1. Overview

What we are consulting on – in brief

On 17 January 2020, we published a consultation document setting out our proposals for enabling greater access to Extremely High Frequency (EHF) spectrum in the 100-200 GHz frequency range. In response to this consultation, some stakeholders told us that they would find it useful to have sight of further detail of our technical analysis in order to reach a firmer view on our proposals. In light of these comments, we are publishing additional details about the technical analysis underlying our proposals and inviting any comments that stakeholders might have by 17 June 2020. For the avoidance of doubt, this information does not modify the proposals that we made in the January 2020 consultation nor our underlying analysis.

Introduction

Our proposals for supporting innovation in the 100-200 GHz range

1.1 On 17 January 2020, we published our proposals for increasing terrestrial access to three bands in the 100-200 GHz range (the "**January 2020 consultation**").[1]

1.2 Innovative technology using Extremely High Frequency (EHF) spectrum in the 100-200 GHz bands has the potential to develop a range of new services and applications. To help foster this innovation, we proposed to enable simple, flexible access to over 18 GHz of radio spectrum across three bands (116-122 GHz, 174.8-182 GHz and 185-190 GHz). We proposed that this spectrum could be accessed using lower power licence-exempt devices or increased power devices under a new licence on an uncoordinated shared basis.

1.3 Under our proposals, devices would be authorised subject to certain technical conditions designed to protect Earth Exploration-Satellite Services (EESS) from undue interference. We proposed maximum permitted equivalent isotropically radiated power (EIRP) levels, with additional technical restrictions to minimise emissions in the direction of EESS when devices are used outdoors.

1.4 For outdoor use, we proposed to limit the amount of signal radiation towards EESS by placing limits on the EIRP at increased angles relative to the main beam in the elevation plane. Specifically, we proposed maximum permitted device EIRP levels specified at angles of 0, 10, 40 and 60 degrees from the direction of its main beam. These angles are shown as (a) to (d) in Figure 1.1. For increased power licensed use outdoors, we additionally proposed an installation restraint which would require the maximum elevation angle of the main beam of the installed equipment to be less than 20 degrees.

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[1] Ofcom's consultation of 17 January 2020 entitled *Supporting innovation in the 100-200 GHz range*. On 7 February 2020 we published a revised version of that consultation document to incorporate a number of clarifications, including on the proposed technical conditions that would apply to licensed devices used indoors.

1.5 The consultation closed on 20 March 2020. We received 14 responses and have published the non-confidential responses on our website.

Update to technical annex

1.6 Annex 6 (Coexistence analysis with Earth Exploration-Satellite Services (passive)) set out our assessment of our proposed approach for ensuring that potential interference from future terrestrial devices would not affect the operation of EESS.

1.7 Some stakeholders told us that they would find it useful to have sight of further detail of our technical analysis in order to reach a firmer view on our proposals. In light of these comments, we are providing further details about the assumptions and results of the technical analysis which informed our proposals. For the avoidance of doubt, this information does not modify the proposals that we made in the January 2020 consultation nor our underlying analysis.

Section 2

1.8 In Section 2 of this document, we provide an updated version of our Coexistence analysis with Earth Exploration-Satellite Services (passive) (Annex 6 to the January 2020 consultation), containing further clarifying information about the assumptions underlying our technical analysis. All material in Section 2 which is additional to that which was published in the January 2020 consultation (as Annex 6) is presented in grey boxes. Where words have been added for clarity, these are presented in square brackets. In Table 2.3 (Table A6.3 in the January 2020 consultation), updated values are shown in red. Figures 2.4 and 2.6 (Figures A6.4 and A6.6 in the January 2020 consultation) have been corrected.

Section 3

1.9 In Section 3 of this document, we have set out further details of the coexistence analysis which informed our January proposals.

Consultation

1.10 If stakeholders have any comments on our consultation proposals in light of these additional technical details, they should please send them by email to **EHFspectrumaccess@ofcom.org.uk** by **17 June 2020**.

> ***Question:*** *Do you have any comments on the consultation proposals and analysis set out in the January 2020 consultation in light of the additional technical details which we are publishing in this document (see text added in grey boxes in Section 2 and the whole of Section 3)?*

Next steps

1.11 We are reviewing the comments received in response to the January 2020 consultation and will consider any further comments that stakeholders might wish to make in light of the additional technical details that we are now publishing. We aim to publish our decisions on the proposals set out in the January 2020 consultation in Q2 2020-21.

2. Updated version of Annex 6 to the January 2020 consultation: Coexistence analysis with Earth Exploration-Satellite Services (passive)

> Below we provide an updated version of Annex 6 to the January 2020 consultation, containing further clarifying information about the assumptions underlying our technical analysis. All material which is additional to what was published in Annex 6 to the January 2020 consultation is presented in grey boxes. Where words have been added for clarity, these are presented in square brackets. In Table 2.3 (Table A6.3 in the January 2020 consultation), updated values are shown in red. Figures 2.4 and 2.6 (Figures A6.4 and A6.6 in the January 2020 consultation) have been corrected.

Introduction

2.1 This annex describes our assessment of the potential interference caused by future terrestrial devices operating under our proposals to Earth Exploration-Satellite Services (EESS). It also describes our proposed approach for ensuring that potential interference from these devices does not affect the operation of EESS.

2.2 An assessment of the potential interference caused by short-range devices (SRDs) to EESS (passive) in the 122-122.25 GHz band has previously been provided in the ECC Report 190. This considered a future scenario in which geographic clusters of devices are deployed, operating continuously at their maximum permitted power. Whilst this will most likely represent a worst-case interference scenario, we have adopted a similar modelling approach for assessing the potential for interference to be caused by new devices operating in the three proposed bands. This approach provides a high degree of surety that the new devices operating in these bands would not affect the future operation of EESS.

2.3 We also note that our proposals involve making significantly more spectrum available (over 18 GHz) for use by terrestrial devices. This makes it less likely that devices will operate on the same frequencies. This wider distribution in the frequencies used by devices reduces their likely combined effect in the frequency bands used by EESS. In our analysis we have not taken this potential reduction in interference [power] into account, leading to a potential overestimate of the potential interference they might cause to EESS.

2.4 We have extended the analysis in the ECC Report 190 to account for the different coverage footprints and sensitivities of the EESS sensors used in each of the proposed frequency bands. We have also included the effect of terrestrial devices using directive narrower beam antenna systems. These narrower beams reduce the signals radiated upwards into space and hence the potential interference they cause to EESS.

2.5 The ECC Report 190 assumed that the attenuation caused to signals propagating from devices sited inside buildings to outdoors is likely to be greater than 60 dB in the 122 GHz band. Based on this, it was concluded in this report that devices operating indoors were unlikely to be a source of interference to EESS. Similar levels of loss would be expected [in the range of] 116-122 GHz and as the signal attenuation caused by buildings generally increases with frequency its level is likely to be at least that in the newly proposed bands as in the 122 GHz band.

A relatively cautious set of modelling assumptions have been used to assess the effects of interference

2.6 The EESS technical parameters used in our analysis are set out in Recommendation ITU-R RS.1861[2] and the protection criteria for the EESS sensors in Recommendation ITU-R RS.2017.[3] These parameters are summarised in Table 2.3.

