WILTSHIRE & GRANNIS LLP

October 26, 2009

Ex Parte

Julius P. Knapp
Chief, Office of Engineering and Technology
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Unlicensed Operation in the TV Broadcast Bands, ET Docket No. 04-186

Dear Julie,

I write on behalf of Microsoft Corp. regarding petitions for reconsideration of the Commission's *White Spaces Order* addressing protection for authorized Part 74 wireless microphones. The purpose of this *ex parte* is to provide real world data and analysis demonstrating that the existing criteria for both wireless microphone protection radii and white space device sensing requirements are overly restrictive.

As the attached report by Shared Spectrum Company ("SSC") explains, man-made noise is a significant and frequently dominant factor in wireless microphone operation that should be taken into account when defining white space device operating parameters. Disregarding man-made noise leads to the conclusion that excessively large exclusion zones and extremely low sensing thresholds are required to protect wireless microphone operations. Conversely, accounting for man-made noise permits the creation of significantly less restrictive requirements for sensing thresholds and exclusion zones that will still provide sufficient protection for authorized wireless microphone operations. Specifically, SSC's analysis demonstrates that exclusion zones of 130 meters and sensing thresholds less sensitive than -111 dBm would more than adequately protect wireless microphones. Indeed, these parameters are quite conservative.

I hope you will find the attached technical analysis helpful. We would be pleased to organize a session with you to discuss these findings in more detail. Pursuant to the Commission's rules, a copy of this letter is being filed electronically in the above-referenced docket. If you require any additional information please contact the undersigned.

Sincerely yours,

Edmond Thomas
Senior Technology Policy Advisor

Cc: Dr. Rashmi Doshi
Walter Johnston

Attachment

The impact of man-made noise on protection requirements for wireless microphones

A report on research commissioned by Microsoft

October 26, 2009

This report presents the results of measurement and simulation work conducted by Shared Spectrum Company under contract to Microsoft. Microsoft also wishes to acknowledge the valuable input of Monisha Ghosh of Philips Research North America in the preparation of this report.

Executive summary

The opening of white spaces to new applications promises a range of economic and social benefits by enabling the use of spectrum which has lain either unused or underused. Regulators in the US and the UK have sought to enable these gains without impacting the operations of existing licensees: mainly television broadcasters and wireless microphone users. However, difficulty in obtaining data on wireless microphone use has led regulators towards an unnecessarily conservative approach that does not account for real-world conditions found at major venues.

A key example is man-made noise, which has a significant if not dominant effect on the operation of wireless microphones in the field. By neglecting the impact of man-made noise in the calculation of wireless microphone protection requirements, regulators have arrived at technical criteria which overprotect microphones and unnecessarily impede new applications of white spaces.

Earlier this year, Microsoft commissioned a program of measurements and analysis to fill this information gap. The results presented in this report demonstrate that regulators can relax key technical constraints on white space devices while still providing sufficient protection to licensed wireless microphone operations.

Background

Across the world, regulators are becoming aware of the importance of opening up white spaces for unlicensed use. In the US, proceedings on white spaces are now well advanced, building on the FCC's favorable decision [1] at the end of last year. In the UK, Ofcom published proposals earlier this year for opening up white spaces to new applications [2].

One particularly challenging aspect of establishing rules for white space devices is determining how to protect licensed wireless microphone operations used in the broadcast and movie industries. Data concerning real world wireless microphone system performance is sparse and operating practice not well documented. It is for this reason, we believe, that regulators have taken an overly cautious approach to the protection of wireless microphones.

In order to provide additional information useful to determine the level of protection necessary to accommodate licensed wireless microphones operations, Microsoft commissioned Shared Spectrum Company to carry out a program of measurements, simulation, and analysis. The results were used to estimate:

1. The minimum separation needed to avoid interference between a wireless microphone system and a white space device operating in the same UHF channel. This separation defines the 'exclusion zone'.
2. The minimum level to which white space devices relying on sensing technology would have to detect wireless microphone operations to ensure that they avoid using an occupied channel. This is related to the exclusion zone since, by definition, there is no interference risk from white space devices which are outside the zone.

The rest of this paper is structured as follows:

- Section 1: The measurement and analysis program that was undertaken
- Section 2: Establishing the level of man-made noise
- Section 3: Estimating the exclusion zone
- Section 4: Estimating the sensing threshold
- Section 5: Recommendations
- Section 6: References
- Appendix: Further details on the noise measurement process and the results

Section 1: Measurement and analysis program

The work was organized in three phases:

1. Man-made noise measurements.
2. Propagation loss measurements.
3. Analysis, using the propagation loss measurements, to estimate the exclusion zone and sensing threshold values required to avoid impairing wireless microphone operation.

Noise and interference measurements were conducted in a range of locations, including private dwellings and public venues, in Virginia in April 2009.

A brief lexicon of noise

Noise forms a backdrop to wireless communications, determining the lowest signal level that can be received: *i.e.* receiver sensitivity. It has two key components: thermal noise and receiver noise.

Thermal noise (also known as Johnson–Nyquist noise) is generated in electrical conductors at the radio frequency RF input of the receiver. These conductors include the antenna and any lead connecting it to the receiver. Thermal noise power can be calculated using the following formula[1]:

$$P_{dbm} = -174 + 10 \log10 (\Delta f)$$

Where:

P_{dbm} is the thermal noise power, referred to 1 milliwatt

Δf is the bandwidth of the receiver input

The receiver also generates noise, further limiting its sensitivity. This latter component of noise, quantified in the receiver's *noise figure,* is a function of the nature and configuration of the components in its RF input stage. This report brackets thermal noise and receiver noise together and refers to the combination as the *reception noise floor*.

[1] Based on an assumption of a 50 ohm source resistance at the receiver

In addition to noise arising in the receiver, there may be signals arising from external sources, which the receiver can detect. These may be either 'wanted' signals from which the receiver can extract useful information, or unwanted signals that impair the receiver's ability to recover the wanted signal. The unwanted signals are often referred to collectively as *interference* or *man-made noise*. In the case of TV-band wireless microphone operations, common examples of unwanted signals include signals from other wireless microphones operating in the vicinity and television transmissions.

