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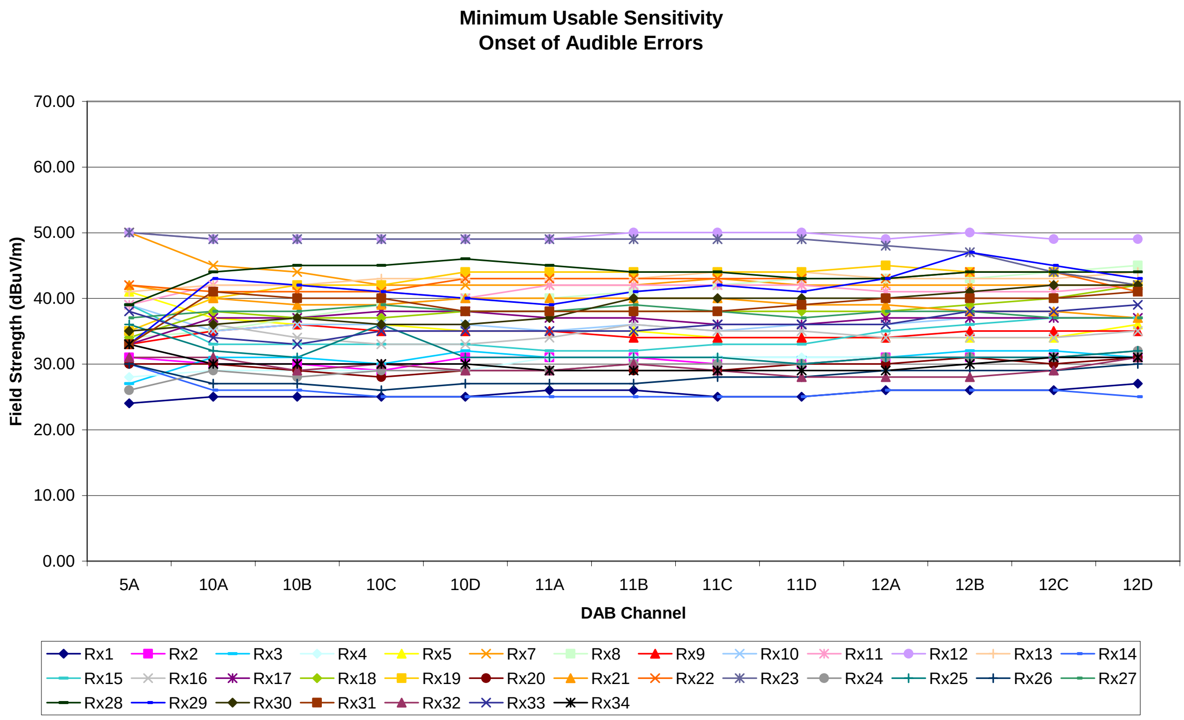
## Summary

This report presents the results of radiated measurements to determine the minimum usable sensitivity and selectivity for thirty three different Digital Audio Broadcast receivers available on the UK market in March/April 2011. The study only considers in-home receivers; in-car radios or adaptors such as USB devices for laptop computers have not been considered.

Representative devices were selected from six main groups: personal, portable, clock radio, docking stations, Hi-Fi and devices enabled for Wi-Fi internet streaming. Some receivers can be classified under more than one group, e.g. clock radios may also have a docking station. In these cases the receivers have been grouped according to their primary function as described by the manufacturer. In all cases the receivers were tested with their factory default settings. No attempt was made to investigate the impact of changing any settings on receiver performance.

The results for minimum usable sensitivity (MUS) at the onset of audible errors are summarised in the figure below.

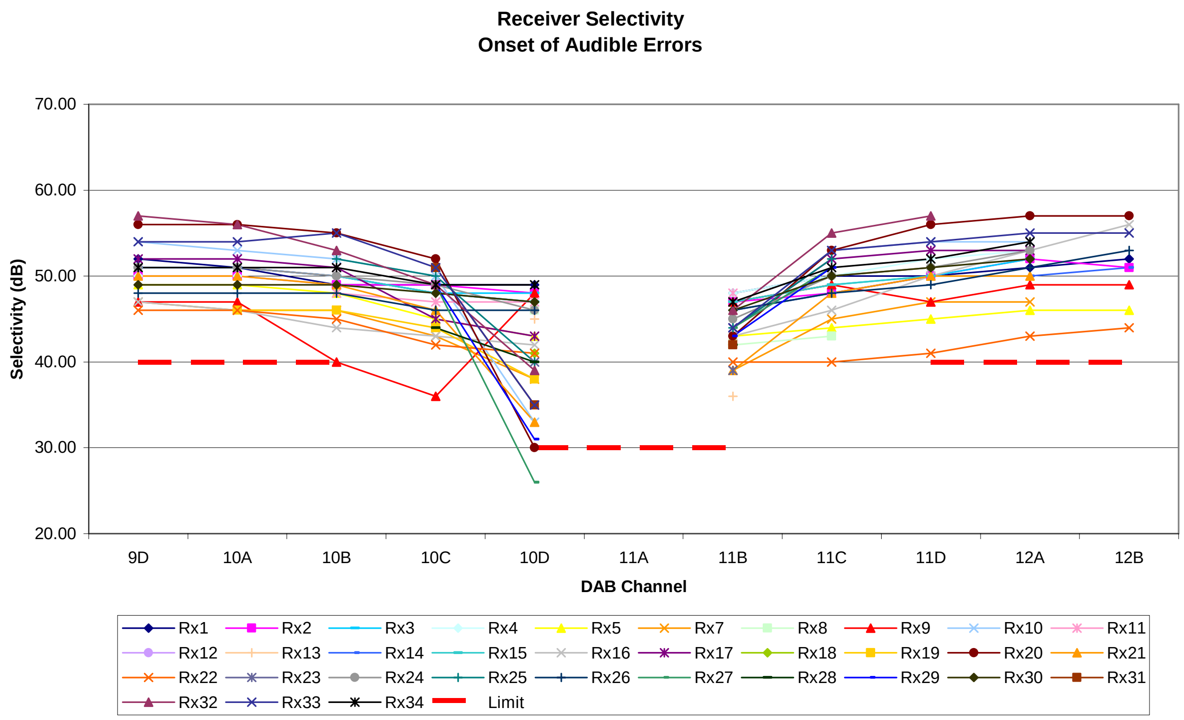



The results show that:

- There is a difference of 24 dB between the best and worst performing receivers, with the best receiver having a MUS of 25 dBuV/m and the worst having a MUS of 49 dBuV/m;

- The average MUS across all 33 receivers at Channel 11A is 36.05 dBuV/m; the average across all receivers and all channels is 36.33 dBuV/m.

The results for receiver selectivity at the onset of audible errors are summarised in the figure below.




The results show that:

- For the first adjacent channel (N±1) all of the receivers except Rx27 meet the minimum requirement in BS EN 62104:2007 [3] of ACS ≥ 30 dB;
- For frequency offsets ≥ 5 MHz from the centre of the wanted DAB signal all of the receivers meet the minimum requirement in BS EN 62104:2007 of 40 dB. (*Note that this requirement is specified in EN 62104 for an FM modulated signal.*).

Additional testing shows that MUS is degraded slightly when receivers are operated on mains power compared to battery. The average reduction in MUS across all receivers tested is 1.28 dB.

Analysis of antenna type and orientation shows that this can have a large impact on the results. Telescopic antennas provide better sensitivity than wire or headphone antennas. However, the orientation of a telescopic antenna with respect to the polarisation of the transmitted signal can reduce sensitivity by up to 20 dB.

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# 1. Introduction

This report presents the results of a measurement programme to determine Minimum Usable Sensitivity (MUS) and Selectivity performance for thirty three different Digital Audio Broadcast (DAB) receivers available on the UK market in March/April 2011.

The study was commissioned by the Department of Culture, Media and Sport (DCMS) and Ofcom in response to the Government's Digital Radio Action Plan [1], which sets out the process and requirements for the switchover from analogue to digital radio. The results of the study will be used by DCMS (and Ofcom) to improve understanding of the performance of DAB receivers currently in the UK market and provide robust evidence to inform the work of the Technology and Equipment Group and the Coverage and Spectrum Planning Group, established under the Digital Radio Action Plan. These two Groups have been tasked with, amongst other things:

- Developing a common set of specifications for digital radio receivers and technology;
- Developing a strategy for quality assurance of digital radio receivers, including testing against agreed specifications;
- Advising on the design and implementation of receivers;
- Determining the current level of FM coverage and developing a range of options to increase DAB coverage to match FM, including defining DAB field strengths.

# 2. Equipment Under Test

DAB receivers can be grouped under the following three categories:

- **In-home receivers.** These include portable receivers, hand-held receivers, clock radios, CD players, docking stations and tuner / hi-fi systems.
- **In-car receivers**. These include standard fit digital radios, line or factory fit options.
- **Adaptors and add-ons.** These include accessories, adaptors and add-ons for products such as mobile phones, PCs and in-car.

This study only considers in-home receivers which have been further sub-divided into the following six groups:

- **Personal Receivers:** These are small battery powered "pocket" receivers intended to be worn on the person. In most cases audio output is via headphones which also act as the antenna.
- **Portable Receivers:** These are larger than personal receivers and are intended to be used in different rooms around the home. They can be powered by both battery

and mains power supply. Audio output is through a speaker or via a headphone socket. These receivers tend to have an integral telescopic antenna. In many cases they have a dual DAB/FM tuner.

- **Clock Radios:** These tend to be similar in size to portable receivers and are used in the bedroom. They tend to be mains powered and audio output is via speaker only. These receivers can have either a telescopic or wire antenna. They tend to have a dual DAB/FM tuner and in many cases they have a docking station or CD player.
- **Docking Station:** These receivers are characterised by an integrated docking station for iPod or other MP3 player as well as DAB and FM tuners. They tend to be larger than portable receivers and are usually mains powered. Audio output is through speakers or via a headphone socket. These receivers can have either a telescopic or wire antenna.
- **Hi-Fi:** These receivers are typically "micro hi-fi" systems and usually have an integrated docking station and CD player, as well as DAB and FM tuners. They generally have twin stereo speakers that can be separated from the main unit. They are mains powered, include a headphone socket and have a wire antenna.
- **Wi-Fi Internet:** These receivers can be either portable, docking stations or hi-fi. They are able to connect wirelessly to a broadband internet connection in order to stream internet radio stations. They can be powered by battery or mains power supply and audio output can be via speakers or headphone socket. These receivers can have either a telescopic or wire antenna.

