Potential for LTE interference to Wireless Audio

Report

Research Document

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Summary

Overview

This report sets out the results of a study that Ofcom has undertaken to investigate the potential impact from a 4G mobile phone or dongle operating in the frequency band 791 – 862 MHz into wireless audio devices (e.g. wireless microphones or headphones) operating between 863 – 865 MHz. The study is part of the continuing work that Ofcom is undertaking towards the combined auction of the 2.6 GHz and 800 MHz band.

The study examined a range of different audio devices to see how their performance might be affected by a 4G mobile phone or dongle operating nearby. For the purpose of these tests we assumed that the phone or dongle was being operated at maximum power and uploading very large amounts of data close to the receiver unit of the wireless audio device. The study indicated that in these extreme circumstances the maximum possible range of the audio device (e.g. the distance between a wireless microphone and its receiver unit) can be reduced. However, we anticipate that this is unlikely to cause operational problems unless very extended range is needed and the 4G phone or dongle is operating very close by.

Tests also indicated that very strong signals from a nearby 4G phone or dongle can affect the RF display indicator and some types of automatic channel scanning. When these functions are being used during equipment set-up, organisers are likely to have a reasonable amount of control over the positioning of the wireless audio transmitter, its receiver unit and any 4G phones or dongles which may be causing interference. Some types of RF display are also used to monitor reception while the audio transmitter is in active use and, here too, very strong signals from a 4G phone or dongle can cause interference, but only where the 4G device is significantly closer to the audio receiver than is the microphones itself. Many instruction manuals for wireless microphones already provide guidance on interference management, and we anticipate that where a particular device is found to be susceptible, the manufacturer may choose to provide further practical guidance.

In all cases the “squelch” control on the audio device, which mutes the audio output, can be used to reduce sensitivity to interference from a 4G phone or dongle, albeit with some loss of range.

Radio channels in this 863-865 MHz band are not generally used by professionals as this licence exempt band offers no guarantee of protection from interference. Professionals tend to use channels which are individually licensed to ensure interference-free quality.

The approach taken

The aim of this study was to take a range of commercially available wireless audio devices and to better understand how Long Term Evolution (LTE) could affect the different features of these devices. The devices were chosen to ensure a range of manufacturers and price points. Additionally most devices were pre-owned, which allowed us to understand the effects on a current snapshot of the UK installed market.

The LTE user equipment (UE) signal was simulated from a signal vector generator which was adjusted to match the spectral parameters of a commercially available LTE UE. The UE selected operates within the out of band emission (OOB) requirements set out in ETSI EN301 908-13. The signal vector generator was set to Block C, centre frequency of 857 MHz (this being the block of frequencies closest to the band used by SRDs and therefore most likely to cause interference). However, the OOB emissions were based on those in the

adjacent 10 MHz from a Block B UE as these were the only measurements available at the time of recording. Ongoing work by Ofcom with LTE vendors has shown that when UE operates in Block C additional filtering is required which has the effect of reducing the OOB emissions. This has not been accounted for in this report but implies that the impact of LTE on the wireless audio receiver will be less than suggested in this report.

It should also be noted that tests assume that the LTE UE is operating at full power and utilising all resource blocks. This is a “worst case” scenario. In practice, we consider it highly unlikely that the maximum number of resource blocks will be allocated to one call as this would exhaust the capacity of the cell site and deny other customers any ability to upload data. We also consider it highly unlikely that an LTE UE will transmit at full power while using a large number of resource blocks since high device power indicates that a user is close to the cell edge and, in these circumstances, the network must manage interference between cells. Nevertheless, the “worst case” assumption enables a theoretical bound to be placed on the possible impact of interference from LTE user equipment.

The wireless audio equipment was tested against five main characteristics and interference effects:

- Minimum Usable Sensitivity (MUS)
- RF activity light performance
- Auto scan functionality
- Squelch performance
- Protection ratio

Measurements were carried out against equipment interface performance and audio output quality using Signal to Interference plus Noise And Distortion (SINAD) of the audio channel.

The study leads to the following conclusions:

Minimum Usable Sensitivity (MUS)

This is a measure of how low the wanted signal can drop whilst allowing the device to operate to a satisfactory standard. For the purpose of this report the minimum performance was defined as a SINAD of +30dB[1] on the audio output. In practice, wireless equipment would typically be expected to operate at a level above the minimum usable sensitivity to offer a margin of protection against local radio environment effects.

Measurements showed that devices typically had a minimum usable sensitivity of -90 to -105dBm in a lab environment. In additional radiated measurements the majority of equipment operated over the full extent of the 430m test range, the poorest performing device failed at a range of 290m.

The test range was flat and did not contain ‘clutter’ normally associated with wireless audio device operation, which would attenuate the signal and thereby reduce the range achievable.

RF activity light performance

[1] Based on an ETSI standard methodology for testing these types of devices

Most devices have some form of RF activity light or meter. In the case of the low cost range of systems this is often a single light indicating which of the antennas is being used as part of the switch diversity system. In the mid and high end range of professional microphones this is a series of points on a display indicating received RF level.

The results showed that in the majority of cases the unwanted LTE signal can cause a response; however the wideband LTE UE power required was often significantly higher than the required narrowband wanted signal to produce the same response, typically around 50 to 57dB more, and therefore the unwanted LTE device would need to be significantly closer than the wanted wireless audio transmitter for this situation to arise.

Automatic scan function

Wireless audio systems may incorporate an automatic scan function that searches a bank of channels and automatically selects an operating channel for the user.

With one of the tested devices, interference levels greater than -25dBm caused the auto scan function to fail and this corresponds to a free space separation of 7m from an LTE mobile transmitting at full power. It is therefore likely that in the typical use case, whereby the auto scan function is used when the device is set up prior to an event, that LTE interference will have no detrimental effect on the operation of the autoscan function.

Squelch measurements

To improve rejection of interference some wireless audio equipment offer an adjustable squelch setting.

As might be expected, the results showed that the user adjustable squelch setting affected the minimum usable sensitivity in all measured cases, with an increase in the selected squelch level resulting in a desensitisation of the wireless audio receiver. This would also limit the operating distance of the system. Adjustment of the squelch function may therefore allow the user to limit the effects of LTE interference albeit with a reduction in range.

For all other testing in the study, the squelch was set to its minimum setting (i.e. highest sensitivity).

Protection Ratio

Signal to Interference plus noise ratio (SINR) performance showed that there was a range of different protection ratios between different models of wireless microphone within and across different manufacturers product portfolios. As might be expected, the low end range of devices did tend to perform slightly worse than the mid and high end range of devices. The single example of headphones and the in-ear monitors tested showed protection ratios that were poorer than the wireless microphones at higher wanted signal levels, indicating a poorer receiver performance, probably as a result of battery, space and weight constraints in the receiver design.

The negative protection ratios measured suggest that the power at the receiver from an LTE terminal can be significantly higher than that of the wanted wireless audio transmitter by between 26 and 40dB without causing degradation of the wanted signal. This suggests that for an LTE device within 5m of the wireless audio microphone receiver, the wireless audio system would still operate satisfactorily up to a distance of 63m in a typical indoor environment. Headphones and In-Ear-Monitoring might have a lower distance range.