White space devices are also a potential source of interference, if operating in the same channel and sufficiently close to the microphone receiver. Accordingly, the enabling regulatory framework for white space devices includes measures to protect wireless microphone operations. These measures should reflect a complete understanding of the interference risk posed by white space devices.

In this paper, the risk of impairment to wireless microphone operation is gauged by determining the *Carrier to Interference and Noise Ratio* (CINR). CINR is the ratio between the wanted signal (referred to as the carrier) and an aggregated unwanted signal, in which man-made noise (aka interference), receiver noise, and thermal noise are all included. Figure 1, below, illustrates how CINR relates to the received signal level, reception noise floor, and an *interference and noise* floor (in which man-made noise is also included).

The resulting value can be compared directly with the minimum value of CINR needed by a wireless microphone ($CINR_{min}$), to assure reliable operation. The minimum value of CINR is not published. However, the ERA report for Ofcom on cognitive access indicates that 25 dB is a representative figure [2].

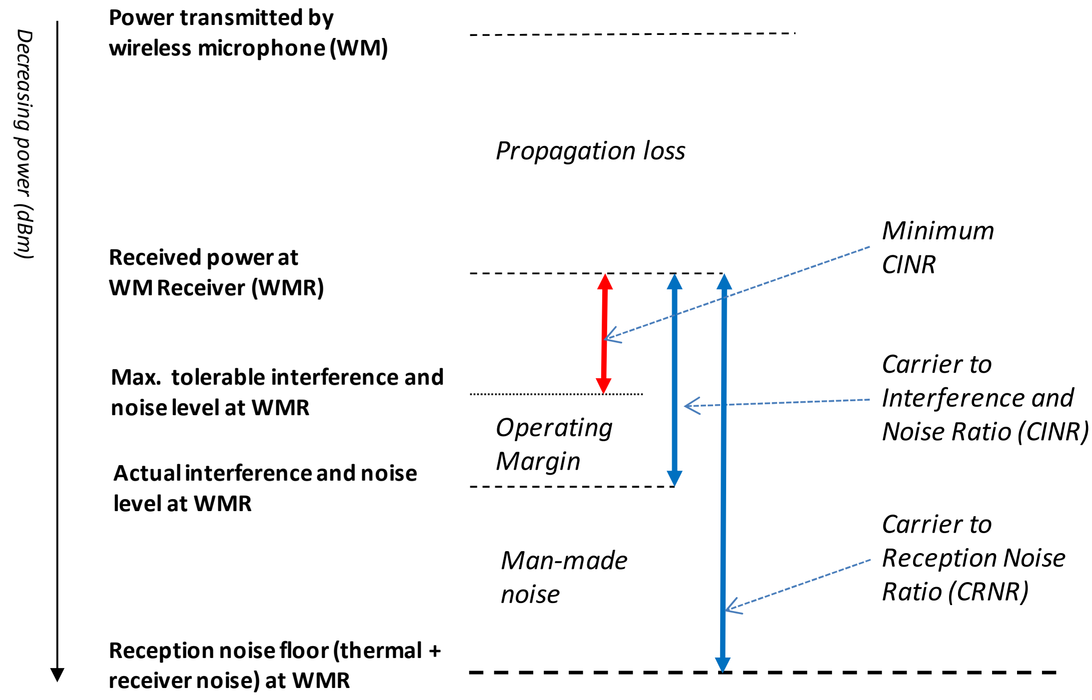

Figure 1: *Carrier to Interference and Noise (CINR)* takes into account man-made, thermal and receiver noise in assessing the margin available

Section 2: Establishing the level of man-made noise

Regulatory analyses of wireless microphone protection requirements thus far have largely assumed that the noise floor at the wireless microphone receiver is equal to the reception noise floor – a parameter that is easily calculated from the bandwidth of the channel in question and the noise figure of the receiver. Little account has been taken of potential sources of interference other than white space devices. For example, although Ofcom's statement on cognitive access [Reference 2, Section 5.30 on page 21] notes that the typical set-up signal level at the wireless microphone is -67 dBm, it does not elaborate on the reasons that level was established.

Sources of man-made noise include television stations, electrical equipment in homes, offices, factories, etc. In addition, studio and stage environments have their own sources of noise, particularly other wireless microphones, as well as lighting systems, lifting machinery, and other equipment found in these settings.

The characteristics of man-made noise are well understood. Indeed, the ITU has long-established guidelines on typical levels of man-made noise that are to be expected in a range of different locations (ITU-R Recommendation P.372-9). These are illustrated in the appendix of this paper.

However, the ITU recommendation provides only *mean* levels, which are insufficient to determine the risk of interference to wireless microphones. Peak levels of such noise must also be considered because the human ear is sensitive to even brief interruptions or artifacts in an audio signal. Microsoft therefore commissioned Shared Spectrum Company to make noise measurements that took temporal variation into account.

Assessing the impact of man-made noise

In the first phase of the program, Shared Spectrum Company (SSC) measured the level of man-made noise in four locations in the suburbs. At each of the locations, SSC took a series of ten noise level samples, over a period of approximately 20 minutes, in each of 150 potential microphone channels distributed over 10 UHF channels. Thus, a total of 1500 samples were taken in each measurement position. The process was repeated at between four and five measurement positions in each location, yielding a total approaching 30,000 noise measurements.

Figure 2 shows the distribution of noise levels found in one of these locations, a condominium. In this chart, it can be seen that man-made noise can range up to 30 dB above the reception noise floor. [The reception noise floor here is -115 dBm, using a receiver bandwidth of 200 kHz and a receiver noise figure of 6dB.]

