td>
</tr>
<tr>
<td></td>
<td>-37.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required filter rejection @ EESS bands</td>
<td>0.0</td>
<td>0.0</td>
<td>3.8</td>
<td>22.0</td>
<td>34.2</td>
<td>35.0</td>
</tr>
<tr>
<td>(See Note):</td>
<td>17.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>UE</strong></td>
<td>-20.0</td>
<td>-20.0</td>
<td>-20.0</td>
<td>-38.0</td>
<td>-50.4</td>
<td>-51.0</td>
</tr>
<tr>
<td></td>
<td>-37.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required filter rejection @ EESS bands</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>18.0</td>
<td>30.4</td>
<td>31.0</td>
</tr>
<tr>
<td>(See Note):</td>
<td>17.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: In estimating the required filtering levels for BSs, there are 3 classes of BSs to be considered under the 3GPP standard, wide area BS, medium area BS and local area BS. The required filter rejection estimated in the above table is for the wide area BS case which represents the worst case, since these BSs operate with the highest transmit power. Given their lower output power, the required filter rejection for the medium area BS and local area BS is 7 dB lower than for the wide area BS case and therefore the filter rejection is relaxed by the same number.

In total, this leads to following main parameters for the filters:
- Pass band: 24.25 - 27.50 GHz (relative bandwidth: 12.56%)
- Pass band loss: as minimum as possible
- Stop bands: ≤ 24.00 GHz, ≥ 27.50 GHz
- Stop band attenuation (filter rejection) below pass-band loss: 0dB, 3.8 dB, >20 dB, >31 dB
- Maximum size: 3 mm x 5 mm
- PCB mountable or PCB structure
8 Filter Technologies in mmWave Bands

8.1 Theoretical Design of Filter

Taking the requirements as derived in the former chapters and based on the evaluation of the discussed regulations an ideal filter would have the following main parameters:
- Pass band: 24.25 - 27.50 GHz
- Stop bands: <24.00 GHz, >28.00 GHz
- Stop band attenuation (filter rejection): at least 20 dB
- Size: 3 mm x 5 mm

Taking some theoretical calculations to achieve this kind of filter performance this leads to the following architectures based on different topologies. Various filter technologies exist to achieve multiple goals, including signal roll off. A Butterworth topology is not promising as it would need an order of 19 which is not possible to realize.

In addition, one of the most challenging tasks is to provide a technology which can be manufactured with a high yield.

If a Guard Band has to be introduced, this will add to the lower pass-band edge (24.25 GHz + Guard Band) and therefore reduces the usable bandwidth for 5G/IMT.

8.1.1 Cauer or Elliptical Filter

Using an elliptical or Cauer filter one would need a filter of fifth order. This could be realized in microstrip technology.

The following Figure 8-1 shows the topology of the filter. It has been simulated using lumped elements which are not available for this frequency range, especially values of some pH. Nonetheless, this architecture would have to be translated to a microstrip filter approach.

![Figure 8-1: Topology of 5th order Cauer filter](image)

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As can be seen in Figure 8-2 the Cauer filter approach may be used to fulfil the different filter requirements. It could also achieve the 35 dB filter rejection with some additional Guard Band to protect EESS.

8.1.2 Chebyshev Filter

To implement this requirements a Chebyshev filter of 9th order would be needed. This may also be realised in microstrip technology.
As can be seen from Figure 8-4 also a Chebyshev type of filter can be used to achieve the needed requirements.

### 8.1.3 Microstrip and Stripline Filter Topologies

The following Figure 8-5 shows a short summary of different filter topologies.

![Types of filters for usage on microstrip or stripline technology](image)

Figure 8-5: Types of filters for usage on microstrip or stripline technology [ref]

The design of such filters uses filter synthesis design tools which allow to design distributed designs such as edge coupled, hairpin, interdigital and combline, based on ideal distributed microstrip and stripline models. Incorporating manufacturing limits and tolerances can be very difficult and can last very long.

- Interdigital band pass structures consist of a number of coupled shortened quarter-wavelength resonators
- Tapped combline filters are of the same structure as interdigital filters, just adding a capacitive load at the open ended side
- Hairpin filters consist of folded half-wavelength resonators with edge coupling
- A optimum distributed bandpass structure uses a stepped impedance approach to achieve the filter properties
- A short stub bandpass filter consists of a transmission line symmetrically loaded with a number of short circuited stubs
- Edge coupled microstrip line filters consist of a number of half-wavelength filters coupled at the edge by defining the distance and the coupling length
### 8.1.4 Currently Available Filters on the Market

The following Table 8-1 gives an overview of different available filters on the market.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Device</th>
<th>Passband (GHz)</th>
<th>Size (mm)</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini-Circuits</td>
<td>BFCN-1262+</td>
<td>12.1 – 13.2</td>
<td>3.2 x 1.6</td>
<td>LTCC</td>
</tr>
<tr>
<td>Knowles Dielectric Labs</td>
<td>B274MB1S</td>
<td>26.5 – 29.5</td>
<td>11.4 x 2.7</td>
<td>Microstrip</td>
</tr>
<tr>
<td>Knowles Dielectric Labs</td>
<td>B260MB2S</td>
<td>24.25 – 27.5</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>SAGE Millimeter Inc.</td>
<td>SCF-26301370-</td>
<td>25 – 26</td>
<td>47.5 x 15.0 x 9.0</td>
<td>Coaxial Bandpass Filter (SMA)</td>
</tr>
<tr>
<td>SAGE Millimeter</td>
<td>SWF-24323340-</td>
<td>&gt; 24.1</td>
<td>88.9 x 22.3 x 11.4</td>
<td>Waveguide Highpass Filter</td>
</tr>
<tr>
<td>Pasternack</td>
<td>PE8747</td>
<td>27.5 – 31</td>
<td>40.6 x 9.7</td>
<td>Coaxial Bandpass Filter (SMA)</td>
</tr>
<tr>
<td>Corry Micronics</td>
<td>CMIBPF-23G-2G</td>
<td>22 – 24</td>
<td>12.7 x 5.0 x 3.0</td>
<td>Strip Line</td>
</tr>
<tr>
<td>ATLANTA micro</td>
<td>AM3066</td>
<td>12 – 26.5</td>
<td>6.0 x 6.0</td>
<td>Digitally Tunable Bandpass Filter</td>
</tr>
</tbody>
</table>

Mini-Circuits provides a filter for Ku-Band [15] and does currently not provide filters for K-Band. We believe that they are working on this kind of filters as a large demand is expected. The current implementation at Ku-Band has a passband insertion loss of 5 dB and a lower stop band filter rejection of about 20 dB starting at 600 MHz distance from the pass-band. Translating this performance to K-Band would lead to even higher insertion losses which seem to be not acceptable. The cost of such a filter is $ 3.85 when ordering 500 pc. It is expected to drop to about $ 2.00 or lower when ordering high volumes.

Knowles Dielectric Labs has a filter on stock (B274MB1S, [16]) and is currently developing a filter (B260MB2S, [17]) which is targeting the application discussed here. With a length of about 12 mm these filters are still a little too large so that 3D approach to reduce the size would be necessary. Unfortunately, we do not have insight in their technology, so we cannot predict if they are able to reduce the size accordingly. The current available filter has an insertion loss of 3.5 dB and a stop band filter rejection of 20 dB at 25.8 GHz with pass-band starting at 26.5 GHz. We except a similar behavior for the 26 GHz approach.
Table 8-2: Performance of B274MB1S [16]

To implement this kind of filter one would have to go for a multi-layer approach on the antenna PCB. This would increase the complexity of the stack-up. Additionally, the antenna element distances would have to be increased to 6 mm (see Figure 8-6), leading to a slightly reduced steering capability of the antenna. Still, most applications could be addressed with this kind of antenna.