Thirty three receivers were tested in total, as shown in Table 1 below. Table 2 provides a summary of the number of receivers tested by antenna type and power supply. The majority of devices tested (51%) were portable receivers with telescopic antennas.

Some receivers could be classified under more than one group, e.g. clock radios may also have a docking station. In these cases the receivers have been grouped according to their primary function, as described by the manufacturer.

In all cases the receivers were tested with their factory default settings. No attempt was made to investigate the impact of changing any settings on receiver performance.

**Table 1:**
**DAB Receivers Under Test**

| ID | Receiver Type | Antenna | Power Supply |
|---|---|---|---|
| 1 | Portable | Telescopic | Battery |
| 2 | Portable | Telescopic | Battery & Mains |
| 3 | Portable | Telescopic | Battery |
| 4 | Portable | Telescopic | Mains |
| 5 | Docking Station | Telescopic | Mains |
| 6 | **Not used** | | |
| 7 | Portable | Telescopic | Mains |
| 8 | Hi-Fi | Wire | Mains |
| 9 | Portable | Telescopic | Battery |
| 10 | Wi-Fi Internet | Telescopic | Mains |
| 11 | Portable | Telescopic | Battery |
| 12 | Hi-Fi | Wire | Mains |
| 13 | Portable | Telescopic | Battery & Mains |
| 14 | Portable | Telescopic | Battery & Mains |
| 15 | Clock Radio | Wire | Mains |
| 16 | Portable | Telescopic | Mains |
| 17 | Portable | Telescopic | Battery & Mains |
| 18 | Personal | Headphones | Battery |
| 19 | Clock Radio | Wire | Mains |
| 20 | Docking Station | Wire | Mains |
| 21 | Wi-Fi Internet | Telescopic | Mains |
| 22 | Wi-Fi Internet | Telescopic | Mains |
| 23 | Portable | Telescopic | Mains |
| 24 | Wi-Fi Internet | Telescopic | Mains |
| 25 | Portable | Telescopic | Battery |
| 26 | Portable | Telescopic | Battery & Mains |
| 27 | Clock Radio | Wire | Mains |
| 28 | Personal | Headphones | Battery |
| 29 | Portable | Telescopic | Battery |
| 30 | Hi-Fi | Wire | Mains |
| 31 | Clock Radio | Wire | Mains |
| 32 | Portable | Telescopic | Mains |
| 33 | Wi-Fi Internet | Telescopic | Mains |
| 34 | Portable | Telescopic | Mains |

**Table 2:**
**Receiver summary by antenna type and power supply**

| Receiver Type | Antenna | | | Power Supply | | |
|---|---|---|---|---|---|---|
| | Telescopic | Wire | Headphone | Battery | Mains | Battery & Mains |
| Personal | - | - | 2 | 2 | - | - |
| Portable | 17 | - | - | 6 | 6 | 5 |
| Clock Radio | - | 4 | - | - | 4 | - |
| Docking Station | 1 | 1 | - | - | 2 | - |
| Hi-Fi | - | 3 | - | - | 3 | - |
| Wi-Fi Internet | 5 | - | - | - | 5 | - |

# 3. Test Methodology

## 3.1 Wanted Signal Parameters

The wanted DAB signal was produced by a Rohde & Schwarz SFE Broadcast Transmitter. Signal parameters comply with ETSI Standard EN 300 401 [2], summarised in Table 3 below.

**Table 3:**
**Wanted DAB Signal Parameters**

| Parameter | Value |
|---|---|
| Frequency | Band III (174 – 240 MHz) |
| Transmission Mode | Mode 1 |
| Modulation | OFDM |
| Sub-carriers | 1,536 |
| Guard Interval | 246 µs |
| Error Coding[1] | UEP 3 |
| Data Rate[2] | 128 kbps |

**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 should comply with the "critical" mask specified in Clause 15 of EN 300 401, as shown in Figure 1. This was verified with a spectrum analyzer and the recorded emissions are shown in Figure 2.

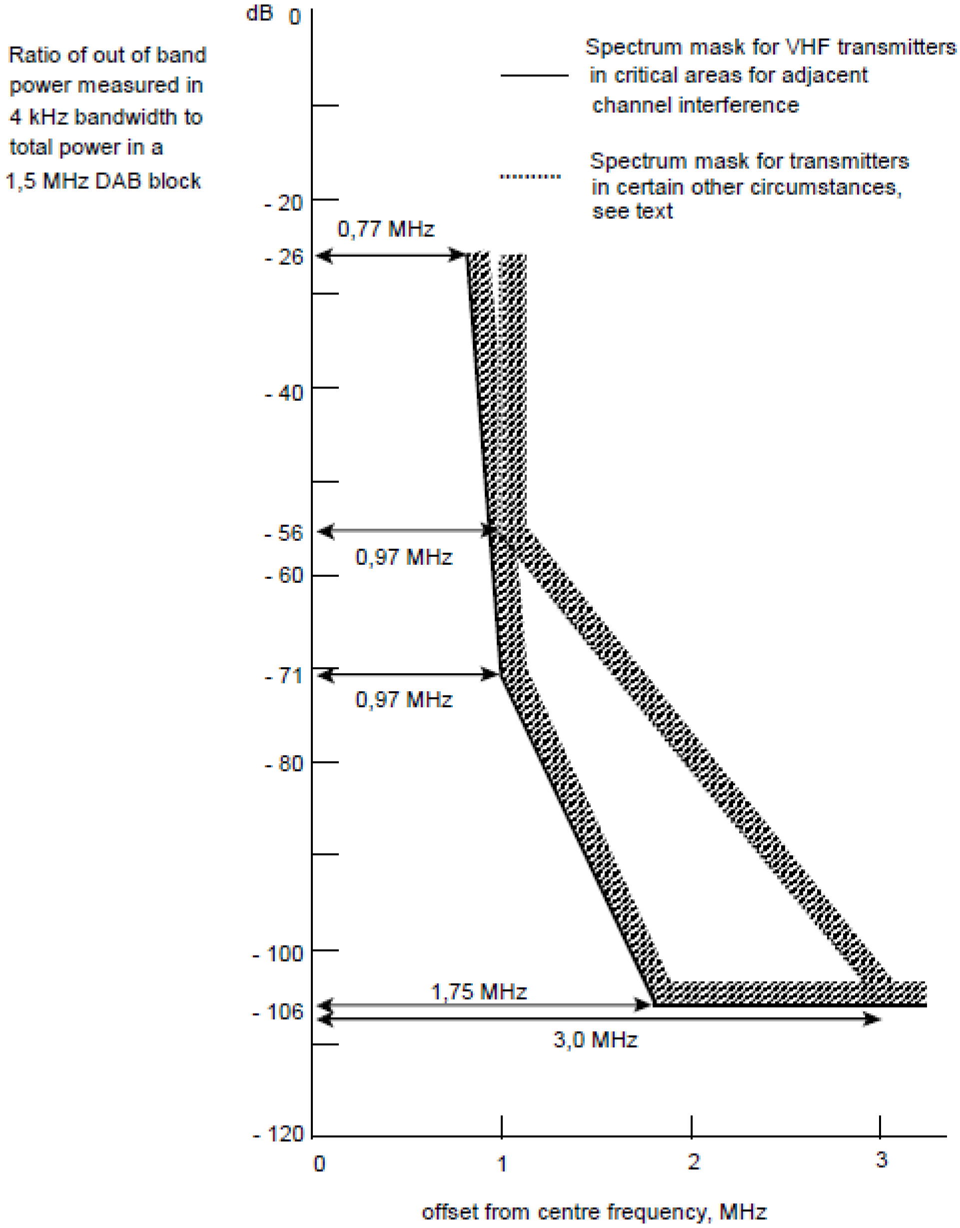



**Figure 1: DAB spectrum mask from EN 300 401**

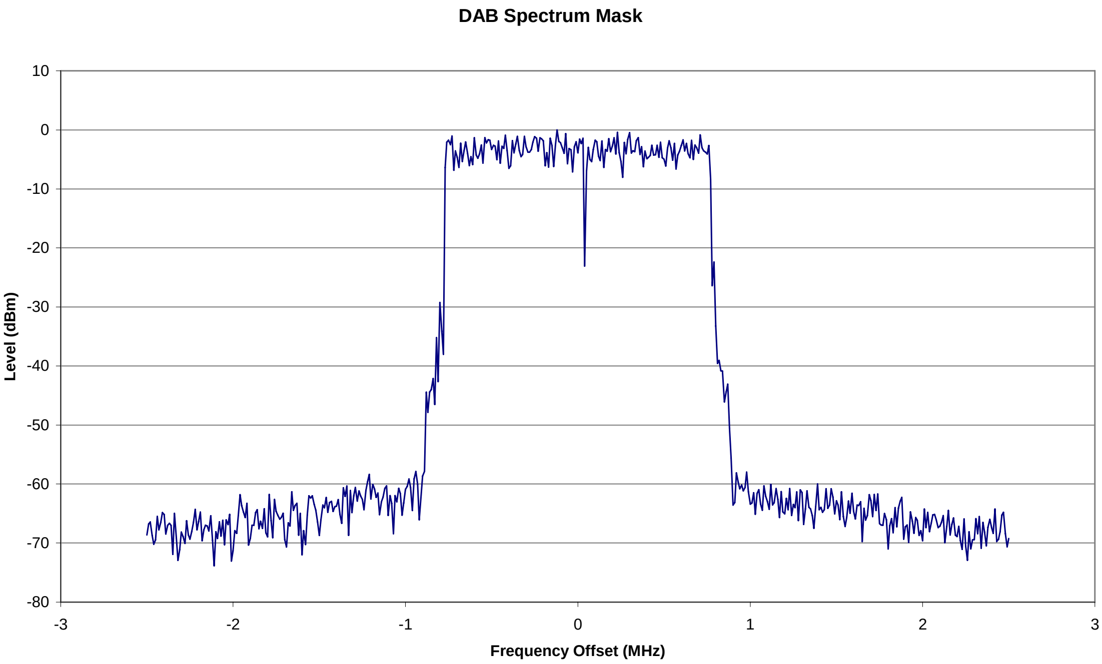



**Figure 2: DAB spectrum emissions from SFE signal generator**

## 3.2 Failure Criterion

BS EN 62104:2007 [3] defines the test criteria for minimum sensitivity as:

- *The sensitivity is the input power expressed in dB(mW) at which the bit error ratio (BER) reaches $10^{-4}$.*

The minimum requirement is specified as -81 dB(mW) for VHF and L-band.

Measurement of BER can be very erratic with some types of impairment and an accurate measure can be hard to achieve. Furthermore, there is often no direct method of measuring BER in commercial receivers; objective tests are unlikely to be possible without connections to internal circuitry or access to receivers with specific test ports.