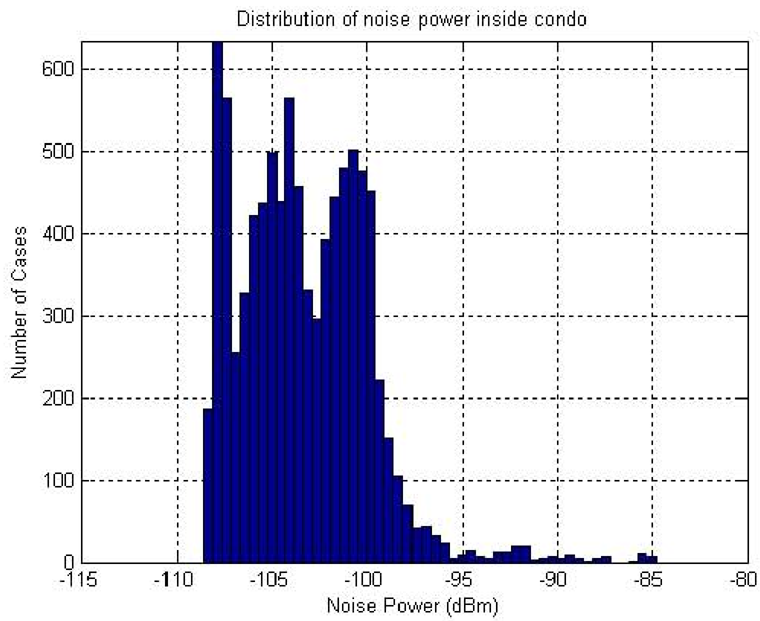

Figure 2: Noise levels distribution from measurements taken inside a condominium

Histograms illustrating the noise level distribution at other locations, together with further details of the sampling structure used in the measurements, may be found in the appendix.

In order to assess the potential impact of man-made noise, SSC considered each of the 6000 to 7500 noise level samples taken, per location. For each of a range of wanted signal (carrier) levels at the wireless microphone receiver, and each measurement sample, it calculated the Carrier to Interference and Noise Ratio (CINR). If the result was greater than 25 dB, it was deemed that the noise level was *sub-critical* and thus microphone operation would not have been impaired in that particular channel at that time and place. The results of the calculation across the measurement sample base for each location are summarized in Table 1, below.

- The left hand column of the table indicates the signal level at the receiver in terms of its ratio to the reception noise floor (*i.e.* the Carrier to Reception Noise Ratio (CRNR)). The adjacent column, on the right, shows the absolute signal power level received by the wireless microphone receiver.[2]

- Each of the remaining cells in each row gives a score for each location, at the given CRNR value, corresponding to the ratio of *the number of samples in which the noise level was found to be sub-critical to the total number of noise level samples taken in that location*. For example, if, in 99 of 100 samples, the noise level was found to be sub-critical, then the *impairment-free* score would have been 99%.

[2] This was obtained by adding the CRNR value in the first column to the reception noise floor level (which is effectively a constant, with value -115 dBm, calculated by adding the receiver noise figure of 6dB to the thermal noise power (-121 dBm (with a receiver bandwidth of 200 kHz)).

- The right hand column of the table shows an impairment-free score calculated from samples aggregated across all the locations used.

It may be observed in Table 1 that a *Carrier to Reception Noise Ratio* (CRNR) of around 60 dB is needed to ensure impairment-free scores of 100% in all locations. Given that wireless microphones require a minimum *Carrier to Interference and Noise Ratio* (CINR) of 25 dB, this implies a man-made noise increment of around 35 dB (60-25=35 dB).

		Location				
		Church Parking Lot	Inside Single Family House	Inside Condo	Wolf Trap Arena Parking Lot[3]	All Locations
Wireless Microphone CRNR (dB)	Received power level dBm	Proportion of samples where microphone operation would not have been impaired (%)				
10	-105	0%	0%	0%	0%	0%
20	-95	0%	0%	0%	0%	0%
30	-85	0%	0%	0%	0%	0%
40	-75	98.3%	91.8%	84.2%	99.1%	91.5%
50	-65	100%	99.3%	99.5%	100%	99.6%
60	-55	100%	100%	100%	100%	100%
70	-45	100%	100%	100%	100%	100%

Table 1: The potential impact of man-made noise on wireless microphone operation

The results of the measurements and analysis, presented in Table 1, show that wireless microphone links typically need to be set up with a minimum Carrier to Reception Noise Ratio of approximately 60 dB to be sufficiently protected from the impact of man-made noise in each of the venues measured.

Significantly, the noise measurements described above were made in suburban areas. Man-made noise levels in urban and metropolitan venues can reasonably be expected to be even greater.

Users compensate for man-made noise by ensuring higher received signal levels

To compensate for the relatively high level of man-made noise experienced at most major venues, wireless microphone users need to ensure that received signal levels are much greater than those that would be needed if reception noise were the only consideration. These augmented signal levels, achieved by minimizing the distance between microphone and receiver, allow wireless microphone systems to tolerate higher white space device signal levels than regulators have so far assumed.

[3] Wolf Trap is a public venue, which is known as a normally quiet location.

Section 3: Estimating the required exclusion zone size

Geo-location is one method of protecting wireless microphone operations from impairments caused by white space devices. Since the geo-location database provides the list of available channels at a given location, it is straightforward to leave out any channels which are being used by licensed wireless microphones in that area. The exclusion zone is the circular area around a particular wireless microphone receiver within which the channels used by the microphones would be excluded from the list available to white space devices. This section explains how the minimum radius of the exclusion zone can be estimated to ensure that licensed microphone operation is not impaired.

In order to estimate the required separation of a white space device from a wireless microphone receiver using the same channel, it is necessary to be able to predict the propagation loss on a path between the two devices. However, there is no single propagation loss value corresponding to a particular distance, but rather a probability distribution of loss values. The measurement process described below enabled the Shared Spectrum Company to compile a database of propagation values over a range of distances, up to two kilometers from the test transmitter position.

Propagation loss measurements

SSC carried out measurements of propagation loss for 4,094 possible white space device to wireless microphone receiver separation distances, ranging up to 2.7 km.

