PMSE Spectrum Usage Rights & Interference Analysis

SAGENTIA

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.

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Contents

1 Spectrum usage rights

We were asked to suggest how usage rights for the interleaved spectrum might be formulated so as to allow the primary user (broadcast TV) unfettered use of the spectrum in order that consumers can continue to receive broadcast TV without suffering interference. There was a widespread view that the protection methodology for analogue TV cannot be simply applied to digital TV.

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. 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 currently used for planning analogue microphones into digital TV is 1dB.

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.

Multiple microphones into digital TV

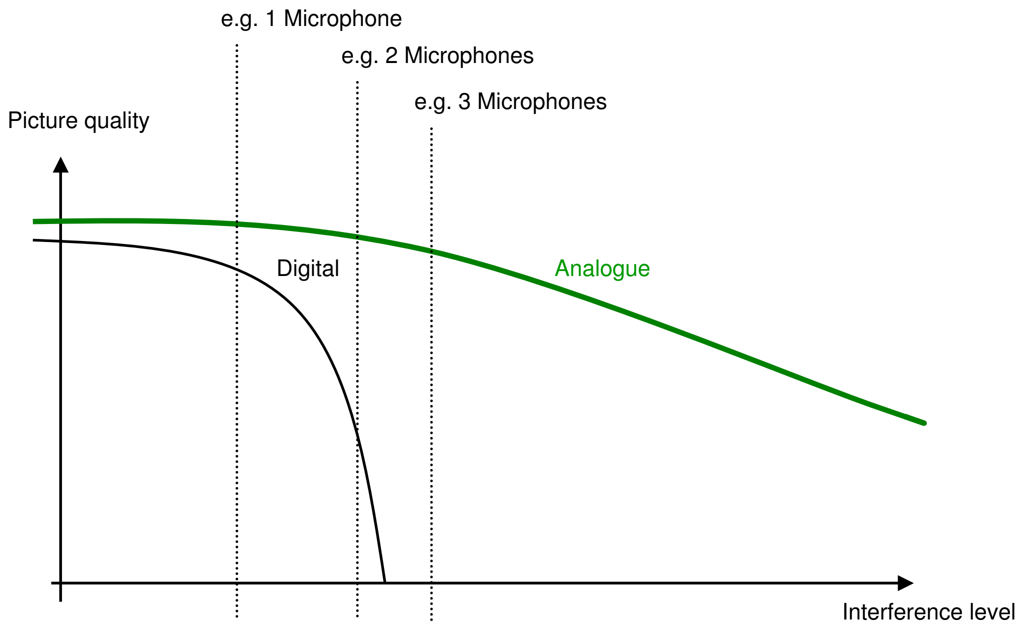
While it is common to pack several microphones into one 8MHz channel, we have been unable to find published results for protection ratios for DTT with multiple analogue or digital microphone interference.

Accordingly we have conducted some lab tests using signal generators and a consumer DTT receiver and obtained the following results. 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.

No microphones in channel	PR for Analogue microphones	PR for Digital microphones
1	+1dB	+1dB
2	+4dB	+6dB*
3	+8dB	
4	+10dB	
5	+13dB*	
6	+13dB*	

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

Protection ratios are expressed per microphone. It should be noted that we found a very fast failure of the DTT signal with increasing numbers of microphones in these tests. 1dB increase in interference level caused the DTT receiver to go from no visible degradation to complete loss of service. This is a significantly different failure mode to analogue TV. This difference is illustrated in the diagram below.



Degradation of TV picture with interference level. Analogue and Digital.

Digital TV services clearly need to be afforded greater protection than the current protection methodology for analogue TV allows. A key question is whether to continue to use the protection ratio approach. This approach is flexible but complicated to administer, especially where there may be many different microphones in use at different densities. It also does not encourage spectral efficiency in its broadest sense.

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 starts by calculating the allowable PMSE field strength relative to the broadcast TV field strength at the edge of a DTT service.

- The UK spec for broadcast DTT (post DSO) requires approximately 20dB SIR (Signal to Interference Ratio) at the receiver to operate. (This is the protection used for incoming DTT interference).
- Protection is not to be provided for portable reception and we assume that no PMSE use will be allowed within the coverage area of the TV transmission. We may therefore assume that the front to back ratio of the TV receiving antenna will provide additional interference rejection which we assume to be 15dB.
- There is already interference being received from other broadcast TV transmitters. To take account of this we add an additional 3dB to the protection required.

