PMSE Spectrum Usage Rights & Interference Analysis

Revised

This document is prepared for Ofcom

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Executive Summary

Sagentia was commissioned by Ofcom to provide ad hoc, independent technical advice during the process of determining the coexistence arrangements between PMSE, local TV and the new digital television services.

This report brings together this advice under three headings:

- Spectrum usage rights (Chapter 1)

  We found that the current approach to co-existence is flawed. We suggested an alternative approach that provides better protection to the main TV services but reduces the protection of out of area TV services.

  We also noted that DSO changes the interference environment for PMSE users and this is likely to require some changes to equipment usage practice.

- Potential interference to channel 69 (Chapter 2)

  We identified that the possible use of channel 68 for UMTS services will have impact on PMSE use of channel 69 unless licence constraints are introduced.

- Use of UHF spectrum (Chapter 3)

  We explored some technical issues that may need to be taken into account in the setting of licence conditions and packages.

Since the publication of our report on 10 December 2008 Chapter 1 has been superseded a more recent report (PMSE: Future Spectrum Access). The original Chapter 1 has been replaced with the more up-to-date material.

It has become apparent that there were errors in the calculation of protection distances for programme links in Chapter 2. We have taken the opportunity to fully revise Chapter 2 in order to make the logic clearer to follow. The protection distances for wireless microphones have been also slightly revised. The original report used a range of 100m between the wireless microphone and its receiver. In this report shorter ranges have also been considered.

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1 Spectrum usage rights

We were asked to examine the existing parameters for coexistence between PMSE and broadcast television and propose any necessary modifications.

1.1 Current protection of TV reception

The current approach to protection of TV reception uses the concept of protection ratio (PR). This is the number of dBs below the wanted TV signal that the PMSE (usually microphone) signal must be to avoid visible interference effects. The PR is determined empirically by a simple measurement for any two pieces of equipment (one generating the interference and one receiving it).

A complication arises where more than one microphone is being used in a single TV channel. TV channels are 8MHz wide in the UK. Wireless microphone channels are 200kHz or less. It is quite common to have several microphones operating in a single TV channel. Current protection ratios are only measured for one microphone, however.

Analogue microphones into analogue TV

The current PR for analogue TV from wireless microphones is 47dB.

Analogue microphones into digital TV

The protection ratio recommended in section 3.3.1 of ERC Report 88[1]. for analogue microphones into digital TV is -3dB.

This reflects the very rugged nature of the digital TV (DTT) signal in the presence of narrow band interference. This is a design feature of the digital TV signal to ensure that it doesn't suffer from interference from analogue TV transmissions.

For interfering signals of less than 1MHz bandwidth the forward error correction (FEC) incorporated in the digital TV signal corrects for the disruption from even very high levels of interference. The coding system is particularly suited to 'peaky' analogue interference as it can tolerate several of the OFDM subcarriers being blocked. The lost data is recovered using FEC.

An analogue microphone has a peaky spectrum approximately 150kHz wide. Beyond about 6 microphones the total bandwidth blocked reaches 1MHz and the FEC becomes unable to cope.

Digital microphones into digital TV

If the interfering microphone is digital, the situation is different. The spectrum of a digital signal is likely to be wider and flatter with a bandwidth of about 200kHz. This means that more subcarriers of the DTT signal are likely to be blocked by a single digital microphone than by an analogue one. As a result, fewer digital microphones can be tolerated in a single 8MHz channel than analogue microphones.

[1] ERC Report 88, "Compatibility and sharing analysis between DVB-T and radio microphones in bands IV and V", Naples, February 2000

Multiple microphones into digital TV

While it is common to pack several microphones into one 8MHz channel, we have been unable to find published results for protection ratios for DTT with multiple analogue or digital microphone interference. Published results have tended to concentrate on single microphone interferers. Accordingly we have conducted some lab tests using signal generators and a consumer DTT receiver and obtained the results in Table 1. These should be taken as qualitative as the test signals were not true microphones and the DTT signal was received off air and so was already subject to some degradation.

Table 1: Protection ratios for DTT signals in the presence of interference from multiple microphones

Number of microphones in an 8MHz channel	PR for analogue microphones	PR for digital microphones
1	+1dB	+1dB
2	+4dB	+6dB*
3	+8dB	Not measured
4	+10dB	Not measured
5	+13dB*	Not measured
6	+13dB*	Not measured

Protection ratios are expressed per microphone.

* Indicates simulated interference using a smaller number of wider bandwidth sources.

It should be noted that we found a very fast failure of the DTT signal with increasing numbers of microphones in these tests.

1.2 Proposed protection of digital TV reception

The different types of PMSE equipment operate in different bandwidths to each other and to broadcast TV. This results in the current protection ratio approach being not very meaningful as the different signals are measured in different bandwidths. In particular digital and analogue microphone are treated the same despite having different interference characteristics into DTT. Protection ratios should also vary with the number of microphones as the DTT receiver is sensitive to all the interference received not just that from each microphone individually. Our approach, therefore, is to define coexistence criteria that provide appropriate protection to broadcast TV in this worst case, multiple microphone interferer situation.

Rather than “start from scratch” our approach has been to start from an existing, recognised publication considering interference from a single microphone into broadcast TV and then modify this as required. The basis of our approach is the co-existence analysis in ERC Report 88[2]. The full process is defined in this document and is not repeated here but some parameters, such as

[2] ERC Report 88, “Compatibility and sharing analysis between DVB-T and radio microphones in bands IV and V”, Naples, February 2000

minimum field strength and maximum interferer levels were modified to reflect agreed planning parameters in Document JPP/MB/1[3].

