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Summary

This report presents the results of practical measurements undertaken by ERA Technology and Aegis Systems detailing the minimum usable sensitivity and selectivity of Assistive Listening Devices (ALDs), In-Ear Monitor (IEM) and wireless microphone (PMSE) receivers to co-channel DAB interference.

Five SRD devices available in the UK operating in the ETSI license exempt band of 169 MHz to 175 MHz were identified and tested. The devices tested included three ALDs, one IEM and one amateur wireless microphone sourced from different manufacturers and suppliers.

Measurements have been undertaken in a Fully Anechoic Room to determine minimum usable sensitivity and selectivity for these SRDs.

The results suggest that adjacent-channel interference to IEM systems is unlikely, and co-channel use is likely to be possible except in very close proximity to a DAB transmitter, owing to the low sensitivity of the devices and the low audio signal-to-noise ratio at which they operate. Sharing will be further eased when building penetration loss is allowed for.

It will be harder to ensure compatibility with the ALDs, as these have good sensitivity and can offer high audio quality; outdoor, co-channel use is unlikely to be feasible anywhere within a DAB service area. The selectivity of those ALDs tested is, however, very good, so adjacent channel use may be possible in many circumstances; For indoor use, the combination of building loss on the interfering signal and high FM link margin will often (e.g. in school classrooms) be sufficient to protect against DAB interference.

The wireless microphone system provides the worst compatibility, combining fairly high sensitivity with very poor selectivity.

The compatibility testing described here should provide a basis for the statistical modelling that will be necessary to determine the risk of interference to short-range audio FM systems from DAB transmissions.
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<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>ALD</td>
<td>Assistive Listening Device</td>
</tr>
<tr>
<td>AM</td>
<td>Amplitude Modulation</td>
</tr>
<tr>
<td>BNC</td>
<td>Bayonet Neill-Concelman</td>
</tr>
<tr>
<td>DAB</td>
<td>Digital Audio Broadcasting</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DUT</td>
<td>Device Under Test</td>
</tr>
<tr>
<td>EEP</td>
<td>Equal Error Protection</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunication Standards Institute</td>
</tr>
<tr>
<td>FAR</td>
<td>Fully Anechoic Room</td>
</tr>
<tr>
<td>FM</td>
<td>Frequency Modulation</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
<tr>
<td>IEM</td>
<td>In-Ear Monitor</td>
</tr>
<tr>
<td>IF</td>
<td>Intermediate Frequency</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
</tr>
<tr>
<td>MUS</td>
<td>Minimum Useable Sensitivity</td>
</tr>
<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
</tr>
<tr>
<td>OOI</td>
<td>Onset of Impairment</td>
</tr>
<tr>
<td>PMSE</td>
<td>Programme Making And Special Events</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal –To- Noise ratio</td>
</tr>
<tr>
<td>SINAD</td>
<td>Signal-Noise And distortion Ratio</td>
</tr>
<tr>
<td>SRD</td>
<td>Short Range Devices</td>
</tr>
<tr>
<td>UEP</td>
<td>Unequal Error Protection</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
</tr>
</tbody>
</table>
1. Introduction

Ofcom is currently considering the potential deployment of DAB services in the 174.160 – 175.696 MHz frequency block 5A. As part of this consideration, Ofcom wants to develop a better understanding of the ability of DAB services to co-exist with short range devices (SRD) currently operating in the frequency range of 169 – 175 MHz, which include assistive listening devices (ALD) and programme making & special event (PMSE) wireless microphones.

A measurement programme was undertaken to verify the performance of a small sample of devices and to quantify the impact of co-channel DAB interference. This study addresses the following questions:

1. Determine the SRDs receiver sensitivity, expressed in dB(μV/m);
2. Determine the maximum in-channel interfering DAB field strength at which they are able to continue to reliably operate using a typical range of SRD received signal strengths.

