Performance of personal active noise reduction devices

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Abstract - This paper presents the results of objective tests performed on 13 personal active noise reduction devices (earmuffs, headphones, headsets and insert earphones) divided into four groups based mainly on structure, using an acoustic test fixture (ATF). Each device was examined on its attenuation of broadband noise, overload response, internally generated noise, attenuation of impulse noise, and stability to movement. The results show a large range of responses between devices in terms of attenuation and overload, and highlight distinctive differences between the device groupings.

Keywords: Active noise reduction; Hearing protector; Headphone; Headset; Earphone

1. Introduction

Active noise reduction (ANR) is a technique that utilises the principle of superposition to reduce low frequency noise energy without the need for bulky and expensive passive sound barriers. The technology was proposed as early as the 1930's by Paul Lueg [1], but practical and affordable products were not introduced until the 1980's. Today's commercially available ANR technology is used in a variety of applications including personal devices for domestic applications such as headphones, headsets, and earphones, and personal devices for industrial applications such as aviation and military hearing protectors/communications headsets.

In addition to providing superior low frequency attenuation of external noise and hence reduced low frequency noise exposure compared to passive devices, ANR devices can increase speech intelligibility. Through reducing the level of low frequency environmental noise reaching the ear, the upward spread of masking caused by this noise is reduced (see [2] for an explanation of this phenomenon). As a result, the masking of speech at higher frequencies, as well as at the frequency where the noise reduction occurs, is reduced and its intelligibility is improved. In particular, speech reproduced from an external audio signal by a headset, headphone or earphone will benefit, as the speech is preserved while the masking is reduced. Removal of low frequency components in noisy environments such as aircrafts and offices also reduces fatigue and physical stress [3].

Given the applications and benefits of ANR, both Buck and Steeneken have argued that the performance of an active noise reduction device should be evaluated on more than just its total attenuation [4,5]. Since an ANR system includes an electronic component, it is important to characterise how the system responds to excessive noise levels (its overload response), to look at the internally generated noise and to examine its stability to movement. The overload test should also include an impulse noise component. There also exists a range of subjective tests that may be employed to fully characterise a device, such as rating of sound quality and rating of the comfort of wearing the system over long periods of time.

Past publications on devices featuring ANR generally lack in the variety of devices and features evaluated. For example, while Buck discusses a number of possible tests, only sample product data is used to illustrate points. Crabtree et al. conducted an in-depth study of device attenuation, overload response, self noise, impulse response and various metrics for speech intelligibility [6]. They also looked subjectively at fit and stability. However their round-robin test only included five products and the

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primary goal was to determine the validity of ANR assessment methods, rather than to report on the product results. Only a small subset of the data obtained was published, and there was minimal analysis of the products and minimal comparison between the properties of the devices tested.

Published studies that compare ANR products have so far only tested broadband noise insertion loss, and generally have done so in an effort to validate a new test method. Zera et al. reported on the testing of three ANR devices in an attempt to develop subjective test methods for device attenuation, while Cui et al. conducted a test on five ANR devices in order to examine the feasibility of using an acoustic test fixture for the measurement of the insertion loss of hearing protectors [7,8]. It would appear that the limited publication of results for personal ANR device performance reflects the absence of a global standard covering active device testing.

The aim of this study was then to examine and present data for a large number of devices, covering a variety of different tests, and to explore the variations between different types of ANR products. It is expected that this information will be useful for the comparison of ANR devices, highlighting safety and performance issues. The tests conducted are outlined in Sections 2 to 7.

2. Materials

2.1. Devices tested

The devices chosen for testing are given in Table 1. They have been divided into four groups based on their intended application and physical structure.

Group	Device
(1) Industrial Circumaural	Pro Tech Comm. Noisebuster PA4000
	NCT PA3500
	Telex Stratus 50D
	Lightspeed Zulu
(2) Domestic Circumaural	Bose QC2
	Sennheiser PXC450
	Jabra C820s
(3) Domestic Supra-aural	Bose QC3
	Sennheiser PXC250
	Pro Tech Comm. Noisebuster NB-FX
	Plane Quiet NC7
	Sony MDRNC20
(4) Domestic in-ear	Sony MDRNC22

Table 1: Devices tested in this experiment

Only one group 4 device was obtained for testing due to the small number of domestic in-ear active devices available. Figures 1-4 display photographs of the Group 1 to 4 devices respectively. With the exception of the NCT PA3500, all the devices were new and purchased for this study. Only a single sample of each device was evaluated and no assessment was made as to how representative this sample is of the device type in general.