Figure 8-6: Sketch of implementation of Knowles Dielectric Labs filter in antenna sub-element

The cost of these filters is not stated and we were not able to get any information.

The filters from SAGE Millimeter Inc. [14] and Pasternack are based on classical coaxial or waveguide concepts and are way too large for this application. Corry Micronics with its CMIBPF-23G-2G [18] provides a filter for 23 GHz which can easily be adjusted to the required 26 GHz range. They claim to have a pass-band insertion loss of 2.0 dB but do not tell the stop-band rejection close to the lower edge of the pass-band.
8.2 Short List of Filter Technologies as discussed in Current Literature

8.2.1 LTCC Filters

The paper “RF and Microwave Component Development in LTCC” discusses the usage of LTCC technologies at mm-wave frequency bands. As an example, an edge coupled four section 28 GHz version has been designed and manufactured. This was not designed for an optimum low edge performance as required for the application of this study. Figure 8-7 shows the implementation of such a filter with a size of 3 x 6 mm². The minimum dimensions used were 160 μm for line widths and spacing. Currently LTCC provides as minimum dimensions 100 μm for widths and spacing with an accuracy of about 5% which leads to variations of about 5 to 10 μm. The most problematic property is that this accuracy mostly relates to the line widths and not the gaps. So, for specific designs these deviations add up in the design.

![Figure 8-7: Example implementation of 28 GHz bandpass filter, total size of tile 15 x 15 mm² [15]](image)

The measured results are shown in Figure 8-8. What can be seen is a slight frequency deviation and an insertion loss of about 2 dB down to 1.5 dB. It was realized on a Dupont 951 substrate.

![Figure 8-8: Simulated and measured performance of LTCC band pass filter [15]](image)

This shows that also LTCC can be used to design such filters. One possible issue is the manufacturing accuracy which could lead to a low yield and would
imply a measurement of each and every device at the end of the manufacturing process.

8.2.2 SIW Filters

Substrate-Integrated-Waveguides (SIW) show one of the most promising technologies to be used in the future for implementing filters in K- and Ka-Bands. In most implementations the usage of high performance substrates based on PTFE is used. The following section will summarize some of the latest papers using this technology.

The paper "A Cascaded Six Order Bandpass SIW Filter Using Electric and Magnetic Coupling Technology" [15] describes a filter based on an "ordinary" Rogers RO4003 substrate with a thickness of 0.304 mm. It has been optimized for a passband at around 15 GHz. The following Figure 8-9 shows a photo of the realized filter together with the main size. Due to the relatively low dielectric constant of RO4003 the size of the filter is around 40 mm in length and 15 mm in width.

Figure 8-9: Photo of 6th order band pass [15]

The filter has a bandwidth of about 2 GHz with a pass band insertion loss of about 5 dB in this implementation (Figure 8-10). The simulated values were significantly better which the authors trace back to their implementation and some insufficient ground contacts.

Figure 8-10: Simulated and measured performance of the proposed filter [15]

This concept can be reduced in size by using thin-film technology on a Al₂O₃ substrate with a possible size reduction factor of 1.7 and an additional size reduction of 1.7 by moving to 26 GHz, leading to a total size reduction of a factor of 3 and therefore 13 mm.
The paper “A miniaturized quasi-elliptic BPF with high selectivity based on combining CPWs (Coplanar Waveguides) and CSRR in a single dual-mode SIW cavity” [15] describes a SIW filter with an additional coupled split ring resonator (CSRR) optimized for operation at 5.8 GHz with a bandwidth of a little more than 500 MHz. It is implemented on a RO5880 substrate of height 0.508 mm with a dielectric constant of 2.2. The size of this implementation is 37.4 mm x 37.4 mm. The following Figure 8-11 shows a photo of this filter.

*Figure 8-11: Photo of implemented filter [15]*

The performance of the filter in pass- and stop-bands is shown in the following Figure 8-12. It can be seen that a quite low passband insertion loss is achieved with about 1.5 dB and quite steep drop at the lower frequency end with a filter rejection of 20 dB at about 5.4 GHz. Scaling this behavior to the 26 GHz region we would expect a size reduction of 70% also leading to higher accuracy demands for manufacturing this kind of filter. This would lead to a filter size of 11 x 11 mm². The main point to be seen here is the proper choice of transmission zeros which should also be applied to the requested filters.

*Figure 8-12: S-parameters of measured vs. simulated filter [15]*
8.3 Outlook to New Filter Implementations

8.3.1 SMT Filters based on Microstrip Technology

Knowles Precision Devices recently published a comparison of different filter technologies in Microwave Journal of May 2019 [22]. There, they discuss different approaches for filtering in the 5G mmWave bands. As shown before, a filter placed directly at the antenna element is the preferred solution.

Figure 8-13: Performance of a Knowles Precision Devices 26 GHz microstrip band-pass filter on a single-layer [22]

The filter has a very small footprint of 4 x 1.6 x 1.6 mm³ based on a proper choice of the filter structure and the substrate it is built on. As can be seen in Figure 8-13 the pass-band insertion loss is about 3 dB, whereas stop-band filter rejection is below 60 dB for a wide frequency range. As we here focus on the close-by filter rejection especially between 23.6 GHz and 24 GHz we have to zoom in to find an indication of the performance. Currently, this frequency band is in the pass band. So, we have to consider Guard Bands to fulfil the performance and consider an improvement of 500 MHz to achieve the correct passband performance.

Then, we end up with an additional Guard Band ranging from zero to approximately 500 MHz or 1 GHz, depending on the type of 5G BS used and depending on the required emission suppression level.

Any such Guard Band would reduce the usable bandwidth for 5G services provided by wide area BSs by the same amount (24.25 GHz to 24.75 GHz or 25.25 GHz as lower edge of the band resulting in 3.25 GHz, 2.75 GHz or 2.25 GHz of available bandwidth for 5G within the band up to 27.5 GHz).

8.3.2 Coaxial Line Filters based on Polystrata® Technology

Cubic Nuvotronics has implemented a manufacturing technology based on chip technology. It is using lithography to generate metallic layers on a substrate based on former chip manufacturing technologies. It operates with a resolution of about 1 μm. Therefore, small structures can be built up and manufactured. The main building blocks of this technology are based on coaxial lines which can operate up to 200 GHz. With this technology very compact structures can be achieved for a reasonable price, even at high frequencies.
It is patented by (among others) US 9,312,589 B2 [15], which is the base patent of this technology. The structures will be built up in a multi-layered approach as shown in Figure 8-14 and Figure 8-15. With this kind of layered approach and the small sizes of the coaxial lines different structures of RF devices can be built.

![Figure 8-14](image1.png)

*Figure 8-14: Layered approach of manufacturing method of Nuvotronics [15]*

![Figure 8-15](image2.png)

*Figure 8-15: Stacked approach to build up space-efficient devices [15]*

Currently, the height of these structures is limited to about 3 coaxial devices on top of each other. Additional structures can be glued together with properly defined interfaces. This technology offers a good alternative to classical PCB- or hybrid-based approaches. Filters using this technology have been built and operated at frequencies as high as 60 GHz.