The minimum sensitivity was therefore determined through subjective testing. The difference between the 'onset of interference' and the 'total loss of signal' can vary widely between receivers and in order to ensure repeatable results the following criteria was assumed:

- Onset of interference: More than one audible error in a five second interval;
- Complete failure: Total loss of audio signal.

## 3.3 Equipment Set-Up

All measurements were performed inside a Fully Anechoic Room (FAR) to minimise the possibility of outside interference from local DAB multiplexes. The usable dimensions of the FAR are 8.2m x 3.2m x 3.2m (*length x width x height).* The test equipment set-up is shown in Figure 3 below.

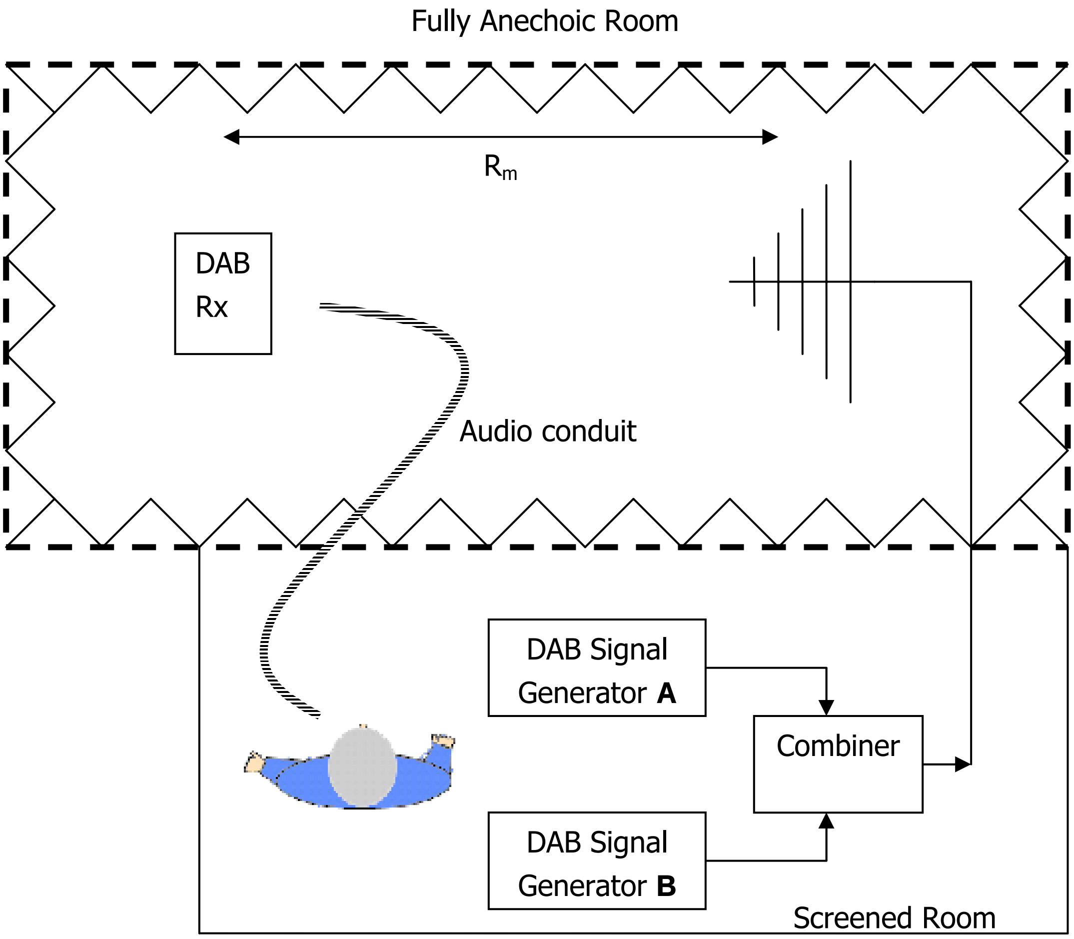



**Figure 3: Test set-up using anechoic and screened rooms**

- The DAB receiver under test was placed 1.0m above ground level on a non-conducting (wooden) table. The distance (R) between the receiver and transmit antenna was 4.8m, sufficient to ensure the receiver was in the far field of the antenna radiation pattern. This distance is dependent on the dimensions of the transmit antenna and can be calculated from Equation 1:

$$R > \frac{2D^2}{\lambda} \qquad \text{(Eq1)}$$

where: R = distance between transmit antenna and DAB receiver (m)

D = maximum linear dimension of antenna

λ = wavelength

- The DAB signal generators A and B were located in an adjacent screened room to reduce the possibility of unwanted signals being picked up and re-radiated into the FAR. The signal generators were connected to the transmit antenna via a combiner.
- The audio output from the receiver was monitored using an acoustic conduit connected between the FAR and screened room. The connection of external leads was minimised as far as possible to prevent re-radiation of unwanted signals.
- For receivers with a telescopic or wire antenna, the antenna was fully extended and placed in the vertical polarisation. Wire antennas were suspended above the receiver on a non-conducting structure to ensure that any interaction between the antenna and mains lead was minimised, as shown in Figure 4. The mains lead (where used) was run from the back of the receiver and down to the ground.

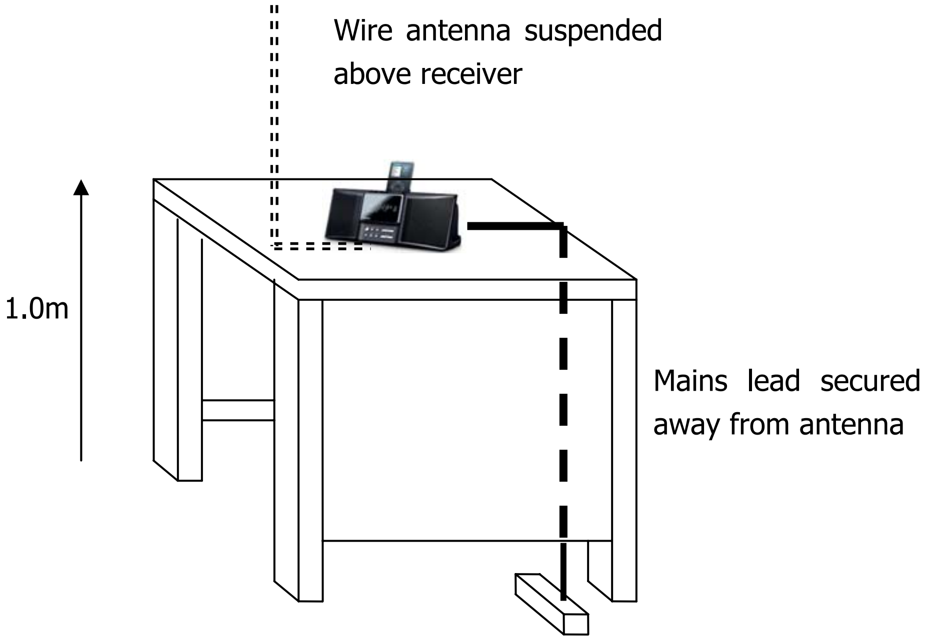



**Figure 4: Arrangement for wire antennas**

- For personal receivers, where headphones act as the antenna, an engineer stood directly behind the receiver to monitor the audio output through the headphones as the wanted signal level was varied, as shown in Figure 5 below. This measurement was repeated with the engineer in front of the receiver to provide an indication of body loss.