2.7 For the 116-122 GHz band, we have included the effect of potential interference to the new EUMETSAT sensor described in ECC Report 190.

2.8 The interfering signals from terrestrial devices are not received with the same intensity all of the time by the EESS sensors due to their changing orbital positions. In our analysis no reduction was made to the estimated levels of interference caused by terrestrial devices to account for this, leading to a potential overestimate of the interference caused to EESS. In addition, we have also only considered the reduction in EESS sensor antenna gain with elevation angle and not azimuth angle. In practice, the EESS antenna will be constantly moving and this angle will vary in time. This, again, is likely to have led to some degree of overestimate of the potential level interference that might be caused to EESS.

2.9 The following assumptions were used relating to the deployed terrestrial devices in our analysis:

a) **Device power** - All devices were modelled as operating at their maximum permitted power level. In practice, it is likely that not all applications will require operation at maximum permitted power and this assumption is likely to lead to an overestimate of interference they will cause.

b) **Device activity factor** - All devices were modelled as operating on a continuous basis (i.e. a 100% duty cycle). This increases the joint effect of interference from different devices at any given time. For example, the cumulative interference provided by five devices operating with a 20% duty cycle[4] would be broadly equivalent to [a] single device operating on a continuous basis. The ECC Report 190 also recognized that practical devices are likely to operate with a duty cycle below 50%. Hence, our assumption that all devices will operate on a continuous basis will most likely overestimate the potential interference caused to EESS.

[2] Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz.

[3] Performance and interference criteria for satellite passive remote sensing.

[4] A 20% duty cycle was assumed by the FCC in their interference analysis. See FCC 19-19.

c) **Device bandwidth** - We have used a minimum transmission bandwidth for the terrestrial devices of 100 MHz. In practice many applications may use larger bandwidths than this, for example to support higher capacity connections.[5] These wider transmission bandwidths reduce the effect of interference to EESS. No adjustment for this was made in our analysis, leading to a potential overestimate of the actual interference caused to EESS.

d) **Frequency of operation** - The propagation losses specific to the three proposed frequency bands were used in our analysis. The lowest propagation losses in each band were considered which, again, represents a worst-case interference scenario.

e) **Device directivity** - We have included the effect of the gain and directivity of the antennas used by devices. This directivity, coupled with the transmitter and receiver beams aligning horizontally for terrestrial use, further reduces the emission of unwanted signals from the devices towards the EESS.

2.10 Based on the device assumptions above, we sought to identify through our analysis the technical parameters for new terrestrial devices that would provide at least the same level of interference protection for EESS as that identified in the ECC Report 190. Whilst our analysis, for the reasons described above, has most likely overestimated the actual protection required, this approach provides a high degree of surety that EESS will not be affected by our proposals.

Modelling approach

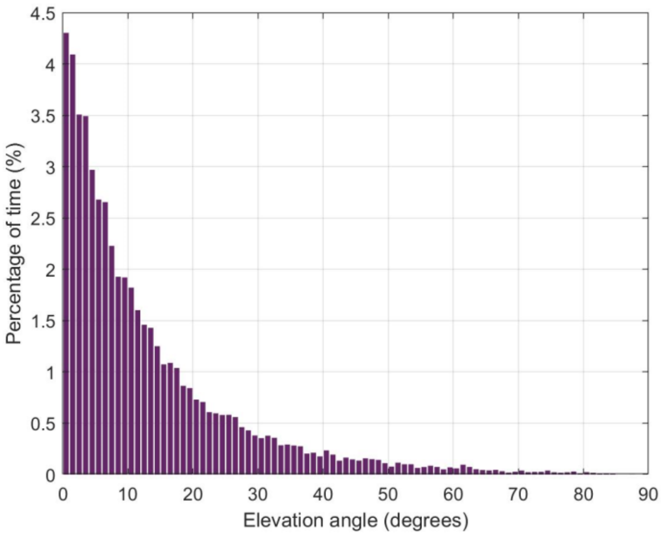
2.11 The orbits associated with the different EESS were modelled to provide the distribution of elevation angles from potential future terrestrial devices operating in the UK to the sensors on the EESS. These are shown in Figure 2.1. In this distribution, a zero-degree elevation angle is taken to be tangential to the Earth.

2.12 At a zero-degree angle, the potential interference path from the terrestrial devices to the EESS sensors is the longest and these paths have the greatest atmospheric attenuation. Hence, the potential interference caused by terrestrial devices is the lowest over these paths. Signals travelling along these paths will also be further reduced by terrain and clutter. These additional reductions were not taken into account in our analysis as this interference path geometry is not the limiting case.

2.13 At an elevation angle of 90 degrees the interference path is at its shortest and has the lowest level of atmospheric attenuation. This path provides the highest level of potential interference to EESS but, as Figure 2.1 shows, these paths to the EESS occur for only a small percentage of time. No adjustment was made for this in our analysis.

[5] The ECC Report 190 also noted that transmission bandwidths are likely to be larger than 500 MHz.

Figure 2.1: Distribution of elevation angles



2.14 The interference path between the terrestrial devices and the EESS sensor receiver was modelled to obtain the power received at the EESS receiver taking into account the propagation losses, terrestrial device transmit power, antenna gain and pointing, and the pointing of the EESS antenna.

$$P_{received} = P_{terrestrial} + G_{terrestrial} - L_{propagation} + G_{EESS}$$

Where:

$P_{received}$ is the power received at the EESS sensor;

$P_{terrestrial}$ is the power transmitted by the terrestrial device;

$G_{terrestrial}$ is the antenna gain of the terrestrial device in the direction of the EESS sensor;

$L_{propagation}$ is the propagation loss between the terrestrial device and the EESS sensor;

G_{EESS} is the antenna gain of the EESS sensor in the direction of the terrestrial device.

Power transmitted by the terrestrial device

2.15 A range of different input power levels and antenna gains, and hence Effective Isotropic Radiated Powers (EIRPs), were modelled for the terrestrial devices to assess their impact on the potential interference caused to EESS.

> The range of transmit powers considered was -15 to 55 dBm. For each transmit power, antenna gains of 0 to 55 dBi were modelled giving a range of EIRPs from -15 to 110 dBm. For isotropic radiators, we considered a 0 dBi gain antenna.

Antenna gain of the terrestrial device in the direction of the EESS sensor

2.16 Two different types of terrestrial device antennas were considered:

a) Isotropic radiators where the EIRP is the same in all directions; and

b) More directive, narrower beam antennas where the EIRP is higher in the direction of the main beam and lower at angular offsets from the main beam.

2.17 The directional antenna pattern was modelled using Recommendation ITU-R F.1245.[6] The proposed new frequency bands do not fall within the range of this model but after comparison with a selection of directional antenna patterns operating at frequencies above 90 GHz, we considered that it was appropriate to use this model in our analysis.

2.18 To assess the average interference from a typical device, an average antenna pattern was created to account for the variation in azimuth and elevation pointing. This was derived to represent an equal probability of any of the pointing angle combinations of azimuth and elevation of the device. Interference assessments were made over the full range of elevation angle paths to the satellites (0 to 90 degrees). For this:

- The device antenna main beam elevation pointing angle was assumed to lie in the range -20 to 20 degrees.
- The relative angle between the main beam of the terrestrial device and the elevation angle at 0 degrees azimuth was calculated over 0 to 359 degree range in azimuth.
- The device antenna gain at each relative angle was found using the antenna models described above and the values for each elevation angle were averaged and used in the assessment.