Nuvotronics has already implemented an antenna structure for mmWave 5G operations. It offers a phased array beam forming solution to cover over ±45° steerability and can lower the power consumption by implementing a low-loss feeding network.
Nuvotronics has started developing filters for 5G mm-wave base stations. For one particular filter designed to provide 20 dB of insertion loss at 24 GHz, Nuvotronics are stating a filter performance as shown in Figure 8-18 and Figure 8-19. The implementation is based on PolyStrata® technology intended for surface mount assembly. The following Figure 8-17 shows such filters with a size of 3 x 4 x 1 mm³. It was designed for a pass-band of 24.25 – 27.5 GHz with 20 dB suppression at 24.0 GHz (EESS band).
Figure 8-18: Simulated performance of a PolyStrata® 24.25-27.5 GHz filter designed for -20 dB filter rejection over temperature, [25]

Figure 8-19: Simulated insertion loss of a PolyStrata® 24.25-27.5 GHz filter designed for -20 dB filter rejection over temperature, [25]
This would fully satisfy the requested filter performance of 20 dB filter rejection with reasonable insertion loss (approximately 1 dB) in the passband. The size of such a filter would be in the range of 3 x 4 x 1 mm³.

- As noted above, based on the 3GPP specifications, no additional filtering is necessary to achieve the -20 dBW/200 MHz unwanted emission level.

- This example PolyStrata® filter meets the -42 dBW/200 MHz requirements as defined by the EC in the case of 5G medium range and local area BS, and would nearly meet the same requirement in the case of wide area BS.

- The above PolyStrata® filter example with some design adjustments could fully satisfy that EC requirement for wide area BS.

The following Figure 8-20 shows an implementation example of such a filter in a 2 x 2 antenna sub-element. It can be seen that with this kind of filters such antennas will be feasible.

The manufacturing technology was developed under different NASA and DoD contracts. It seems to be stable and working as already some examples and components have been produced. As the technology is based on chip manufacturing technology it should be capable of mass manufacturing.
To have a first assessment, we consider the following:
- 8” substrate: 203,20 mm diameter
- Wafer area: 32429,28 mm²
- area efficiency: 95%
- effective wafer area: 30807,81 mm²
- filter area: 12 mm²
- possible number of filters: 2567
- yield: 98%
- effective number of filters: 2516

In essence, on processed wafer can contain about 2500 working filters. With increased area efficiency and yield one could get up to 2600 working filters.

Depending on the array structure of 5G mmWave base stations, 16 – 64 filters may be used. So, one wafer can serve best case 163, worst case 39 base station antennas.

The main question will then be how many wafers can be processed in a certain time-frame. As the technology is based on chip manufacturing it should be possible to use other foundries to increase volumes.

The above example PolyStrata® filter permits use of the full 3.25 GHz passband in the 26 GHz IMT band at 24.25 – 27.5 GHz under the EC protection level (-42 dBW/200 MHz) for medium range and local area BS types.

Since the PolyStrata® filter in this report was designed specifically for 20 dB out of band filter rejection, the resulting response can not be interpreted as providing the minimum possible Guard Band necessary for achieving higher levels of rejection.

As noted above, with a small design change this example PolyStrata® filter can meet the stricter required unwanted emission level of -42 dBW/200 MHz of the EC for wide-area BS types with similar level of insertion loss (approximately 1 dB to 1.5 dB).

Other PolyStrata® designs with greater stop band filter rejection (e.g. > 30 dB) to meet or nearly meet the requirements of the WMO should be possible. Trade-offs would need to be made on these other designs in size, cost, insertion loss etc.

More generally, millimeter wave filter technology is advancing rapidly and new technologies that improve the rejection without compromising other parameters are likely to emerge given the high level of interest and investment.

8.4 Summary of Filter Technologies

Table 8-3 shows a summary of the characteristics of the filter technologies discussed above. As can be seen technologies based on SMT microstrip and PolyStrata® are the most promising for using them in 5G mmWave applications.
### Table 8-3: Summary of filter characteristics for the different technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Microstrip on Alumina</th>
<th>SMT microstrip</th>
<th>Coaxial</th>
<th>LTCC</th>
<th>SIW on LTCC</th>
<th>PolyStrata® (Note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insertion loss</td>
<td>3.5 dB</td>
<td>3 dB</td>
<td>3 dB</td>
<td>2 dB</td>
<td>2 dB</td>
<td>1 dB</td>
</tr>
<tr>
<td>Guard Band to achieve proposed UWE levels&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(see Notes)</td>
</tr>
<tr>
<td>IMT [-20 dBW/200 MHz] (Note 2)</td>
<td>0 MHz</td>
<td>0 MHz</td>
<td>0 MHz</td>
<td>0 MHz</td>
<td>0 MHz</td>
<td>0 MHz</td>
</tr>
<tr>
<td>EC [-42 dBW/200 MHz]</td>
<td>1500 MHz</td>
<td>500 MHz</td>
<td>400 MHz</td>
<td>1500 MHz</td>
<td>750 MHz</td>
<td>0 MHz (Note 3)</td>
</tr>
<tr>
<td>WMO [-55 dBW/200 MHz]</td>
<td>Not possible</td>
<td>1000 MHz</td>
<td>800 MHz</td>
<td>Not possible</td>
<td>1500 MHz</td>
<td>Under study (Note 4)</td>
</tr>
<tr>
<td>Size [mm³]</td>
<td>11 x 3 x 2</td>
<td>4 x 1,6 x 1,6</td>
<td>50 x 15 x 3</td>
<td>3 x 4 x 1&lt;sup&gt;4&lt;/sup&gt;</td>
<td>3 x 4 x 1&lt;sup&gt;5&lt;/sup&gt;</td>
<td>3 x 4 x 1</td>
</tr>
<tr>
<td>Technology maturity</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>medium</td>
<td>high&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
<tr>
<td>Manufacturing stability</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>medium</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>Estimated cost</td>
<td>10 $</td>
<td>1-2$</td>
<td>50 $</td>
<td>2-4 $</td>
<td>2-4 $</td>
<td>1-2 $</td>
</tr>
</tbody>
</table>

**Note 1:** The evaluation of the PolyStrata® filter examined used the values as displayed in the above figures at the worst case temperature curve and added 50 MHz to compensate for manufacturing tolerances.

**Note 2:** For the IMT required unwanted emission level of -20 dBW/200 MHz, no additional filter is required, since the unwanted emission level under the 3GPP specification is also -20 dBW/200 MHz.

**Note 3:** The EC Guard Band value for the PolyStrata® filter examined is 0 MHz for the case of medium range BS and local area BS. For the wide area BS, the Guard Band for the PolyStrata® filter examined would be 200 MHz, but this Guard Band value can be reduced to 0 MHz when the PolyStrata® example filter discussed above is adjusted slightly to add additional rejection (of about 2 dB) in the stop band.

**Note 4:** The WMO Guard Band is presently under study using an adapted filter design.

---

<sup>3</sup> Any required Guard Band would be added to the lower edge of the 26 GHz bandwidth for 5G, therefore reducing the usable bandwidth by that amount.

<sup>4</sup> Estimated size

<sup>5</sup> Estimated size

<sup>6</sup> Not yet being mass produced
PolyStrata® would be a very promising technology to provide the needed performance at reasonable cost and with the lowest impact on Guard Bands for all the different requirements imposed by IMT, EC or WMO.