ERC Report 88 calculates protection distances separately for single hand-held and body worn microphones. For countries, such as the UK, that have adopted ERC Recommendation 70-03, ERC Report 88 recommends using the calculation defined for 50mW e.r.p. body worn radio microphones be applied to both body worn and handheld devices.

Our approach starts by considering the minimum median field strength associated with DTT reception for the DTT encoding scheme employed. From JPP/MB/1, the minimum value defined for this is Variant I use in Band IV and is 53.8dBµV/m. This is based on a minimum receivable field strength of 46.8dBµV/m.

ERC Report 88 then applies a location correction factor to take account of the standard deviations in the distributions of both the wanted (DTT) and unwanted (microphone) signals. For distances above 100m, reflecting our worst case scenario, the factor is 13dB.

The UK spec for broadcast DTT (post DSO as in JPP ref) requires 19.8dB C/I (carrier to interference ratio) at the receiver to operate. This is the protection used for incoming DTT interference. In the worst case there may be multiple microphones interfering across a channel therefore we use this value as the limit for PMSE interference. ERC Report 88 calculates a protection ratio for a single microphone of -3dB. We have already indicated that this ratio must be modified to protect for multiple, rather than single, microphones. A modified approach for calculating allowable PMSE field strength relative to the broadcast TV field strength at the edge of a DTT service is needed.

There is already interference being received from other broadcast DTT transmitters. To take account of this we add an additional 3dB to the protection required.

Protection is not to be provided for portable reception and we assume that no PMSE use will be allowed co-channel within the predicted coverage area of a TV transmission. Our approach is to protect all predicted receivable channels and we therefore assume that the front to back ratio of the TV receiving antenna will provide additional interference rejection. We assume this to be 16dB as defined in reference JPP/MB/1.

After all these factors are taken into consideration this leads to a limit for PMSE field strength of 53.8 - 13 - 19.8 - 3 + 16 = **34dBµV/m** which we adopt as the limit. This is the maximum field strength allowed for any PMSE microphone. Note that this is a cautious limit that does not allow any carriers of the OFDM signal to suffer any interference induced errors.

We then use the same piece-wise propagation model for path loss used in ERC Report 88 diagram 9 to calculate the relevant protection distance:

- 20dB per decade up to 100m;
- 30dB per decade between 100m and 1km;
- 40dB per decade beyond 1km.

This is the basis that used to calculate channel availability at a given location and indicates where a microphone is “allowed” to be used as it will not interfere with broadcast TV. Whether interference from broadcast digital TV impacts radio microphone use at that location is considered later.

[3] JPP/MB/1 Version 2, 4 July 2003, Technical Planning Parameters and Algorithms

Spectrum availability is calculated for indoor and outdoor radio microphone use. In the case of indoor use, 7dB is added to the PMSE field strength limit (reference ERC report 88) to allow for in building attenuation.

This method calculates an outdoor protection distance of 1.4km and an indoor protection distance of 900m for rural locations.

We were not able to find directly suitable published sources for calculated the effect on propagation in moving from rural to urban environments. The current licensing approach applies an extra 12dB attenuation in urban environments. Comparison of Hata propagation predictions for urban environments with the predictions using the path loss model from ERC report 88 found an extra urban attenuation of 13dB.

If 12dB additional path loss is assumed in an urban environment, the protection distances for outdoor and indoor reduce to 0.65km and 0.4km respectively.

One consequence of protecting against multiple microphone interferers across a channel is that DTT is over-protected in locations of low radio microphone demand, however in these situations there is likely to be sufficient capacity to meet this demand. It should also be noted that as we protect all broadcast TV services that are predicted to be receivable post DSO (and in a number of cases digital coverage is improved over analogue), it is possible that in locations where a number of transmitter service areas overlap there are some TV services being protected which are not being used by a large number of households. These situations cannot be easily or reliably identified from simple database analysis, however if this results in a predicted capacity shortfall a simple site survey will determine what transmitters local households are actually using.

1.3 Spectrum use inside the protected area

When considering whether to grant a license for PMSE use at a given location one not only has to consider protection of broadcast digital TV, but also whether converse is true: will broadcast TV interfere with radio microphone operation to an unacceptable level.

We adopt the same approach outlined in ERC Report 88:

- Use the 68dBμV/m maximum DTT field strength quoted in Chester '97. Apply the 12dB protection ratio indicated in Chester '97 for a radio microphone 1.5m a.g.l. at the DTT channel centre frequency

1.4 Guard band for PMSE in adjacent channels to DTT.

The DTT channel bandwidth is 8MHz. However real DTT receivers have intermediate frequency (IF) bandwidths that are greater than the 8MHz TV channel. This means that signals from beyond the 8MHz bandwidth are able to enter a DTT receiver and interfere with wanted signals in adjacent channels. Operation of PMSE equipment within this wider bandwidth i.e. at the edge of the adjacent channel, is likely to give rise to interference within a DTT receiver. The question is how big the guard band needs to be in order to protect receivers in the adjacent channel.

We conducted a brief survey of IF filters made for DTT receivers. This suggests that they have significant attenuation beyond 5MHz from their centre frequency. Protecting a guard band of 1MHz each side of the used TV channel should give adequate protection from PMSE use.

ERC report 88 has measured the actual adjacent channel performance of receivers in the presence of PMSE interference and suggests that a guard band of 500kHz is required, although this report notes that only professional receivers were used in the testing.

We understand that some newer DTT receivers are using a direct conversion architecture and have less good adjacent channel rejection. Further investigation of these is required and this may result in revision to the above recommendation.

We believe that a 1MHz guard band should be adopted until it is demonstrated that a narrower guard band is safe.