2.19 This gives an antenna pattern which accounts for the terrestrial device antenna orientation relative to the EESS. It is appropriate for the assessment of interference from multiple devices but will overestimate the likely interference caused by a specific device.

Propagation loss between the terrestrial device and the EESS sensor

2.20 As radiowaves pass through the atmosphere they interact with the gas molecules. These interactions generally attenuate the signals. This attenuation is largest closer to the resonant frequencies of the gas molecules. The most relevant gases in our proposed frequency bands are oxygen and water vapour. Oxygen has a resonant frequency at around 119 GHz, whilst water vapour has resonances at 120 GHz and 183 GHz.

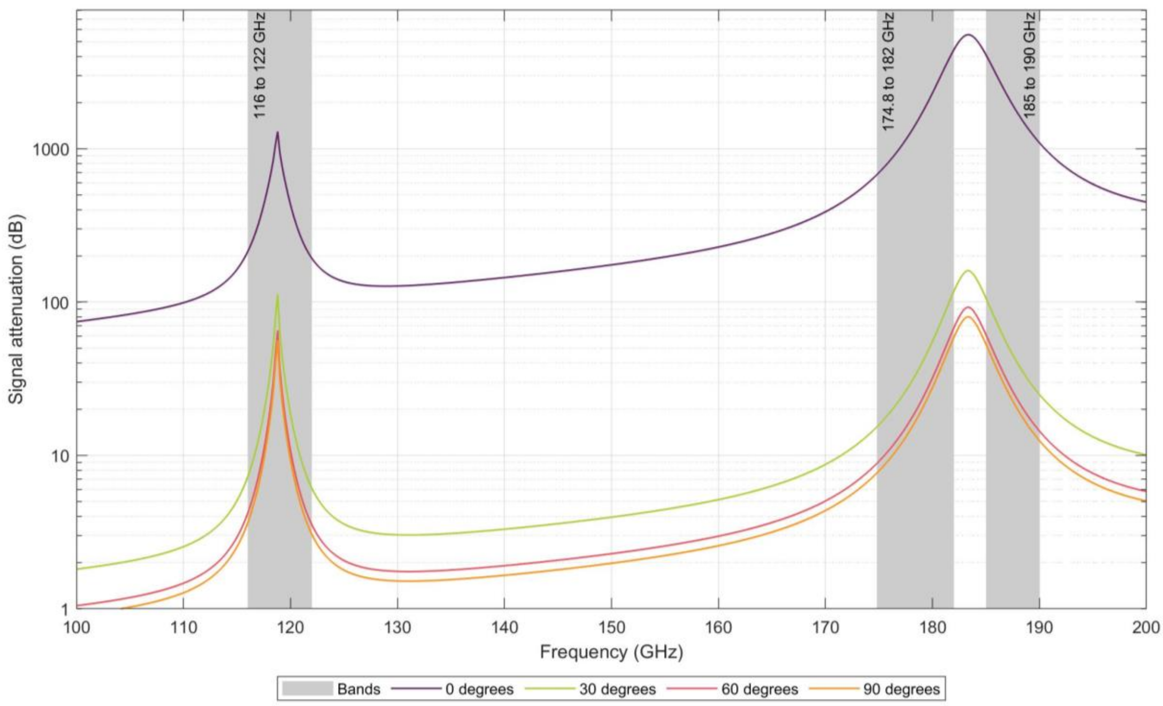
[6] Mathematical model of average and related radiation patterns for point-to-point fixed wireless system antennas for use in interference assessment in the frequency range from 1 GHz to 86 GHz.

We note that ECC Report 190 used an approximation of the loss due to atmospheric gases. In our analysis, the Recommendation ITU-R P.676 line by line summation method was used (Recommendation ITU-R P.676-12 Annex 1 section 2.2.1 Slant paths). The atmospheric attenuation was calculated for all elevation angles from the Earth and used in the assessment. Example loss values are given in Figures 2.2 and 2.3.

2.21 The atmosphere is highly variable in both time and with altitude. Atmospheric pressure and temperature affect the magnitude of the signal attenuation. Altitude variation is modelled by splitting the atmosphere into sections. By estimating the temperature and pressure in each section and the distance travelled by radio waves through it, the loss due to the interaction with gases can be assessed. The losses from each section are then summed to find the total propagation loss. The losses due to interaction with gas molecules vary with frequency and elevation angle, as shown in Figure 2.2. This variation plays an important part in our assessment of potential interference to EESS and was modelled for elevation angles between 0 and 90 degrees.

Elevation angles 0, 30, 60 and 90 degrees in Figure 2.2 refer to the angles of the slant path through the atmosphere relative to horizontal.

Figure 2.2: Signal attenuation due to gases for varying elevation angles



2.22 To derive the aggregate interference value, the propagation losses were determined using Recommendation ITU-R P.525[7] for free-space loss (L_{fs}) and Recommendation ITU-R P.676[8] for attenuation by atmospheric gases (L_{ga}) (with the mean annual global reference atmosphere taken from ITU-R P.835[9]).

$$L_{propagation} = L_{fs} + L_{ga}$$

Where:

$L_{propagation}$ is the propagation loss between the terrestrial device and the EESS sensor;

L_{fs} is the free-space loss between the terrestrial device and the EESS sensor; and

L_{ga} is the loss due to atmospheric gases between the terrestrial device and the EESS sensor.

Antenna gain of the EESS sensor in the direction of the terrestrial device

2.23 The EESS antenna gain was calculated using Recommendation ITU-R RS.1813.[10] The proposed bands under consideration do not fall within the range of this model but after comparison with Figure 12 in Recommendation ITU-R RS.1861, we considered it was an appropriate model to use for this analysis.

> Recommendation ITU-R RS.1813-1 section 2 antenna pattern for peak interference values was used.

2.24 To determine the EESS antenna gain, the difference between its off-nadir angle and the angle of arrival at the sensor was used. This off-axis reduction in EESS antenna gain only accounts for changes in elevation angle, and no adjustment was made to account for the potential further reduction in gain provided by offsets in azimuth angle.

Interference margin

2.25 An interference margin was obtained for each elevation angle by comparing the power received and the sensor protection limits. The protection limits were scaled to a minimum bandwidth of 100 MHz.

$$I_{margin} = I_{max} + 10log\left(\frac{100}{BW_{ref}}\right) - P_{received}$$

Where:

I_{max} is the maximum interference level from the sensor protection criteria (see Table 2.3);

BW_{ref} is the reference bandwidth from the sensor protection criteria (see Table 2.3);

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[7] Calculation of free-space attenuation.
[8] Attenuation by atmospheric gases. Annex 1 for Slant path attenuation, this section remains unchanged in ITU-R P.676-12 (updated August 2019).
[9] Reference Standard Atmospheres.
[10] Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz.

$P_{received}$ is the power level received at the sensor.

2.26 The calculated interference margin provides an indication of the number of terrestrial devices that can operate simultaneously without exceeding the maximum interference level defined in Recommendation ITU-R RS.2017.