As a result of the lack of availability and variety of SRDs operating within the ETSI license exempt band relevant to this study, it was possible to assess the performance of only five devices.

A previous study undertaken by ERA Technology Ltd assessed the potential for interference from new Terrestrial Digital Audio Broadcast (T-DAB) allocations to Radio Microphones operating in VHF Band III, sub-band 3. Details of the results can be found in [5].

2. Background: Compatibility of Licence Exempt Devices with DAB Transmissions in Block 5A

The tuning range of VHF DAB radios is from 174 MHz to 240 MHz (Blocks 5A to 13F, see Figure 1 for lower end spectrum, i.e. Blocks 5A and 5B). Since the launch of DAB, services in the UK have only used the sub-band 218 – 230 MHz (Blocks 11B-12D). The UK does, however, have international clearance for the use of Block 5A, and planning is underway to examine the implications of bringing this channel into use.

One significant issue is that Block 5A overlaps with existing licence-exempt allocations in the UK. These allocations\(^1\) are typically used for low-power, short range audio devices such as

\(^1\) The bands are listed in Table 2 of Annex B of the UK Frequency Allocation Table. Bands R2 (microphones) and H1 (Hearing Aids) are indicated in Figure 1.
wireless microphones, cordless headphones and ‘assistive listening devices’ (ALD) for the hard of hearing.

![Figure 1: Sketch of spectrum relationships](image)

The simplified sketch above shows the potential for mutual interference between these devices. The present study was required to quantify the impact of DAB transmissions on typical low-power audio devices in this band.

The DAB signal consists of 1536 individual OFDM carriers, at a spacing of 1 kHz. The carrier at the centre frequency (corresponding to DC in a direct conversion receiver) is suppressed. The lowest carrier is 768 kHz below the channel centre, and the edge of the DAB signal is, therefore, at f_c – 768.5 kHz. For channel 5A, this point is at 174.928 – 0.7685 MHz = 174.1595 MHz.

Although the DAB signal power falls off very sharply at +/- 768.5 kHz, intermodulation in the transmitter or generator amplifier ensures that out-of-band emissions in the adjacent spectrum are likely to be at levels of only around 30 dB below the wanted signal\(^2\) and this will limit the improvement in protection ratio expected as an FM system moves outside the DAB channel bandwidth.

3. An Overview of the Devices Tested

Five devices were tested for this study:

- Three Assistive Listening Devices (hereafter called ALD1, ALD2 and ALD3);
- One Amateur Radio Microphone (hereafter called MIC);
- One In-Ear Monitoring Device (hereafter called IEM).

\(^2\) The standard transmitter mask (EN 300 401) requires a 30dB suppression at 200 kHz from the nominal band edge. For the ‘critical mask’ this is tightened to 45dB.

Ref: 1\(^{st}\)enc\Projects Database\Ofcom - RAD0006001-7A0719001 - ALD and Radio Mics\ERA Reports\Main report\Rep-6965 - 2012-0337 (Issue 2).docx
3.1 Assistive Listening Devices

Assistive Listening Devices (ALDs) with specific frequency response and dynamic characteristics are used by persons with impaired hearing. They are normally used to enhance audio reception when watching TV and by students in classrooms. Some ALDs work alongside traditional hearing aids while many others are stand-alone products. ALDs differ from traditional hearing aids as ALDs are intended to amplify specific sound sources while hearing aids aim to amplify all ambient sounds.

A typical ALD system works on a similar basis to a commercial VHF radio network. The system includes a transmitter unit which is made up of an internal microphone unit, an FM modulating sub-system and a frequency selector for selecting a transmit frequency. There is also a receiver unit that receives and demodulates the transmitted FM signal for the hearing aid user.

The transmitter can be used with either its internal microphone or a range of audio inputs using suitable leads.

There are two types of receiver units on the market in the UK today. They are the types worn over the ear which have an integrated FM receiver and a loud speaker and the body-pack worn type with a headphone for listening by the user. Examples of the types of ALD receiver units tested are shown in Figure 2 below.