- Extensive measurements were conducted at three public venues, which were not in use at the time and whose wireless microphone systems had been switched off.
- A test transmitter with an emission power of 20 dBm (using a pure tone from a signal generator, centred on 556.36 MHz, with a stable frequency reference) was co-located with each venue's wireless microphone receiver, and coupled to an omni-directional antenna.
- A test receiver mounted in a van was used to measure the signal strength at a large number of locations around the outside of the venue. The receiver had an input bandwidth of 2.7 Hz, to facilitate a sensing limit of -158 dBm [calculated by adding the thermal noise power (-174+10log10 (2.7) = -169 dBm) to the receiver noise figure (11 dB)].
- The receiver was linked to an omni-directional antenna, mounted on the roof of the van, with its height matched to that of the test transmitter (2 meters above the ground). This elevated location for the receiver antenna means that the measurement results understate the likely propagation loss suffered by a signal from a real white space device, leading to a conservative exclusion zone estimate.
- In total, measurements were made at 4,094 discrete positions, achieved by driving the van around the outside of each building and tracking both the received signal level and the van position (using GPS). The measurements were captured and post-processed in MATLAB™, allowing propagation loss to be measured down to -178 dBm (= -20-158).
- The precise position of the receiver was recorded in the measurement process, but only the magnitude of its separation from the test transmitter at each measurement point was used in the subsequent analysis.

Since the measurements from each of the buildings were similar, it was reasonable to combine them into a single data set consisting of a grid of 1 dB by 1 meter 'buckets'. A simplified representation of the data set is shown in the scatter plot (Figure 3) below. For each value of separation between the transmitter and receiver locations, the plot shows the distribution of corresponding measurements of the propagation loss. Lighter blue denotes a higher density of measurement points (2 to 3) than darker blue (1).

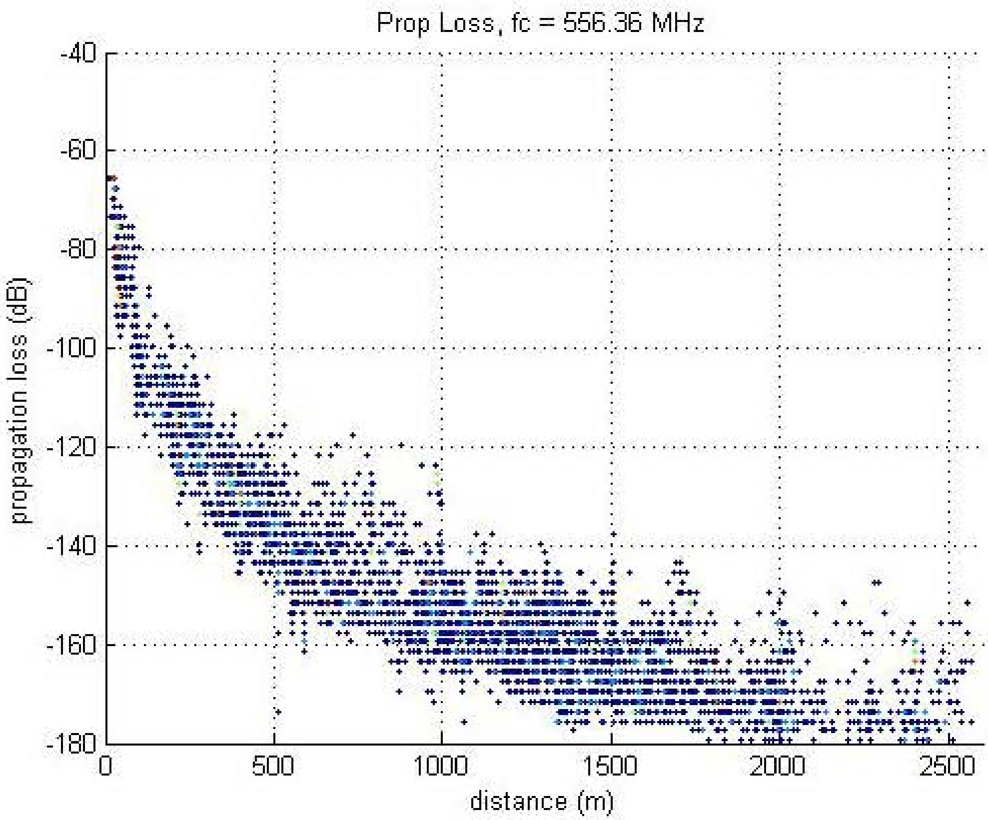

Figure 3: Propagation loss plotted against the distance between transmitter and receiver, for each of the 4,094 receiver positions at which a signal level measurement was made

Estimating the required exclusion zone size

Using the propagation loss measurements acquired through the process described above, Shared Spectrum Company was able to estimate the separation required for white space device and wireless microphone receivers.

For each of a range of signal (carrier) levels at the wireless microphone receiver, it was possible to calculate the propagation loss required to prevent interference from a white space device. The calculation assumed a white space device transmission power density of 4.4 dBm in a 110 kHz channel (equivalent to 20 dBm in a 4 MHz channel). The white space device was deemed not to cause interference in a particular position when the Carrier to Interference and Noise Ratio (CINR) remained above 25 dB at the wireless microphone receiver.

Figure 4 shows the same scatter plot as in Figure 3, overlaid with a red horizontal line showing the propagation loss required between the white space device and the wireless microphone receiver to ensure a CINR (for the wanted signal) greater than 25 dB when the wireless microphone signal level (CRNR) at the receiver is 60 dB (*i.e.* a wanted signal carrier level of greater than -54.9 dBm, *see* Table

1). The matching vertical red line indicates the distance beyond which all data points had a propagation loss equal to or greater than the minimum needed, *i.e.* all data points fell below the horizontal line. This provides the most conservative (largest) estimate of the size required for the exclusion zone.