Setting the technical device specifications

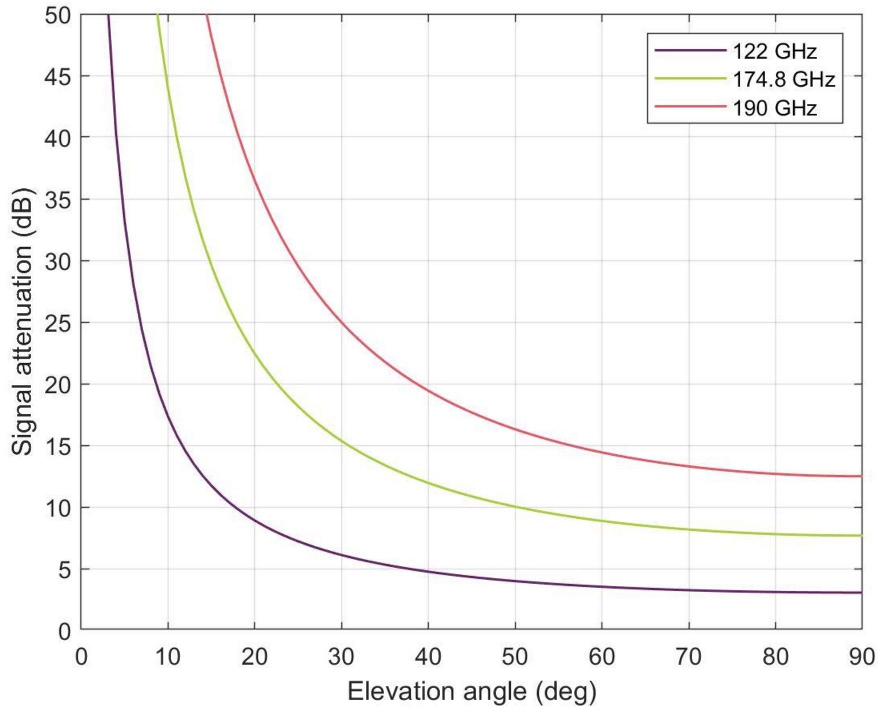
2.27 In setting the technical specifications, we have considered the two main factors which influence the interference margin:

a) The variation in the signal attenuation due to interaction with gases. In the 116-122 GHz band there is an oxygen absorption line at 118.75 GHz which leads to high attenuation in the middle of the band but lower attenuation towards the edges of the band. The 174.8-182 GHz and 185-190 GHz bands are on the lower and upper slopes of the water vapour peak at 183.3 GHz. Comparing the lowest losses in each band at elevation angles between 20 and 40 degrees, there is an increase of at least 10 dB in losses per band due to gases. 174.8-182 GHz has at least 10 dB greater loss than 116-122 GHz and there is a further increase in loss of at least 10 dB in the 185-190 GHz band. This is illustrated in Figure 2.3.

b) The antenna pointing of the EESS sensors. The configuration of the EESS sensors vary between the bands. The EUMETSAT sensor in 116-122 GHz has a smaller off-nadir pointing angle than the sensors in the 174.8-182 GHz and 185-190 GHz bands which are the same in both bands.

2.28 When assessing the potential risk of interference for each band we found that the configuration of the EUMETSAT sensor in the 116-122 GHz band required the same level of protection as the EESS sensors in 174.8-182 GHz after taking into consideration the difference in attenuation due to gases. The EESS sensor configurations in the 174.8-182 GHz and 185-190 GHz bands are the same, so the difference in gaseous attenuation between the bands enabled the setting of higher maximum EIRP levels in the upper band.

Figure 2.3: Comparison of signal attenuation due to gases

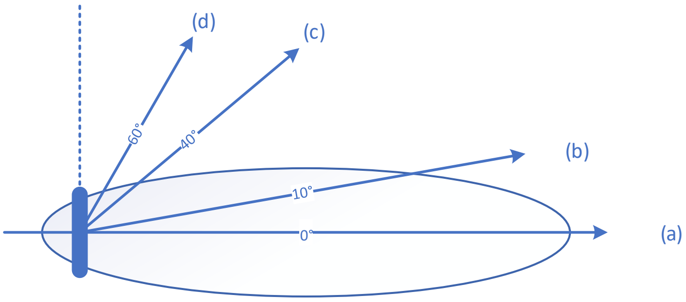


2.29 For licence-exempt use outdoors, we are proposing maximum permitted device EIRP levels specified at angles of 0, 10, 40 and 60 degrees from the direction of its main beam in Table 2.1. These angles are shown as (a) to (d) in Figure 2.4. We are proposing lower limits for higher elevation angles given their greater potential effect on the EESS. It is expected that most outdoor terrestrial applications will operate with device antenna pointing horizontally. However, in developing these proposed EIRP limits, we have also included scenarios where their beams are tilted upwards with and elevation angle of up to 20 degrees. We believe that this is a reasonable assumption given the likely practical deployment of devices for terrestrial use where the main antenna beams for the transmitter and receiver devices will most likely need to align horizontally.

Table 2.1: Licence exemption EIRP limits

Power limits (*max EIRP in dBm*) and emissions restrictions on outdoor use			
USE	**116-122 GHz**	**174.8-182 GHz**	**185-190 GHz**
Indoor	40	40	40
Outdoor	20(a)	20 (a)	40 (a)
For outdoor use, EIRP at angles (degrees°) relative to main beam in [the] elevation [plane] shall not exceed			
	13 at > 10° (b) 1 at > 40°(c) -3 at > 60°(d)	13 at > 10° (b) 1 at > 40°(c) -3 at > 60°(d)	25 at > 10°(b) 14 at > 40°(c) 10 at > 60°(d)

Figure 2.4[11]: EIRP variation relative to the antenna main beam



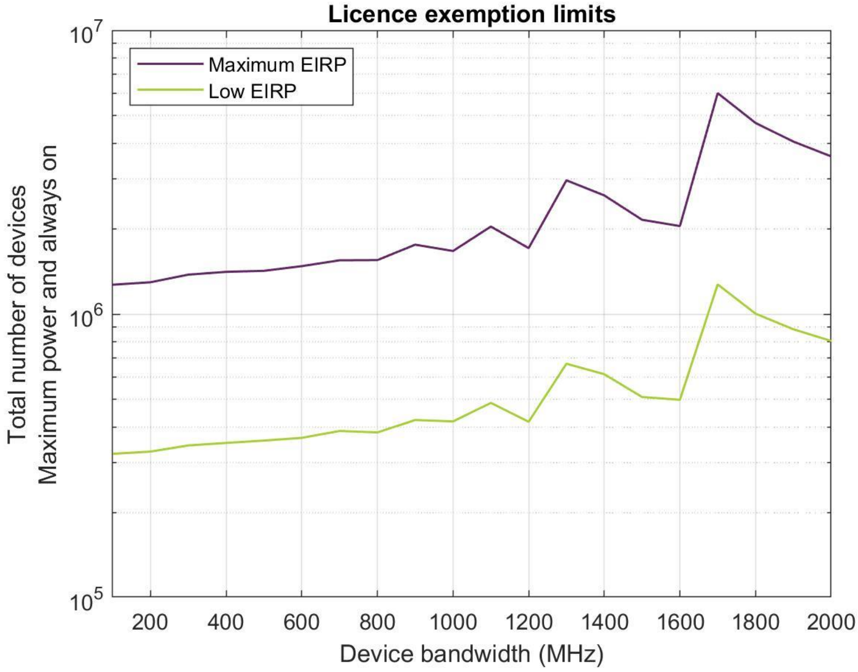
2.30 In ECC Report 190 it was estimated that the maximum number of devices that are likely to be visible to the EESS at any one time is 2100 in 250 MHz. If we scale this assumption for the total amount of spectrum in the newly proposed bands, this would be equivalent to a much higher 150,000 devices. This reflects the wider distribution of devices across a wider frequency range.