Three different types of ALDs were sourced and tested: two ALDs with separate headphones and one over-ear ALD.
3.2 In-ear Monitoring Devices

In-ear monitoring (IEM) devices are often used by musicians, conductors, audio engineers and audiophiles to provide a high level of noise reduction from ambient surroundings.

This small device is, as the name implies, designed to be worn in the ear and might be used, for example, to provide cues to television presenters. The antenna is a very short wire (~1cm) protruding from the device (see Figure 3).

A typical IEM device has a FM transmitter having a frequency selector module with suitable audio input ports and a portable receiver unit that is placed in the user’s ear to receive and demodulate the transmitted signal.

No details of the internal circuitry are known, although the unit appears to use some form of tone squelch, as the earpiece does not respond to signals from a signal generator - the associated transmitter presumably adds a sub- or supersonic tone to the normal modulation.

Figure 2: Two types of ALD receivers
The unit tested (see Figure 3) was set to operate at a frequency of 200.3 MHz.

![Figure 3: In-Ear Monitor and its associated transmitter](image)

**3.3 Wireless Microphone (PMSE) Device**

This budget wireless microphone system (see Figure 4) features two entirely separate VHF FM receivers, tuned to different (fixed) frequencies, in the same box, each fed from its own telescopic aerial. The device is supplied with a pair of microphones, one working on 174.1 MHz and the other on 175.0 MHz. The audio outputs of the two receivers are combined into a single channel.

The two receivers are very simple, each consisting of a single IC, an AM/FM broadcast receiver with the AM section disabled. This is configured to use a pair of cascaded ceramic IF filters with a nominal bandwidth of 120 kHz (much wider than that required by the transmitted signal).

The specification quotes a peak deviation of 30 kHz, although measurement showed the value to be closer to 15 kHz, with normal speech or singing giving values of around 8 – 12 kHz.

The output of this device feeds the ‘expander’ part of a compander IC, marketed for use in cordless telephone handsets, and the circuit is completed with a two-transistor audio amplifier and a comparator IC to drive the muting circuit. The use of the expander implies...
that the system should be tested only using a compatible transmitter (i.e. the supplied microphones) rather than a standard signal generator.

To allow testing, one of the microphones was modified with a BNC connector on the RF output.

**Figure 4: Wireless microphone system**
4. Test Set-Up - DAB Interference into SRD

This section provides information on the test set-up and configurations.

4.1 Unwanted DAB Interference Parameters

The unwanted DAB signal (see Figure 5) was produced by a specialised signal generator. The signal parameters complied with ETSI Standard EN 300 401 [1]; the main parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1: Unwanted DAB Signal Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Transmission Mode</td>
</tr>
<tr>
<td>Modulation</td>
</tr>
<tr>
<td>Sub-carriers</td>
</tr>
<tr>
<td>Guard Interval</td>
</tr>
<tr>
<td>Error Coding¹</td>
</tr>
<tr>
<td>Data Rate²</td>
</tr>
</tbody>
</table>

Notes:

1. EN 300 401 defines two kinds of error protection: Unequal Error Protection (UEP) used for audio sub-channels, and Equal Error Protection (EEP) tailored for data services. The protection level is an indication of the used code rate.

2. Typical data rate for stereo music and speech services in the UK is 128 kbps, although other data rates are in use.

The spectrum mask produced by the signal generator was verified using a spectrum analyser prior to commencement of the measurements, in order to ensure that it complied with the "Critical" mask specified in Clause 15 of EN 300 401 (reproduced in Figure 6).
Figure 5: Simulated DAB signal emissions from signal generator
Figure 6: DAB spectrum mask

4.2 Typical Equipment Arrangement

All measurements were performed inside a Fully Anechoic Room (FAR) to minimise the possibility of outside interference from local DAB multiplexes.