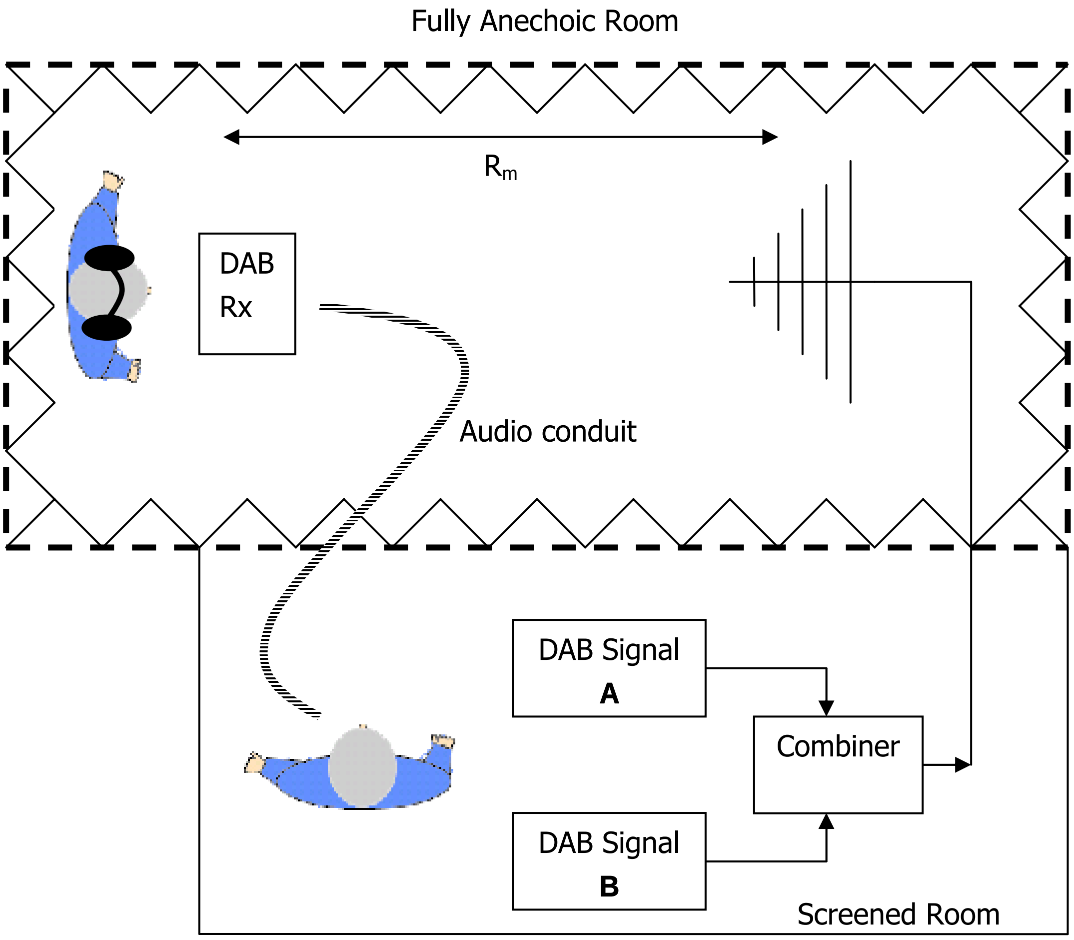



**Figure 5: Test configuration for personal receivers**

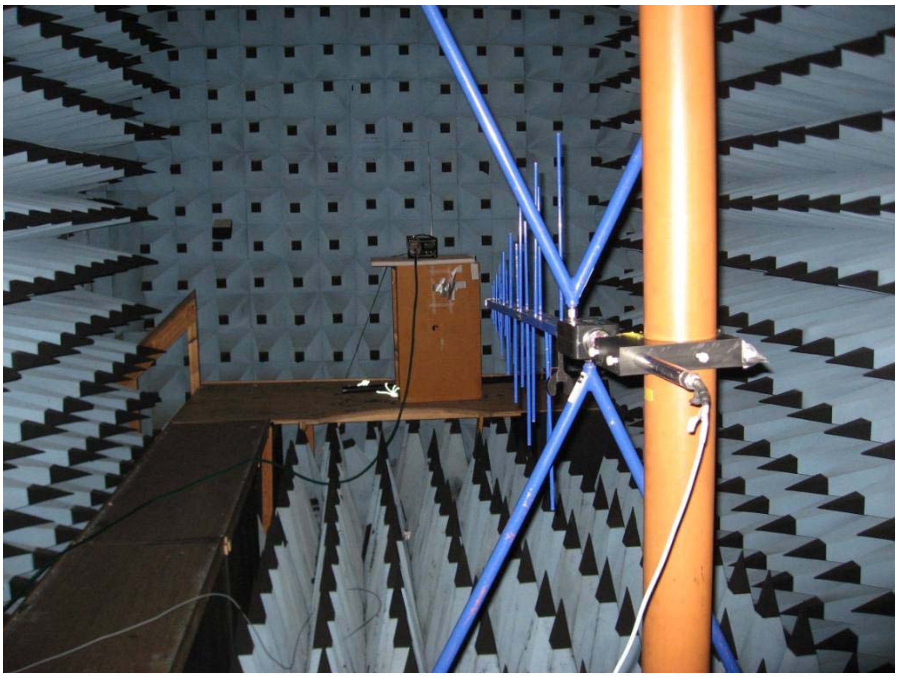


**Figure 6: Receiver under test in anechoic room**

## 3.4 Test Procedure

### 3.4.1 Minimum Usable Sensitivity

For measurements of Minimum Usable Sensitivity Signal Generator B was switched off.

The following test procedure, based on EN 62104:2007, was used to determine MUS:

1. Signal Generator A was configured to transmit a 1 kHz audio test tone with a data rate of 128 kbps using the parameters described in Table 3;
2. The frequency was initially set to 174.928 MHz (Ch 5A);
3. The Signal Generator output power level ($P_{wanted}$) was set to a high value (-20 dBm) and the DAB receiver was tuned to the correct channel, ensuring that the 1 kHz tone could be heard clearly with no audible errors;
4. The power level $P_{wanted}$ was reduced in 1 dB steps to achieve the required degradation in audio quality;
5. Field strength at the DAB receiver was calculated from:

$$EIRP = P_{wanted} - L + G_{tx}$$

$$E_{dB\mu V/m} = EIRP - (20 \times LOG(R_m)) - 104.8 \qquad \text{(Eq2)}$$

where L = transmit cable loss (dB)

$G_{tx}$ = Gain of transmit antenna (dBi)

$R_m$ = distance between transmit antenna and DAB receiver (m)

6. Steps 2 to 5 were repeated for the DAB frequencies shown in Table 4.

**Table 4:**
**DAB Test Frequencies**

| **Ch** | 5A | 9D[1] | 10A | 10B | 10C | 10D | 11A |
|---|---|---|---|---|---|---|---|
| **Freq (MHz)** | 174.928 | 208.064 | 209.936 | 211.648 | 213.360 | 215.072 | 216.928 |
| **Ch** | 11B | 11C | 11D | 12A | 12B | 12C | 12D |
| **Freq (MHz)** | 218.640 | 220.352 | 222.064 | 223.936 | 225.648 | 227.360 | 229.072 |

**Notes:**

1. Channel 9D used for selectivity testing only.

### 3.4.2 Selectivity

Selectivity determines the ability of a receiver to receive a wanted signal when a strong unwanted signal occurs in a frequency band adjacent to the wanted frequency.

EN 62104:2007 describes two types of selectivity measurements: Adjacent Channel Selectivity (ACS) and far-off selectivity. The test method between the two differs in that EN 62104 prescribes a DAB signal as the interferer for ACS measurements and a standard FM modulated signal for far-off selectivity.

In this report we define selectivity to include both the first adjacent channel and non-adjacent channels from N-5 to N+5, and use a single test procedure. The interferer was assumed to be a DAB signal, rather than the FM signal described in EN 62104.

The following test procedure was used to determine receiver selectivity:

1. With DAB Signal Generator B switched off, the wanted frequency (N) of Signal Generator A was set to 216.928 MHz (Ch 11A);
2. The power level of Signal Generator A was adjusted such that the wanted signal ($P_{wanted}$) at the DAB receiver was ≥ 3 dB above the Minimum Usable Sensitivity. The 1 kHz tone was checked to ensure it could be heard clearly with no audible errors[1];
3. The output power level ($P_{unwanted}$) of Signal Generator B was initially set to a low value (-120 dBm) and the unwanted frequency was set to N-5 channel offset (208.064 MHz);
4. Signal Generator B was switched on and the level of $P_{unwanted}$ increased in 1 dB steps to achieve the required degradation in audio quality at the wanted frequency (N);
5. Selectivity was calculated from:

$$Selectivity = P_{unwanted} - P_{wanted} \quad \text{(Eq2)}$$

6. Steps 3 to 5 were repeated for channel offset N+5, N±4, N±3, N±2 and N±1

EN 62104 defines the minimum requirements for Adjacent Channel and far-off selectivity performance as:

- ACS ≥ 30 dB

[1] If errors were heard at MUS +3 dB, the wanted level was increased further to the point of no interference and the test conducted at this elevated power level.

- Selectivity: 40 dB for any in-band or out-of-band interfering frequency with an offset ≥ 5 MHz from the centre of the wanted DAB signal[2].

# 4. Results

## 4.1 Minimum Usable Sensitivity

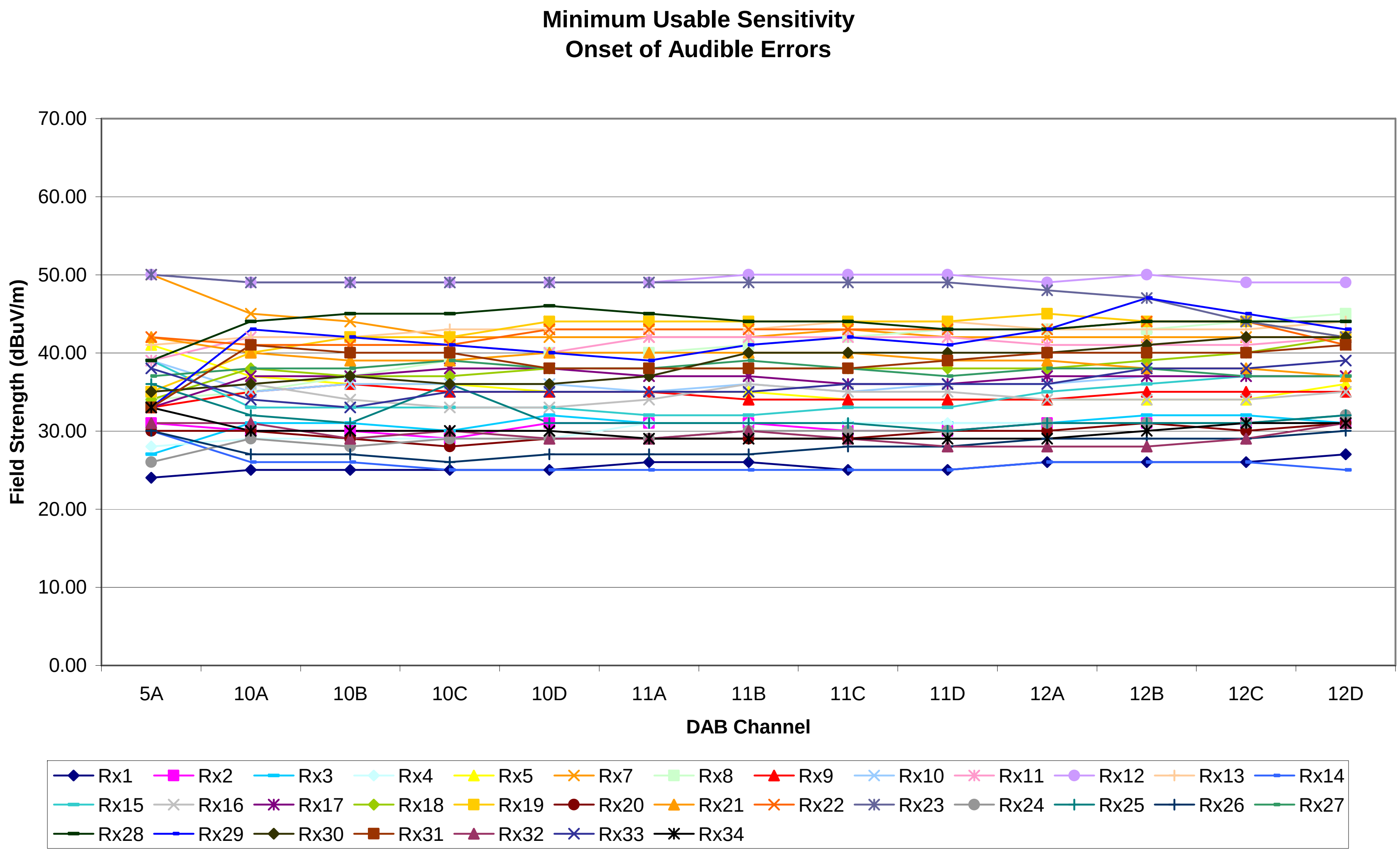
Figure 7 and Figure 8 provide a summary of MUS at the onset of audible errors and complete loss of audio tone, respectively, for all thirty three receivers under test. The results are presented as Field Strength (dBuV/m) at the receiver against DAB Channel.