2.31 The EIRP limits set out in table 2.1 would ensure that the emissions from over 300,000 outdoor licence exempt devices visible to the satellite at the same time and operating continuously would not exceed the maximum interference levels from Recommendation ITU-R RS.2017. The number of devices that could operate at maximum EIRP using directive antennas at the same time across the newly proposed bands is higher and exceeds one million devices (see Figure 2.5). This figure also shows that for less directive antennas (operating with a lower permitted EIRP) more than 300,000 devices could be supported. The number of devices also rises significantly as the device bandwidth increases.

> In Figure 2.5 'Maximum EIRP' is the maximum permitted licence exempt EIRP of 20 dBm using a 23dBi antenna, 'Low EIRP' is 7 dBm using a 10 dBi antenna.

[11] Diagram corrected to show (c) as the 40 degree limit

Figure 2.5: Permitted number of devices operating continuously outdoors under licence exempt operation which are visible to the satellite at any one time



2.32 For indoor use, we have considered that a higher proportion of devices may operate indoors than outdoors. The ECC Report 190 estimates that 95% of devices will operate indoors. Taking into account the high propagation losses from devices sited indoors to outdoors in these frequency bands, we do not believe that devices operating indoors will affect EESS. Given this, we are proposing a 40 dBm EIRP limit across all of the proposed bands with no additional angular emission constraints.

> The attenuation caused to signals propagating from devices sited inside buildings to outdoor, as discussed in paragraph 2.5, was considered to reduce the emission levels from devices operating indoors to below the maximum levels proposed for outdoor devices.

2.33 We recognise that longer range high capacity applications may require higher levels of EIRP. An EIRP limit of 55 dBm was established for high capacity longer range applications in the 57 to 71 GHz bands as part of our 2018 Review of spectrum used by fixed wireless services.

2.34 We are also proposing to allow operation of devices in the proposal bands above 100 GHz with EIRP levels up to 55 dBm. We are proposing that the use of these higher EIRPs would only be permitted under a licensing regime. For outdoor use, this would also require the use of directive antennas and an additional constraint on their installation. The installation constraint would require the maximum elevation angle of the main beam of the installed equipment to be less than 20 degrees. This would provide additional protection to EESS by reducing the signals radiated into space.

Summary

2.36 Our proposals are intended to protect EESS from undue interference. For outdoor use, we are proposing to impose maximum EIRP limits which restrict radiated levels for the devices at different elevation angles. We are proposing to set lower limits for higher elevation angles relative to the main beam given their greater potential effect on the EESS.

2.37 We believe that these technical restrictions will provide a high degree of surety that EESS would not be affected by our proposals, because as detailed above they were developed based on a number of potentially conservative assumptions including:

a) All devices operate continuously at full power. This is unlikely to occur in practice.

b) All devices assumed to operate with narrow bandwidths. Many devices are likely to use larger bandwidths to support higher capacity applications.

c) The lowest propagation losses and hence highest levels of interference were assumed for each band. It is likely that devices will spread across parts of bands with higher propagation losses and hence less interference.

d) An equal probability of device antenna elevation pointing was assumed across the range ±20 degrees. In practice, the majority of the devices are likely to have an installed elevation angle of close to zero degrees.

Table 2.3: EESS sensor parameters[13]

Sensor ID	M1	EU	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Frequency range (GHz)	114.25-122.25		174.8-191.8						
Sensor type	Limb	Conical scan	Conical scan	Cross-track scan	Limb	Mechanical nadir scan	Conical scan	Nadir scan	Nadir scan
Orbit parameters									
Altitude (km)	705	800-850	828	705	705	824	835	867	822
Inclination (°)	98.2	98.7	98.7	98.2	98.2	98.7	98.85	20	98.7[14]
Eccentricity	0.0015	0	0	0	0	0	0	0	0.001
Repeat period (days)	16	9	17	16	16	9	N/A	7	29
Sensor antenna parameters									
Maximum beam gain (dBi)	60	55	54	45	60	43.9	60	49	44.8
-3 dB beamwidth (°)	0.19 x **0.245**	0.35	0.39	1.1	0.19 x **0.245**	1.1	0.2	0.66	1.1
Off nadir pointing angle (°)	**64.2**	45.2	46.8	±48.95	**64.2**	±52.725	55.4	42	49.4
Sensor protection criteria									
Reference bandwidth (MHz)	10	200	200	200	10	200	200	200	200
Maximum interference level (dBW)	-189	-166[13]	-163	-163	-189	-163	-163	-163	-163
Percentage of area or time permissible interference level may be exceeded (%)	1	0.01	0.01	0.01	1	0.01	0.01	0.01	0.01

[13] Values in bold highlight assumptions used in the analysis. Where two values are specified the bolded number has been used in the calculation of EESS antenna gain. When the incidence angle at the Earth has not been provided in the specification, the angle has been deduced from the sensor description.
[14] Values in red correct typographic errors in the table. The correct values were used in our analysis.

3. Additional information on coexistence studies

3.1 Our coexistence analysis considered the potential interference from terrestrial devices into the EESS sensors for both a single device and aggregate emissions. We adapted the minimum coupling loss (MCL) analysis of ECC Report 190 which assessed compatibility between Short-Range Devices (SRD) and EESS (passive) in the 122 to 122.25 GHz band.

3.2 We considered the likely use of highly directional narrow beam antennas in devices and their terrestrial use. These narrower beams reduce the signals radiated upwards into space and hence the potential interference power at the EESS.

3.3 As explained in detail in paragraphs 2.6-2.10, we used a relatively cautious set of modelling assumptions. This Section provides further detail of our modelling as summarised below:

a) A comparison with ECC Report 190 MCL analysis;

b) Terrestrial device orientation and the likelihood of antenna alignment with EESS sensors;

c) Predicted interference margin results underlying our proposed technical conditions.

Single device interference analysis approach

3.4 ECC Report 190 employed a static MCL to define a maximum EIRP limit for the 122-122.5 GHz sub-band. In Table 3.1 we provide a comparison with ECC Report 190 using our proposed maximum permitted licence-exempt power levels for outdoor use. The proposed EIRP levels are 20 dBm for the 116-122 GHz and 174.8-182 GHz bands, and 40 dBm for the 185-190 GHz band.

3.5 We chose to use the more precise ITU-R model[15] for the loss due to atmospheric gases[16] at the required elevation angle. The MCL assessment showed that the EUMETSAT sensor at 122 GHz was the most sensitive EESS sensor in the proposed bands. The comparison with ECC Report 190[17] confirms that the parameters and propagation models used in our coexistence analysis align with ECC Report 190. It also corroborates the use of the most limiting MCL geometry to set the maximum EIRP density of 10 dBm/250 MHz for the 122-122.5 GHz sub-band.