The following generic test set-up was used to conduct the radiated measurements for this study. Figure 7 shows the test set-up.
4.3 Minimum Useable Sensitivity of the Receivers

The test methods for characterising the MUS are defined in ETSI standards:

- EN 300 422-1 V1.3.2 [2] for ALDs;
- EN 301 357-1 [3] for the IEM;

Each of the receivers was placed, in turn, in a fully anechoic room, with the audio output carried outside the chamber through a dielectric tube (a hosepipe). In the case of the IEM and the ALDs, the earpiece was taped directly to the end of the pipe; in the case of the wireless microphone receiver, a separate amplified loudspeaker was fed from the receiver (line-level) output, and the pipe was taped to the loudspeaker. For the ALDs where the
earphone leads act as antennas (ALD 2 and ALD 3), these were taped to a plastic support, running vertically with the receiver at the bottom. The telescopic whip on the microphone receiver was fully extended and vertical.

In each case, the associated transmitter was placed outside the chamber, and connected to a calibrated log-periodic antenna within the chamber. The IEM transmitter had a BNC connector, and the wireless microphone was modified to feed a BNC socket rather than the usual short internal antenna. In the case of ALD2/3, the inner of a coaxial cable was taken to the socket normally used for the wire antenna and the coaxial outer taken to ground at the line input connector. The power measured from each device (except ALD1) is shown in Table 2. It should be borne in mind that the devices may not be intended to provide a match to a 50Ω system.

<table>
<thead>
<tr>
<th>Device</th>
<th>Measured power</th>
<th>Specified power</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALD1</td>
<td>Not recorded</td>
<td>-</td>
</tr>
<tr>
<td>ALD2</td>
<td>-2.4 dBm (0.6 mW)</td>
<td>0.1 / 1.0 mW (standard / extended)</td>
</tr>
<tr>
<td>ALD3</td>
<td>-4.1 dBm (0.4 mW)</td>
<td>-</td>
</tr>
<tr>
<td>IEM</td>
<td>+25.1 dBm (324 mW)</td>
<td>50mW / 100mW / 300 mW</td>
</tr>
<tr>
<td>MIC</td>
<td>+2.4 dBm (1.7 mW)</td>
<td>&lt; 10 mW</td>
</tr>
</tbody>
</table>

The receivers under test were placed at a distance of 4.45m from the transmit antenna in the chamber. Knowing the transmitter powers, feeder losses and antenna gain, the field strength at the receiver position can be calculated. The predicted field strengths were verified using a biconical dipole probe feeding a spectrum analyser. In all cases, measured and predicted values were within 0.5 dB.

Due to the difficulty of interfacing to the devices under test (due to the use of headphone leads as antennas and the absence of test points on the IEM) all measurements were made subjectively. Sensitivity was assessed at the ‘onset of impairment’ (OOI) and at the point of muting. The former criterion corresponded to Grade 4 on the ITU-R five-grade impairment scale (i.e. Perceptible, but not annoying).

4.4 Selectivity

The key receiver characteristic of interest to this study is blocking / desensitization. This is usually defined as “a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unmodulated input signal at any frequency within a defined distance”.

Ref: J:\emc\Projects Database\Ofcom - RAD0006001-7A0719001 - ALD and Radio Mics\ERA Reports\Main report\Rep-6965 - 2012-0337 (Issue 2).docx
Blocking is specified as the ratio in dBs of the level of an unwanted signal to a specified level of the wanted signal at the receiver input for which a defined degradation of the received signal occurs.

As the FM devices are either fixed in frequency or can tune only between predefined channels, the selectivity of the FM systems has been explored by changing the frequency of the interfering DAB signal in small increments. This is an artificial situation as DAB signals would only ever be radiated on the channels defined in the specification, but it is a valid approach to measurement.