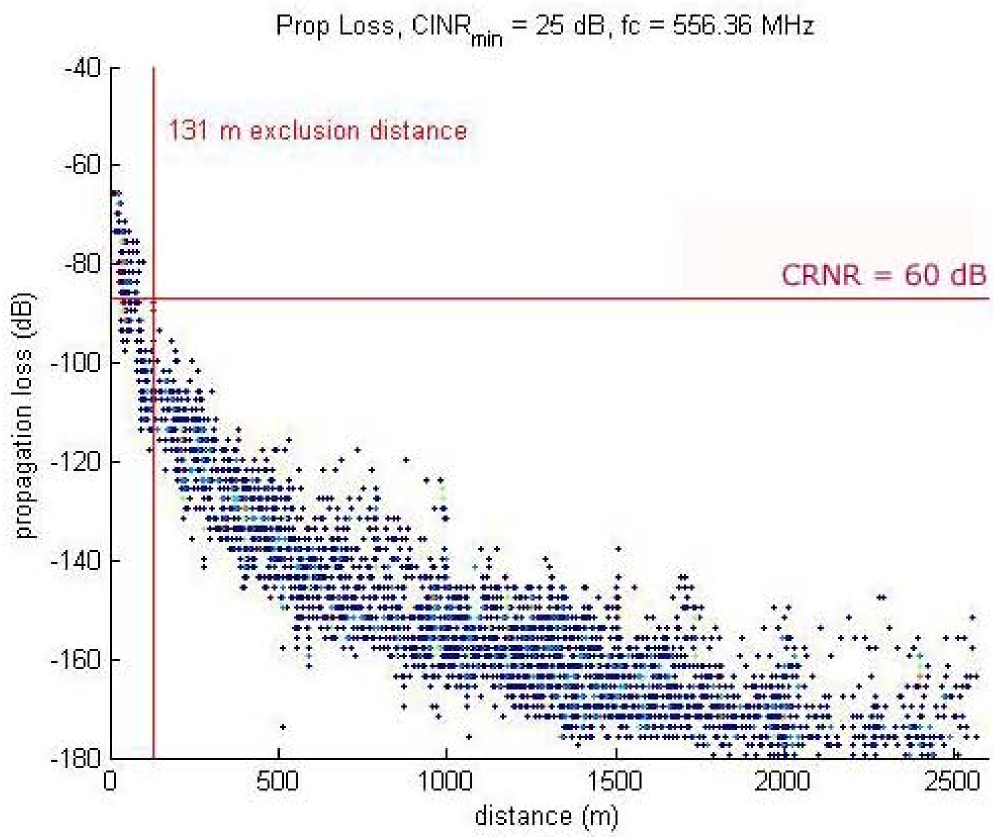

Figure 4: Required WSD exclusion zone size for a given wireless microphone signal level

[The reception noise floor used in this analysis is -117.5 dBm, calculated using a bandwidth of 110 kHz and assuming a receiver noise figure of 6 dB.]

At the microphone signal level illustrated by the horizontal red line (-57.5 dBm, corresponding to CRNR = 60 dB), the required propagation loss to avoid impairing microphone operation can be seen from Figure 4 to be around -87 dB. This minimum value of propagation loss can be seen from the figure to have been achieved at all possible values of distance greater than that marked by the vertical red line, which can therefore safely be chosen as the boundary of the exclusion zone.

The results of exclusion zone size estimations for a range of CRNR values are summarized in Table 2. The proportion of measurements made at distances greater than or equal to the chosen exclusion zone size which meet the minimum propagation loss requirement is referred to here as the *impairment-free score*. It corresponds to the percentage of positions outside the chosen exclusion zone at which a white space device would not have impaired microphone operation when operating on the same channel. A score of 100% means that a white space device operating on the same channel as the wireless microphone would not cause interference when located anywhere outside the exclusion zone.

The estimated exclusion zone sizes (radii) corresponding to various received microphone signal levels are presented in Table 2 below. The two right-hand columns of the table show how the exclusion zone could be contracted if lower levels of impairment risk were tolerable.

		Impairment-free microphone operation score		
		100%	**99.9%**	**99%**
Wireless Microphone CRNR (dB)	**Received power level dBm**	**White space device exclusion distance (m)**		
30	-87.5	732	513	280
40	-77.5	304	246	132
50	-67.6	187	131	64
60	-57.5	131	82	<50
70	-47.5	81	52	51

Table 2: Estimates of required exclusion-zone size for the data set in Figure 1 (with a WSD transmission power of 20 dBm into 4 MHz)

Since man-made noise is significantly higher than reception noise in areas where wireless microphones are used, such systems are evidently deployed with a much higher received signal than would be justified based on an assumption that only reception noise applied. It is estimated that the received signal level used is typically in excess of 60 dB above the reception noise floor (*i.e*. Carrier to Reception Noise Ratio (CRNR) = 60 dB). As set forth in Table 2, at this received signal level, a requirement for 100% impairment-free operation at this received signal level given these measurements leads to an exclusion zone for white space devices with a radius of 131 meters.

In the typical downtown settings of major theatres and studios, public access is more restricted than at the venues where our measurements were made. For acoustic isolation as well as safety reasons, access to the stage and adjacent areas is often isolated from main roads, and well separated from other internal areas such as the foyer and auditorium where the public are likely to be found. Assuming higher RF propagation loss at these locations, the exclusion zone estimates set forth above are probably higher than are needed in practice.

[The reception noise floor used here is -117.5 dBm, calculated assuming a microphone receiver bandwidth of 110 kHz and a receiver noise figure of 6 dB, to be comparable with the values used in ERA's analysis for Ofcom [3].]

Section 4: Estimating the sensing threshold

The white spaces rules established by the FCC require white space devices to find vacant UHF channels through geo-location. However, these rules also contemplate a class of devices that rely solely on spectrum sensing as an alternative method of finding vacant channels. Spectrum sensing can be used independently of geo-location and vice versa.

For devices that use spectrum sensing instead of geo-location, it is important that sensing thresholds are sufficiently low to protect licensed wireless microphones (and TV reception), but not so low as to make white space devices unnecessarily costly, difficult to produce, and likely to determine that unoccupied channels are occupied.

The previous section established that taking man-made noise and real world propagation losses into account justifies reducing the exclusion zone needed with geo-location considerably. In this section, the report considers how these factors impact the alternative spectrum sensing approach by enabling estimates for the sensing threshold required to protect licensed microphone operations.

To establish a relationship between impairment-free wireless microphone operation and the value chosen for the sensing threshold, around one million randomly-chosen possible combinations of wireless microphone, wireless microphone receiver, and white space device positions were considered using the propagation loss data gathered as described above. For each position combination, a calculation was made to determine whether microphone operation might have been impaired.

In order to generate the large number of possible position combinations required, Shared Spectrum Company used a Monte Carlo simulation. Fixing the wireless microphone receiver at the center, the simulation generated one million different combinations of wireless microphone (transmitter) and white space device positions over an area of 1 square kilometer. This is illustrated in Figure 5, below.