[15] Recommendation ITU-R P.676-12 line by line summation method, Annex 1 section 2.2.1.
[16] Report 190, Section 5, employs a simplified model for gas attenuation.
[17] Table 3.1 data columns 1 and 2.

Table 3.1: Ofcom MCL results and comparison with ECC Report 190 table 6

Sensor ID	ECC Rep 190 Table 6	Ofcom Conical EU		Ofcom Limb Q3		Ofcom Nadir Q6	
Frequency (GHz)	122	122	119	174.8	190	174.8	190
Common bandwidth (MHz)	250	250	250	250	250	250	250
EESS sensor parameters							
Elevation angle relative to the horizon (deg)	37	37	37	0	0	35	35
Distance (km)	1219	1254[18]	1254	3079	3079	1361	1361
Antenna gain (dBi)	55	55	55	60	60	49	49
Terrestrial device parameters							
EIRP (dBm) (dBW)	20 -10	20 -10	20 -10	20 -10	40 10	20 -10	40 10
Propagation losses							
Free space basic transmission loss (space attenuation) (dB)	195.9	196.1	195.9	207.0	207.7	199.9	200.7
Atmospheric loss (dB)	4.2	5.1	52.8	677[19]	1090[19]	13.4	21.8
Interference assessment							
Signal received by the EESS (dBW)	-155.1	-156.2	-203.7	-834	-1227.7	-174.3	-163.5
EESS max. interference level in the reference bandwidth (dBW)	-166	-166	-166	-189	-189	-163	-163
EESS reference bandwidth (MHz)	200	200	200	10	10	200	200
Maximum interference level in 250 MHz (dBW)	-165	-165	-165	-175	-175	-162	-162
Interference margin (dB)	-9.9	-8.8	38.7	659	1052.7	12.3	1.5

3.6 In addition to the conical sensor considered in ECC Report 190 for the 116-122 GHz band, margins are provided for the limb sensor and one of the nadir sensors in the 174.8-182 GHz and 185-190 GHz bands. These margins are for frequencies with the lowest atmospheric loss.

3.7 The results provided in Table 3.1 for 119 and 122 GHz show the frequency dependency of the interference margin. A greater degree of variation in the available margin was observed for all other EESS sensors in the proposed bands.

[18] As specified in Table 2.3 the orbit height given in ECC Report 190 is 800-850 km. We have used 825 km.
[19] Limb sensors operate tangentially to the Earth so the path between the terrestrial device and the EESS sensor has high gaseous attenuation, this is illustrated by the purple curve in Figure 2.2.

3.8 Terrestrial devices are likely to use directive antennas as acknowledged by ECC Report 190 stating "*Antennas will more than likely be directive with a gain up to around 35 dBi*" but this was not taken into account in the MCL analysis. It is highly unlikely that boresight to boresight antenna alignment with EESS sensors will occur as devices will not track the constant movement of the EESS sensors. We would therefore expect the interference margin to be greater when antenna directivity is considered.

Aggregate interference analysis approach

3.9 We have taken account of the likelihood of terrestrial device antenna directivity and orientation in the assessment of potential aggregate interference to EESS sensors. To reflect this in our modelling, we have created an average antenna gain pattern as explained in detail in paragraphs 2.16-2.19.

3.10 We note that the ECC Report 190 aggregate interference margin approach considered a simplistic scenario of 21 outdoor devices per km^2 over a sensor footprint of 100 km^2 with all 2100 devices operating at full power in perfect boresight to boresight alignment at all times. It established an EIRP limit of -48 dBm/MHz for elevation angles greater than 30 degrees.[20] However, the report does not indicate the methodology for how the limit of 30 degrees elevation was determined.

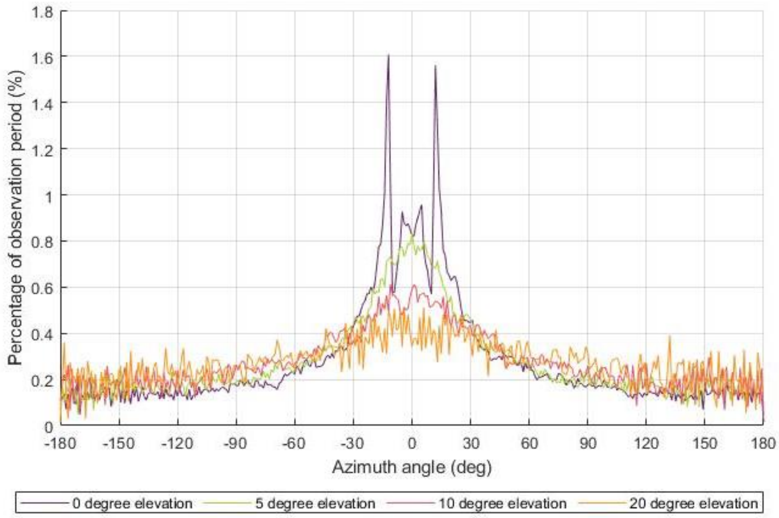
EESS sensors and terrestrial device antenna alignment

3.11 Terrestrial devices are likely to be stationary during operation and any movement would not be correlated to that of the EESS sensor which follows a set pattern. This suggests boresight to boresight alignment would rarely occur and that any alignment that did occur would not be sustained for a significant period of time. The resultant antenna discrimination would bring attenuation to the received signal level at the EESS sensor.

3.12 To quantify the potential extent of antenna alignment, we simulated the azimuth and elevation angle pairs from a terrestrial device to EESS sensors for every second over a month from 2 locations in the UK.[21] The distribution of azimuth and elevation angle alignment is shown in Figure 3.1. As expected, we observed that for each elevation angle the azimuth varied across the full range of values.[22] For the ease of readability, Figure 3.1 shows four elevation angles of 0, 5, 10 and 20 degrees from the Earth plotted against the full range of azimuth angles. It can be observed that in each case a single azimuth angle aligns for a small percentage of the observation period.[23]

[20] 2100 devices correspond to $10\log_{10}(2100)$ = 33.2 dB of interference margin.
[21] Locations in the north and south of the UK were selected and the same distribution on angles was observed.
[22] -180 to 180 degrees east of true north.
[23] The observation period is the total time within a month that the elevation angle occurs, this is not a continuous period and is shown in Figure 2.1.