This leads to a limit for PMSE field strength of 20+3-15 = -8dB relative to the broadcast TV field strength at edge of DTT service. So we may adopt this as the limit. Note that this is a cautious limit that does not allow any carriers of the OFDM signal to suffer any interference induced errors.

The minimum field strength required for reception of UK standard broadcast DTV 47dBµV/m at the antenna.

So the PMSE field strength must be below 47-8 = 39dB.

A measurement that is frequently used where the equipment characteristics are not known in advance is the Field Spectral Density (FSD). It is advantageous in that it can be measured for an individual interference source. However it is much more difficult to derive the requirement for FSD than for protection ratio, which can be measured directly in the laboratory with an interference source, a wanted signal source and a wanted signal receiver. Once the FSD is derived it can be calculated for each potential interfering signal using measurements on just the interference source.

The FSD is usually specified in terms of dBµV/MHz. However 1MHz is too large a bandwidth to measure in as current microphones operate in 200kHz and other PMSE devices use 25kHz or less. We need a measurement bandwidth that is appropriate for protecting TV and applicable to all PMSE equipment including digital and analogue equipment.

DTT uses an OFDM system where there are many carriers, currently these are at a 4kHz spacing although this will change to 1kHz at Switchover. It is therefore appropriate that the protection should reflect the needs of this. DTT can tolerate a certain proportion of blocked carriers though the exact proportion varies with the operating mode. For the post DSO operating mode of 64QAM 2/3 we have made some lab measurements and we find that at a significant interference level of 900kHz bandwidth the TV services starts to fail. This suggests we can loose up to 900/8000 of the carriers and the FEC will correct the error introduced. This represents 12% of the occupied bandwidth. Where we have multiple interference sources operating in a single TV channel this degradation must be partitioned between the users. So we should set a bandwidth measure that is 12.5% of the occupied bandwidth of the PMSE equipment. For wireless microphones this should be 25kHz. The ratio between 8MHz and 25kHz is 25dB.

We therefore recommend and FSD limit of 47-[20+3-15]-25 = 14dBµV/m/25kHz. (at 10m)

This is the same as:

30dBµV/m/MHz measured in 25kHz bandwidth.

Our analysis suggests that this is over onerous to current generation analogue microphones because of the limited number that can be used in a single TV channel (because of intermodulation products). For this reason we suggest that as an interim measure the measurement bandwidth for Wireless microphones be set to 50kHz, allowing up to 20 Interference sources to co-exist in a single TV channel. Note that the number 20 reflects the number of interference sources close to a TV receiver, not the number of microphone in use on one site within a single TV channel. The number of microphones in use at a single site will be lower than this in areas of dense usage. We believe this corresponds roughly to an average of 12 microphones/TV channel. Therefore these interim rules should be allowed only until the typical number if microphone/TV channel starts to exceed 12.

The alternative FSD approach is likely to support higher spectral efficiency, but is unnecessarily restrictive in situation where spectral efficiency is not required (e.g a single microphone in use at a sports event). However there is plenty of spectrum for these low density users so this should not be a limiting factor.

We therefore conclude that the usage right should be set as a FSD at approximately 30dBµV/m/MHz measured in a 25kHz bandwidth.

This approach is slightly biased against current analogue microphones so encouraging the adoption of the potentially more spectrally efficient equipment.

1.3 Spectrum use inside the protected area.

In principle indoor PMSE equipment can be used co-channel with broadcast TV if portable reception is not protected.

A brief analysis follows:

1. The typical maximum operating range for a wireless microphone is 100m (Source JFMG).
2. For 10 mW ERP this give an edge of service field strength of approximately 75 dBuV/m (mid band, free space).
3. The protection ratio required for analogue wireless microphones from digital TV is 12dB. (Source: ERC report 088).
4. This yields a max broadcast DTT field strength of 63dBuV/m for co-channel operation with analogue radio microphones.

Notes:

- This analysis ignores potential height differences between the measured DTT field strength and the radio microphone receive antenna.
- This analysis ignores potential directionality of the radio microphone receive antenna.
- This analysis is for outdoor use. Indoor use will have greater protection from the building penetration loss.

The above factors will increase the DTT field strength in which wireless microphones are usable.

A TV field strength of 63dBuV/m is a usable TV signal and under current guidelines a wireless microphone would not be allowed to operate as it would interfere with a receivable TV signal. With the adoption of DPSA this will be relaxed as many (but not all) areas with this signal strength from one transmitter will actually be receiving their protected service(s) from a different transmitter on different channels.