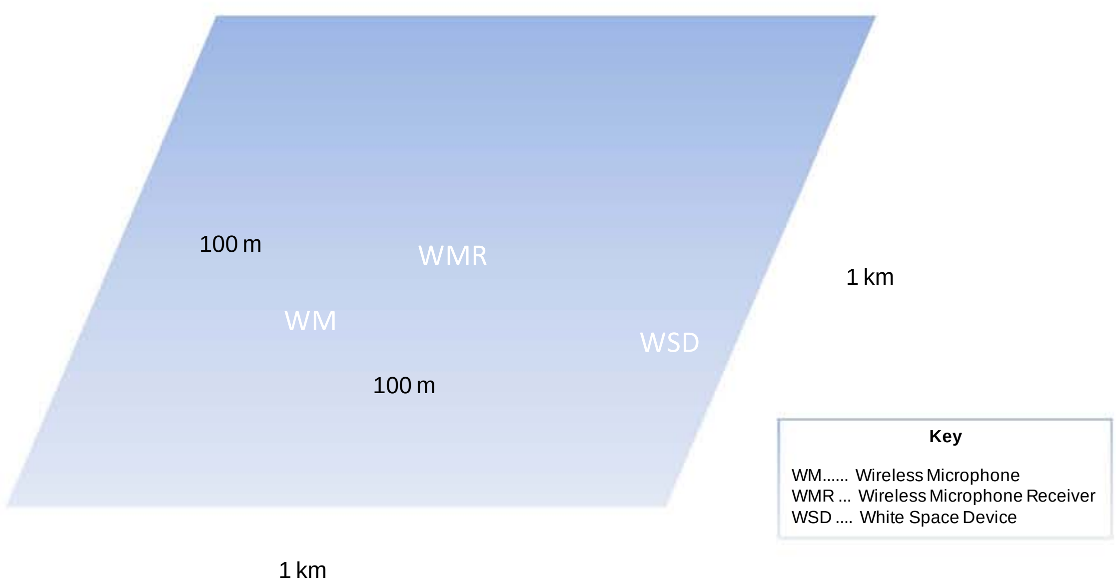

Figure 5: Simulation field for analysis of the sensing threshold requirements for white space devices

The basis for the simulation was as follows:

- The wireless microphone receiver (WMR) was positioned at the center of the grid.
- The wireless microphone (WM) was limited to positions within a 100 m square subset of the 1 km square grid, quantized to the nearest meter in each of two dimensions.
- The white space device was allowed to range anywhere within the 1 km by 1 km grid – with its position quantized to the nearest meter in each of two dimensions.

- For each point in the simulation, a propagation loss value was chosen at random from the values measured earlier for the given distances between wireless microphone and white space device and between white space device and wireless microphone receiver.
- In 5% of the points, the propagation loss was increased by 20 dB to account for body loss (applying to 50,000 out of the 1 million simulated cases).
- The wireless microphone transmission power was taken as 14.8 dBm, with a system bandwidth of 110 kHz. [A noise figure of 6 dB was used for the wireless microphone receiver, yielding a reception noise floor of -117.5 dBm.]
- The white space device's (WSD) transmission power was taken as 20 dBm within a transmission bandwidth of 4 MHz, amounting to 4.4 dBm in a 110 KHz channel.

The propagation loss model used in the simulation drew directly on the measurements described in the previous section. It was applied to transmissions between the wireless microphone and the white space device as well as between the white space device and wireless microphone receiver. Using the assumption that the model was applicable to all paths ending within the central 100 square meter zone allowed for microphone roaming in the simulation.

For each synthesized position combination generated by the simulation, the distances between the three devices were calculated and corresponding propagation loss values retrieved from the propagation loss measurement base. Since the measurement base included a number of possible propagation loss values for each value of distance, the particular value retrieved by the simulation was chosen at random from the set of applicable values for the distance in question. For example, if a distance of 90 meters corresponded to propagation loss measurements of between -80 and -100 dB, the value used by the simulation would have been chosen at random from values measured within that range.

In 5% of cases, 20 dB was added to the propagation loss to simulate the effect of body absorption.

The results of the simulation are presented in Table 3 below, with estimated sensing thresholds corresponding to a range of possible wanted signal levels at the microphone receiver. In the third column, the sensing threshold value given ensures 100% impairment-free operation – meaning that in all the cases in the simulation, either the wireless microphone signal was detected by the white space device or the white space device was sufficiently separated from the wireless microphone receiver for its transmissions not to impair microphone operation. For example, if the Carrier to Reception Noise Ratio (CRNR) equalled 60 dB, a sensing threshold requirement of -111 dBm for the white space device would have been sufficient to protect wireless microphone operation from impairment when both were using the same microphone channel. Either the white space device would have been able to detect the wireless microphone at the specified threshold and would have moved to an alternative channel or its signal would have been too weak to cause impairment of wireless microphone operation.

The two right hand columns of Table 3 show how the required sensing threshold could be relaxed if a negligible impairment risk to microphone operation were tolerable.

		Impairment-free microphone operation score		
		100%	99.9%	99%
Wireless Microphone CRNR (dB)	Received power level (dBm)	White space device detection threshold (dBm)		
30	-87.5	-144	-144	-141
40	-77.5	-133	-122	-98
50	-67.6	-119	-101	-84
60	-57.5	-111	-85	-69
70	-47.5	-104	-71	>-60

Table 3: Estimated sensing threshold values for white space devices (with a WSD transmission power of 20 dBm into a 4 MHz channel)

The reception noise floor used as the reference for CRNR here is -117.5 dBm, calculated assuming a bandwidth of 110 kHz and an equipment noise figure of 6 dB, comparable with ERA's analysis for Ofcom [3].

Section 5: Our recommendations

We appreciate the FCC's desire to take a "cautious and conservative" first step in establishing operating parameters for white space devices, including paramenters intended to protect licensed wireless microphones. However, we believe that the effects of man-made noise should be accounted for when determining those parameters. When this is done using real-world propagation loss estimates, the required exclusion zone for geo-location based protection can be safely and conservatively set at around 130 m (see Table 2). For applications that rely on the alternative sensing-based protection, white space devices can safely use a sensing threshold which is at a level that is less sensitive than -111 dBm (in a 110 kHz channel) – (see Table 3). This finding supports prior industry suggestions to use -107 dBm as a threshold for sensing [4].