1.5 Comparison of old and new regimes

When considering the overall effect of DSO on capacity for PMSE there are many factors to be taken into account. Digital TV has negative protection ratios throughout most of the adjacent channel compared with the significant protection required for analogue TV reception. This in itself means that more of the adjacent channel to a Digital TV broadcast is usable for PMSE than the channel adjacent to an analogue TV broadcast.

2 Potential interference to channel 69

UHF channel 69 is used exclusively for PMSE in the UK. We were asked to assess the potential interference if channel 68 became used for re-banded 3G mobile telephones (UMTS700).

2.1 Current uses of channel 69

Two classes of use are considered.

2.1.1 Wireless microphones

Wireless microphones are mainly used in theatres, concert halls and studios.

Table 2: Relevant characteristics of wireless microphones

Characteristic	Value
Transmit power	10mW (10dBm) which is the maximum allowed in the UK for handheld wireless microphones[4]
Frequency band	854MHz – 862 MHz
Antenna (transmit and receive)	Omnidirectional (0dB gain)
Bandwidth	200kHz[5]
Typical range	100m
Modulation	FM
Receiver carrier to noise ratio (C/N)	12dB (from ERC Report 88[6])

2.1.2 Programme links

Programme links are audio links typically used for outside broadcast or electronic news gathering between a location and the studio. They may be either analogue or digital. The analogue ones use FM and the digital ones use QPSK.

[4] See Ofcom report 'UK Interface Requirement 2038' Annex A1. www.ofcom.org.uk/radiocomms/ifi/tech/interface_req/ir2038.pdf
[5] See Ofcom report 'UK Interface Requirement 2038' Annex A1. www.ofcom.org.uk/radiocomms/ifi/tech/interface_req/ir2038.pdf
[6] ERC Report 88 Compatibility and sharing analysis between DVB-T and radio microphones in bands IV and V. www.erodocdb.dk/Docs/doc98/official/pdf/REP088.pdf

Table 3: Relevant characteristics of programme links

Characteristic	Value
Frequency band	854MHz – 862 MHz
Bandwidth	200kHz
Typical range	1km to 10km
Modulation	FM or QPSK

2.2 Potential uses of channel 68

Post switchover, channel 68 (846MHz to 854MHz), immediately below channel 69 in frequency, will be auctioned and may be used for other purposes. Potential other purposes include:

- Broadcast DTT, which is the current use of that channel and should present no new interference problems.
- UMTS 700, a re-banded version of UMTS 2100. This is considered attractive because the coverage provided by a UMTS base site at 2100MHz is very limited and is impeding rollout of 3G services except in urban areas. This is a new use of the spectrum so the interference issues need exploring.

This chapter concentrates on the issues that might arise for PMSE use in channel 69 if channel 68 is used for UMTS700. *Note that this section of the report does not deal with interference between digital television signals and radio microphones. It deals entirely with UMTS 700 adjacent channel issues and their effect on PMSE equipment.*

2.3 Emission specification for UMTS700 user equipment operating in channel 68

The specification for this user equipment is given in a 3rd Generation Partnership Project (3GPP) specification[7]. This report is based on Release 8, version 8.3.0.

The interference from channel 68 into channel 69 is classed as an ‘out of band emission’.

The worst case situation is where a UMTS handset is operating closest to channel 69 and at the highest allowable power.

- The highest transmit frequency[8] permitted in the specification is 849MHz which is 5MHz below the bottom of channel 69. The specification may be changed in future to allow the highest centre frequency to be 859.5 MHz in line with the co-primary (with TV broadcasting) mobile allocation of 790 – 862 MHz in Region 1 agreed at WRC-07. In this report, we use 849 MHz.

[7] Technical Specification Group Radio Access Network; User Equipment (UE) radio transmission and reception (FDD) (Release 8) TS 25.101
[8] Ibid, Section 5.2

- Maximum allowed transmit power[9] is 24dBm (250mW) known as class 4.

The out of band emission specification for user equipment is set in section 6.6.2 of the 3GPP specification. There are four types of out of band limit described in the document. Here we describe all of these limits, and then conclude that the most relevant for our purposes is the spectrum mask. The four limits are:

- The spectrum mask[10]
- The adjacent channel leakage ratio (ACLR)[11]
- The additional spectrum emission limits for Band V[12]
- The spurious emissions limit[13]

The spectrum mask

The spectrum mask is specified as in table 6.10 of the 3GPP specification. Substituting the carrier frequency of 849MHz (and covering only frequencies falling within TV channel 69) we obtain the following table:

Table 4: Spectrum mask for UMTS, derived from the 3GPP specification and applied to the 'worst case' scenario

f in MHz	Higher of		Measurement bandwidth
	Relative requirement	Absolute requirement	
854 – 856.5	$\left\{-35-1\cdot\left(\frac{\Delta f}{MHz}-3.5\right)\right\} dBc$	-55.8 dBm	1MHz
856.5 – 857.5	$\left\{-39-10\cdot\left(\frac{\Delta f}{MHz}-7.5\right)\right\} dBc$	-55.8 dBm	1MHz
857.5 – 861.5 MHz	-49 dBc	-55.8 dBm	1MHz

Δf is the frequency offset, ie f-849

In this table, the maximum allowable signal is the higher of the relative requirement and the absolute requirement. Because the handset is assumed to be operating at high power, it is the relative requirement that sets the power in this report.