If one takes the EC required unwanted emission levels for BSs, the use of PolyStrata® filters in 5G BSs should allow for development of 5G services using the entire 24.25 – 27.5 GHz band.

If the high requirements on the insertion loss as requested by WMO are to be implemented it even seems to be a possible short term solution.
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11 Discussion of Regulatory Documents

11.1 ITU requirements for adjacent band protection (ID1.1)

ID1.1 (ITU-R RS.515-5, “Frequency bands and bandwidths used for satellite passive remote sensing”) describes the measurement methods for passive sensing of atmospheric parameters like temperature and water vapor as well as surface parameters like roughness and vegetation covers, ice thickness and moisture content.

No specific requirements for adjacent band protection are given in this ITU-R document. However, the referenced ITU-R RS.2017 (“Performance and interference criteria for satellite passive remote sensing”) gives more insight and maximum allowed interference levels, see below. A level of -166 dBW in 200 MHz bandwidth is reported within the band of 23.6 to 24.0 GHz. Only 0.01% time share is allowed where this value may be exceeded.

Since the interference will be created by a multitude of uncorrelated FR2 base stations and UEs within the sensing coverage area, the specified time share seems to be more or less irrelevant. Even in case of a completely synchronous network, the different slant range to the satellite will lead to an averaging of the unwanted emissions over time at the satellite receiver.

It is assumed that the total sum power of the out-of-band emissions from all FR2 base stations and UEs arriving at the satellite receiver have to be always below the maximum interference level, as stated below.

A very rough estimation of the total received interference power on the satellite with the expected interference levels from 3GPP (see next chapter). A detailed study of interference levels is in ECC document (ID1.4):

\[
P_{\text{total}} = -20 \text{ dBW} / 200 \text{ MHz} - 20 \text{ dB (out of band emissions towards sky, conservatively estimated; assuming that beam forming with multi antenna elements is no more calibrated and working properly outside the specified frequency range)}
\]

\[
+ 30 \text{ dB (~1000 terrestrial transmission points in urban and suburban areas; footprint in ID1.4 is >= 201 km²)}
\]

\[
- 180 \text{ dB (free space loss, FSL, for a medium 1000 km distance)}
\]

\[
+ G_{rx} (\text{Receiver antenna gain}) = -190 \text{ dBW} + G_{rx} = -160 \ldots -148 \text{ dBW, which is >> -166 dBW, so indeed the interference level from 3GPP is too high.}
\]

EIRP per TP to sky = -20 dBW – 20 dB = -40 dBW

\[
\text{FSL} = (4*\pi*d^2) / (4*\pi) = 183 \text{ dB, assuming } d=1000 \text{ km and } \lambda = 1.2 \text{ cm}
\]

\[
G_{tx} (\text{Beam gain}) \text{ is between 30.4 and 52 dBi according to ID1.4 “ECC PT1(18)049_UK EESS passive study 26 GHz.docx”}
\]
11.2 ITU WP5D liaison statement with ITU IMT characteristics (ID1.2)

Mainly three documents are relevant here from ID1.2. However some more Liaison Statements (LS) have been exchanged between WP5D and 3GPP:

1. [R4-1707004] LS from ITU-R WP5D to RAN4 “Unwanted emission for IMT-2020”
   “ITU-R WP 5D notes that 3GPP is studying the feasibility of more stringent spurious domain emission limits than the -13 dBmW/MHz limit (Category A) for base stations. WP 5D would like to know the feasibility of achieving - 30 dBmW/MHz spurious limits (Category B) in a practical design for base stations and user terminals. If achieving this limit is not feasible, WP 5D would like to know what is achievable and under which conditions or circumstances”

2. [R4-1710084] 1st LS from 3GPP RAN4 to WP5D (September 2017)
   “…Considering the complexity of reaching a stricter spurious emission level, and taking into account state-of-the-art mm-wave technologies on transmitters and filtering, integration and power efficiency aspects, further investigations are needed. RAN4 will continue to study the possibilities and will update ITU-R WP 5D when further progress is achieved.”

3. [R4-1714090] 2nd LS from 3GPP RAN4 to WP5D (December 2017)
   “An additional requirement to protect specific sensitive services (e.g. passive services) is under discussion in RAN4 and several observations were already given in the previous LS from 3GPP (R4-1710084). In addition to
those preliminary observations made, the following can be said... RAN4 will continue to study the possibilities and will update ITU-R WP 5D when further progress is achieved.

4 [R4-1809643] LS from WP5D to RAN4, “Definition of and test methods for OTA unwanted emissions of IMT radio equipment”, (RAN4#88 June 2018) “Therefore, ITU-R is not planning to update Recommendation ITU-R SM.329 until additional information is received. Furthermore, ITU-R WP 5D is aware of regional activities (e.g. work in CEPT SE21 to finalize the revision of ERC Recommendation 74-01) as well as in 3GPP RAN4 to try to address this issue. In order to progress the work within ITU-R, WP 5D would like to request further information on the definition and test methods of unwanted emissions for AAS for IMT radio equipment above and below 6 GHz. WP 5D is particularly interested in information on the definition and test methods for OTA (over the-air) unwanted emissions.”

5 [R4-1900024] LS on Definition of test methods for Over-The-Air unwanted emissions of IMT radio equipment: Responses from RAN4 and RAN5, “The test cases are defined in 3GPP TS 38.521-2 and 3GPP TS 38.521-3. The test cases are now expected to be complete by March 2019 after final definition of measurement uncertainty and test tolerances. RAN WG5 will continue to work closely with RAN WG4 and the test and measurement industry concerning maintenance of test procedures for additional permitted OTA test methods”

6 [R4-1902824] WP5D REPLY LIAISON STATEMENT TO ITU-R WP 1A, WP 1C, COPY TO 3GPP RAN4/RAN5, TEST METHODS FOR OVER-THE-AIR TRP MEASUREMENTS OF IMT RADIO EQUIPMENT UTILIZING ACTIVE ANTENNAS, “As stated in these materials, the work within 3GPP RAN is ongoing on this topic. However, the task of 3GPP RAN and its expertise are within the area of measuring TRP in a controlled environment such as an anechoic chamber. WP 5D has reviewed and analyzed this material and further discussed possible test methods for field measurement of Over-The-Air (OTA) unwanted emissions of IMT radio equipment (BS & UE) with active antennas, which administrations may use as a guide when monitoring IMT transmitters. As this topic of field measurements is one important element within regulatory compliance, WP 5D will communicate its findings and further development of the field measurement procedures with WP 1A and WP 1C in due time.”

Conclusion for ITU-R WP5D:
- Final 3GPP specification is in TS 38.104 (BS) and TS 38.101-2/-3 (UE for Standalone / non-standalone), specifying -20 dBW / 200 MHz. This means, 3GPP did not implement the reduced emissions as requested by WP5D.
- It seems that after the response from RAN4 (R4-1714090, Dec 2017), WP5D did not insist on the lower interference levels in 3GPP any more.
Also 3GPP did not give any update specifically on out-of-band emissions to WP5D.

3GPP differentiates between spurious emission requirements (-13 dBmW / MHz) and unwanted emission limits (tables, see below in next chapter on 3GPP).