Contents

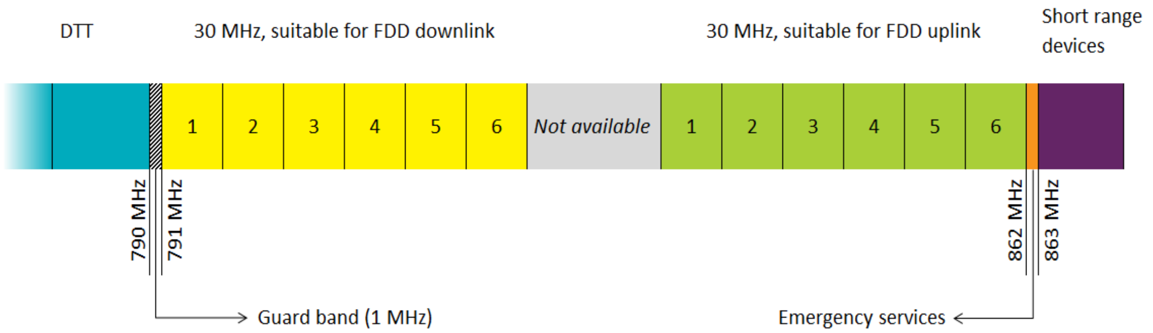
Section 1

Introduction

In June 2011 Ofcom published a consultation document setting out proposals for the combined award of spectrum in the 800 MHz and 2.6 GHz frequency bands[2]. We envisage that the 800 MHz band will be used to deliver the next generation of mobile broadband services using technologies such as LTE and WiMAX.

The harmonised frequency arrangement for the 800 MHz band in Commission Decision 2010/267/EU is 2 x 30 MHz with a duplex gap of 11 MHz, based on a block size of 5 MHz, paired and with a guard band at 790-791 MHz. The Frequency Division Duplex (FDD) downlink starts at 791 MHz and FDD uplink starts at 832 MHz. This is illustrated by Figure 1 below.

Figure 1: 800 MHz band plan



As part of the June 2011 consultation, we published a detailed initial study of potential interference issues[3]. The results of that study indicated that, under certain assumptions about LTE, UE operation and wanted Short Range Devise (SRD) signal level, there is the potential for interference into some types of SRD equipment if the UE is placed within a certain minimum distance of the receiving unit. One area of potential interference is to wireless audio devices operating in the 863-865 MHz band. These are generally used by non commercial organisations (professional use tending to operate in licensed spectrum bands to minimise the risk of interference from other systems).

A number of respondents to the June 2011 consultation raised concerns around possible interference to the use of channel 70 wireless audio devices operating in the 863-865 MHz SRD band. Some stakeholders also expressed concern about possible impacts on wireless audio devices operating in licensed spectrum below 790 MHz, however this is not studied here.

In the subsequent Information Update, published in November 2011, Ofcom set out details regarding the responses that we had received to the June 2011 consultation and the latest information and thinking around possible interference to devices operating in the SRD band. We also committed to providing results from an additional study into potential interference to

[2] http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/summary/condoc.pdf
[3] ERA Technology: Investigation on the receiver characteristics of SRD equipment in the 863 – 870 MHz band (http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/SRD-Study.pdf)

wireless audio equipment operating in the band 863 – 865 MHz from UEs operating in the 800 MHz band.

This study does not seek to provide an exhaustive investigation into equipment from every available manufacturer across their entire product range (current and previous models). Instead a sample of wireless audio equipment was selected from different equipment makers and covering products from entry-level systems to high-end systems used by professional users. Equipment was provided from a number of sources. A significant amount of equipment was provided from the stocks of equipment surrendered as part of the Ofcom compensation scheme for Programme Making and Special Events (PMSE) users in channel 69. This equipment also operates in the 863 - 865 MHz band (generally referred to as channel 70). Other equipment was either purchased or obtained on loan to ensure that a good mixture of equipment that is representative of the installed base was available for the study.

For the purpose of this report the equipment has been categorised as low-, mid- and high-end equipment, based on the following criteria:

System	Criteria	Notes
Low	System Cost[4] < ~£250	Units often have integrated antennas and are the base entry product in the channel 70 Range
Mid	Cost > ~£250	
High	Top 1 or 2 products in Manufacturers' range. Stated as for professional use	Typically this equipment also covers current or previously licensed bands and not just 863-865 MHz.
IEM	In-Ear Monitoring	
Headphones	Wireless headphones in the band 863 – 865 MHz	

[4] System cost includes wireless transmitter and receiver and is based on current price or where this is not available best estimate based on equivalent current products.

Section 2

Minimum Sensitivity

2.1 Introduction

In order to understand the effects of varying levels of LTE UE interference at the wireless audio receiver it is necessary to determine the Minimum Usable Sensitivity (MUS) in an interference free environment. The MUS will be used as the reference point for the subsequent investigation.

The operation of the radio microphone with its paired receiver is, of course, representative of typical usage, however better control of the experimental parameters can be achieved by using a Frequency Modulated (FM) carrier generated from a signal generator coupled to a calibrated transmit antenna or directly to the receiver.

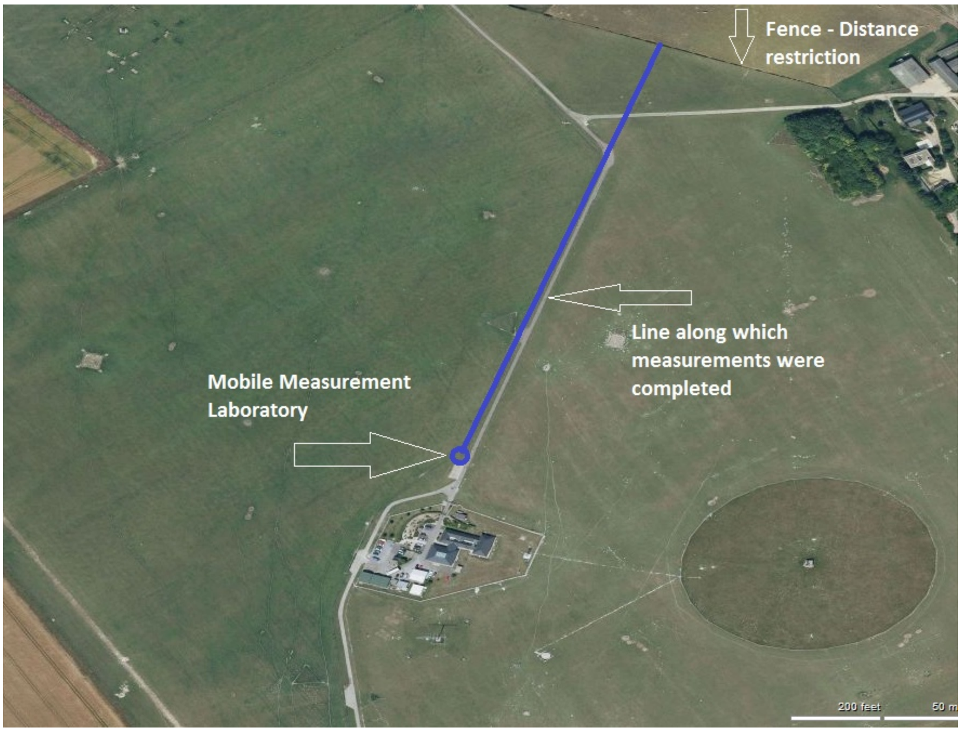
Measurements of the MUS were made by using the wireless audio receiver in conjunction with both its paired transmitter (radiated measurements) and a simulated FM carrier (conducted measurements). These results were compared to ensure consistency within the test setups.

2.2 Radiated MUS Measurements

Methodology

Measurements of the MUS were undertaken by the Technical Division of Ofcom Business Services at the Radio Monitoring Station in Baldock. Details of the test range can be seen in the Figure 2 below.

Figure 2: Site plan of test locations



The measurements were carried out on an open air test range with a maximum separation of 430m. To determine the propagation characteristics of the test range one of the wireless audio transmitters (ManE-High1) was moved along the length of the range in pre-defined increments and the received signal strength was recorded. The measured signal strength was corrected for the effects of the reference antenna[5] and associated cable.