Section 6: References

1. FCC (2008), Second Report and Order and Memorandum opinion and Order (FCC 08-260), 1:85, p. 35, 4 November.

2. Ofcom (2009), 'Digital dividend: cognitive access, Statement on licence-exempting cognitive devices using interleaved spectrum ', 2:2, p. 2- 4, 1 July.

3. Cobham/ERA (2009), 'Analysis of hidden node margins for cognitive radio devices potentially using DTT and PMSE spectrum', January 2009.

4. Comments of Shure Incorporated in the matter of Unlicensed Operation in the TV Broadcast Bands (ET Docket No. 04-186) and Additional Spectrum for Unlicensed Devices below 900 MHz and in the 3 GHz Band (ET Docket No. 02-38), before the FCC, November 30, 2004.

Appendix

A1 Measuring man-made noise

A spectrum analyser and digitizer were used in conjunction with an omni-directional antenna to conduct measurements of noise (including the man-made element) in 150 potential wireless microphone channels (200 kHz), distributed over ten vacant UHF channels, at a number of measurement points in each location. Shared Spectrum Company made up to ten measurements on each of the 150 potential wireless microphone channels over a period of up to 20 minutes. The measurement process was repeated at each of four to five positions at the four chosen locations.

High speed sampling was used to record noise in a central 3 MHz band in each of ten vacant UHF channels. Post processing was then used to subdivide each 3 MHz segment into 15 potential microphone channels (200 kHz in width) and to measure the noise level in each, as shown in Figure A1. Thus, distributed over ten UHF channels, there were 150 potential microphone channels examined at each location.

Calibrating the noise measurements

The first step in the measurement process was to determine the reception noise floor of the measurement system. To confirm the theoretical noise calculation, noise measurements were first performed at a relatively quiet location: the car park at Wolf Trap, Virginia. The reception noise floor of the measurement equipment (using a 200 kHz bandwidth) was confirmed as -110 dBm, given a thermal noise floor value of -121 dBm and equipment noise figure of 11 dB. Any signal value above this level was interpreted as man-made noise.

The Carrier to Reception Noise Ratio (CRNR) values given earlier in this paper are referred to a reception noise floor of:

1. -115 dBm (rounded down from -114.9), in the man-made noise impact sections (Sections 1 and 2), corresponding to a noise figure of 6 dB and a channel bandwidth of 200 kHz.
2. -117.5 dBm, in the exclusion zone and sensing threshold section (Section 3), corresponding to a noise figure of 6 dB and a channel bandwidth of 110 kHz. These bandwidth and noise figures were chosen to allow comparison with the results of ERA's analysis for Ofcom [3].

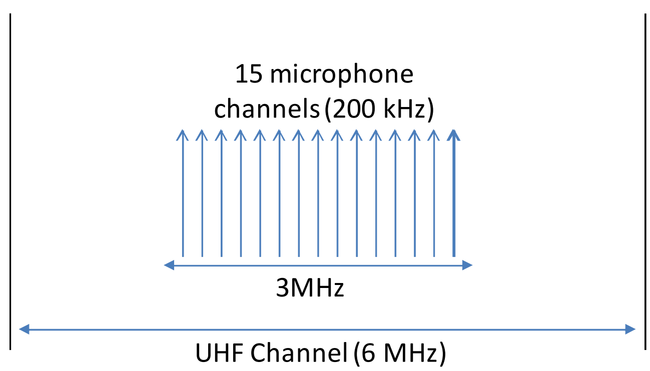

Figure A1: Measurements made in vacant UHF channels were post-processed into 150 microphone channels (200 kHz wide)

At each measurement position, each channel was sampled for 163 ms on 10 separate occasions during a period of approximately 20 minutes to examine temporal changes in the noise level. This timing is illustrated in Figure A2.

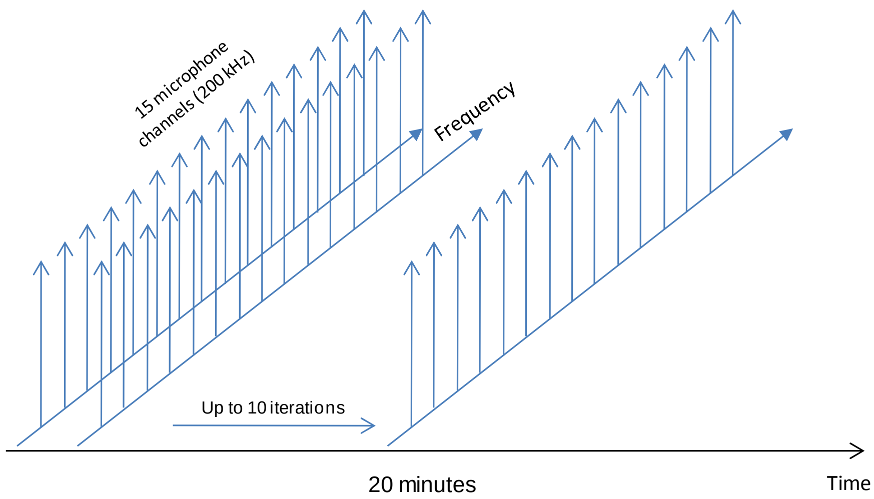

Figure A2: The time structure of the noise measurement sampling

Measurement Locations

A total of 19 measurement points were used, distributed across four locations as follows:

1. Single family house and Apartment 5
2. Apartment (condo) 5
3. Car park 4
4. Wolf Trap (an open air venue) 5

A2 Noise Power Distribution – from the measurements

The following charts summarize the results of the measurements conducted in Phase 1 of our research, showing the distribution of noise power measurements in each of four locations. The location is indicated at the top of each chart. The reception noise floor for the measurement system was determined to be -110 dBm.