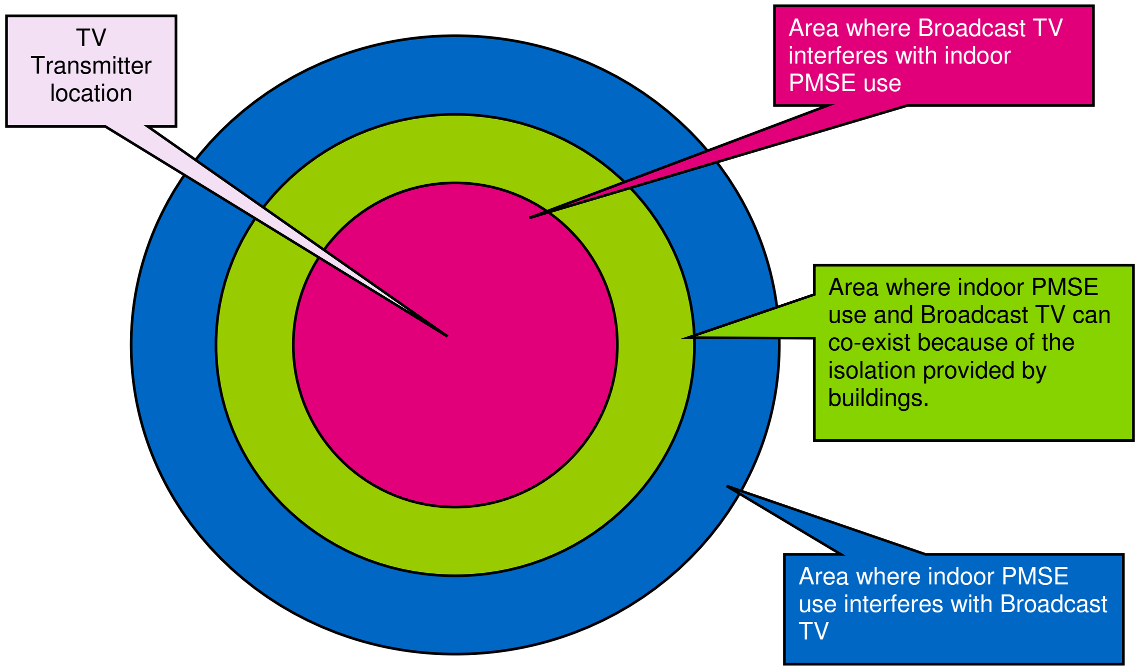
When use is indoors, the additional protection required between the different services is provided by the building penetration loss. Use is not possible over the whole coverage area as illustrated below. The outdoor TV field strength must be high enough that the microphone signal strength outside the building is insignificant. Similarly the TV signal strength inside the building must be small compared with the microphone signal.

A calculation for indoor low power microphones, assuming a building penetration loss of 12 dB yields:

The DTT signal strength can be increased by 12 dB to 75dBuV/m.

The 100m field strength of the microphone can be reduced by 12 dB. Assuming that there will be no TV receiver antenna within 100m of the microphone transmitter (i.e. in the same building) yields an indoor equivalent outdoor microphone field strength of 63dBuV/m. (this is a number for planning purposes only. It does not represent a real measurable field).

The size of this "green" band will vary with the type of PMSE equipment. Digital equipment will generally have a larger band then analogue equipment (because of the better interference resilience of digital modulations) and this may be a way to encourage digital takeup.



Defining spectrum usage right for this situation must rely on signal strength ratios rather than a single FSD approach used above. Use of the single FSD calculation will suggest that the PMSE use will interfere with TV reception. This is not in fact the case as the TV signal strength is higher and therefore more resistant to the co-channel PMSE interference. A FSD ratio may be an appropriate measure, combining the advantages of Protection ratio and FSD.

This cautious approach outlined above allows limited indoor co-channel use. However in practice we anticipate that there will be adequate non co-channel spectrum for sites where there is high demand.

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, however this report notes that only professional receivers were used in the testing.

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

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.

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 from adjacent channels where re-banded 3G mobile telephones might be used.

There are two main uses of channel 69: shared wireless microphones operate on fourteen 200kHz channels; co-ordinated programme links and co-ordinated wireless microphones operate across the remainder of the channel.

Post switchover, channel 68, immediately below channel 69 in frequency, will be sold off 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.

We consider below the issues that might arise for PMSE use if Channel 68 is used for UMTS700.

UMTS700 is in the process of standardisation so as such the exact co-existence problems cannot be established with certainty. In particular it is not yet clear whether channel 68 will be occupied by transmissions from the base station or the handset. So we consider both.