To measure the MUS of each system the wireless audio receiver was set in a fixed location and the matched transmitter moved away in increments along the test range. The wireless audio transmitter and receiver were positioned at a height of 1.6m above ground level (AGL) on non-conductive stands. A 1 kHz test tone was played via an mp3 player and small speaker into the radio microphone transmitter. The wireless audio receiver was monitored via a set of PC speakers that were connected to the output of the wireless microphone receiver.

The MUS was determined as the maximum separation distance at which the tone could be heard without degradation in the audio output on the wireless audio receiver (subjectively measured on the speakers at the wireless audio receiver).

The received power level was measured via a calibrated reference antenna placed adjacent to the wireless audio receiver and connected to a spectrum analyser. The received power from the radio microphone was measured using a channel bandwidth of 200 kHz. The received power level was considered to be the value at the input port of the wireless audio receiver (assuming a 0dBi gain in the wireless receive antennas). Further equipment details are provided in Annex 2.

Results

Validation measurements of the test range using the received signal strength at varying separation distances from wireless audio transmitter ManE-High1 are shown in the table below, Table 1.

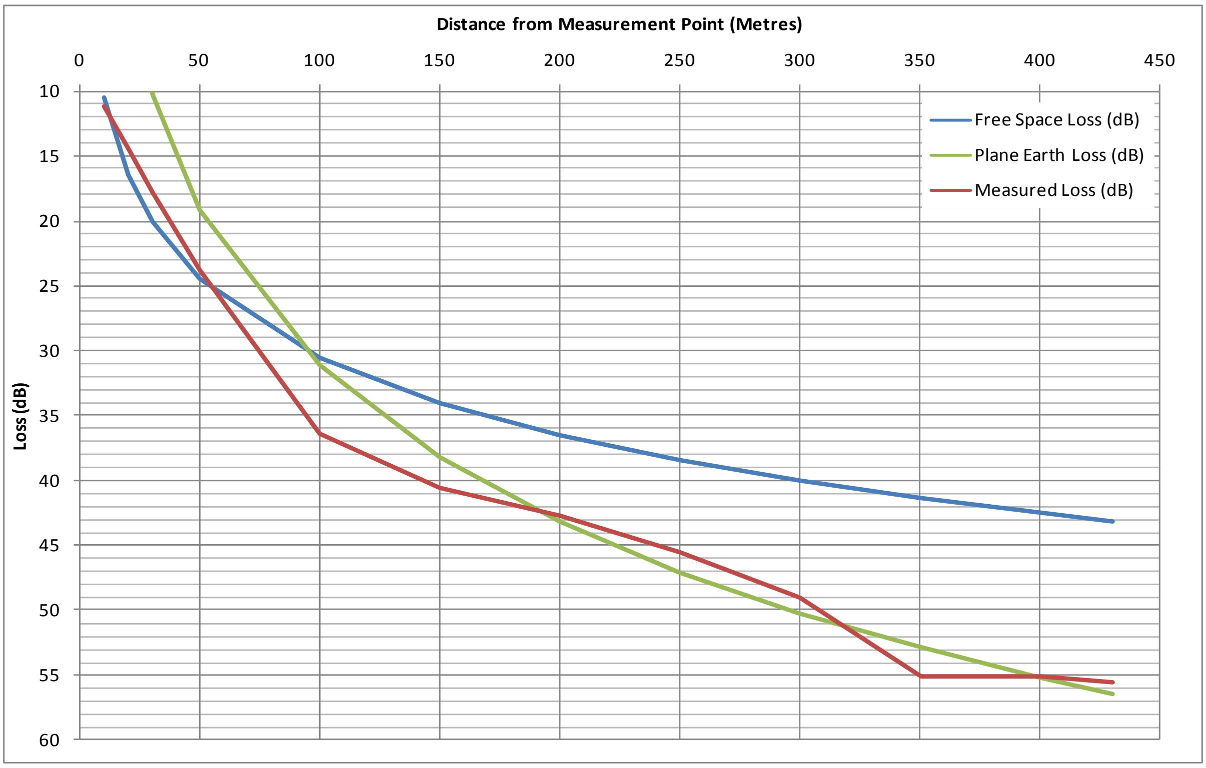
Table 1: Received signal strength measurements for ManE-High1

Distance from receiver (m)	Corrected Peak Level (dBm)
3	-42.9
10	-54.1
30	-60.8
50	-66.7
100	-79.3
150	-83.5
200	-85.6
250	-88.4
300	-91.9
350	-98.1
400	-98.0
430	-98.5

[5] The calibrated reference antenna had an Antenna Factor of 20.2dB/m and a gain of 8.7dBi at the test frequency of 863.125 MHz

The losses were normalised and compared with a theoretical free space6 and plane-earth7 loss models in Figure 3 below.

Figure 3: Normalised path loss



The received signal strength from each of the tested wireless audio systems was first determined at a separation distance of 3m from the transmitter.

The failure point was then determined as the separation between transmitter and receiver at which the received audio signal had audible noise present. The maximum separation achievable on the test range was 430m; in several of the test cases the wireless audio system was still operational at the maximum achievable separation distance. The received signal strength was measured at the point of failure or at the full extent of the test range (430m).

[6] Free space loss = $20\ log(4\pi df/c)$ where *d* is the separation between the microphone and receiver in metres, *f* is the frequency in MHz and *c* the speed of light.

[7] Plane Earth Loss = $-10\log((h1h2)^2/d^4)$ where *h1* and *h2* are the heights in metres of the microphone and receiver.

Table 2: Minimum sensitivity for wireless microphones in an open test range

Microphone	3m Measurement (dBm)	Maximum separation (metres)	Failure	Determined Min. Sensitivity (dBm)
ManB-Low1	-42.0	290	Y	-92.4
ManE-Low1	-41.9	430	N	-95.2
ManG-Low1	-41.8	340	Y	-93.7
ManC-Mid1	-38.3	430	N	-89.8
ManD-Mid2	-39.1	430	N	-97.1
ManE-high1	-42.9	430	N	-98.4

2.3 Conducted MUS Measurements

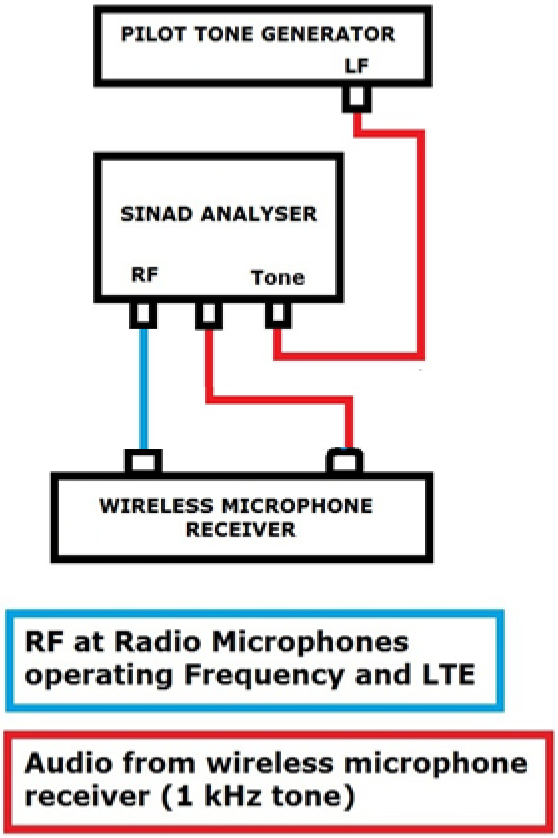
Methodology

To complement the radiated measurements a series of coupled measurements were conducted. This allowed for more control over the test variables and provided a quantifiable measurement of the interference effects.