For an FM system with a nominal 25 kHz channel bandwidth, it would be expected that significant interference would start to occur as the separation between FM and DAB channel centres falls below \((12.5 + 768.5 =) 781\) kHz. The worst-case interference situation will be reached at separations of \((768.5 – 12.5 =) 756.0\) MHz or less, as the IF passband of the FM receiver falls wholly within the DAB spectrum.

In the measurement arrangement chosen, the ‘wanted’ field strength at the device under test was set to be 10 dB above the ‘onset of impairment’ (OOI) level, using a variable attenuator in the transmitter output.

The ‘interfering’ DAB signal from the generator was combined with the wanted signal, and the power required to degrade the wanted signal to ITU-R Grade 4 was noted for a range of frequency offsets. The DAB signal used was representative of standard UK transmissions (Mode 1, UEP level 3).
5. Results

Minimum Usable Sensitivity

Table 3 shows the measured minimum useable sensitivities (MUS) of the five receivers tested during this study using a calibrated antenna and a spectrum analyser within their respective operational bandwidth.

Table 3: Minimum useable sensitivity of the devices tested

<table>
<thead>
<tr>
<th>DUT</th>
<th>MUS</th>
<th>OOI</th>
<th>Receiver Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALD1</td>
<td>56.2 dB(μV/m)</td>
<td>Not measured</td>
<td>&lt;25 kHz</td>
</tr>
<tr>
<td>ALD2</td>
<td>37.4 dB(μV/m)</td>
<td>51.3 dB(μV/m)</td>
<td>&lt; 30 kHz</td>
</tr>
<tr>
<td>ALD3</td>
<td>37.5 dB(μV/m)</td>
<td>55.9 dB(μV/m)</td>
<td>&lt; 30 kHz</td>
</tr>
<tr>
<td>IEM</td>
<td>52.1 dB(μV/m)</td>
<td>61.1 dB(μV/m)</td>
<td>&lt; 5 kHz</td>
</tr>
<tr>
<td>MIC</td>
<td>42.4 dB(μV/m)</td>
<td>46.4 dB(μV/m)</td>
<td>&lt; 120 kHz</td>
</tr>
</tbody>
</table>

It was not possible to compare the MUS levels measured with manufacturers specifications as the manuals did not provide such information.
The information given in Table 3 is presented graphically in Figure 8.

It should be noted that the wireless microphone has a very aggressive muting system, which silences the microphone very close to the onset of interference. The other systems allow significant degradation by noise before the mute operates.

The relatively low sensitivity of the IEM is undoubtedly due to the very small antenna size possible in this application.

The apparently rather small difference (5 dB) in OOI sensitivity between ALD3 and the IEM is misleading, and is a reflection of the fact that the absolute audio noise level of the IEM, even with a fully-quieting input, is very high and this tends to hide any FM noise due to a low RF signal. On the other hand, ALD3 has a much higher sensitivity, but any degradation is very obvious owing to the high quality of the received audio.

The difference in the OOI point between ALD2 and ALD3 is due to the fact that the earphones are of different types; although performance was very similar when listening directly, when coupled via the acoustic conduit some of the high-frequency noise from ALD2 was lost, masking FM hiss and giving an apparently better performance.
5.1 Selectivity

The results are presented in terms of the difference between the DAB centre frequency and the FM audio carrier frequency. In all cases, the FM carrier is on the low-frequency side of the DAB signal. The actual frequency used by each of the audio devices is given in the table below.

<table>
<thead>
<tr>
<th>DUT</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALD1</td>
<td>174.880 MHz</td>
</tr>
<tr>
<td>ALD2</td>
<td>173.350 MHz</td>
</tr>
<tr>
<td>ALD3</td>
<td>173.350 MHz</td>
</tr>
<tr>
<td>IEM</td>
<td>200.300 MHz</td>
</tr>
<tr>
<td>MIC</td>
<td>175.000 MHz</td>
</tr>
</tbody>
</table>

The protection ratio curves for the devices are given in Figure 9 and Figure 10. In all cases, the protection ratio is the ratio between the FM carrier power and the total DAB channel power (measured in a 1.536 MHz bandwidth). The largest offsets that could be investigated were limited by the output power available from the generator.