2.1 UMTS700 handset transmit (68) into wireless microphone receive (69)

(Based on the 2100MHz specifications for IMT 2000)

UMTS 2100 maximum handset transmit power is 2W (33dBm) (in 5MHz) (Class 1, although 250mW (24dBm) Class 3 is currently the highest used at 2100MHz)

Class 1 leads to transmit PSD of 26dBm/MHz or 19dBm/200kHz microphone channel.

There are two specifications for adjacent channel leakage in the UMTS 2100 specifications.

- The adjacent channel leakage ratio (ACLR), specified as the total power in the UMTS adjacent (5MHz) channel.
- The spectrum mask defines the drop off of emissions with frequency. This is measured in a smaller bandwidth but is only specified for frequency offsets greater than 3.5MHz.

In addition there is a spec that 99% of the emitted power must fall within the 5MHz occupied channel.

A simple calculation based on ACLR, and approximating the UMTS emission as flat in the adjacent channel follows.

1. 33dB ACLR gives -14dBm power emitted in the adjacent microphone channel.
2. Wireless microphone ERP is 10dBm in 200kHz, it requires 20dB SIR at the receiver to operate.
3. At equal distance from the receiver the UMTS emission is 24 dB below the microphone, or 4 dB below the SIR limit.
4. 4dB in free space terms is a 3:2 ratio

So where the UMTS 700 device is less than 2/3 the microphone distance to the receiver, the microphone service will fail. Note that at the very bottom of the channel this situation may be worse as the 99% limit will be higher than the ACLR limit here. Since the lowest microphone frequency is 900kHz above the channel edge we ignore this. This gives the UMTS700 the same guard band that effectively exists for TV.

We think this is probably acceptable. Most situations represent no problem because microphone users are likely to have control of the area. But there could be a problem in small gatherings where the microphone receiver is at the back of the audience. In practice if the handset transmit power class is 9dB below the maximum as with UMTS 2100 handsets this is not an issue.

Where a microphone operates very close to the bottom of the TV channel the UMTS emissions may exceed this level. To achieve the same level of protection the UMTS emissions should be limited to -14dBm measured in 200kHz in the adjacent channel. A more cautious limit would be to allow a 10:1 distance ratio leading to an emissions limit of -30 dBm/200kHz. As noted above there is already a guard band to protect from TV interference so this limit need only be applied above 800kHz from the bottom of Channel 69.

This represents adding an additional spectrum mask limit to UMTS700 of -30dBm/200kHz between 800KHz and 3.5MHz from the channel edge.

A similar calculation arises for base stations however the higher ACLR (40dB) and their sighting away from microphone use makes real problems less likely.

2.2 UMTS700 handset transmit (68) into programme link receive (69)

(Based on the 2100MHz specifications for IMT 2000)

Based on the same argument presented above we obtain:

1. Handset transmit is 2W (33dBm) max (in 5MHz) (Class 1, although 250mW (24dBm) Class 3 is likely to be the highest used).
2. Leads to FSD of 26dBm/MHz or 19 dBm/200kHz microphone channel.
3. 33dB ACLR gives -14dBm in the adjacent microphone channel.

And

1. Taking the spectrum emissions mask for the UMTS2100 handset.
2. 3.5MHz up from the bottom of channel 69 the power in a 200kHz channel might be -42dBm
3. At the top of channel 69 the power in a 200kHz channel might be -51dBm
4. Assuming a digital programme link operating at 256kbps in 200kHz, this is likely to require only QPSK coding, requiring no better than 14dB SIR (based on standard Eb/No curves for coherent QPSK and 10^{-6} BER).
5. Receiver sensitivity assuming 4dB NF will be -102dBm. (we assume the fade margin and antenna gain are approximately equal so can be ignored).
6. So the path loss from the UMTS700 antenna to the programme link receive antenna needs to be greater than:

Freq Offset **(from bottom of Channel 69)**	**UMTS Sig level in 200kHz**	**Path loss required**	**Protection zone length**
<3.5	-3dBm	99dB	3.5km
3.5	-42dBm	60dB	40m
5	-43dBm	59dB	35m
8	-51dBm	51dB	15m

We have not taken into account any further reduction in the area that may accrue from the low antenna height of the handset transmitter and the lower power class of real 3G handsets.

So digital programme links will either need a protection zone in front of the receive antenna; or need an interference margin on top of sensitivity to allow for UMTS 700 interference, or need the out of band emissions of the UMTS devices to be tightened up for offsets less than 3.5MHz.