Figure 3.1: Azimuth vs elevation angle alignment distribution of a terrestrial device with EESS sensors



Aggregate interference results

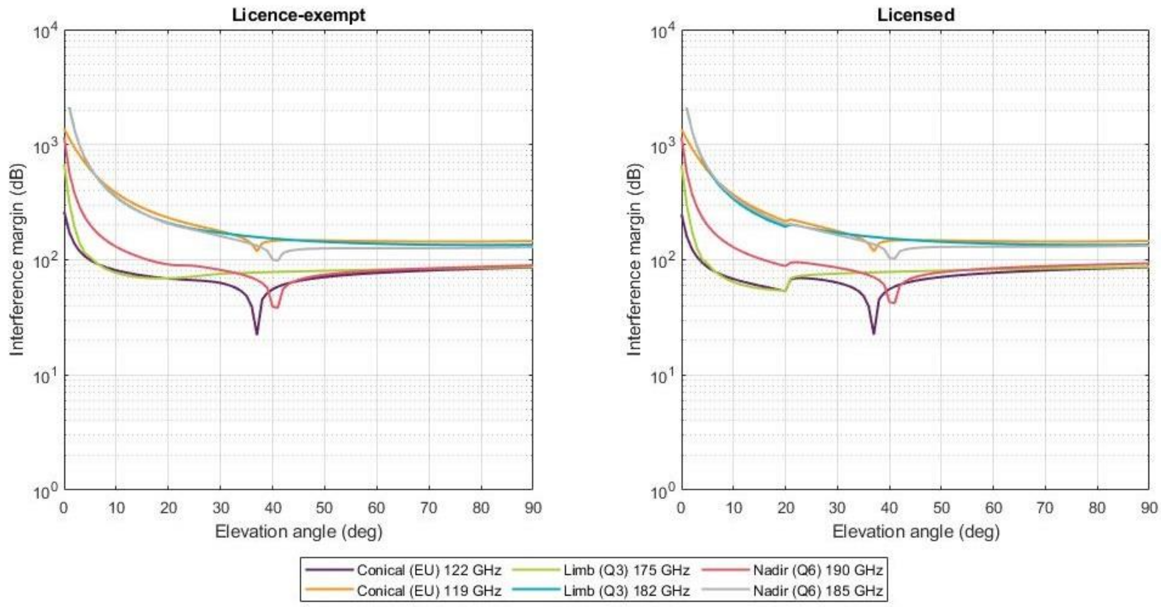
3.13 To assess the interference margin, we considered the full range of input powers and antenna directivity as described in paragraph 2.15 using the average antenna pattern. We also considered the variation of atmospheric loss as elevation angle changes when calculating the potential interference margins. Our analysis considered all of the EESS sensors specified in Recommendation ITU-R RS.1861 and the EUMETSAT sensor (as described in Table 2.3).

3.14 The interference margin, as explained in paragraph 2.25, is the difference between the signal level from a single terrestrial device with averaged antenna pattern and the maximum interference level in Recommendation ITU-R RS.2017, represented by 0 dB on the vertical axis of the plots. This margin is the logarithmic form of the indicative number of devices that can operate within the protection level for our conservative assumptions, which include a narrow bandwidth device[24] operating continuously at maximum power.

3.15 In Figure 3.2, we present predicted aggregate interference margin results for the proposed licence-exempt[25] and licensed[26] devices, selecting frequency channels within each band with the lowest and highest atmospheric losses to demonstrate the variation of predicted margins. The results are provided for each type of EESS sensor, i.e. conical, limb and nadir. Whilst our analysis considered all of the EESS sensors described in Table 2.3, for the ease of readability a selection of results is provided in Figure 3.2.

[24] The analysis considered a device bandwidth of 100 MHz as described in paragraph 2.9. It was acknowledged by ECC Report 190 that devices in this spectrum are likely to have bandwidths greater than 500 MHz.
[25] Produced for EIRPs of 20 dBm with 23 dBi antenna gain in the 116-122 GHz and 174.8-182 GHz bands and 40 dBm with 30 dBi antenna gain for the 185-190 GHz band.
[26] Produced for EIRPs of 55 dBm with antenna gains of 52 dBi for the 116-122 GHz and 174.8-182 GHz bands and 45 dBi for the 185-190 GHz band.

Figure 3.2: Predicted aggregate interference margins using the average antenna pattern for licence-exempt[Error! Bookmark not defined.] and licensed[Error! Bookmark not defined.] devices



3.16 The results highlight that in the 116-122 GHz band, even for the most sensitive EUMETSAT sensor, the aggregate interference margin exceeds 50 dB for the majority of elevation angles, only falling below this value between 35 and 40 degrees at 122 GHz. The minimum value at 37 degrees is 22 dB for a 100 MHz bandwidth device. When adjusted to a 250 MHz bandwidth, the aggregate interference margin becomes 26 dB[27] resulting in an excess margin of 35 dB as compared to the single device MCL in Table 3.1.

3.17 In the 174.8-182 and 185-190 GHz bands, the aggregate interference margin is generally greater than 50 dB for all of the EESS sensors (Q1 to Q7). Both conical and nadir sensors fall below this level[28] to a minimum value of 40 dB but only for a small range of elevation angles.

3.18 The plots for licensed and licence-exempt devices are very similar. However, a step at 20 degrees in the curves for licensed devices can be observed highlighting the effect of the elevation angle restriction with the high gain antennas.

3.19 Our provisional conclusion is that our proposals to authorise future terrestrial use of these bands for innovation would not be expected to affect the operations of EESS. This is based on the aggregate interference margin results, the predicted level of protection across all bands and our conservative modelling assumptions.

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[27] Using the bandwidth conversion from 100 to 250 MHz is $10\log_{10}(250/100)$ = 4 dB the aggregate margin becomes 26 dB.
[28] The minimum value occurs at an elevation angle between 20 and 45 degrees dependent on the specification of the EESS sensor.

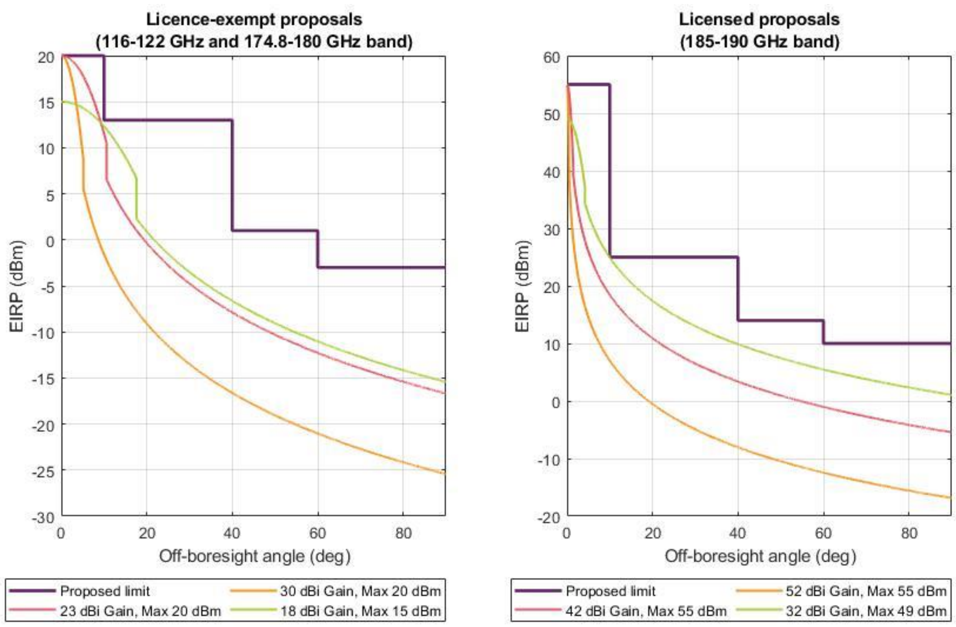
Setting the proposed technical licence conditions

3.20 Our proposals set out EIRP limits for both licence-exempt and licensed access to the spectrum as future devices in these bands are likely to have integrated antennas. As explained in section 2 in paragraphs 2.16-2.19 , we used an average antenna pattern for a single device to account for the variation of orientation and directivity of devices. This approach gave an average interference margin for the potential deployment of multiple devices with varying orientations.