11.3 Relevant 3GPP documents (ID1.3)

11.3.1 3GPP TS 38.101-2 NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone

For user equipment’s (UEs) in FR2, the over the air (OTA) requirements of the technical specification TS 38.101-2[9] are applicable.

The occupied bandwidth is defined as the bandwidth containing 99% of the total integrated mean power of the transmitted spectrum on the assigned channel. In total 4 different channel bandwidths are defined: 50 MHz, 100 MHz, 200 MHz, and 400 MHz.

The out of band (OOB) emissions are unwanted emissions immediately outside the assigned channel bandwidth resulting from the modulation process and non-linearity in the transmitter but excluding spurious emissions. This OOB emission limits of FR2 are specified in the table below.

Table 11-1: General NR spectrum emission mask for frequency range 2: Spectrum limit (dBmW)/Channel bandwidth

<table>
<thead>
<tr>
<th>Δf_OOB (MHz)</th>
<th>50 MHz</th>
<th>100 MHz</th>
<th>200 MHz</th>
<th>400 MHz</th>
<th>Measurement bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 0-5</td>
<td>-5</td>
<td>-5</td>
<td>-5</td>
<td>-5</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 5-10</td>
<td>-13</td>
<td>-5</td>
<td>-5</td>
<td>-5</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 10-20</td>
<td>-13</td>
<td>-13</td>
<td>-5</td>
<td>-5</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 20-40</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>-5</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 40-100</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 100-200</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 200-400</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>1 MHz</td>
</tr>
<tr>
<td>± 400-800</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>-13</td>
<td>1 MHz</td>
</tr>
</tbody>
</table>

The spurious emissions are emissions which are caused by unwanted transmitter effects such as harmonics emission, parasitic emissions, intermodulation products and frequency conversion products, but exclude out of band emissions. The spurious emissions are apply for frequency ranges that are more than $f_{OOB}$ (MHz) of Table 11-1. The boundary between NR out of band and spurious emissions equals two times the regular channel bandwidth (e.g. 100 MHz for 50 MHz channel).
The spurious emission limits for FR2 is defined as follows: “12.75 GHz ≤ f < 2nd harmonic of the upper frequency edge of the UL operating band in GHz” and is set to a maximum level of -13 dBmW at a measurement bandwidth of 1 MHz.

11.3.2 3GPP TS 38.104: NR; Base Station (BS) radio transmission and reception

For base stations (BS) in FR2, the OTA requirements are applicable in TS 38.104[10].

In general the following different types of base station are defined:

- BS type 1-C: NR base station operating at FR1 with requirements set consisting only of conducted requirements defined at individual antenna connectors
- BS type 1-H: NR base station operating at FR1 with a requirement set consisting of conducted requirements defined at individual TAB connectors and OTA requirements defined at RIB
- BS type 1-O: NR base station operating at FR1 with a requirement set consisting only of OTA requirements defined at the RIB
- BS type 2-O: NR base station operating at FR2 with a requirement set consisting only of OTA requirements defined at the RIB

However, in this study the focus is on FR2, so only BS type 2-O requirements are of interest.

Unwanted emissions consist of so-called out-of-band emissions and spurious emissions according to ITU definitions ITU-R SM.329. In ITU terminology, out of band emissions are unwanted emissions immediately outside the BS channel bandwidth resulting from the modulation process and non-linearity in the transmitter but excluding spurious emissions. Spurious emissions are emissions which are caused by unwanted transmitter effects such as harmonics emission, parasitic emission, intermodulation products and frequency conversion products, but exclude out of band emissions.

The OTA out-of-band emissions requirement for the BS type 1-O and BS type 2-O transmitter is specified both in terms of Adjacent Channel Leakage power Ratio (ACLR) and operating band unwanted emissions (OBUE). The OTA Operating band unwanted emissions define all unwanted emissions in each supported downlink operating band plus the frequency ranges Δf_OBUE above and Δf_OBUE below each band. OTA Unwanted emissions outside of this frequency range are limited by an OTA spurious emissions requirement.

The maximum offset of the operating band unwanted emissions mask from the operating band edge is Δf_OBUE. The value of Δf_OBUE is defined in Table 11-2 for BS type 2-O.

<table>
<thead>
<tr>
<th>BS type</th>
<th>Operating band characteristics</th>
<th>Δf_OBUE (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS type 2-O</td>
<td>FDL,high – FDL,low ≤ 3250 MHz</td>
<td>1500</td>
</tr>
</tbody>
</table>
11.3.2.1 OTA Adjacent Channel Leakage Power Ratio (ACLR)

The OTA ACLR limit is specified in Table 11-3. The OTA ACLR absolute limit is specified in Table 11-4. The OTA ACLR (CACLR) absolute limit in Table 11-4 or Table 11-7 (unless stated differently in regional regulation) or the ACLR (CACLR) limit in Table 11-3, Table 11-5 or Table 11-6, whichever is less stringent, shall apply.

### Table 11-3: BS type 2-O ACLR limit

<table>
<thead>
<tr>
<th>BS channel bandwidth of lowest/highest NR carrier transmitted (MHz)</th>
<th>BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted</th>
<th>Assumed adjacent channel carrier</th>
<th>Filter on the adjacent channel frequency and corresponding filter bandwidth</th>
<th>ACLR limit (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50, 100, 200, 400</td>
<td>BW_Channel</td>
<td>NR of same BW (Note 2)</td>
<td>Square (BWConfig)</td>
<td>28 (Note 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>26 (Note 4)</td>
</tr>
</tbody>
</table>

**NOTE 1:** BW_Channel and BWConfig are the BS channel bandwidth and transmission bandwidth configuration of the lowest/highest NR carrier transmitted on the assigned channel frequency.

**NOTE 2:** With SCS that provides largest transmission bandwidth configuration (BWConfig).

**NOTE 3:** Applicable to bands defined within the frequency spectrum range of 24.25 – 33.4 GHz

**NOTE 4:** Applicable to bands defined within the frequency spectrum range of 37 – 52.6 GHz

### Table 11-4: BS type 2-O ACLR absolute limit

<table>
<thead>
<tr>
<th>BS class</th>
<th>ACLR absolute limit</th>
<th>Equivalent level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide area BS</td>
<td>-13 dBmW/MHz</td>
<td>-20 dBW/200 MHz</td>
</tr>
<tr>
<td>Medium range BS</td>
<td>-20 dBmW/MHz</td>
<td>-27 dBW/200 MHz</td>
</tr>
<tr>
<td>Local area BS</td>
<td>-20 dBmW/MHz</td>
<td>-27 dBW/200 MHz</td>
</tr>
</tbody>
</table>
### Table 11-5: BS type 2-O ACLR limit in non-contiguous spectrum

<table>
<thead>
<tr>
<th>BS channel bandwidth of lowest/highest NR carrier transmitted (MHz)</th>
<th>Sub-block gap size (Wgap) where the limit applies (MHz)</th>
<th>BS adjacent channel centre frequency offset below or above the sub-block edge (inside the gap)</th>
<th>Assumed adjacent channel carrier</th>
<th>Filter on the adjacent channel frequency and corresponding filter bandwidth</th>
<th>ACLR limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>50, 100</td>
<td>Wgap ≥ 100 (Note 5)</td>
<td>25 MHz</td>
<td>50 MHz NR (Note 2)</td>
<td>Square (BW_Config)</td>
<td>28 (Note 3)</td>
</tr>
<tr>
<td></td>
<td>Wgap ≥ 250 (Note 6)</td>
<td></td>
<td></td>
<td></td>
<td>26 (Note 4)</td>
</tr>
<tr>
<td>200, 400</td>
<td>Wgap ≥ 400 (Note 6)</td>
<td>100 MHz</td>
<td>200 MHz NR (Note 2)</td>
<td>Square (BW_Config)</td>
<td>28 (Note 3)</td>
</tr>
<tr>
<td></td>
<td>Wgap ≥ 250 (Note 5)</td>
<td></td>
<td></td>
<td></td>
<td>26 (Note 4)</td>
</tr>
</tbody>
</table>