The conducted MUS measurements were made using a SINAD analyser. This analyser measures the Signal to Interference plus Noise And Distortion (SINAD) of the audio signal from the wireless audio receiver. This is based on a 1 kHz test tone that was transmitted to the receiver. All measurements were undertaken in a conducted manner, meaning that RF signals were coupled directly into the receiver and therefore not transmitted “over the air”. Where receivers had integrated antennas (typically the Low-end category of devices) these were disconnected via the internal connectors inside the receiver and the RF signal connected directly to the internal RF connector. In one case, the integrated antenna was permanently disconnected and a cable connected to allow testing to be undertaken.

For the purposes of testing, the SINAD analyser acted as the transmission source and thus, unlike the outdoor range testing above, the associated wireless microphones were not used. The SINAD analyser was setup with the required frequency, FM modulation and appropriate deviation (0.707) of the manufacturer’s published maximum deviation to avoid audio clipping. The system setup is shown in Figure 4. The use of a hybrid coupler allowed interference to be added to the system (see Section 4) and a spectrum analyser to monitor the signals without changing the RF path for the wanted signal to the receiver.

Figure 4: Wireless audio minimum sensitivity equipment setup



Many of the wireless microphone systems use a pilot-tone based squelch system. This system causes the audio output of the receiver to stay muted unless a high frequency audio tone (typically 32.768 kHz) is detected. This helps to avoid unwanted interference when the associated microphone is not switched on. The pilot tone is generated within the wireless audio transmitter, therefore in order to test the performance of the receiver our test setup also included a pilot tone generator.

The SINAD analyser was used to determine the MUS of the receiver. The MUS is defined as the signal level that resulted in a measured SINAD of 30dB in an interference free environment. Some of the wireless audio receivers did not support this level and therefore an alternative value was used and noted in the results below.

Where available, tests were undertaken at 863.15 MHz. However, some receivers operate on a preset channel allocation; in these cases the closest channel to 863.15 MHz was used.

Results

The measured RF levels are recorded at the input to the wireless audio receiver. In cases where no radiated failure was recorded, the measured power at the full extent of the test range has been included (see column 4 in Table 3).

Table 3: Minimum sensitivity results

Device	Min Sensitivity Conducted (dBm)	Min Sensitivity Radiated (dBm)	Measured Level at 430m (dBm)
ManA-Low1	-98.2		
ManA-Low2*	-97.9		
ManB-Low1	-92.2	-92.4	
ManB-Low2	-91.0		
ManC-Mid1	-90.1		-89.8
ManD-Low1	-100.7		
ManD-High1	-102.5		
ManD-Mid2	-102.3		-97.1
ManD-Mid1	-105.0		
ManE-High1	-101.1		-98.4
ManF-Mid1	-98.2		
ManD-IEM	-98.2		
ManD-Head	-102.9		

*ManA-Low2's minimum achievable SINAD was 41 dB.

2.4 Comparison between conductive and radiated test results

Due to the limited availability of test equipment during the two phases of the measurement program (conductive and radiated) an overlap for comparison occurred in only four instances. Three of these audio devices had their sensitivity determined on a radiated basis at the maximum range of 430m which the test site afforded, giving an indicative measure of minimum sensitivity. The fourth, ManB-Low1, had reached the limit of its operational range in less than 430m, which enabled the absolute minimum sensitivity to be measured. In the latter case, there was no material variation between the radiated and conducted measurement results. As would be expected, in the three other cases, there was some small improvement in indicated minimum sensitivity when measured conductively, compared to the levels measured on a radiated basis at 430m, confirming that the actual achievable range would be greater than 430m, although only slightly so in the case of ManC-Mid1. These results are shown in the two right hand columns of Table 3.

Section 3

RF Interference Effects

3.1 Introduction

In our November 2011 Information Update and other publications, we note that the biggest impact to devices operating in the SRD band is from Out Of Band (OOB) emissions from adjacent LTE services. This means that LTE handsets operating in the highest 10 MHz allocation (Block C - corresponding to locations 5 and 6 in Figure 1) will have the greatest impact.

Previous research on interference effects to SRDs undertaken by Ofcom8 shows that OOB emissions are at their greatest when all 50 Resource Blocks (RB) of a 10 MHz channel are in use. The signal generator used in the test was, therefore, set to emulate LTE usage with a 10 MHz channel centred on 857 MHz (corresponding to Block C) and all RBs in use.

Interference may have a variety of effects on wireless audio equipment. Conducted measurements were carried out to define the interference effects on the following wireless audio receiver functions:

- False readings on RF activity lights.
- Errors in automatic scan functions.
- Interference effects on Squelch Settings.
- Effect on audio quality, resulting in a potential reduction in range depending on the proximity of the interference source to the wireless receiver.

The wireless audio equipment was set to 863.15 MHz. Where the frequency of the wireless audio system could not be set to 863.15 MHz, the centre frequency of the LTE channel was adjusted to ensure a consistent +6.15 MHz frequency offset.

3.2 Interference to RF Activity Displays

Most devices have some form of RF activity light or meter. In the case of the low end range of systems this is often a single light indicating which of the antennas is being used as part of the switch diversity system. In the mid- and high-end range of professional microphones this is a series of points on a display indicating RF level. In most cases, operational manuals suggest that if these indicators are seen without the microphone transmitting (i.e. when it is turned off) then there is interference present. The manuals usually advise that this interference is likely to be from other wireless audio systems and that the microphone and receiver channel should be changed.

Methodology

The effects of power into RF displays was investigated for two modes:

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[8] Investigation on the receiver characteristics of SRD equipment in the 863-870 MHz band http://stakeholders.ofcom.org.uk/binaries/consultations/tlc/annexes/SRD-Study.pdf

- Wanted level to produce indicator response.
- Unwanted level to produce indicator response.

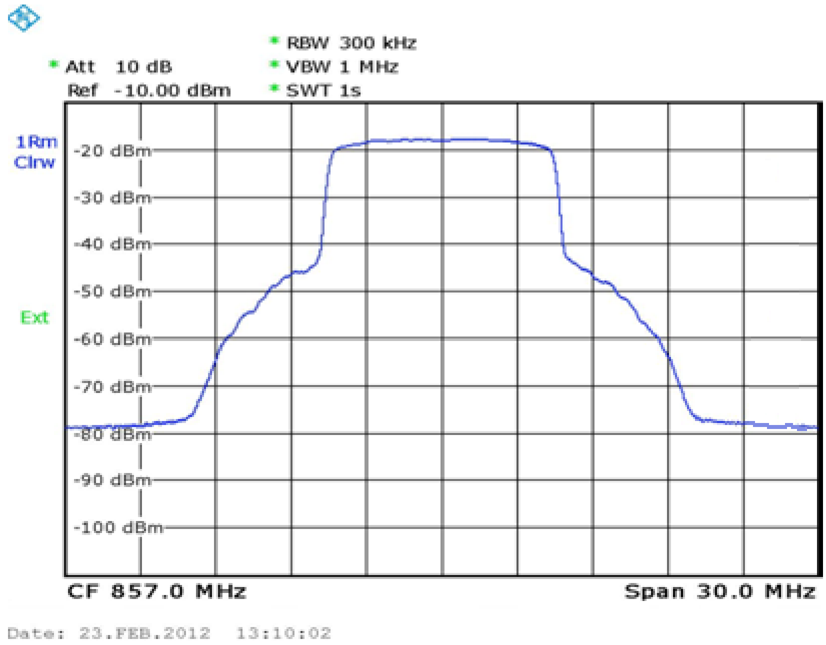
The wanted signal was fed into the wireless audio receiver under test using the test configuration shown in Figure 6, with the resultant RF indication being recorded against the level of signal at the input port to the wireless audio receiver.

The wanted signal was then turned off and the wireless audio receiver was subjected to an unwanted 10 MHz LTE UE signal instead, with the impact on the RF indicators being recorded.