The results show that, taking Channel 11A as an example:

- There is a difference of 24 dB between the best and worst performing receivers, with Receiver 14 having a MUS of 25 dBuV/m and Receivers 12 and 13 having a MUS of 49 dBuV/m.
- The average MUS across all 33 receivers at Ch11A is 36 dBuV/m.
- The average difference between the onset of audible errors and complete loss of audio tone is 5.73 dB. However, this difference could be as small as 3 dB (Rx14) or as large as 12 dB (Rx13).
- Receiver performance is fairly consistent across Channels 10A to 12D. The results are more variable at Ch5A, most likely due to receiver filter response at the edge of the DAB band.

Results for the six receiver groups, for the onset of audible errors, are shown in Figure 9 through to Figure 14.

[2] Note that this requirement is based on an FM interferer




## Figure 7: Minimum Usable Sensitivity at onset of audible errors

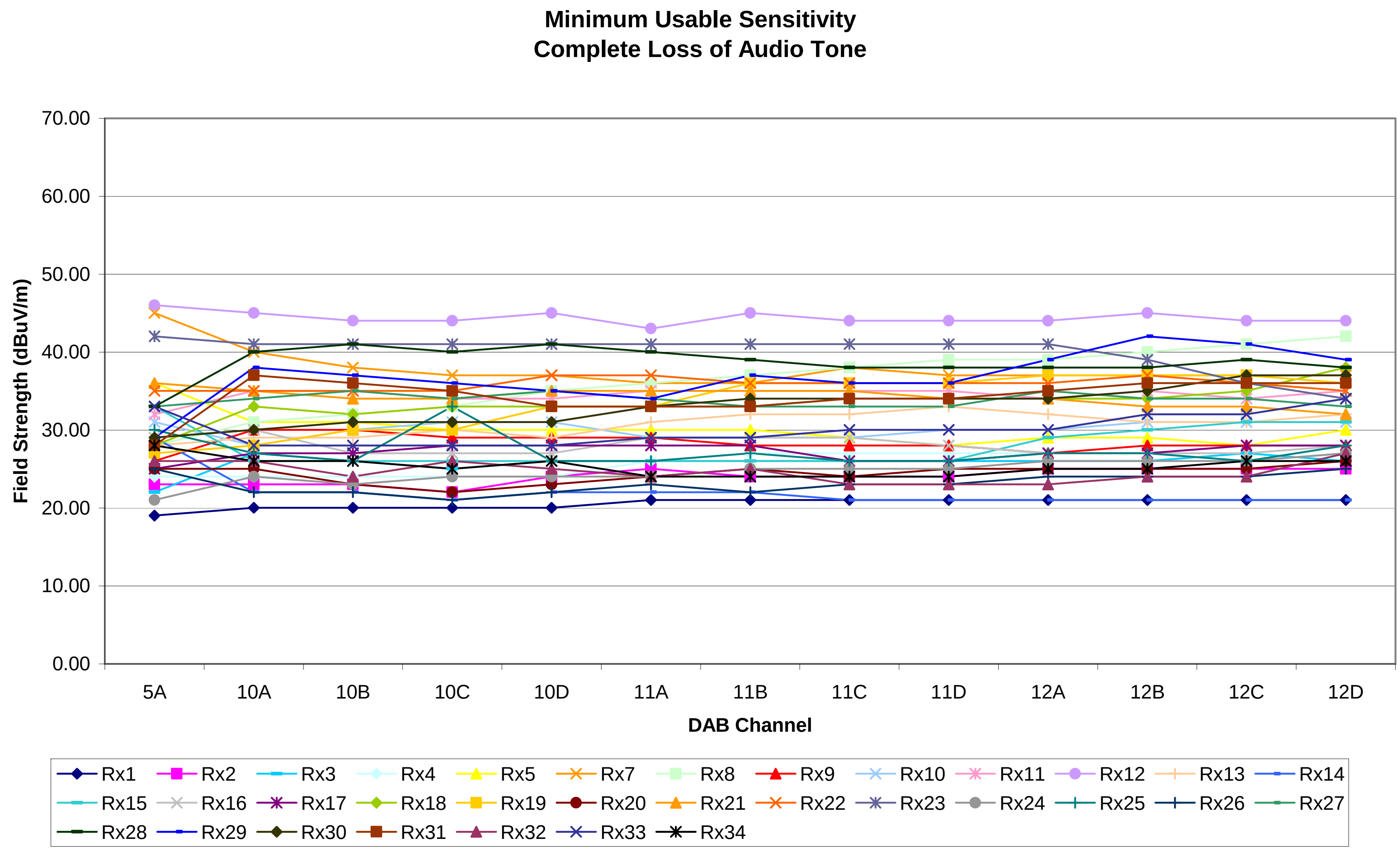
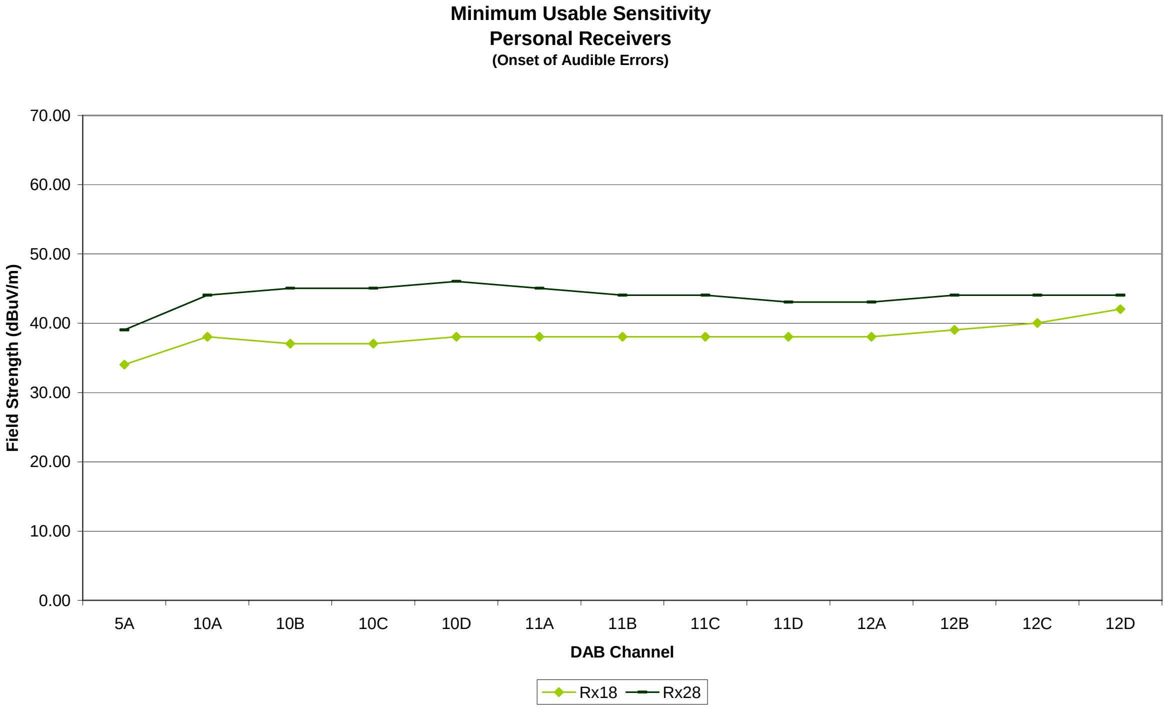
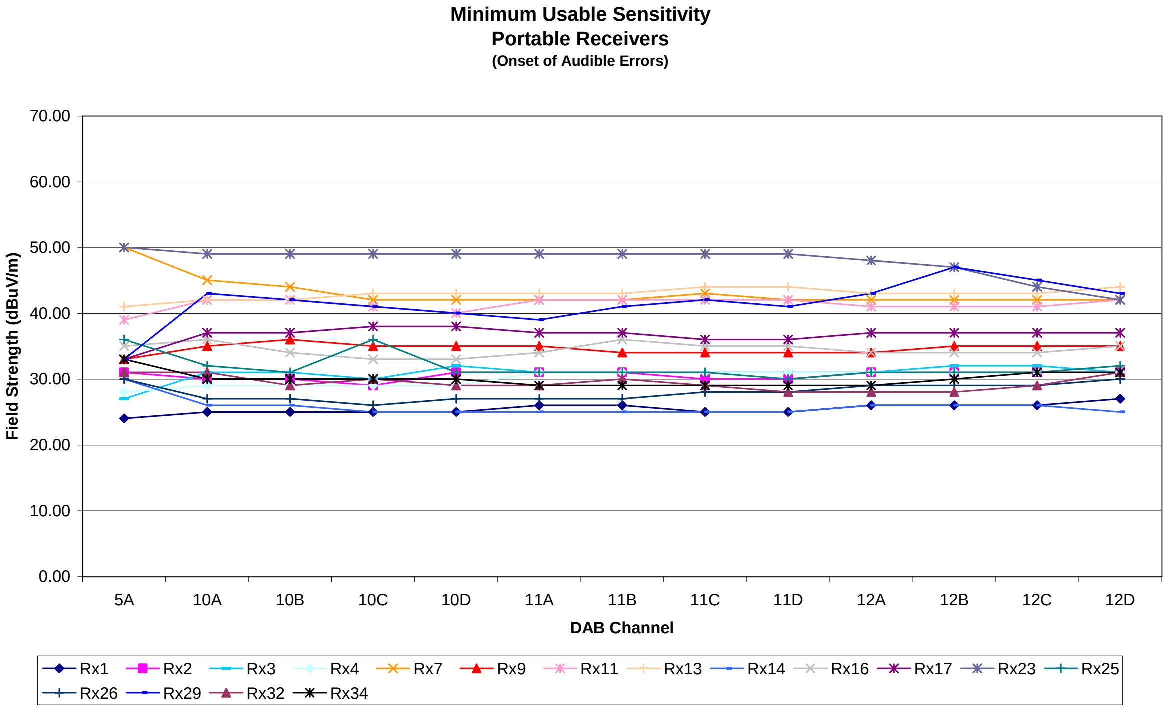