**NOTE 1:** BW_Config is the transmission bandwidth configuration of the assumed adjacent channel carrier.

**NOTE 2:** With SCS that provides largest transmission bandwidth configuration (BW_Config).

**NOTE 3:** Applicable to bands defined within the frequency spectrum range of 24.25 – 33.4 GHz.

**NOTE 4:** Applicable to bands defined within the frequency spectrum range of 37 – 52.6 GHz.

**NOTE 5:** Applicable in case the BS channel bandwidth of the NR carrier transmitted at the other edge of the gap is 50 or 100 MHz.

**NOTE 6:** Applicable in case the BS channel bandwidth of the NR carrier transmitted at the other edge of the gap is 200 or 400 MHz.
Table 11-6: BS type 2-O CACLR limit in non-contiguous spectrum

<table>
<thead>
<tr>
<th>BS channel bandwidth of lowest/highest NR carrier transmitted (MHz)</th>
<th>Sub-block gap size (Wgap) where the limit applies (MHz)</th>
<th>BS adjacent channel centre frequency offset below or above the sub-block edge (inside the gap)</th>
<th>Assumed adjacent channel carrier</th>
<th>Filter on the adjacent channel frequency and corresponding filter bandwidth</th>
<th>CACLR limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>50, 100</td>
<td>50 ≤ Wgap &lt; 100 (Note 5)</td>
<td>25 MHz</td>
<td>50 MHz NR (Note 2)</td>
<td>Square (BW_Config)</td>
<td>28 (Note 3)</td>
</tr>
<tr>
<td></td>
<td>50 ≤ Wgap &lt; 250 (Note 6)</td>
<td></td>
<td></td>
<td></td>
<td>26 (Note 4)</td>
</tr>
<tr>
<td>200, 400</td>
<td>200 ≤ Wgap &lt; 400 (Note 6)</td>
<td>100 MHz</td>
<td>200 MHz NR (Note 2)</td>
<td>Square (BW_Config)</td>
<td>28 (Note 3)</td>
</tr>
<tr>
<td></td>
<td>200 ≤ Wgap &lt; 250 (Note 5)</td>
<td></td>
<td></td>
<td></td>
<td>26 (Note 4)</td>
</tr>
</tbody>
</table>

NOTE 1: BW_Config is the transmission bandwidth configuration of the assumed adjacent channel carrier.
NOTE 2: With SCS that provides largest transmission bandwidth configuration (BW_Config).
NOTE 3: Applicable to bands defined within the frequency spectrum range of 24.25 – 33.4 GHz.
NOTE 4: Applicable to bands defined within the frequency spectrum range of 37 – 52.6 GHz.
NOTE 5: Applicable in case the BS channel bandwidth of the NR carrier transmitted at the other edge of the gap is 50 or 100 MHz.
NOTE 6: Applicable in case the BS channel bandwidth of the NR carrier transmitted at the other edge of the gap is 200 or 400 MHz.

Table 11-7: BS type 2-O CACLR absolute limit

<table>
<thead>
<tr>
<th>BS class</th>
<th>CACLR absolute limit</th>
<th>Equivalent level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide area BS</td>
<td>-13 dBmW/MHz</td>
<td>-20 dBW/200 MHz</td>
</tr>
<tr>
<td>Medium range BS</td>
<td>-20 dBmW/MHz</td>
<td>-27 dBW/200 MHz</td>
</tr>
<tr>
<td>Local area BS</td>
<td>-20 dBmW/MHz</td>
<td>-27 dBW/200 MHz</td>
</tr>
</tbody>
</table>
11.3.2.2 OTA operating band unwanted emissions

Out-of-band emissions in FR2 are limited by OTA operating band unwanted emission limits. Unless otherwise stated, the OTA operating band unwanted emission limits in FR2 are defined from $\Delta f_{OBUE}$ below the lowest frequency of each supported downlink operating band up to $\Delta f_{OBUE}$ above the highest frequency of each supported downlink operating band. The values of $\Delta f_{OBUE}$ are defined in Table 11-2 for the NR operating bands.

### Table 11-8: OBUE limits applicable in the frequency range 24.25 – 33.4 GHz

<table>
<thead>
<tr>
<th>Frequency offset of measurement filter -3B point, $\Delta f$</th>
<th>Frequency offset of measurement filter centre frequency, $f_{offset}$</th>
<th>Limit</th>
<th>Measurement bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MHz $\leq \Delta f &lt; 0.1*BW_contiguous$</td>
<td>0.5 MHz $\leq \Delta f_{offset} &lt; 0.1* BW_contiguous$</td>
<td>Min(-5 dBmW, Max(P_rated,t,TRP – 35 dB, -12 dBmW))</td>
<td>1 MHz</td>
</tr>
<tr>
<td>$0.1*BW_contiguous \leq \Delta f &lt; \Delta f_{max}$</td>
<td>$0.1* BW_contiguous +0.5 MHz \leq \Delta f_{offset} &lt; f_{offset_{max}}$</td>
<td>Min(-13 dBmW, Max(P_rated,t,TRP – 43 dB, -20 dBmW))</td>
<td>1 MHz</td>
</tr>
</tbody>
</table>

NOTE 1: For non-contiguous spectrum operation within any operating band the limit within sub-block gaps is calculated as a cumulative sum of contributions from adjacent sub blocks on each side of the sub block gap.

As a worst case assumption, the -13 dBmW per MHz result in +10 dBmW / 200 MHz (-20 dBW / 200 MHz).

11.3 Change Requests on 3GPP TS 38.104: NR; Base Station (BS) radio transmission and reception

During the 3GPP RAN#84 Plenary in Newport Beach, California between the 3rd and 6th of June 2019, change requests (CRs) for 3GPP TS 38.101-2 [9] and 3GPP TS 38.104 [10] have been introduced via 3GPP RP-191240: RAN4 CRs to New Radio Access Technology, part 5 [26]. One of this change requests introduces additional OBUE limits for the frequency range 24.25 – 33.4 GHz for the emission limits of “Category B”.

The “Categories” are defined in ITU-R SM.329 [11], as follows:

### Table 11-9: Category definition according to ITU-R SM.329:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>Category A limits are the attenuation values used to calculate maximum permitted spurious domain emission power levels. RR Appendix 3 is derived from Category A limits. These limits are given in § 4.2.</td>
</tr>
<tr>
<td>Category B</td>
<td>Category B limits are an example of more stringent spurious domain emission limits than Category A limits. They are based on limits defined and adopted in Europe and used by some other countries. These limits are given in § 4.3.</td>
</tr>
</tbody>
</table>
Category C

Category C limits are an example of more stringent spurious domain emission limits than Category A limits. They are based on limits defined and adopted in the United States of America and Canada and used by some other countries. These limits are given in § 4.4.