The unwanted signal was produced using a vector signal generator using a simulated LTE UE profile. The out of band emissions were adjusted to correspond with a previously measured commercially available LTE USB modem device.

A spectral plot of the unwanted LTE UE signal can be seen in Figure 5.

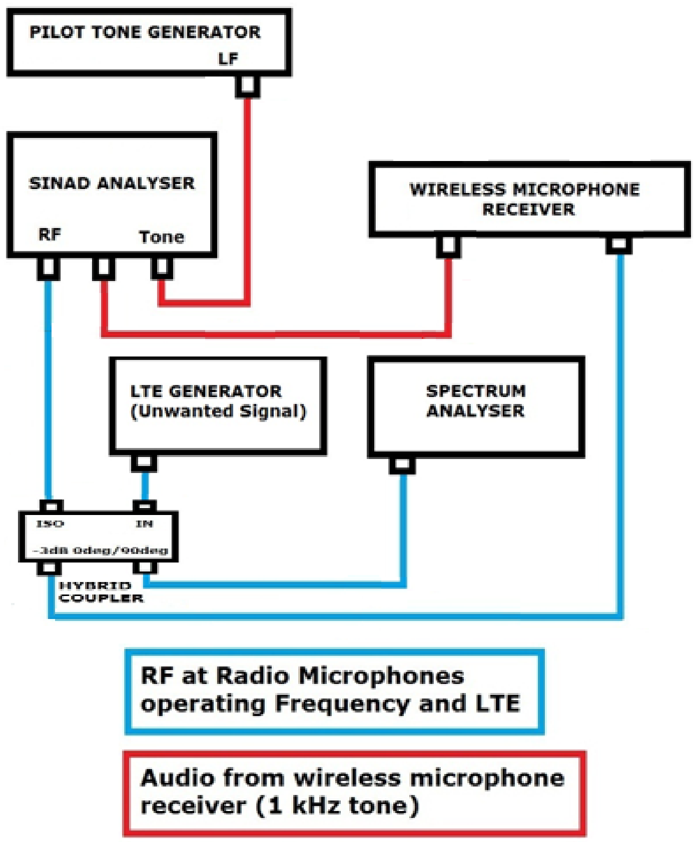
Figure 5: Spectral Plot of Unwanted LTE UE Signal



Test Setup

The equipment setup as in Figure 6 was used:

Figure 6: **LTE UE into Wireless Audio Receiver Setup**



Results

The RF indicator displays operate in various forms: LEDs, LCD bars or a single LED. The displays vary in format, with simple LEDs displaying whether RF is present (on/off) through to LCD bars indicating the strength of RF on a given channel.

It should be noted that all values relate to the point where the increase in RF level illuminates the display with no visible flicker. In cases where less than 10 indicator bars were present the numbering works from left to right with shading representing no further indicators. The recorded effects are shown below, Table 4 and Table 5.

Table 4: Wanted power required to illuminate RF activity displays

	RF Level Indication for Wanted Signal Level (dBm)									
	Low	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**High**
Man A Low1	-94.0									
Man A Low2	-99.5	-93.5	-88.5	-83.1	-74.1	-69.5				
Man B Low1	-93.6									
Man B Low2	-91.3									
Man C Mid1	-101.0	-94.0	-90.0	-84.0	-81.0	-77.0	-72.0			
Man D Low1	-101.6	-94.3	-83.2	-70.1						
Man D High1	-102.6	-93.2	-85.6	-82.6	-75.4	-70.8	-66.7	-63.9	-58.7	-51.6
Man D Mid1	-101.6	-97.9	-93.4	-88.7	-83.6	-79.5	-76.0			
Man D Mid2	-101.9	-95.9	-92	-88.1	-83.5	-78.5	-72.7	-67.8		
Man D IEM	-103.0	-97.0	-88.3	-82.1	-77.4	-71.9	-66.6			
Man E High1	-103.0	-97.0	-90.7	-82.7	-75.0					
Man F Mid1	-101.6	-94.3	-82.8	-68.8						

Table 5: LTE channel power required to illuminate RF activity displays

	RF Level Indication for LTE Signal Level (dBm)									
	Low	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**High**
Man A – Low 1	-37.0									
Man A – Low 2	-45.9	-40.8	-35.1	-28.8	-22.9	-15.3				
Man B – Low 1	-37.7									
Man B – Low 2	-38.0									
Man C – Mid 1	-46.0	-39.0	-33.0	-31.0	-29.0	-26.0	-22.0			
Man D – Low 1	-66.2	-59.4	-47.8	N/A[9]						
Man D – High 1	LIT	-89.7	-85.9	-81.8	-75.2	-70.9	-66.8	-63.8	-58.7	-51.8
Man D – Mid 1	LIT	-96.3	-92.3	-88.3	-83.6	-79.4	-75.9			
Man D – Mid 2	Device not available for this test									
Man D – IEM	-45.9	-40.1	-34.3	-28.5	-22.2	-16.1	-10.3			
Man E – High 1	-52.7	-44.0	-35.1	-27.1	-18.6					
Man F – Mid 1	Not lit in presence of LTE									

[9] Possible hardware fault prevented further testing of this device.

Table 6: Difference in unwanted LTE UE power required to produce comparative response compared with wanted signal

	Difference in Signal Level (dB)									
	Low	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**High**
Man A – Low 1	57.0									
Man A – Low 2	53.6	52.7	53.4	54.3	51.2	54.2				
Man B – Low 1	55.9									
Man B – Low 2	53.3									
Man C – Mid 1	55.0	55.0	57.0	53.0	52.0	51.0	50.0			
Man D – Low 1	35.4	34.9	35.4	N/A						
Man D – High 1	LIT	3.5	-0.3	0.8	0.2	-0.1	-0.1	0.1	0.0	-0.2
Man D – Mid 1	LIT	1.6	1.1	0.4	0.0	0.1	0.1			
Man D – Mid 2	Device not available for this test									
Man D – IEM	57.1	56.9	54.0	53.6	55.2	55.8	56.3			
Man E – High 1	50.3	53.0	55.6	55.6	56.4					
Man F – Mid 1	Not lit in presence of LTE									

Conclusions

The effects of LTE signals on the RF indicator lights varied depending on the wireless audio receiver under test. In the majority of measurement scenarios the devices required a higher level of LTE signal to produce the same response on the RF indicator lights as the wanted signal:

- 7 devices required 50 to 57dB more LTE UE power.
- 1 device required 35dB more LTE UE power.
- 2 devices gave matching indicator performance for the same levels of wanted and unwanted signals.
- 1 device did not respond to the LTE signal at all.

Where equivalent levels of wanted or LTE signal are required to illuminate the display, this suggests that the associated power sensor is a rather wideband detector and that the exact frequency and bandwidth of the received signal is not relevant to the mechanism used in the receiver. Those requiring a much larger LTE power will be undertaking a more specific measurement of power, probably in a narrower bandwidth and at the exact frequency of the receiver which will correspond to lower out of band emissions from the LTE device[10]. The one receiver that did not illuminate at all with the LTE signal may be because the measurement is only enabled when the required audio signal is detected, and none was present in this test.

The signal level lights have a number of uses. One of which is to determine the received signal level from the transmitter during operation. Whilst LTE devices may interfere with this function in some cases - by suggesting there is RF signal level from the transmitter when in fact it is from the LTE interferer - for the majority of tested wireless audio receivers, the LTE devices would need to be transmitting data in the uplink at a location significantly closer to

[10] See section below on protection ratios for further details.

the wireless receiver than the wireless audio transmitter. Section 4 provides further detail around the ratio of distances between wanted and interfering devices.