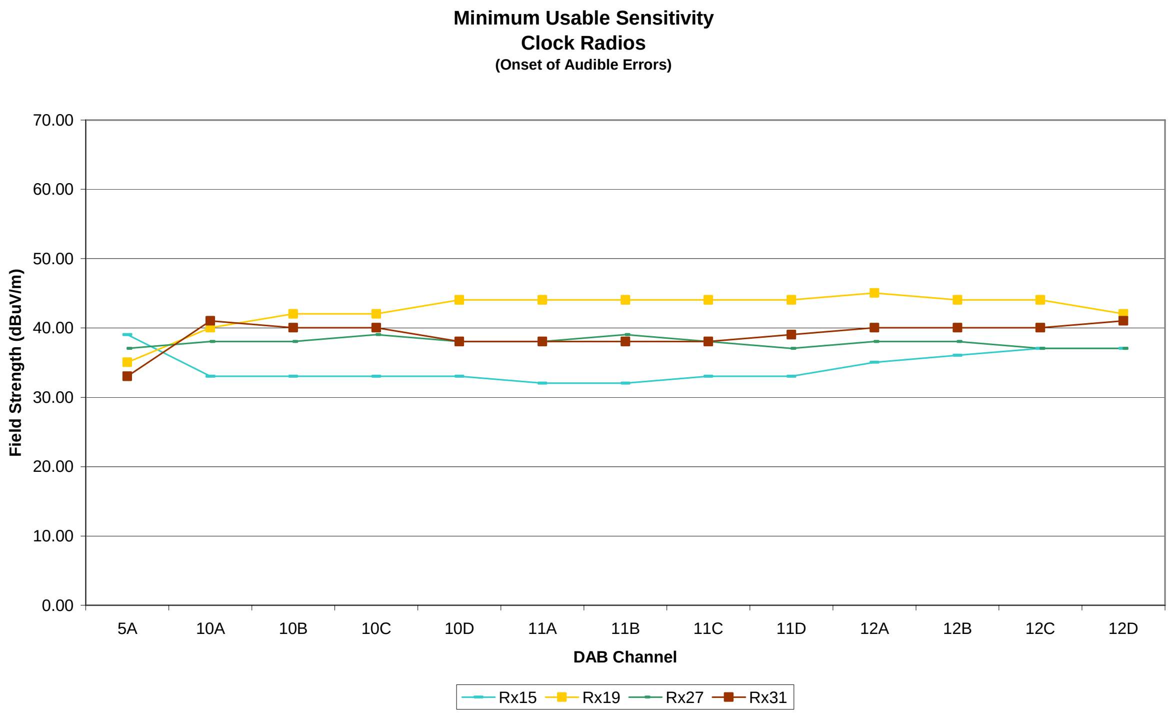

**Figure 8: Minimum Usable Sensitivity at complete loss of audio tone**



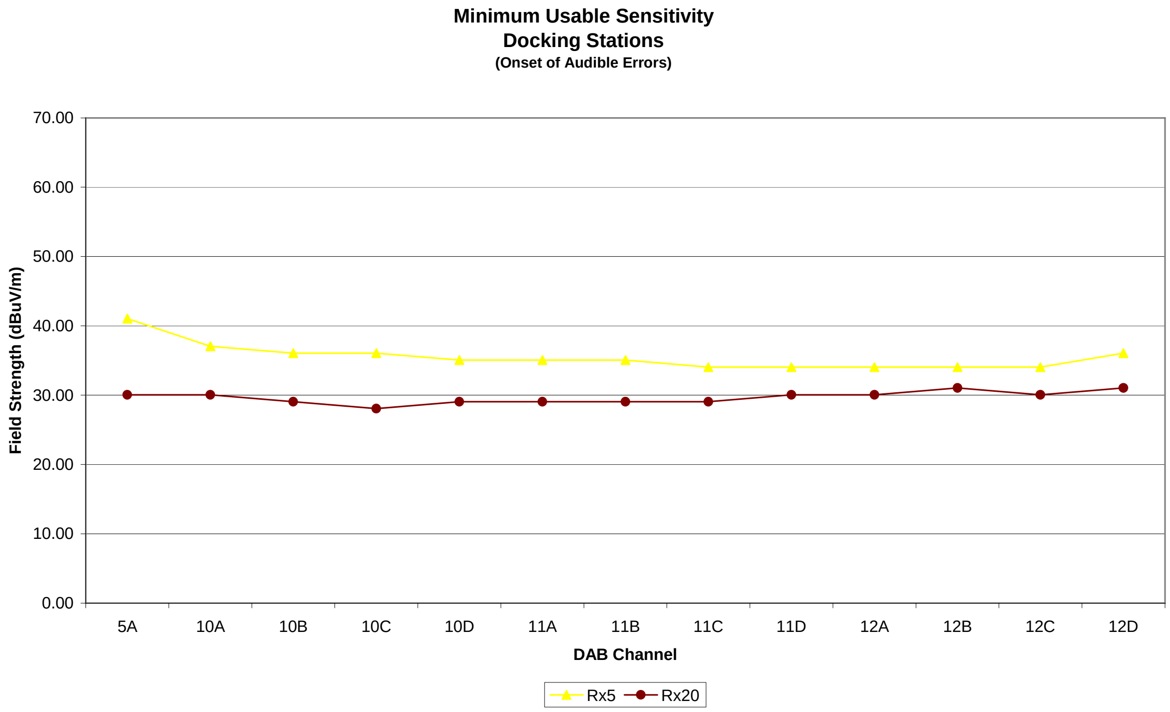

## Figure 9: MUS results for Personal receivers



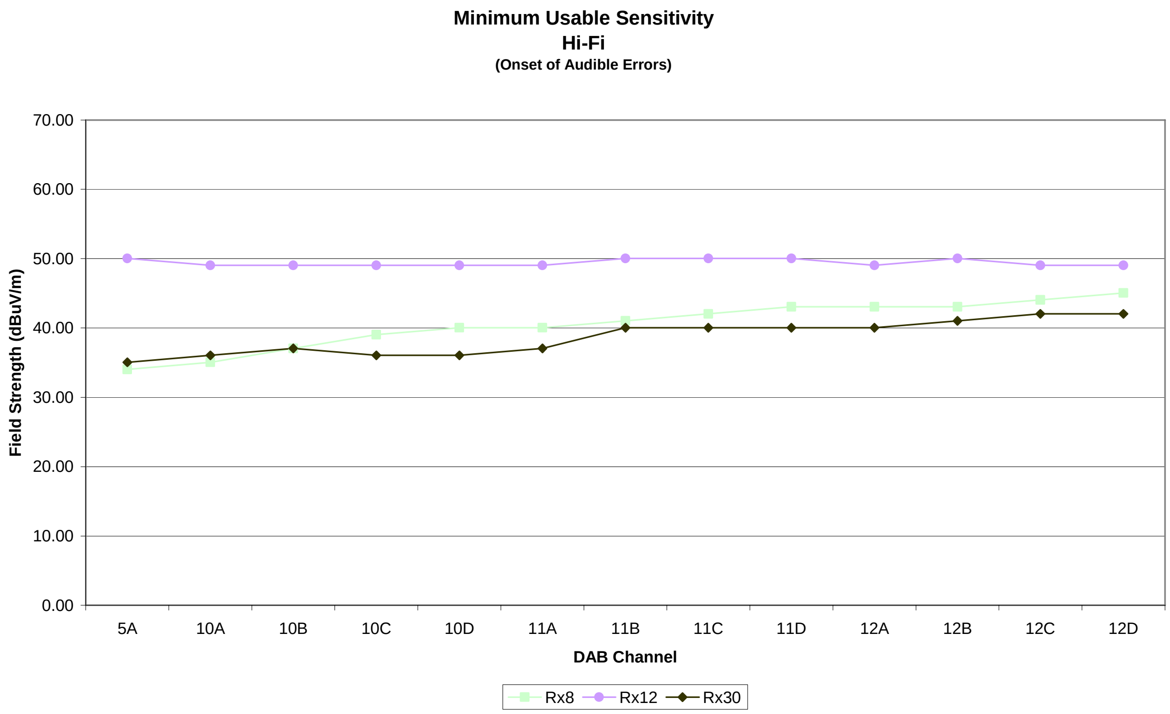

## Figure 10: MUS results for Portable receivers



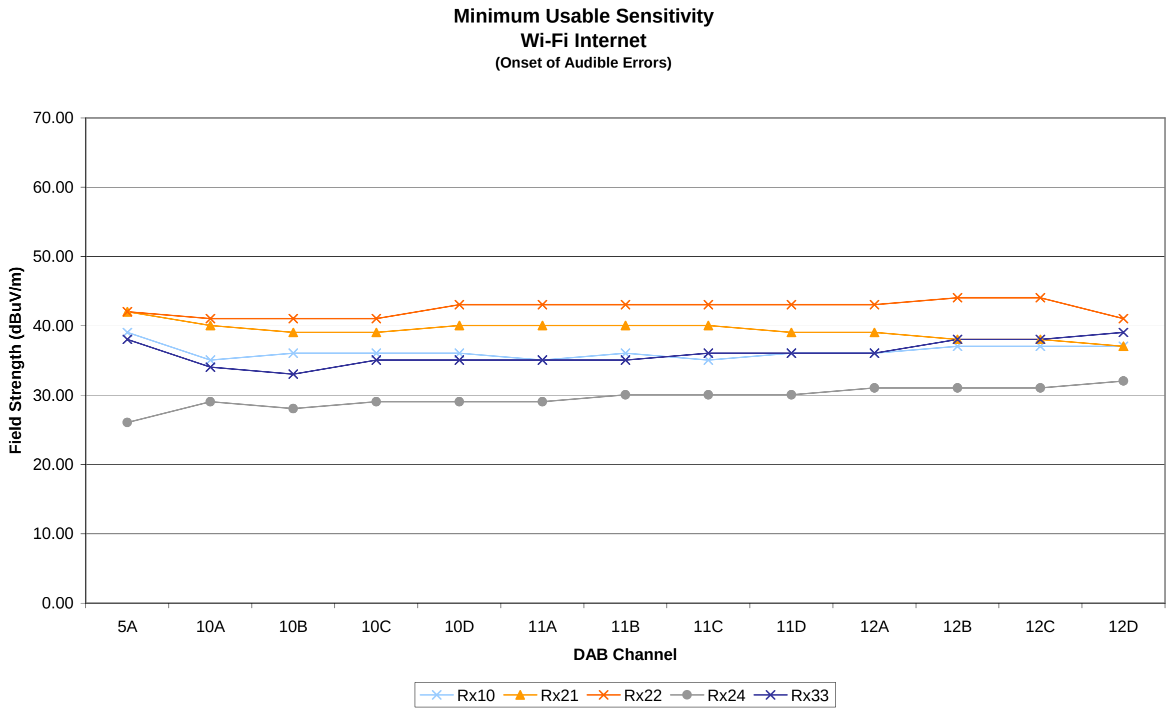

## Figure 11: MUS results for Clock Radios




## Figure 12: MUS results for Docking Stations




## Figure 13: MUS results for Hi-Fi Systems




## Figure 14: MUS for Wi-Fi Internet receivers

## 4.2 Receiver Selectivity

Figure 15 provides a summary of receiver selectivity at the onset of audible errors for all thirty three receivers under test. The results are presented as selectivity (dB) against DAB Channel offset.