The adjacent channel leakage ratio

The adjacent channel leakage ratio (ACLR), specified as the total power in the UMTS adjacent (5MHz) channel. The limit is -33dB in the first adjacent channel which is centred at an offset of +/- 5MHz and -43dB in the second adjacent channel centred +/- 10MHz away. These powers are

[9] Ibid, Section 6.2.1
[10] Ibid, Section 6.6.2.2
[11] Ibid, Section 6.6.2.1.1
[12] Ibid, Table 6.10B
[13] Ibid, Section 6.6.3.1

totals within a 5MHz UMTS channel as received through the filter in a UMTS receiver. The ACLR gives rise to the following limits

Table 5: ACLR for UMTS, derived from the 3GPP specification and applied to the 'worst case' scenario

f in MHz	limit	Measurement bandwidth
851.5 – 856.5	-33 dB	5 MHz
856.5 – 861.5	-43 dB	5 MHz

The additional spectrum emission limits for Band V

The additional limits are specified as in table 6.10B of the 3GPP specification. Substituting the carrier frequency of 849MHz we obtain the following limit.

Table 6: Additional limits for UMTS, derived from the 3GPP specification and applied to the 'worst case' scenario

f in MHz	Additional requirement	Measurement bandwidth
852.5 - 861.5	-13 dBm	100 kHz

The spurious emissions limit

The limit is specified in table 6.12 of the 3GPP specification. Substituting the carrier frequency of 849MHz we obtain the following limit.

Table 7: Spurious emissions limit for UMTS, derived from the 3GPP specification and applied to the 'worst case' scenario

f in MHz	Minimum requirement	Measurement bandwidth
>861.5	-36 dBm	100 kHz

The four limits apply in different measurement bandwidths owing to their different characteristics. We have converted them all to dBm in 200kHz measurement bands to match the channels used in PMSE. For example, the calculation for ACLR of -33dB is

power (dBm) = 24dBm (tx power) -33dB (ACLR) + 10log(200kHz/5MHz) = -23dBm

This process to some extent modifies the intention of the different types of limit, but is unavoidable in the exercise we are undertaking. The four lines are plotted in the graph below.

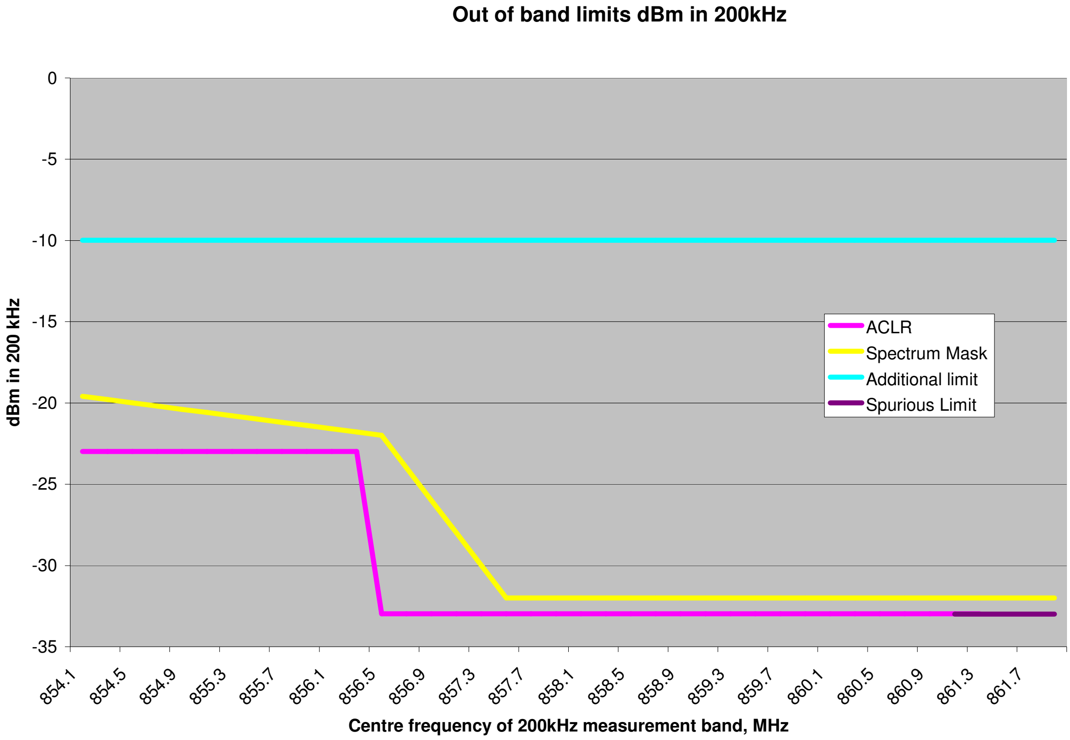

Figure 1. Graph showing the relevant limits for the 'worst case' scenario

For the purposes of our analysis we consider that the spectrum mask is the most appropriate guide to the maximum interference signals from UMTS handsets. While the ACLR is a tighter limit, it applies across 5MHz but as filtered by a UMTS receiver. The spectrum mask on the other hand specifies the limits in narrower frequency bands.

To summarise, for the purposes of this report we are assuming that the out of band interference produced by the UMTS handset will be that allowed by the spectrum mask, as given in the table below.

Table 8: UMTS out of band power levels used in the interference calculations, measured in 200kHz channels

Frequency, MHz	UMTS power, dBm in 200kHz
854	-19.5
854.5	-20.0
855	-20.5
855.5	-21.0
856	-21.5
856.5	-22.0
857	-27.0
857.5	-32.0
858	-32.0
858.5	-32.0
859	-32.0
859.5	-32.0
860	-32.0
860.5	-32.0
861	-32.0
861.5	-32.0
862	-32.0

2.4 Our approach to interference

2.4.1 The scenario considered

The following diagram illustrates the situation being considered. There is a PMSE transmitter attempting to communicate with a PMSE receiver, both in channel 69. A UMTS handset on channel 68 is producing out of band emissions in channel 69. The question is, ‘how far away must the UMTS handset be from the PMSE receiver such that the PMSE signal is not compromised?’. This is known as the ‘protection distance’.