A second use case of these lights is by the wireless audio user during system setup in order to determine if other wireless audio systems are present and if illuminated when the microphone transmitter was switched off the user would select another channel. With an LTE device transmitting nearby users may find all available channels show activity. Again, as set out in Section 4, where considerably more signal strength from LTE is required in order to illuminate the lights, then LTE device would need to be much closer to the receiver than the wireless audio transmitter to have any effect. During this system setup phase it might be expected that there were not many people within the area of the event and therefore LTE interference is unlikely to have any effect, although additional understanding around initial channel selection may be required for certain devices.

3.3 Interference effects on Automatic Scan Functions

Introduction

Some wireless audio systems may incorporate an automatic scan function that searches a bank of channels and automatically selects an operating channel for the user.

Methodology

Within a test pool of wireless audio devices with the autoscan function available we found two types of autoscan features that have different functionality. The first, with effects presented in Table 7 below, automatically tunes to the channel that has the wanted wireless audio signal present. The second, with results reported in Table 8, automatically tunes to a channel that is clear of interference or other wireless audio users.

In order to test the first functionality, we used as an example ManD-High1. Although it did not cover the 863-865 MHz band, the SINAD analyser was set to give a wanted signal level of -55dBm at frequencies of 861.9 and 861.925 MHz. An initial scan was run to ensure that the wireless audio receiver selected the desired channel. The unwanted LTE signal was then fed into the audio wireless receiver at a frequency offset of -6.15 MHz. The unwanted signal was stepped up in power, starting at -50dBm, rising in 5dBm increments to a maximum level of 0dBm. The results are shown in the table below.

For the testing of the second type of functionality, we used ManB-low1. There was no wanted signal and the LTE signal was set to be -6.15 MHz from the lowest frequency channel in the 863-865 MHz range (corresponding to channel 4).

The results for interference into the audio wireless receivers scanning function are below.

Table 7: Results for Interference Effects to Channel Scanning on ManD-High1

LTE Level (dBm)	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0
Tuned to desired frequency?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
False Tuning (MHz)	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL

Table 8: Results for Interference Effects to Channel Scanning on ManB-Low 1

LTE Level (dBm)	-50	-45	-40	-35	-30	-25	-20	-15	-10	-5	0
Tuned to avail channels	Yes	Yes	Yes	Yes	Yes	Yes	NO	NO	NO	NO	NO
Channels not found*	5, 6	5, 6	5, 6	5, 6	5, 6	5, 6	1 – 7	1 – 8	1 - 8	1 – 8	1 - 8

* Available: Ch1 – Ch4 in range 863 – 865 MHz, Other: Ch5 – Ch8: 840 – 855 MHz

Conclusions

Measurements showed ManD-High1 (which tunes to the wanted wireless signal) did not lose the ability to tune to the desired channel. The operating manual recommends that, in any event, after a channel has been found, the headphones should be used to check the audio quality and whether a false channel has been found.

With lower powers of LTE between -50 to -25dBm, ManB-Low1 (which seeks an unused and interference-free channel) detected the Channels 1 to 4 (863 – 865 MHz) and 7 and 8 as available i.e. no channel activity found. Unsurprisingly, channels 5 and 6 (854-855 MHz), which are co-channel with the LTE signal, were identified as being occupied and as such ManB-Low1 did not tune to them. However, it should be noted that all PMSE use of channels 5 to 8 will cease before LTE is deployed.

When the LTE power was increased above -25dBm, the OOB emissions from the LTE source were high enough for ManB-Low1 to see the RF occupancy on all of its operating channels, and this resulted in the device failing to tune to any channel. However, it should be noted that an LTE RF power of -25dBm corresponds to a path loss of 48dB from an LTE device operating at its full +23dBm output power. This corresponds to a free space separation of only 7m. The likelihood of this scenario arising appears low. Furthermore, should this scenario be encountered, the proximity of the LTE device will often be such that the source of interference can readily be identified and addressed.

3.4 Interference Effects on Squelch settings

Introduction

To improve rejection of interference some wireless audio equipment offers an adjustable squelch setting, furthermore some systems also have the concept of a pilot tone that is linked to this. The pilot tone system uses a transmitted high frequency tone from the microphone. The receiver will only open the audio output path once this tone is detected. This provides protection from non-microphone RF interference or off-frequency microphone systems.

Methodology

Using the test configuration as detailed in Figure 4 the audio wireless receiver was adjusted to a given value within its device range.

The wanted signal produced by the SINAD analyser was set to a level where a SINAD of 30dB was achieved on the audio output (as with the minimum sensitivity analysis in Section 2). In a number of scenarios the audio squelch function muted the audio output at a SINAD level higher than the predefined 30dB failure criteria, in these cases the MUS was taken as the point at which the audio muted.

Results

Table 9: MUS variations against Squelch Level Settings

Man A – Low 2		Man D – High 1		Man D – Mid 1		Man E – High 1	
Device squelch range -100 to -80		Device squelch range 0 to 134		Device squelch range 0 to 40		Device squelch range -9 to +9	
Squelch setting	**MUS (dBm)**	**Squelch setting**	**MUS (dBm)**	**Squelch setting**	**MUS (dBm)**	**Squelch setting**	**MUS (dBm)**
-100	-97.8	0	-102.5	0	-105.0	-9	-101.1
-98	-96.1	67	-91.8	5	-101.4	0	-94.8
-96	-93.7	134	-69.7	10	-98.0	9	-89.3
-94	-91.6	-	-	15	-93.0	-	-
-92	-89.9	-	-	20	-89.1	-	-
-90	-88.5	-	-	25	-84.0	-	-
-85	-83.4	-	-	30	-79.0	-	-
-80	-78.9	-	-	35	-76.4	-	-
-	-	-	-	40	-70.6	-	-

Conclusions

The MUS values were dependant on the user defined squelch setting. In all measured cases an increase in the squelch level resulted in a desensitisation of the wireless audio device i.e. the range that the wireless audio device operates is reduced as the squelch setting is increased.

The squelch settings perform as we would expect. We note, therefore, that the squelch setting could be used to mitigate the effects of LTE interference by desensitising the wireless audio receiver to enable the audio device to operate in the presence of higher levels of LTE interference, albeit with some reduction in range.

For the other tests that we carried out the squelch was set to its minimum setting.

Section 4

Protection Ratios

4.1 Introduction

Protection ratios express the sensitivity of the victim device to interference and indicate how much stronger the wanted signal must be than the interferer to protect from a given failure. Protection ratios are defined relative to the bandwidths of each system.

A protection ratio is the minimum value of wanted to un-wanted signal ratio, at the receiver input determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output.

For this testing a degradation of 6dB in audio SINAD value was chosen to represent a change in the signal quality. This method of defining signal quality and impairment is recognised industry practice and is chosen as it gives a more repeatable determined value rather than using subjective judgement where the test engineer listens for degradation in signal quality.

The four levels shown in Table 10 and Table 11, (page 24) 3, 10, 20 and 30dB relate to an offset relative to the MUS (Minimum User Sensitivity). The MUS level is the minimum signal level that the wireless audio device can receive and still function, i.e. maintain the required minimum level of SINAD. When related to distance the MUS can be seen as the maximum distance that the device can operate within a particular environment.

In any radio link, such as the path between a wireless audio transmitter (microphone) and its receiver, the quality of the signal can be affected by a number of different external factors that need to be taken into account when it is being set up. There are two key factors relevant to this report that affect the degradation of SINAD and therefore a worsening of the audio quality: i) reductions in the wanted signal level at the receiver caused by increased path loss as a result of greater separation between transmitter and receiver or as a result of increased clutter11 within the path; ii) additional noise12 or interference (which has the effect of raising the noise).

The four receiver power levels relative to the MUS which were selected represent the movement of the transmitter towards the receiver i.e. the wanted signal becoming either: 3, 10, 20, or 30 dB stronger.