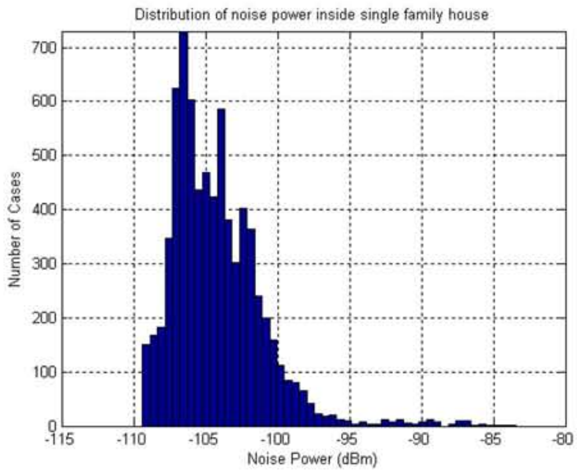

Figure A3: Noise levels distribution from measurements taken inside a house.

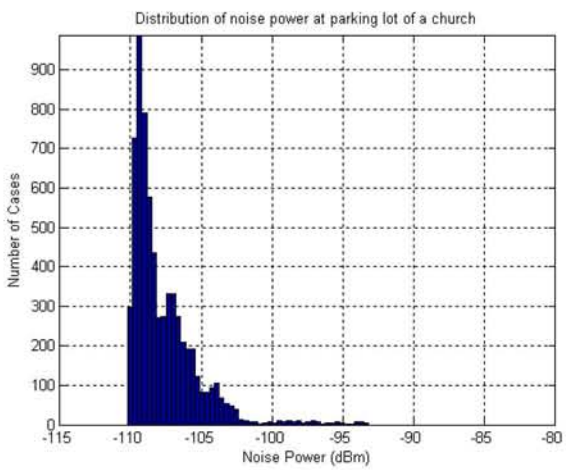

Figure A4: Noise levels distribution from measurements taken in a car park.

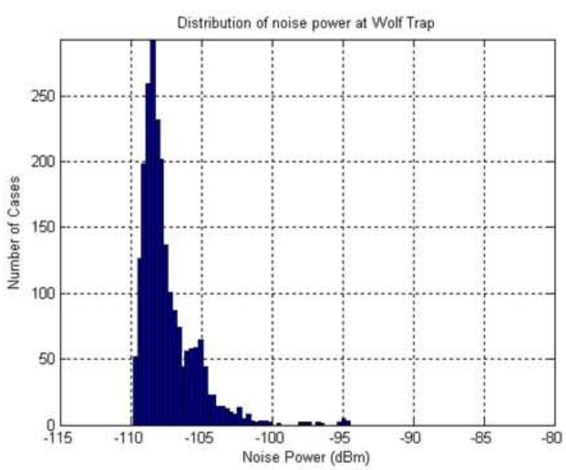

Figure A5: Noise levels distribution from measurements taken at Wolf Trap, VA.

A3 ITU Guidelines on Man-Made Noise Levels

ITU-R Recommendation P.372-9 includes a chart, reproduced in Figure A6 below, which indicates the internationally accepted mean noise levels plotted against frequency, by location category.

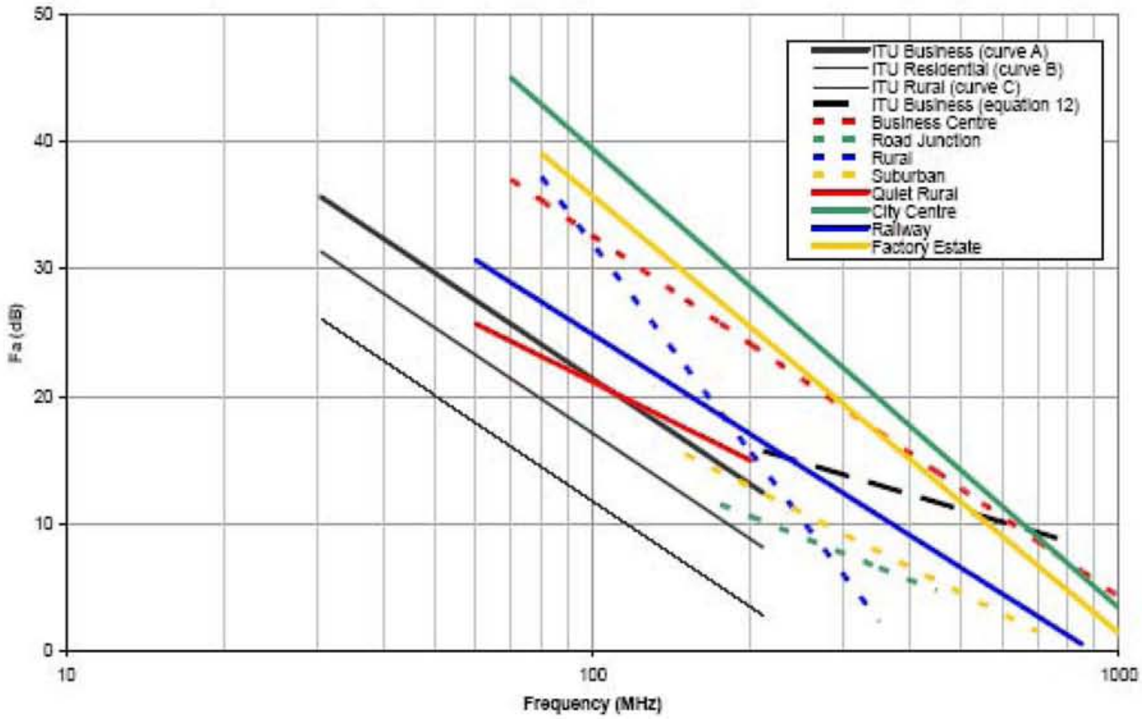

Figure A6: Man-made noise levels by frequency and types of location

F_a, represented by the y-axis, is the external noise figure of the system. It is defined as:

$$F_a = 10\log\left({}^{p_n}/_{kt_ob}\right) \qquad dB$$

Where:

p_n: available noise power from an equivalent lossless antenna

k: Boltzmann's constant = 1.38×10^{-23} J/K

t_o: reference temperature (K) taken as 290 K

b: noise power bandwidth of the receiving system (Hz).