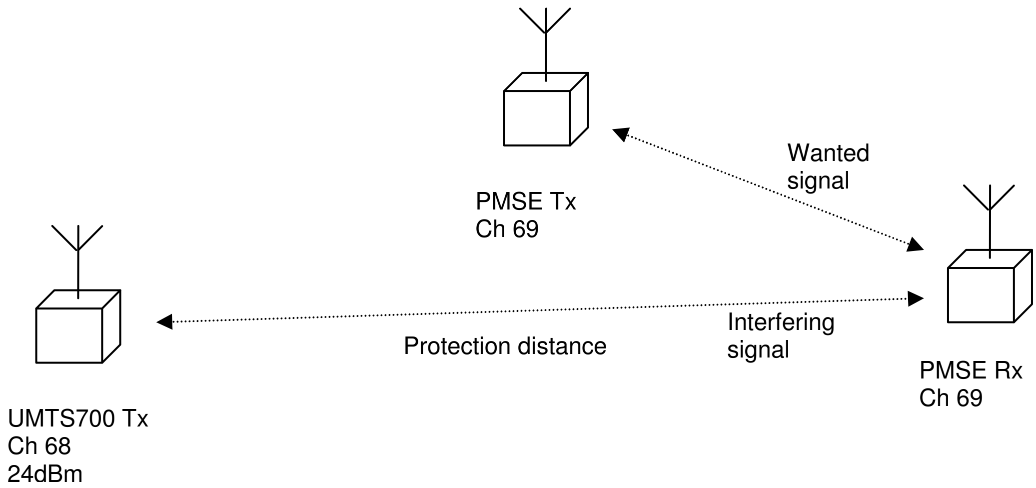

Figure 2. Generic interference scenario showing the concept of 'protection distance'

There are various mechanisms by which a strong interference source can degrade the performance of a radio receiver.

- A strong signal in an adjacent band can pass through wide receiver front end filters and can compress the gain of front end low noise amplifiers or cause blocking. Both mechanisms can cause lower sensitivity in the receiver affecting range. Since existing PMSE equipment will have been designed to operate with potentially high signals within band 68, ie analogue TV transmissions, it is believed that they will have been designed with this kind of nearby strong interference source in mind. We do not therefore consider this type of interference further.
- The out of band emission from the UMTS transmitter can interfere with the PMSE transmission at the same frequency. Here, the extent of interference comes down to the relative signal levels, and both of these signals relative to the noise floor of the receiver.

2.4.2 Maximum permissible interference levels at PMSE receivers

The approach we have taken to determining the protection distance is to assess the range at which the interfering signal would are at the permissible interference level for each system type. These signal levels have been decided as a matter of policy:

- For wireless microphones this level is defined as the interference signal level low enough to allow operation of wireless microphones over a distance of 100m. This is very much a worst case. We have also modelled distances of 50m, 20m and 10m.
- For programme links (both analogue and digital) the interference level is defined as a signal low enough not to degrade the performance of the programme link in any way. This then requires that the interfering signal must not exceed the noise level in the front end of the receiver (known as the 'noise floor').

2.4.3 Distance calculation

Having calculated the maximum allowable interferer signal level, we then calculate the protection distance (ie the distance from the UMTS handset). At the distances involved, the free space propagation model is considered appropriate.

[1]   Free space loss (dB) = 20log(distance) + 20log(frequency) – 27.56

where distance is in metres and frequency is in MHz.

In principle, constructive multipath can cause localised higher signal strength in longer paths. Two equivalent paths can give rise to a signal 3dB higher, although the probability of more paths causing further increases becomes vanishingly small. We have allowed for a 3dB increase in signal strength to cover this eventuality in the case of programme links. Note that use of a fade margin here is exactly the opposite to the normal approach in calculating link budgets. Whereas, normally, one is trying to calculate the minimum signal level likely to be received, here we are trying to calculate the maximum interference signal likely to be received.

2.5 Calculation of maximum interference signals

2.5.1 Wireless microphones

The scenario considered is shown below.

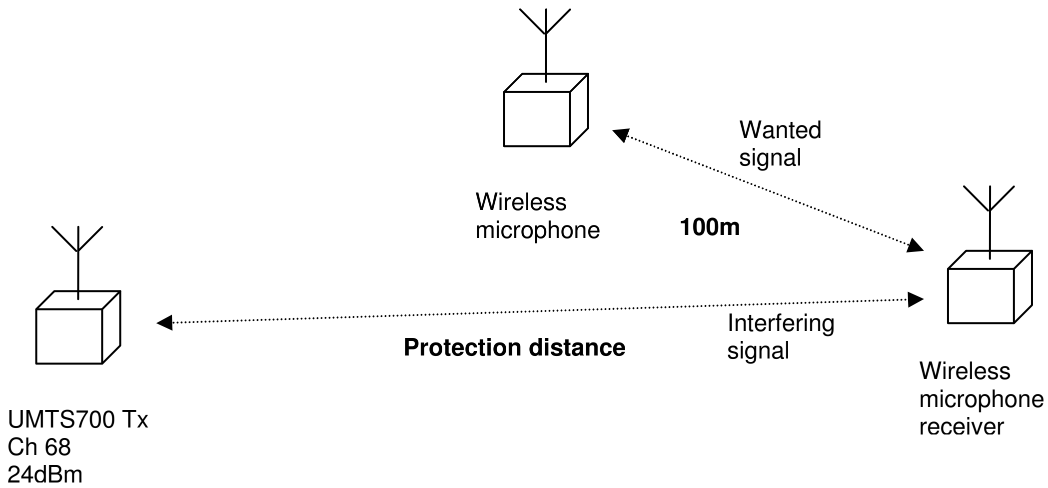

Figure 3. Wireless microphone scenario

The wireless microphone is transmitting 10mW on a carrier frequency between 854MHz and 862 MHz with a unity gain antenna.