The powers, measured at the receiver, of the wanted signal and the interference are used to determine the Protection Ratio[13]. Due to the bandwidth differential and the frequency

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[11] The term clutter is used to describe objects that are in the wireless transmission path between the transmitter and the receiver; these objects attenuate the wanted RF signal. Clutter can include many things such as walls, trees, cars, furniture or people.

[12] Noise is unwanted electrical or electromagnetic energy that degrades the quality of signals and data. Even without any electronic devices transmitting, there is a minimum level of “noise” which can always be detected. This is known as the “Noise Floor” and comes from the general environment and unwanted or out of band emissions from ALL electronic devices within the environment.

[13] Protection Ratio = (wanted signal strength from the wireless audio transmitter) – (signal strength from the LTE User device)

separation the protection ratio can be negative (as in this case). This implies that the power of the LTE signal (measured in its 10 MHz channel) can be greater than that of the wireless audio transmitter (measured in its 200 kHz channel) without causing interference. The more negative the protection ratio, the greater the LTE power relative to the wireless audio power can be before degradation is caused.

The unwanted LTE signal can impact the wireless audio device via two mechanisms:

- LTE in-band power: the power transmitted by the user device in the LTE channel, causes blocking in the wireless audio device.

- LTE out of band power: the out of band emissions from the LTE user device cause in-channel interference into the wireless audio device.

The amount of power that the wireless audio device sees from either in band or out of band transmissions from the LTE user equipment will depend on the filter design in the wireless audio device and also the in band and out of band power being transmitted by the LTE user equipment.

Methodology

Using the equipment setup shown in Figure 6, the SINAD analyser was set up to provide a wanted signal at the wireless audio receiver above the MUS (as determined by conducted measurements in Section 2). Protection ratios were calculated for 3dB, 10dB and 20dB and in a limited number of cases, 30dB above the MUS for each wireless audio system. All measurements were made with the audio volume set at the mid-point and the squelch turned to the minimum setting.

As the wanted signal level was increased above the MUS an improvement in SINAD was typically seen. For each of the wanted signal strengths the corresponding SINAD value was taken as the baseline level. The LTE signal was introduced and the level increased until there was a drop of 6dB from the new baseline SINAD value. This was determined to be the failure point of this test.

The protection ratio is calculated as the power of the wanted signal minus the power of the unwanted LTE UE signal. The signal levels were measured at the input port of the wireless audio receiver. As in Section 3, the centre frequency of the LTE UE source was varied to maintain a constant frequency offset of +6.15 MHz.

Results

The protection ratios for the 4 different wanted signal levels are shown in Table 10 and Table 11:

Table 10: C/I Protection Ratio Results for Wireless Audio Microphones

Device	MUS (dBm)	Protection Ratio (dB)			
		+3dB	+10dB	+20dB	+30dB
ManA-Low1	-98.2	-36.1	-34.3	-32.0	-30.4
ManA-Low2	-97.9	-36.7	-33.8	-33.6	-
ManB-Low1	-92.2	-32.0	-31.3	-31.1	-
ManC-Mid1	-90.1	-36.0	-35.6	-34.5	-29.6
ManD-Low1	-100.7	-38.0	-35.1	-31.1	-
ManD-High1	-102.5	-38.1	-39.0	-39.5	-
ManD-Mid2	-102.3	-36.7	-37.7	-33.2	-
ManD-Mid1	-105.0	-39.6	-39.8	-39.8	-
ManE-High1	-101.1	-35.3	-35.7	-35.5	-35.3
ManF-Mid1	-98.2	-38.7	-37.4	-35.3	-35.8

Table 11: C/I Protection Ratio Results for Wireless Audio Headphones and IEM

Device	MUS (dBm)	Protection Ratio (dB)			
		+3dB	+10dB	+20dB	+30dB
ManD-IEM	-98.2	-38.6	-36.3	-28.8	-
ManD-Head	-102.9	-36.5	-32.2	-26.4	-

Conclusions and Analysis

Typically the protection ratio would be expected to remain constant with increased wanted signal level if the interference mechanism was a raised noise floor caused by OOB emissions. Where the Protection Ratio becomes less negative as the wanted signal increases above MUS, this may be an indication that there are other interference mechanisms at work, including some overall RF blocking of the receiver. However in the tables above we believe that the change in protection ratio may also be related to the change in the SINAD value used as the baseline, although it may be a combination of both mechanisms as in the testing we undertook, it was difficult to separate out the two effects

The results for the protection ratio in the tables above indicate a trend for the Mid- and High-end range of devices to be slightly more resilient to LTE interference than the Low-end range of devices. This can be expected as the Low range products are likely to be designed for a lower cost and are unlikely to have such high quality components fitted. This can be seen for manufacturer 'ManD' where the low priced unit from the same manufacturer is the poorest performer at more than 3dB above MUS.

The headphones and the In-Ear Monitor protection ratios were poorer than the wireless microphones at higher wanted signal levels, indicating a poorer receiver performance. For both of these devices the receiver is worn by the user and battery powered so needs to be small and there is limitation on the power consumption to allow maximum battery life as well as space and form factor constraints. With these constraints we believe that the results obtained suggest that the receivers in these devices are not as resilient to potential interference.

We tested four devices at +30dB above the MUS to see if there was an overload effect from the power combining from the wireless audio device and the unwanted LTE signal to produce a signal strength strong enough to cause a signal that is too large for the receiver to cope with. The results for one of the receivers, ManC-Mid1, show that this may be the case.

Using the Protection Ratio in conjunction with a relevant Propagation Model, we can determine a Distance Ratio. This provides an indication of the likely impact of interference in practical scenarios. For example in some scenarios, whilst LTE interference might be present, it is unlikely that it would cause any detriment to the operation of the wireless audio system.

For typical usage of wireless audio it may be assumed that the wanted transmitter and receiver will be within the same room. In these instances, interference will be greatest when the LTE UE is also in the same room. This being so, for simplicity, we can assume the same propagation mechanisms and therefore models are applicable for the path between wanted transmitter and wireless receiver, d1 (Tx1 to Rx1 in Figure 7) and the LTE source and wireless receiver, d2 (LTE UE to RX1 in Figure 7). Therefore with reference to the SEAMCAT implementation of Hata extended for indoor-indoor propagation[14] several terms tend to 0 as the devices are in the same room and the difference in path loss of the two paths d1 and d2 becomes dominated by the 20log(d) term as the frequencies of the two systems are very close.

Therefore the difference in path loss of the two paths is 20log(d1/d2), where d1/d2 = Distance Ratio

The protection ratios in Table 10 and Table 11 range from almost -40dB to -26dB. As stated above, this demonstrates that the power at the receiver from the LTE device may be between 40dB or 26dB more than that of the wanted wireless audio transmitter before the user will experience an unacceptable level of service degradation. The differential between the maximum power of an LTE UE (under “worst case” assumptions) of 23dBm and the maximum permitted power of a wireless audio transmitter of 10dBm in the 863-865 MHz band accounts for 13dB of the protection ratio. The balance of the protection ratio will be as a result of differences in path loss for d1 and d2 and thus distance as seen in Table 12.