Category D

Category D limits are an example of more stringent spurious domain emission limits than Category A limits. They are based on limits defined and adopted in Japan and used by some other countries. These limits are given in § 4.5.

Category Z

Radiation limits for ITE specified by the International Special Committee on Radio Interference (CISPR). These limits are given in § 4.6.

According to the ITU in ITU-R SM.329 [11], “Category B” is foreseen for Europe and also other countries. In addition to the ITU-R SM.329 also 3GPP states in TR 38.815[27]: “3GPP Technical Specification Group Radio Access Network; New frequency range for NR (24.25-29.5 GHz)” that the more stringent rules of “Category B” shall apply for Europe.

According to the introduced CRs for 3GPP TS 38.104 [10], the following unwanted emission levels are defined for the frequency range 24.25 – 33.4 GHz:

Table 11-10: OBUE limits applicable in the frequency range 24.25 – 33.4 GHz

<table>
<thead>
<tr>
<th>Frequency offset of measurement filter -3B point, Δf</th>
<th>Frequency offset of measurement filter centre frequency, f_offset</th>
<th>Limit</th>
<th>Measurement bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MHz ≤ Δf &lt; 0.1*BW_contiguous</td>
<td>0.5 MHz ≤ Δf_offset &lt; 0.1* BW_contiguous +0.5 MHz</td>
<td>Min(-5 dBmW, Max(P_rated,t,TRP – 35 dB, -12 dBmW))</td>
<td>1 MHz</td>
</tr>
<tr>
<td>0.1<em>BW_contiguous ≤ Δf &lt; 2</em>BW_contiguous</td>
<td>0.5 MHz ≤ Δf_offset &lt; 2*BW_contiguous +0.5 MHz</td>
<td>Min(-13 dBmW, Max(P_rated,t,TRP – 43 dB, -20 dBmW))</td>
<td>1 MHz</td>
</tr>
<tr>
<td>2*BW_contiguous ≤ Δf &lt; Δfmax</td>
<td>2 BW_contiguous +5 MHz ≤ f_offset &lt; f_offsetmax</td>
<td>Min(-5 dBm, Max(Prated,t,TRP – 33 dB, -10 dBm))</td>
<td>10 MHz</td>
</tr>
</tbody>
</table>

NOTE 1: For non-contiguous spectrum operation within any operating band the limit within sub-block gaps is calculated as a cumulative sum of contributions from adjacent sub blocks on each side of the sub block gap.

In addition to that, also the spurious emissions for “Category B” has been updated for the base stations according to the table below.
Table 11-11: BS radiated Tx spurious emission limits in FR2 (Category B)

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Limit</th>
<th>Measurement Bandwidth</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.00 – 22.75 GHz</td>
<td>-10 dBm</td>
<td>10 MHz</td>
<td>Note 1</td>
</tr>
<tr>
<td>29.00 – 30.75 GHz</td>
<td>-10 dBm</td>
<td>10 MHz</td>
<td>Note 1</td>
</tr>
</tbody>
</table>

NOTE 1: Limit and bandwidth as in ERC Recommendation 74-01, Annex 2.

The frequency range between 22.75 – 29.00 GHz is specified according to Table 11-10.

11.4 CEPT ECC Decision on 26 GHz IMT-2020 (ID1.4)

11.4.1 CEPT ECC Decision

In the following we will summarize the CEPT ECC Decision (18)06, “Harmonised technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 24.25-27.5 GHz”, approved 06 July 2018 and corrected 26 October 2018. [7]

For this study the main statements are:

“d) that for a single MFCN network a contiguous block of 800-1000 MHz is desirable to enable the full capabilities of IMT-2020/5G systems;”

“e) that differences in the market demand for spectrum for MFCN and different authorisation regimes across CEPT countries is likely to lead to different timescales concerning the introduction of MFCN in the band 24.25-27.5 GHz;”

“g) that in many CEPT administrations the 26.5-27.5 GHz frequency range is less used by incumbent systems than the 24.5-26.5 GHz frequency range;”

“m) that the 26 GHz band will mainly be used for urban and suburban hotspot areas; however there may be a need for a limited number of hotspots in rural areas; it is not expected that the band will be used for contiguous wide/nationwide coverage of MFCN;”

“n) that a regular assessment of the evolution of MFCN system characteristics, including network deployments, in a timeline consistent with the 5 years review process of the Decision, or sooner if necessary, will provide additional confidence that these LRTC ensure adequate protection of other services, in particular space services;”

“o) that appropriate provisions are needed in the authorisation for MFCN to define precisely how to safeguard in a proportionate way the use of existing EESS/SRS receiving earth stations and the possibility for future earth station deployments in the 25.5-27 GHz frequency band;”

“p) that appropriate provisions are needed in the authorisation for MFCN to define precisely how to safeguard in a proportionate way the use of existing FSS transmitting earth stations and the possibility for future earth station deployments in the 24.65-25.25 GHz frequency band;”
“q) that methodologies will be developed to support coordination/coexistence between MFCN and earth stations in the 26 GHz band (receiving EESS/SRS and transmitting FSS earth stations) through the definition of suitable separation/coordination areas and/or any other solutions as part of appropriate provisions mentioned in considerations o)(and p));”

“r) that most sharing studies have shown that Fixed-Satellite Service (FSS) and the Inter-Satellite Service (ISS) would be protected with a margin of more than 12 dB, based on agreed assumptions, and it will be necessary to ensure that these services remain protected (see considering n);”

“s) that the pointing elevation of the main beam (electrical and mechanical) should normally be below the horizon for outdoor base stations;”

“u) that the protection of the Earth Exploration-Satellite Service (EESS) (passive), requires the introduction of appropriate limits of unwanted emission power in the band 23.6-24 GHz, applying to MFCN operating in the band the 24.25-27.5 GHz; additionally the protection of RAS will require the implementation of suitable separation distances between RAS stations and MFCN transmitters on a case-by-case basis;”

“v) that the protection of the Earth Exploration-Satellite Service (EESS) (passive) in the band 50.2-50.4 GHz and 52.6-54.25 GHz is ensured by the existing generic spurious limits of -30 dBmW/MHz applying to base stations;”

“x) that CEPT is studying usage of MFCN for the command, control and payload link of unmanned aircraft systems (UAS) in MFCN bands, including in the 26 GHz band. However, due to its specific characteristics and usage, the 24.25-27.5 GHz MFCN band is not to be used for connectivity from base stations to terminals on board unmanned aircraft vehicles (UAV). In addition, the connectivity from terminals on board UAV to base stations may have a significant impact, e.g. on separation distance from EESS/SRS earth stations, which requires further study. These UAV operations should not be an obstacle to the deployment of future EESS/SRS earth stations;”

This leads to the following selected decisions:

“3. that CEPT administrations wishing to introduce MFCN in the band 24.25-27.5 GHz shall apply the frequency arrangement and technical conditions according to decides 4, 5 and 7;”

“4. that the MFCN frequency arrangement in the band 24.25 - 27.5 GHz is an unpaired Time Division Duplex (TDD) frequency arrangement as provided in Annex 1;”

“5. that the Least Restrictive Technical Conditions (LRTC) specified in Annex 2 shall apply to the MFCN systems;”

“7. that MFCN in the 24.25-27.5 GHz band shall not be used for connectivity from base stations to terminals on-board UAV and that only communications for connectivity from terminals on-board UAV to base stations is authorised taking into account considering x);”

Annex 1 of the decision describes the frequency arrangement for the band 24.25 – 27.5 GHz, using TDD with a block size of 200 MHz, which can be
adjusted to narrower blocks (multiples of 50 MHz) adjacent to other users for full use of spectrum, with block offsets done in 10 MHz steps if needed.