The results show that:

- For the first adjacent channel (N±1) all of the receivers except Rx27 meet the minimum requirement in BS EN 62104:2007 of ACS ≥ 30 dB. Rx27 is a clock radio with wire antenna operating on mains power. Wire antennas are particularly sensitive and it may be that altering the position of the antenna could significantly improve the results.
- For frequency offsets ≥ 5 MHz from the centre of the wanted DAB signal all of the receivers meet the minimum requirement of 40 dB.
- Receivers enabled for Wi-Fi streaming of internet radio appear to perform more poorly compared to other types of receiver, with 3 of the 5 models tested in the bottom 20% of results.
- Selectivity is non-symmetrical with generally slightly better performance for positive frequency offsets.

ACS for offsets of N±1 is summarised in the table below.

**Table 5:**
**Summary of Adjacent Channel Selectivity**

| Rx | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N-1 (dB) | 49 | 48 | 48 | 47 | 43 | - | 38 | 46 | 48 | 33 | 47 | - |
| N+1 (dB) | 48 | 47 | 47 | 48 | 43 | - | 39 | 42 | 47 | 44 | 48 | - |
| **Rx** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| N-1 (dB) | 45 | 47 | 47 | 42 | 43 | 41 | 38 | 30 | 33 | 41 | 40 | 46 |
| N+1 (dB) | 36 | 46 | 47 | 43 | 44 | 43 | 42 | 43 | 39 | 40 | 39 | 45 |
| **Rx** | **25** | **26** | **27** | **28** | **29** | **30** | **31** | **32** | **33** | **34** | | |
| N-1 (dB) | 40 | 46 | 26 | 40 | 31 | 47 | 35 | 39 | 35 | 49 | | |
| N+1 (dB) | 44 | 46 | 44 | 42 | 43 | 46 | 42 | 46 | 44 | 47 | | |

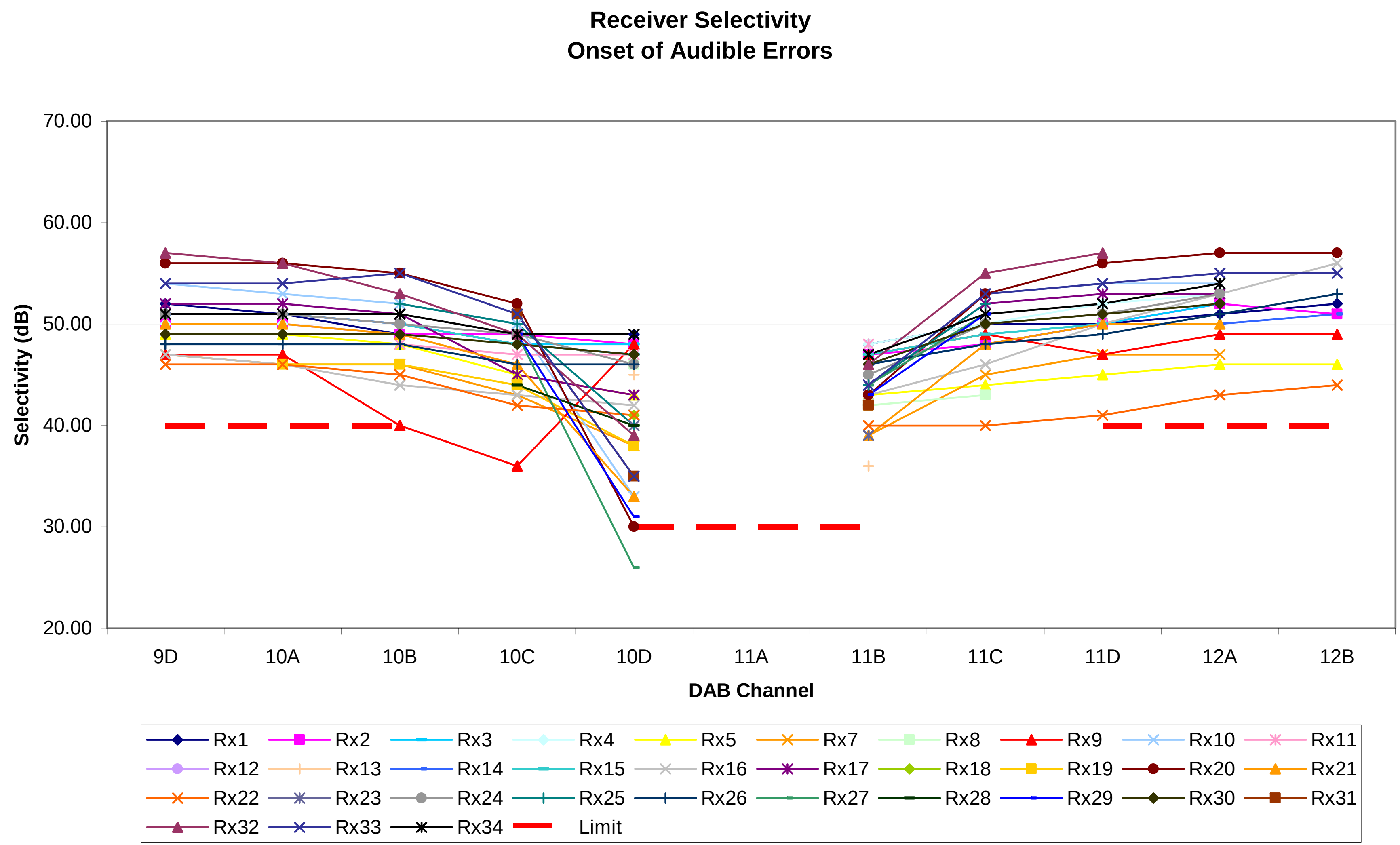



**Figure 15: Receiver Selectivity at onset of audible errors**

## 4.3 Comparison of Mains and Battery Operation

Five portable receivers were tested on both mains and battery operation. The results are shown in the figure below.

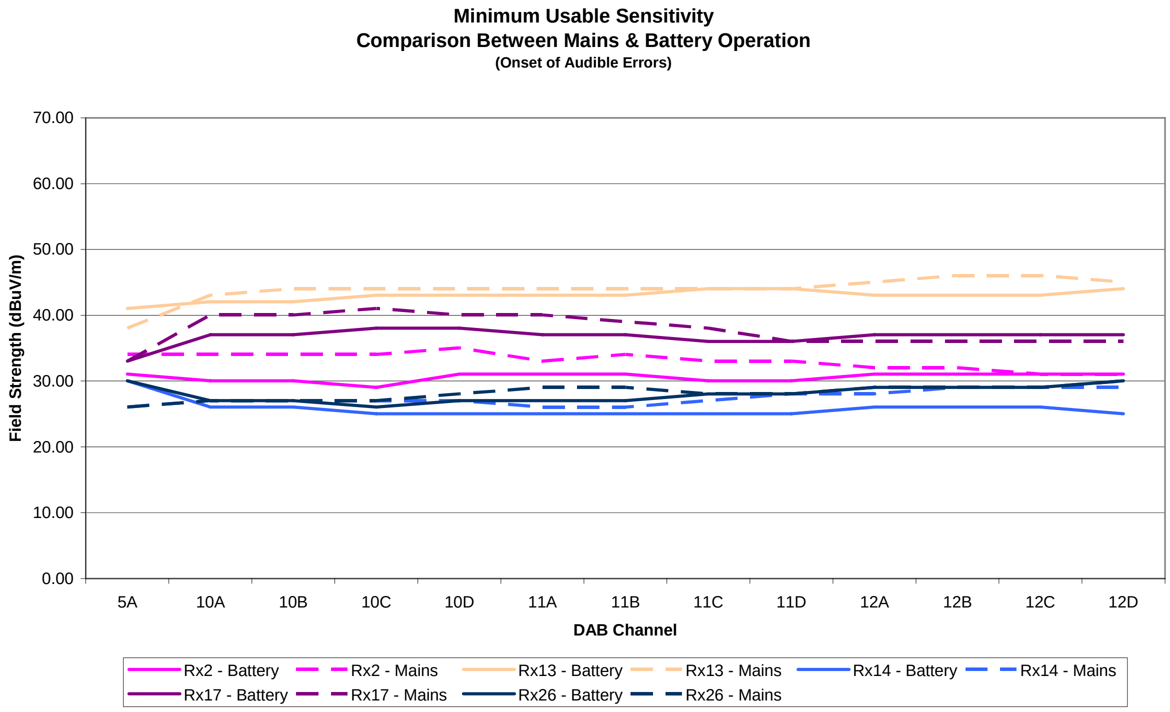



**Figure 16: Comparison between mains and battery operation**

The results show that, for the five receivers tested, MUS is degraded slightly when operating on mains power. Discounting Ch5A:

- The difference in sensitivity between mains and battery operation varies between 0.5 and 2.5 dB for Rx26 and Rx2, respectively. Average difference across all five receivers is 1.28 dB.

## 4.4 Comparison of Antenna Type and Orientation

Of the 33 receivers tested, 23 have telescopic antennas, 8 have wire antennas and 2 use headphones as the antenna.

The average MUS at the onset of audible errors for each antenna type, for Channel 11A, is shown in the figure below.