Table 12: Mean distance ratios for wireless audio interference

Protection Ratio	Resultant Path Loss difference	Distance Ratio
-40dB	-27dB	22.4
-35dB	-22dB	12.6
-30dB	-17dB	7.1
-26dB	-13dB	4.5

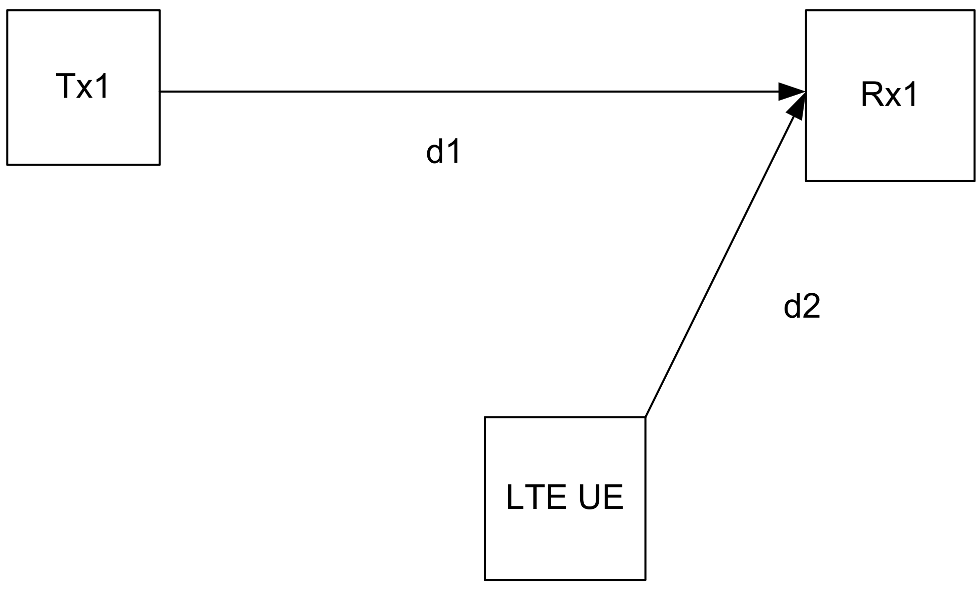
Table 12 may, therefore, be used to estimate the likely maximum range (audio transmitter to audio receiver) at which an audio device may be operated satisfactorily in the presence of an LTE UE device operating at full power with full resource block use and at a known distance from the audio receiver.

[14] Ref: http://tractool.seamcat.org/wiki/Manual/PropagationModels/ExtendedHata

For example, as illustrated in Figure 7below, if an LTE UE operating at full power with full resource block usage was 5m from a wireless audio receiver then for a receiver with a protection ratio of -35dB (a fairly typical protection ratio for the devices and scenarios tested), the associated wireless transmitter should on average be no more than 63m from the receiver to avoid the effects of interference. Even in the case of the headphone, which was the device most susceptible to LTE interference, with the lowest protection ratio of all of the devices tested, the associated transmitter could on average be up to 22.5m away from the headphone/receiver even when just 5m from an LTE UE operating at full power and using all resource blocks.

As noted earlier, and as set out in the November 2011 Update, the base case which we have assumed, of an LTE UE operating at full power and utilising all resource blocks is a "worst case" scenario intended to enable a theoretical bound to be placed on the possible impact of interference from LTE UEs. We consider it highly unlikely that the maximum volume of resource blocks will be allocated to one call as this would exhaust the capacity of the cell site and deny other customers to ability to upload data. It is also Ofcom's view that it is highly unlikely that a handset or dongle will transmit at full power while using a large number of resource blocks since high device power indicates that a user is close to the cell edge and, in these circumstances, the network must manage interference between cells.

Figure 7: **Distance Ratio example**



Annex 1

Glossary

AGL	Above Ground Level
C	Carrier
FM	Frequency Modulated
I	Interferer
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LTE	Long term Evolution
MUS	Minimum Usable Sensitivity
OOB	Out of Band
RB	Resource Block
RF	Radio Frequency
SINAD	Signal to Interference plus Noise and Distortion
SRD	Short Range Device
UE	User Equipment

Annex 2

Equipment and Settings Used

2.1 Microphone Range testing

Figure 8: Equipment Set-up

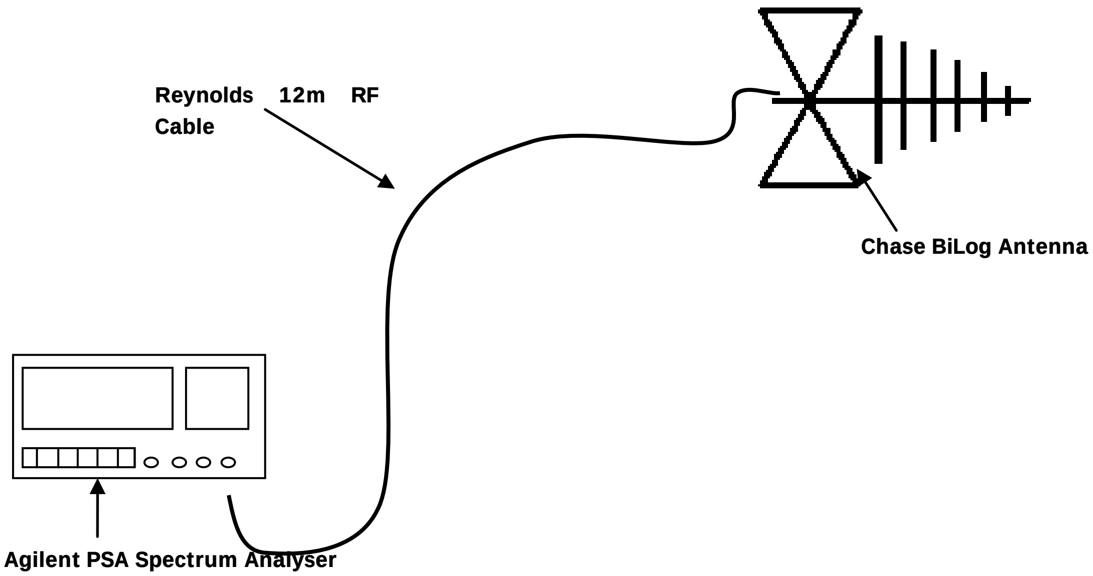


Table 13: Measurement Equipment Calibration

Description	Model	Serial No	Cal Date	Cert No
Spectrum Analyser	E4440A	US44302576	2/12/10	1-2825528317-1B
Antenna	CBL 6112B	2784	7/12/2010	CA5726
RF Cable	Reynolds	138	N/A*	N/A*

*verified by measurements conducted in Baldock September 2011

The Spectrum analyser settings were:

- Frequency: Predefined List
- Detector: Peak
- Attenuator: Off
- Measurement unit: dBm
- Resolution bandwidth: 1 kHz
- Video bandwidth 1 kHz

- Sweep time: ≈ 603 ms (automatic, set by analyser)
- Attenuation: 0dB
- Detector: Peak
- Measurement unit: dBm
- Reference level: -50 to -30dBm

2.2 Laboratory testing

The following equipment was used with reference to Figure 4 and Figure 6. Two different tone generators were used during the measurements due to availability of equipment.

Item	Manufacturer	Model	Serial No.	Description
SINAD Analyser	Wavetek	4032 Stabilock	1688390	Universal Analog/Digital Communication Test Set
Tone Generator1	Rohde & Schwarz	SML 03	100549	Signal Generator 9 kHz to 3 GHz
Tone Generator2	Thurlby Thandar	TG 230	023664	2 MHz Sweep/Function Generator
Spectrum Analyser	Rohde & Schwarz	FSL	101124	Spectrum Analyser 9 kHz to 6 GHz
Interference Source	Rohde & Schwarz	SMBV 100A	1407.6004k02-257074-qv	Vector Signal Generator
Hybrid Coupler	MECA	H705N-0.849	nn	3dB Hybrid Coupler

Hybrid Coupler Losses	
Isolation Loss at -0dBm	-18.7dB
Through Loss (at 863.15 MHz)	-3.2dB

Cable	Serial Number	Length	Loss (at 863.15 MHz)	Note
Reynolds 219-0090-2000 0602	004	2m	0.3dB	SINAD analyser to Hybrid Coupler
Semflex	nn	1m	0.2dB	Interference Source to Hybrid Coupler
Reynolds 0049	079	2m	0.4dB	Hybrid Coupler to Wireless Microphone Receiver