Figure 11-2: Example of possible frequency arrangements for MFCN in the 24.25-27.5 GHz band [7]

Annex 2 describes the least restrictive technical conditions and especially the unwanted emission levels in the bands 23.6-24 GHz.

Base station MFCN BS additional baseline requirement: maximum emissions into the 23.6 - 24.0 GHz band (described in Table 4 of [ref])

- 23.6 – 24.0 GHz: -42 dBW (in 200 MHz bandwidth)

Note: This level requirement applies for BS for all foreseen modes of operation (i.e. maximum in-band power, electrical pointing, carrier configurations)

Table 5 in [7] states that the normal beam pointing of base stations shall be below horizon.

Terminal station MFCN terminal station maximum emissions into the 23.6 – 24.0 GHz band (described in Table 6 of [ref])

- 23.6 – 24.0 GHz: -38 dBW (in 200 MHz bandwidth)

Note: This level requirement applies for terminal station for all foreseen modes of operation (i.e. maximum in-band power, electrical pointing, carrier configurations)
11.4.2 ESA-EUMETSAT-EUMETNET Comment

An investigation performed by ESA-EUMETSAT-EUMETNET reflects the decision of CEPT ECC. There, a compilation of different approaches is given and compromise has been worked out. It is stated that the current limit of -20 dBW/200 MHz is harmful to the EESS (passive) sensors in the 23.6 - 24 GHz band [8].

The draft ECC Decision (18)FF proposes the following possible range of unwanted emission limits, based on a multi-country proposal presented at last ECC meeting (Document ECC(18)021):

- For BS : [-42/-44] dBW/200 MHz
- For UE : [-38/-40] dBW/200 MHz

These values are studied by ESA-EUMETSAT-EUMETNET.

The basic analysis states the a hard protection limit of EESS (passive) sensors in the 23.6 - 24 GHz band for IMT-2020 stations operated in the 24.25 – 27.5 GHz band:

- For BS : -54.2 dBW/200 MHz
- For UE : -50.4 dBW/200 MHz

These limits would ensure the protection of all current and planned EESS (passive) sensors.

Taking these limits the parties state that the above mentioned limits are somehow optimistic to ensure the operation of EESS (passive) sensors. The concerns are the following:

- First of all the concern about the “provisional” nature is stated:
  - It is the assumption that this proposal is only the first step and additional compromises with relaxed limits will be asked for in the future.
  - These levels are based on optimistic assumptions

- A second concern reflects the [90/99]th percentile that is used to balance the fact that the reference pattern underestimates the sidelobes.

There will be ongoing discussions on the used reference pattern, the antenna pointing and the number of base stations considered. These parameters highly affect the calculated levels.

Additionally, it is pointed out that the unwanted emissions are not really beamformed in space as these are a product of all the beam directions will be spatially flat (having the same value in all directions)\(^7\). This will also be applicable to frequencies further away from the carrier as the phase behavior will change dramatically leading to more equally distributed radiated energy. Here, it seems that additional studies have to be performed.

The study provides the following Table 11-12 with the different unwanted emission levels as proposed by 3GPP, the levels needed to fully protect the passive sensors and the compromise which would have to be made to conform with the draft ECC Decision (18)FF.

\(^7\) Spatially flat would also mean that there is no gain in a certain direction, as this would more or less reflect an isotropic approach.
### Table 11-12: Emission levels as summarized in the CEPT study [8]

<table>
<thead>
<tr>
<th>ITU-R SM.329 Category A / B</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GPP 5G unwanted (out-of-band &amp; spurious) emission levels [dBm/W/MHz]</td>
</tr>
<tr>
<td>IMT unwanted emission into the passive band (reference level) based on 5G parameter [dBW/200 MHz]</td>
</tr>
<tr>
<td>Required improvement of 5G unwanted emissions</td>
</tr>
<tr>
<td>CEPT ECC Decision (18)FF [dBW/200 MHz TRP]</td>
</tr>
<tr>
<td>Concession on the protection of passive sensors</td>
</tr>
<tr>
<td>ESA/EUMETSAT/EUMETNET study result [dBW/200 MHz]</td>
</tr>
</tbody>
</table>

| BS | -13.0 | -30.0 | -23.8 | 18.2 / 20.2 dB* | [-42.0/-44.0] | 12.2 / 10.2 dB | -54.2 |
| UE | -13.0 | -30.0 | -20.0 | 18.0 / 20.0 dB* | [-38.0/-40.0] | 12.4 / 10.4 dB | -50.4 |

**Comment**

- BS emission mask: 20.0 dBW/200 MHz, \( \Delta f \leq 400 \text{ MHz} \): 
  - \(-26.4 \text{ dBW/200 MHz}\)
  - \(\Delta f > 400 \text{ MHz} \):
    - \(-20.0 \text{ dBW/200 MHz}\)

*These levels are consistent with calculations from Ericsson (doc. 5-1/235) and Nokia (doc. 5-1/284), taking into account the additional 2 dB channel aggregation factor agreed in ECC/PT1.*

#### 11.5 Statement of World Meteorological Organisation

World Meteorological Organisation (WMO) has formulated its position on WRC-19 agenda item 1.13 which addresses the protection of EESS. It is accepted that there is a large interest in using the mmWave bands by MNOs. Regarding the protection of EESS (passive) bands, WMO stipulates the following protection levels for applications in the 24.25 – 27.50 GHz band:

- -55.0 dBW/200 MHz for base stations,
- -51.0 dBW/200 MHz for user equipment.
WMO will stay with these limits unless new compelling arguments as well as
detailed measurements or better modelling will be shown.

11.6 Commission Implementing Decision (EU) 2019/784

Recently, the European Commission has released decision 2019/784 [12] on
the harmonization of the 24.25 – 27.5 GHz band for terrestrial systems. There,
it is stated that this frequency band can be used by terrestrial systems also in
Europe “as long as it complies with international and cross-border obligations
under ITU Radio Regulations”. In paragraph (10) of [12] it is stated that
existing satellite services “should be appropriately protected from terrestrial
wireless broadband electronic communication services”. Paragraph (11)
highlights the protection of satellite earth stations. In paragraph (19) it is
stated that the terrestrial services “should provide appropriate protection to
the EESS (passive) in the 23.6 – 24.0 GHz frequency band.

Article 3 (a) states that terrestrial systems appropriately protect “systems in
adjacent bands, in particular in the Earth Exploration Satellite Service (passive)
and in the Radio Astronomy Service in the 23.6 – 24.0 GHz frequency band;“.
Article 3 also provides statements for other satellite services.

Next to the protection of satellite systems the decision also covers the
protection of existing terrestrial systems.

Table 11-13: Emission level as defined in EC decision

<table>
<thead>
<tr>
<th></th>
<th>Transitional region power limit (In-band, out-of-block) [dBW/200 MHz]</th>
<th>Baseline power limit for synchronized operation (In-band, out-of-block) [dBW/200 MHz]</th>
<th>Additional baseline (OOB) power limit [dBW/200 MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>-12.0</td>
<td>-20.0</td>
<td>-42.0</td>
</tr>
<tr>
<td>UE</td>
<td>-38.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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