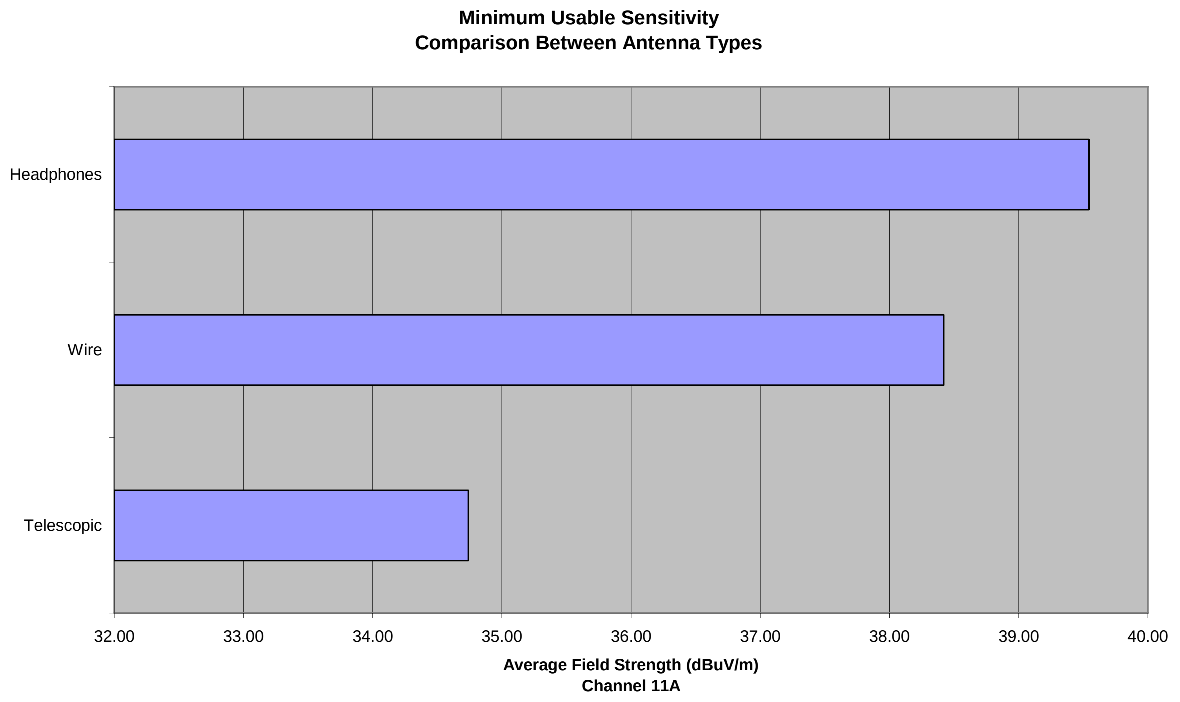



**Figure 17: Comparison of average MUS for different antenna types**

Figure 17 suggests that, for the limited sample of antennas under test, telescopic antennas are the most sensitive, giving the best results in terms of MUS. Wire and headphone type antennas are less sensitive, requiring higher field strengths to provide the desired audio quality.

Wire and headphone antennas are particularly sensitive to position, and even small movement can result in large changes to the received field strength.

A limited set of tests was undertaken on three receivers with telescopic antennas[3] to compare MUS for different antenna orientations:

- Fully extended in the vertical plane (the default for all the tests).
- Fully retracted in the vertical plane.
- Fully extended in the horizontal plane.
- Fully extended at 45° to the horizontal plane.

[3] Representing a receiver with good, average and poor performance

**Table 6:**
**MUS for different telescopic antenna orientations**

| Channel | Receiver | Antenna Orientation | | | |
|---|---|---|---|---|---|
| | | Vertical fully extended | Vertical fully retracted | Horizontal fully extended | 45° fully extended |
| 5A | 23 | 50 | 65 | 72 | 60 |
| | 24 | 27 | 42 | 49 | 29 |
| | 33 | 36 | 49 | 58 | 44 |
| 11A | 23 | 48 | 63 | 67 | 51 |
| | 24 | 29 | 44 | 49 | 33 |
| | 33 | 36 | 46 | 57 | 49 |
| 12D | 23 | 41 | 51 | 62 | 45 |
| | 24 | 32 | 40 | 50 | 36 |
| | 33 | 39 | 46 | 56 | 48 |

The results show that:

- MUS is degraded by around 12 dB if the antenna is not fully extended;
- MUS is degraded by around 20 dB if the antenna is cross-polar with the transmitted signal (antenna in the horizontal plane in this example);
- MUS is degraded by around 6 dB if the antenna is at a 45° angle to the plane of the transmitted signal.

## 4.5 Correlation between Signal Strength and Receiver Display

Many of the receivers have a bar graph or numerical display of signal level / quality. Table 7 below shows displayed signal level for three receivers as the field strength was increased.

There appears to be no clear correlation between field strength and displayed signal level for the receivers tested. However, none of the receivers showed a signal level of 100% until field strength was ≥ 47 dBuV/m.

**Table 7:**
**Relationship between field strength and displayed signal level**

| Field Strength (dBuV/m) | Displayed Signal Level (%) | | |
|---|---|---|---|
| | Rx23 | Rx24 | Rx33 |
| 27 | 63 | 25 | 0 |
| 32 | 63 | 35 | 0 |
| 34 | 63 | 40 | 54 |
| 36 | 63 | 50 | 74 |
| 37 | 63 | 50 | 80 |
| 42 | 72 | 65 | 98 |
| 47 | 79 | 85 | 100 |
| 52 | 96 | 100 | 100 |
| 57 | 99 | 100 | 100 |
| 62 | 100 | 100 | 100 |

## 4.6 Effect of Body Loss for Personal Receivers

For the two personal receivers, Rx 18 and Rx28, measurements were made with an operator standing directly behind and directly in front of the receiver to compare the effects of body loss. The operator monitored the audio tone through a set of professional quality headphones, which also act as the antenna.

Figure 18 shows that for Rx18 MUS is reduced by around 7 dB with the operator standing in front of the receiver. However, for Rx28 MUS is slightly improved (by 2 dB). These results suggest that the position of the headphone lead, rather than body loss, is the dominant factor for personal receivers. Moving the headphone lead evenly slightly can have a large effect on receiver sensitivity.

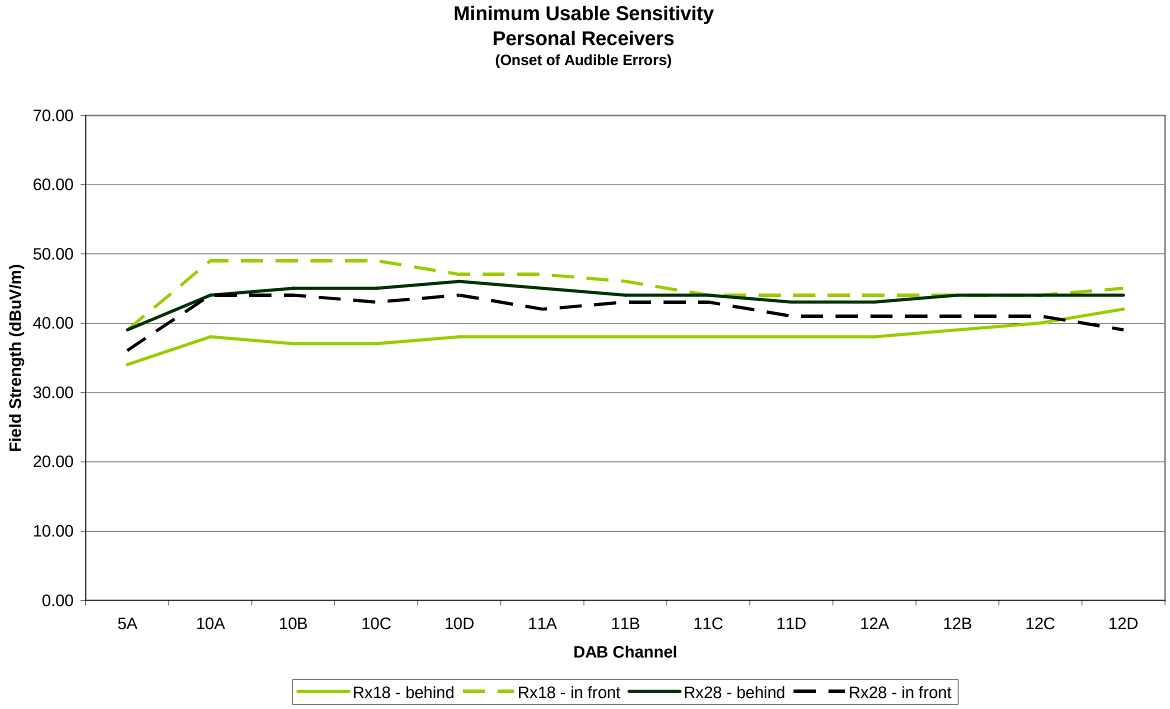



**Figure 18: Comparison of body loss for personal receivers**

## 5. Conclusions

Measurements have been undertaken in a Fully Anechoic Room to determine minimum usable sensitivity and selectivity for thirty three different DAB receivers available on the UK market in March/April 2011.

Measurements of MUS show that:

- There is a difference of 24 dB between the best and worst performing receivers, with the best receiver having a MUS of 25 dBuV/m and the worst having a MUS of 49 dBuV/m;
- The average MUS across all 33 receivers at Channel 11A is 36.05 dBuV/m; the average across all receivers and all channels is 36.33 dBuV/m;
- The difference between the onset of audible errors and complete loss of audio tone at Channel 11A varies between 3 dB (Rx14) and 12 dB (Rx13); the average difference across all receivers is 5.73 dB at Ch11A;
- Receiver performance is fairly consistent across Channels 10A to 12D. The results are more variable at Ch5A, most likely due to receiver filter response at the edge of the DAB band.

Measurements of selectivity show that:

- For the first adjacent channel (N±1) all of the receivers except Rx27 meet the minimum requirement in BS EN 62104:2007 of ACS ≥ 30 dB;
- For frequency offsets ≥ 5 MHz from the centre of the wanted DAB signal all of the receivers meet the minimum requirement in BS EN 62104:2007 of 40 dB. (*Note that this requirement is specified in EN 62104 for an FM modulated signal.*);
- Receivers enabled for Wi-Fi streaming of internet radio appear to perform more poorly compared to other types of receiver, with 3 of the 5 models tested in the bottom 20% of results;
- Selectivity is non-symmetrical with generally slightly better performance for positive frequency offsets.

Comparing receiver operation on mains and battery power shows that, for the limited sample of receivers tested:

- MUS is degraded slightly for mains operation. The reduction in sensitivity varies between 0.5 dB for Rx26 and 2.5 dB for Rx2; average reduction in sensitivity for all receivers tested is 1.28 dB.

Comparing MUS results by antenna type suggests that:

- Telescopic antennas are the most sensitive, giving the best results in terms of MUS;
- Wire and headphone type antennas are less sensitive, requiring higher field strengths to provide the desired audio quality. These antennas are also particularly sensitive to position in areas of low signal strength, and small movements in position can result in large changes to the received field strength;
- For telescopic antennas, received field strength can vary by as much as 20 dB depending on the orientation of the antenna with respect to the polarisation of the wanted signal.

# 6. Recommendations for Further Work

Based on the findings from this study, areas for further work could include:

- Measurements on two or more units with the same model number to determine the extent of any manufacturing tolerances between different batches of receivers;
- Measurements in a multipath propagation channel to investigate whether reflection and scattering have a significant impact on receiver performance;

- Additional measurements on receivers with wire or headphone antennas to improve statistical significance in the results;
- Further measurements on the effect of antenna type and orientation on receiver sensitivity;
- Measurements for different DAB transmit data rates.

# 7. References


[1] Digital Radio Action Plan, Version 1, Department for Culture, Media and Sport, 8 July 2010

[2] ETSI EN 300 401 v1.4.1 (2006-06): Radio Broadcasting Systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers

[3] BS EN 62104:2007 Characteristics of DAB receivers