The signal strength at the receiver, assuming it has a unity gain antenna, is given by subtracting the free space loss eq [1] from the transmit power.

[2]   Rx signal = 10dBm – {20log(100) + 20log(858) - 27.56} = -61.11dBm

Note that we have used the centre of band 69 (858MHz) as the frequency in this calculation.

The interferer signal level needs to be below this by the carrier to interference ratio (C/I).

The C/I for the wireless microphone receiver is set by the ERC Report 88[14] specification for equipment of this type. ERC Report 88 is unusual in the way it defines the required C/I for wireless microphones. It is conventional to define C/I as how much more signal strength is needed in the wanted signal over an unwanted signal with similar characteristics, particularly bandwidth. Therefore all the power of the interfering signal falls in the band of the wanted signal.

In the case that an interfering signal has a wider bandwidth than the wanted signal, it is convenient to adjust the C/I figure by the ratio of the bandwidths. For example, if a demodulator in a 200kHz bandwidth requires a 12dB C/I, and is interfered with by a signal with 2MHz bandwidth, then to achieve a 12dB C/I within the 200kHz bandwidth, the interference signal can have a total power of ten times this, ie 2dB below that of the wanted signal. One tenth of this power (-10dB) falls in the 200kHz bandwidth of the digital audio system. So with an overall ratio of powers (wanted to interferer) of 2dB the 12dB C/I at the detector is maintained.

The ERC Report 88 specification does something different. It is designed to specify the coexistence of a wireless microphone with an 8MHz DTT signal. The DTT signal has much wider bandwidth than the wanted microphone signal.

ERC Report 88 mandates a 12dB C/I as the ratio of full signal powers between the two bandwidth mismatched signals. As such, the 'effective C/I' specified, if only the interference signal power in the wanted signals bandwidth is taken into account, is higher by the ratio of the interferer signal to the wanted signal.

It is therefore necessary to adjust the 12dB C/I mandated by ERC Report 88 by 16dB, where 16dB is 10log (8MHz DTT signal / 0.2MHz wireless microphone signal)

The implied 'same bandwidth C/I' from ERC Report 88 is therefore 12 + 16 = 28dB.

The interference signal must therefore be 28dB below the wanted signal [eq 2]

[3] *Interference signal < -61.11dBm – 28dB = -89.11dBm*

Thus the interference signal, in the relevant 200kHz band, must be below -89.11dBm.

The protection distance (PD) can now be calculated from the free space loss formula eq [1]

[4] $PD = 10\text{^}\{[P_{UMTS} - P_{interference} + 27.56 - 20\log(f)]/20\}$

where P_{UMTS} is the maximum transmit power from the UMTS handset and $P_{interference}$ is the maximum allowable interference signal calculated from eq [3]. This equation reduces to

[5] $PD = 10\text{^}\{[P_{UMTS} - P_{interference} - 31.1]/20\}$.

Using the power levels defined by the UMTS spectrum mask, the protection distances for the situation where the wireless microphone transmitter is 100m away from the wireless microphone receiver are given in Table 9 below. As a separation of 100m is a maximum case we have also repeated the calculations for more typical operating distances of 50, 20 and 10m.

[14] ERC Report 88 Compatibility and sharing analysis between DVB-T and radio microphones in bands IV and V. www.erodocdb.dk/Docs/doc98/official/pdf/REP088.pdf

Table 9: UMTS700 Tx minimum protection distance for wireless microphone Tx/Rx separation distances of 100, 50, 20, 10 metres

Frequency, MHz	Wireless mic protection distance, m			
	Range 100m	Range 50m	Range 20m	Range 10m
854	84.3	42.2	16.9	8.4
854.5	79.6	39.8	15.9	8.0
855	75.2	37.6	15.0	7.5
855.5	71.0	35.5	14.2	7.1
856	67.0	33.5	13.4	6.7
856.5	63.2	31.6	12.6	6.3
857	35.6	17.8	7.1	3.6
857.5	20.0	10.0	4.0	2.0
858	20.0	10.0	4.0	2.0
858.5	20.0	10.0	4.0	2.0
859	20.0	10.0	4.0	2.0
859.5	20.0	10.0	4.0	2.0
860	20.0	10.0	4.0	2.0
860.5	20.0	10.0	4.0	2.0
861	20.0	10.0	4.0	2.0
861.5	20.0	10.0	4.0	2.0
862	20.0	10.0	4.0	2.0

2.5.2 Programme links

The scenario considered is shown below.