The difference between the performance of the wireless microphone (which uses ceramic IF filters with a 120 kHz bandwidth) and that of the ALD2 and ALD3 (crystal filters, dual-superhet) can be seen clearly. The IEM shows surprisingly good selectivity for such a small device (perhaps implementing channel filtering at baseband); its protection ratio requirements are rather low owing to the masking effect of the high audio noise level already mentioned.

As the minimum required field strengths of the devices are known, these curves can be presented in terms of the ‘maximum permissible DAB field strength’ for different frequency offset values. This data is presented in Figure 11, which subtracts the protection ratio from the OOI, as shown in Table 3, in each case.

---

3 At 200 kHz from the edge of the DAB spectrum, the output of the SFE is -50dB with respect to in-band power. The ‘tails’ of the curves in Figure 9 to Figure 11 therefore correctly reflect receiver performance rather than test equipment limitations.

4 The OOI has not been measured for ALD1, therefore the maximum permissible DAB field strength could not be calculated for this device.
Figure 9: Protection ratio curves for DAB interference to FM devices

Figure 10: Protection ratio curves for DAB interference to FM devices (detail)
Figure 11: Implied maximum DAB field strength versus frequency offset

*NB: for the case of a DAB signal on channel 5A, an 800 MHz offset would correspond to an FM carrier frequency of 174.128 MHz*

5.2 Effect of Body Loss for Personal Receivers

As all ALDs and IEM are worn by the users, the effect of body loss for the receivers tested has not been taken into consideration. It was however noted that the position of the ALD and IEM receivers in relation to the transmit antenna in the test set-up caused a slight degradation to the signal quality received.

6. Conclusions

Measurements have been undertaken in a Fully Anechoic Room to determine minimum usable sensitivity and selectivity for five different SRDs comprising three assistive listening devices, one in-ear monitor and one wireless microphone available on the UK market which use ETSI license exempt 169 – 175 MHz frequency range.

The results suggest that adjacent-channel interference to IEM systems is unlikely, and co-channel use is likely to be possible except in very close proximity to a DAB transmitter, owing to the low sensitivity of the devices and the low audio signal-to-noise ratio at which they operate. Sharing will be further eased when building penetration loss is allowed for.
It will be harder to ensure compatibility with the ALDs, as these have good sensitivity and can offer high audio quality; outdoor, co-channel use is unlikely to be feasible anywhere within a DAB service area. The selectivity of those ALDs tested is, however, very good, so adjacent channel use may be possible in many circumstances; For indoor use, the combination of building loss on the interfering signal and high FM link margin will often (e.g. in school classrooms) be sufficient to protect against DAB interference.

The wireless microphone system provides the worst compatibility, combining fairly high sensitivity with very poor selectivity.

The compatibility testing described here should provide a basis for the statistical modelling that will be necessary to determine the risk of interference to short-range audio FM systems from DAB transmissions.

7. References

Radio Broadcasting Systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers

[2] ETSI EN 300 422-1 V1.3.2 (2008-03)
Electromagnetic compatibility and Radio spectrum Matters (ERM); Wireless microphones in the 25 MHz to 3 GHz frequency range; Part 1: Technical characteristics and methods of measurement

Electromagnetic compatibility and Radio spectrum Matters (ERM); Cordless audio devices in the range 25 MHz to 2 000 MHz; Part 1: Technical characteristics and test methods

Electromagnetic compatibility and Radio spectrum Matters (ERM); Technical characteristics for Professional Wireless Microphone Systems (PWMS); System Reference Document

[5] Compatibility study between PMSE radio microphones and terrestrial-digital audio broadcast in VHF Band III, Sub-band 3, Phase 2
ERA Report No 2006-0716, December 2006