Similarly to the microphone analysis above an additional spectral mask limit on the UMTS 700 devices of -30dBm/200kHz between 800kHz and 3.5MHz from the channel edge would significantly improve the situation.

For analogue links the situation will be worse, by about an order of magnitude, as the SIR required for operation will be higher than 14dB.

3 Use of UHF spectrum

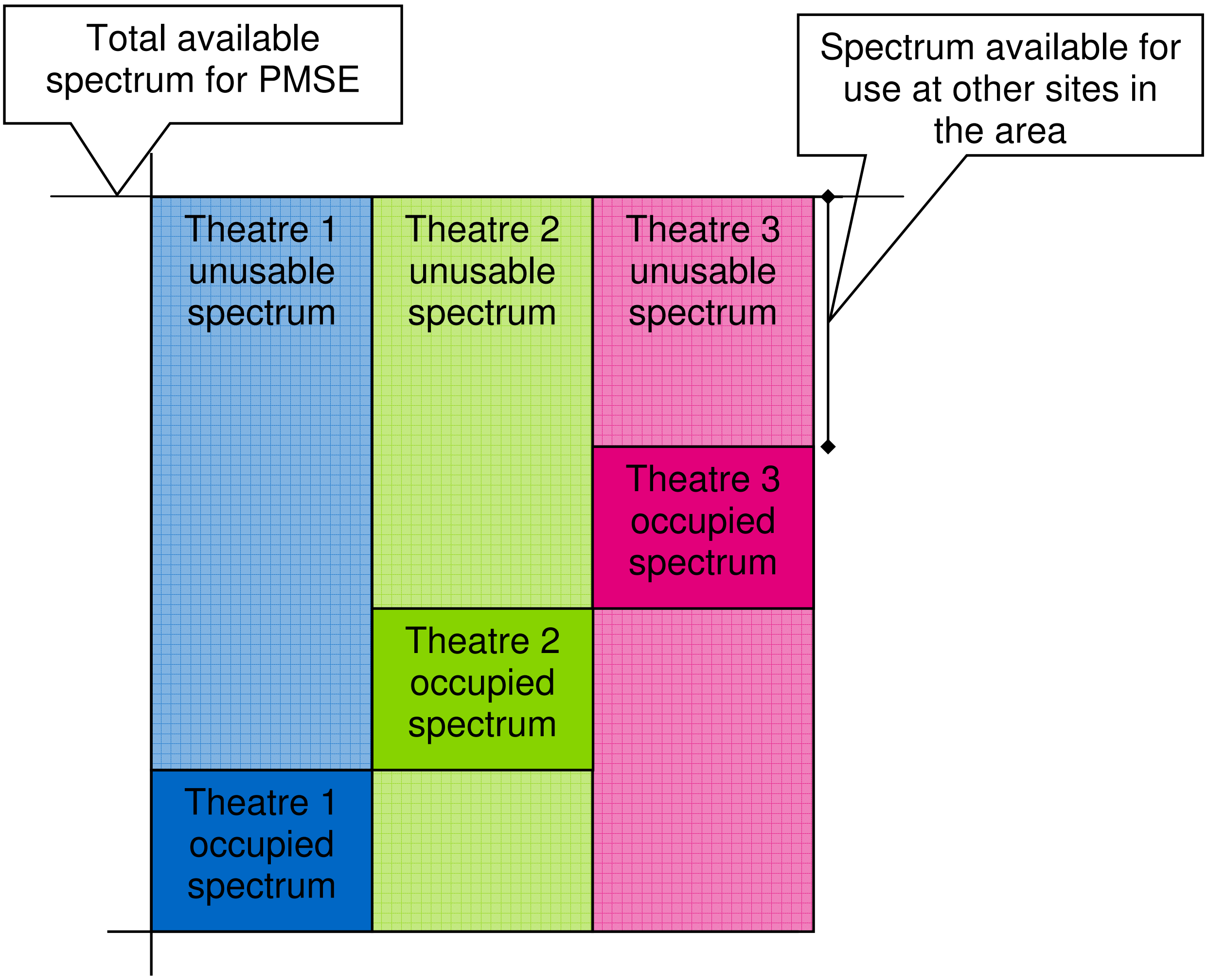
Ofcom has a general predisposition in favour of market mechanisms to allocate spectrum efficiently and to drive innovation. We were asked to comment on the ways in which the existing patterns of PMSE use interact with 'market mechanisms' to encourage or impede these goals.

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 occupy more 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 microphones 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.



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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