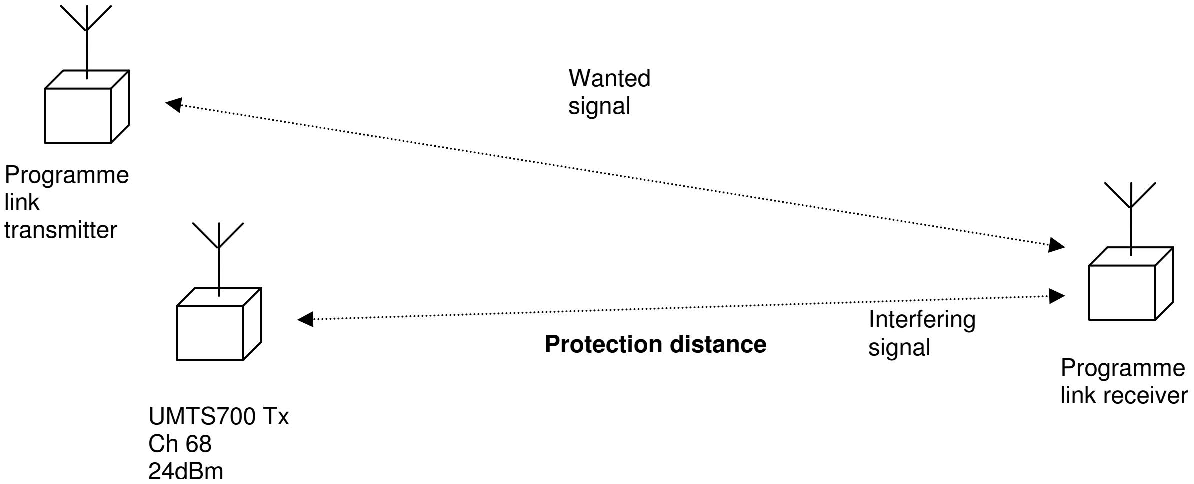

Figure 4. Programme link scenario

For programme links (both analogue and digital) the interference level is defined as a signal low enough that it does not exceed noise level in the front end of the receiver (known as the 'noise floor').

We start by calculating the noise floor at the PMSE receiver.

[6] Noise floor = Thermal noise in the relevant bandwidth + Receiver noise figure

The thermal noise in a 200kHz channel is

[7] Thermal noise (dBm) = log(k.T.bwidth) +30 (to convert Watts to milliwatts) = *-120dBm*

where k = Boltzmann's constant 1.38×10^{-23}, T is the temperature (assumed 300K) and the bandwidth is 200kHz.

We assume a noise figure for the receiver of 4dB.

Therefore the noise floor is -116dBm.

We then assume that that if the interfering signal is at, or below, the noise floor, then it will not affect the receiver. This approximation should hold if the interfering signal appears as white noise, which is probable given that the UMTS spectrum is a wideband digital signal. We have not, in this report, treated the analogue and digital programme links separately. In practice the different modulation characteristics and receiver performance could cause the behaviour of the system in the face of interference at around the level of the noise floor to differ between analogue and digital systems. We conclude, therefore:

[8] Maximum interference signal = noise floor = -116dBm

For the digital and analogue programme links, the protection distances are found using the free space path loss formula for the interference signal:

[9] PD =

$10^{[P_{UMTS} + 3dB \text{ constructive fade} – P_{interference} + 27.56 - 20log(f)]/20}$

The above equation assumes no receive antenna gain. In practice, programme links have directional antennas with gain. This means that if the UMTS handset is within the receive antenna aperture, equation [9] would underestimate the protection distance whereas if the UMTS handset is off axis, equation [9] would overestimate it. TV antennas in band V exhibit at least 16dB discrimination[15] . This implies that the concept of a protection distance is a relatively poor approximation to the situation where there are directional antennas involved. Therefore, the protection distances calculated according to this method can only be a guide to the separations required.

[Eq 9] reduces to

[10] $PD = 10^{[P_{UMTS} - P_{interference} - 28.1]/20}$.

Using the power levels defined by the UMTS spectrum mask, equation [10] gives the protection distances in the table below

Table 10: Programme link protection distances

Frequency, MHz	Programme link protection distance, m
854	2630
854.5	2483
855	2344
855.5	2213
856	2089
856.5	1973
857	1109
857.5	624
858	624
858.5	624
859	624
859.5	624
860	624
860.5	624
861	624
861.5	624
862	624

[15] See ITU-R Recommendation BT419-3 for a discussion of receiving antennas

The free space distances above are slight overestimates owing to atmospheric absorption and other factors.

2.6 Conclusion

The above analysis leads to the following table of indicative protection distances.

Table 11: Summary of calculated protection distances

Frequency offset (from bottom of Channel 69)	Radio mic protection distance				Programme link protection distance
	Range 100m	Range 50m	Range 20m	Range 10m	
< 5MHz	85m	42m	17m	8m	2.5 km
5 - 8 MHz	20m	10m	4m	2m	0.6 km

In the analysis there is no consideration of body loss that occurs with wireless microphones. The 10 dBm transmitter power would be typically reduced to about 4 dBm. This would make the results worse. However in practice the mobile EIRP figures are likely to be much lower, perhaps around 3-6 dBm, than the maximum Class 3 power of 24 dBm figure used in these calculations. Therefore this should more than offset the body loss problem. Measurements by Ofcom[16] at higher frequencies indicate that 3G phones exhibit adjacent channel performance that is typically much better than spec and therefore for wireless microphones the protection distances are likely to be smaller than calculated.

For programme links the use of directional antennas and the fact that the mobile uplink devices typically both transmit at much lower levels than their maximum EIRP capability and have better than specification adjacent channel performance will lower the protection distance. However, the protection distance may still be high for this type of use.

Radio microphones are by far the largest users of channel 69 and they should be able to coexist with mobile uplink devices in channel 68 or below. For programme link operation, interference considerations will be much greater.

[16] http://www.ofcom.org.uk/consult/condocs/2ghzregsnotice/era.pdf Measurements of UTRA FDD user equipment characteristics in the 2.1 GHz band"

3 Use of UHF spectrum

Ofcom has a general predisposition in favour of market mechanisms to allocate spectrum efficiently and to drive innovation. We were asked to comment on the ways in which the existing patterns of PMSE use interact with 'market mechanisms' to encourage or impede these goals.

3.1 Intermodulation

Each wireless microphone occupies 200kHz of spectrum. However in addition each pair of microphones used in close proximity generates one or more intermodulation products which precludes additional radiomicrophone systems in this part of the spectrum. The closer the proximity the higher level the intermodulation product will be. The amount of spectrum occupied by intermodulation products grows quickly with the number of microphones.

Because of the way the intermodulation products make spectrum unusable, we currently achieve only 8-12 Microphones per TV channel against a theoretical maximum of 40. Where spectrum availability is an issue, using newer, better radio microphone systems can already allow more to be used on the site in the same spectrum.