3.21 Our modelling verified that when device orientation is taken into account our proposed EIRP limits would ensure adequate interference margins across all bands. However, this requires that the emissions are restricted in elevation to ensure protection of EESS. These restrictions, given in Tables 2.1 and 2.2 (Tables A6.1 and A6.2 in the January 2020 consultation), are based on the Recommendation ITU-R F.1245[29] antenna radiation pattern.

3.22 Meeting proposed EIRP restrictions for angles relative to main beam in the elevation plane will mean that either antenna directionality or an overall power reduction will be required. This can be seen in Figure 3.3.[30] The maximum achievable EIRP would be reduced when a less directional antenna is used, as demonstrated by the green curves. With the highest gain antennas (shown by the orange curves) the emissions are significantly reduced for angles away from the main beam and our proposed licence conditions would not provide any restriction in practice. EIRP levels at the higher end of the proposed permitted range would only be achievable with higher gain antennas.

Figure 3.3: Illustration of interaction between the proposed EIRP limits and antenna directivity



[29] As discussed in paragraph 2.17, Recommendation ITU-R F.1245 is stated as being valid up to 86 GHz. However, after comparison with a selection of directional antenna patterns operating at frequencies above 90 GHz, we considered that it was appropriate to use this model.

[30] Using the ITU-R F1245 antenna pattern.

Question: *Do you have any comments on the consultation proposals and analysis set out in the January 2020 consultation in light of the additional technical details which we are publishing in this document (see text added in grey boxes in Section 2 and the whole of Section 3)?*

A1. Responding to this consultation

How to respond

A1.1 Ofcom would like to receive views and comments on the issues raised in this document, by 5pm on 17 June 2020.

A1.2 You can download a response form from https://www.ofcom.org.uk/consultations-and-statements/category-2/supporting-innovation-100-200-ghz. You can return this by email to the address provided in the response form.

A1.3 If your response is a large file, or has supporting charts, tables or other data, please email it to EHFSpectrumAccess@ofcom.org.uk, as an attachment in Microsoft Word format, together with the cover sheet. This email address is for this consultation only.

A1.4 We welcome responses in formats other than print, for example an audio recording or a British Sign Language video. To respond in BSL:

- Send us a recording of you signing your response. This should be no longer than 5 minutes. Suitable file formats are DVDs, wmv or QuickTime files. Or
- Upload a video of you signing your response directly to YouTube (or another hosting site) and send us the link.

A1.5 We will publish a transcript of any audio or video responses we receive (unless your response is confidential)

A1.6 If you want to discuss the issues and questions raised in this consultation, please contact EHFSpectrumAccess@ofcom.org.uk.

Confidentiality

A1.7 Consultations are more effective if we publish the responses before the consultation period closes. In particular, this can help people and organisations with limited resources or familiarity with the issues to respond in a more informed way. So, in the interests of transparency and good regulatory practice, and because we believe it is important that everyone who is interested in an issue can see other respondents' views, we usually publish all responses on the Ofcom website as soon as we receive them.

A1.8 If you think your response should be kept confidential, please specify which part(s) this applies to, and explain why. Please send any confidential sections as a separate annex. If you want your name, address, other contact details or job title to remain confidential, please provide them only in the cover sheet, so that we don't have to edit your response.

A1.9 If someone asks us to keep part or all of a response confidential, we will treat this request seriously and try to respect it. But sometimes we will need to publish all responses, including those that are marked as confidential, in order to meet legal obligations.

A1.10 Please also note that copyright and all other intellectual property in responses will be assumed to be licensed to Ofcom to use. Ofcom's intellectual property rights are explained further in our Terms of Use.

Next steps

A1.11 Following this consultation period, Ofcom plans to publish a statement in Q2 2020-21.

A1.12 If you wish, you can register to receive mail updates alerting you to new Ofcom publications.

Ofcom's consultation processes

A1.13 Ofcom aims to make responding to a consultation as easy as possible. For more information, please see our consultation principles in Annex 2.

A1.14 If you have any comments or suggestions on how we manage our consultations, please email us at consult@ofcom.org.uk. We particularly welcome ideas on how Ofcom could more effectively seek the views of groups or individuals, such as small businesses and residential consumers, who are less likely to give their opinions through a formal consultation.

A1.15 If you would like to discuss these issues, or Ofcom's consultation processes more generally, please contact the corporation secretary at corporationsecretary@ofcom.org.uk.

A2. Ofcom's consultation principles

Ofcom has seven principles that it follows for every public written consultation:

Before the consultation

A2.1 Wherever possible, we will hold informal talks with people and organisations before announcing a big consultation, to find out whether we are thinking along the right lines. If we do not have enough time to do this, we will hold an open meeting to explain our proposals, shortly after announcing the consultation.

During the consultation

A2.2 We will be clear about whom we are consulting, why, on what questions and for how long.

A2.3 We will make the consultation document as short and simple as possible, with a summary of no more than two pages. We will try to make it as easy as possible for people to give us a written response. If the consultation is complicated, we may provide a short Plain English / Cymraeg Clir guide, to help smaller organisations or individuals who would not otherwise be able to spare the time to share their views.

A2.4 We will consult for up to ten weeks, depending on the potential impact of our proposals.

A2.5 A person within Ofcom will be in charge of making sure we follow our own guidelines and aim to reach the largest possible number of people and organisations who may be interested in the outcome of our decisions. Ofcom's Consultation Champion is the main person to contact if you have views on the way we run our consultations.

A2.6 If we are not able to follow any of these seven principles, we will explain why.

After the consultation

A2.7 We think it is important that everyone who is interested in an issue can see other people's views, so we usually publish all the responses on our website as soon as we receive them. After the consultation we will make our decisions and publish a statement explaining what we are going to do, and why, showing how respondents' views helped to shape these decisions.

A3. Consultation coversheet

BASIC DETAILS

Consultation title:

To (Ofcom contact):

Name of respondent:

Representing (self or organisation/s):

Address (if not received by email):

CONFIDENTIALITY

Please tick below what part of your response you consider is confidential, giving your reasons why

Nothing	☐
Name/contact details/job title	☐
Whole response	☐
Organisation	☐
Part of the response	☐
If there is no separate annex, which parts?	____

____

If you want part of your response, your name or your organisation not to be published, can Ofcom still publish a reference to the contents of your response (including, for any confidential parts, a general summary that does not disclose the specific information or enable you to be identified)?

DECLARATION

I confirm that the correspondence supplied with this cover sheet is a formal consultation response that Ofcom can publish. However, in supplying this response, I understand that Ofcom may need to publish all responses, including those which are marked as confidential, in order to meet legal obligations. If I have sent my response by email, Ofcom can disregard any standard e-mail text about not disclosing email contents and attachments.

Ofcom seeks to publish responses on receipt. If your response is non-confidential (in whole or in part), and you would prefer us to publish your response only once the consultation has ended, please tick here.

Name Signed (if hard copy)

A4. Consultation question

A4.1 We invite stakeholders to respond to the following question by **17 June 2020**.

> ***Question:*** *Do you have any comments on the consultation proposals and analysis set out in the January 2020 consultation in light of the additional technical details which we are publishing in this document (see text added in grey boxes in Section 2 and the whole of Section 3)?*