The interference range of indoor microphones is only a few hundred metres. So even in central London there are few cases of theatres potentially interfering with one another even when using microphones on the same frequency. In practice they co-ordinate (through the band manager JFMG) ensuring that each theatre uses the spectrum rendered unusable at the adjacent theatres because of intermodulation products.

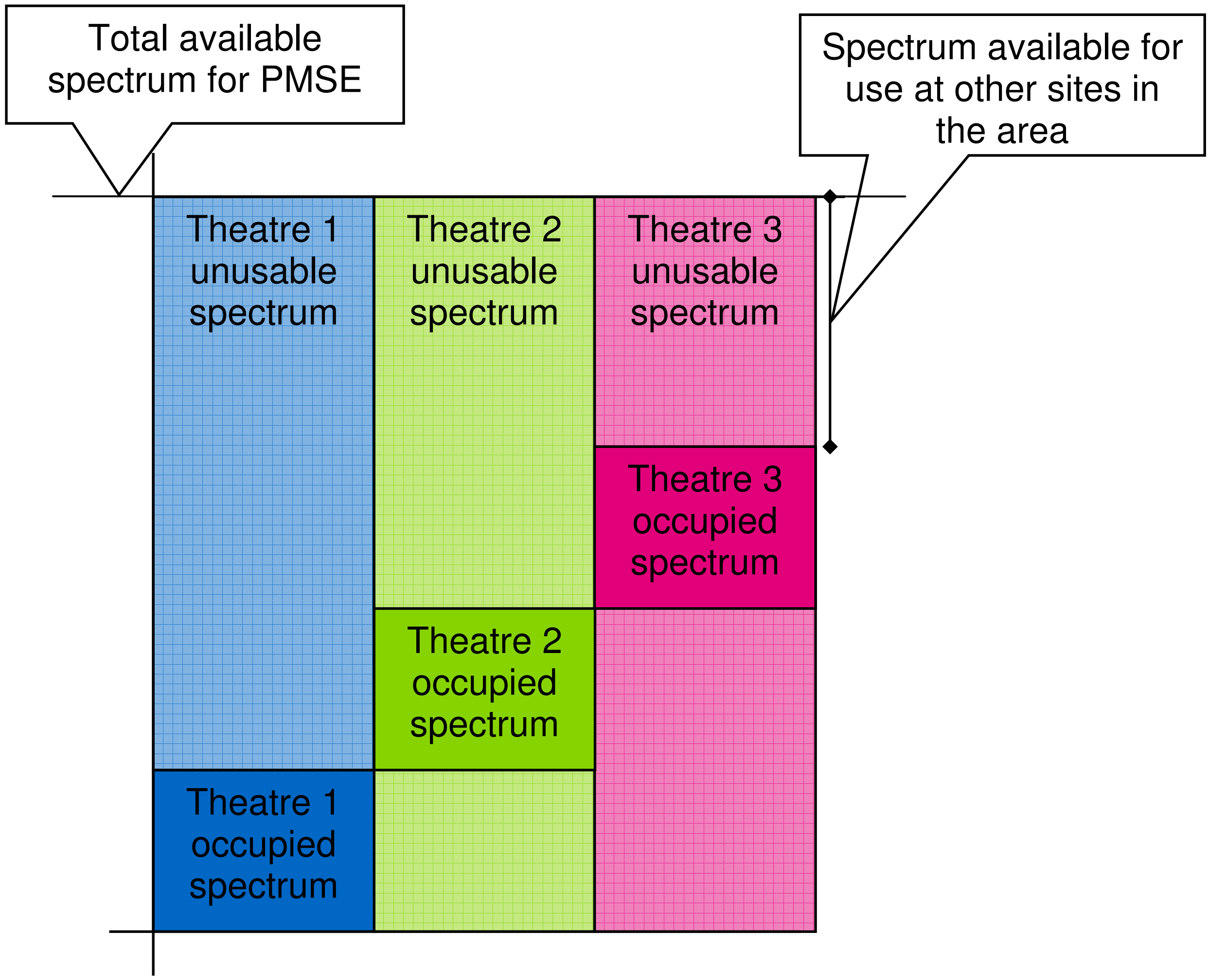

Figure 5. Illustration of spectrum usage among multiple theatres

The diagram above illustrates the effect. Each theatre occupies some spectrum, and renders other spectrum unusable through the intermodulation products. In reality the occupied and unusable spectrum is evenly spread over the band but we have grouped it for clarity in the diagram.

Theatres occupy the spectrum that is unusable at adjacent sites and make unusable the spectrum that is occupied at adjacent sites. There is more spectrum made unusable by intermodulation products than occupied by all adjacent theatres.

This is effectively creating a co-operative strategy that makes the internally unusable spectrum a problem before that of externally occupied spectrum.

3.2 Limited pressure for equipment to be improved

One issue is that only a very small amount of equipment is used in situations of geographic peaks causing a spectrum shortage. Big peaks together only use a few hundred of the total population of about 50,000 microphones. Less than 1% of equipment needs improved spectral efficiency.

This makes it questionable as to when and whether manufacturers will make more spectrally efficient equipment. However there are a number of small manufacturers who supply the high end of the market, these might reasonably be expected to produce suitable equipment.

One could envisage that the band manager might be proactive in resolving these problems. They might be motivated to liaise with equipment manufacturers to produce specification for equipment that is sufficiently spectrally efficient to operate successfully in these environments.

The requirement is not just UK centric. The rest of Europe is allocating more spectrum to broadcast TV as a result of switchover, so reducing the amount of interleaved spectrum available to PMSE. This is particularly true of those countries rolling out single frequency networks (SFNs).

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