Figure 1. Group 1 devices: Pro tech Comm Noisebuster PA4000, NCT PA3500, Telex Stratus 50D and Lightspeed Zulu headset and processor.

Figure 2. Group 2 devices: Bose QC2, Sennheiser PXC450 and Jabra C820s

Figure 3. Group 3 devices: Bose QC3, Sennheiser PXC250 headphone and processor, Pro Tech Comm. Noisebuster NB-FX, Plane Quiet NC7 headphone and processor and Sony MDRNC20

Figure 4. Group 4 device: Sony MDRNC22

2.2. Acoustic Test Fixture

The standard procedure for testing the attenuation of a passive device is to use the REAT method (real ear attenuation at threshold), which measures the shift of hearing threshold between the occluded and unoccluded conditions, and accounts for individual differences in the fit of the device across a sample of subjects [9]. However the REAT method is unsuitable for testing ANR systems for a number of reasons. Most importantly, an active system will produce residual noise. This internally-generated noise will mask the REAT test levels and ultimately elevate the measured attenuation values. Furthermore, there is no guarantee that the low level signals used for determining the occluded threshold will be attenuated by the ANC system in a way that represents its attenuation of higher level environmental noise. Thus physical methods that use microphones for determining attenuation offer advantages over the REAT method for active systems. The two main physical methods available are MIRE (microphone in real ear) and ATF (acoustic test fixture).

In this experiment, the ATF method is employed to test the performance of the devices. This method has the advantage of not requiring any subjects, and therefore there are reduced concerns regarding human exposure to excessive noise levels. Furthermore, the method allows strict control of test conditions, enabling repeatability and consistent test conditions for comparison across products. It also has the advantage of being a quick and cost effective method of data acquisition. However, unlike REAT, the ATF method does not account for bone conduction and therefore the measured attenuation will be an overestimation of the attenuation a human experience. Another drawback of using an acoustic test fixture is that they are, to date, unable to properly simulate all of the features of the human head and auditory system. Differences in resonance, impedance, conductivity, ear seal, and ear transfer function and the lack of variability between subjects limits the validity of results [9].

Regardless of which of the three methods is used, the performance results are still highly dependent on the fit of the device. The flexibility of the pinnae can affect the acoustic seal, the enclosed volume and the positioning of the devices internal transducers in relation to the ear canal. In particular the position of the device's internal microphone relative to the ear canal can affect the performance; a variation in this positioning will alter the noise reduction in the ear canal compared to that at the internal microphone location, where the performance is normally optimised. Cui et al. [8] verified this variability by comparing tests with and without pinnae (using an ATF), and found that the variability of results was greatly reduced without pinnae. To reduce the variability when conducting a number of the tests in the present experiment the results of left and right ear measurements were averaged.

3. Attenuation of broadband noise

3.1. Method

Measurements of broadband noise attenuation were conducted using the following steps:

(a) Generate a diffuse sound field in a large reverberation room using pink noise equalised to within ± 1 dB from 40 Hz to 10 kHz and within -3 dB at 31.5Hz (see below for more details)

(b) Record the open ear (OE) response of a Head And Torso Simulator (HATS) [10] in this diffuse field using pink noise with broadband levels of 80-110 dB SPL incremented in 10 dB steps. Record third-octave levels from 31.5 Hz to10 kHz, linearly averaged over 30 seconds. Record spectrum for both left and right ears (to calculate average)

(c) Fit the test device on HATS and determine passive response (PR) with ANR off (same recording regime as for step (b))

(d) Turn ANR system on and determine total response (TR) of the device (same recording regime as for step (b))

(e) Calculate broadband noise attenuation:
- Passive attenuation = OE – PR
- Total attenuation = OE – TR
- Active attenuation = PR – TR

(f) Repeat for each device being tested

The pink noise signal was produced by a Stanford Research Systems SR780 Network Signal Analyser, and then fed through a Behringer Ultra Curve Pro DSP 8024 equaliser, a NAL remote control attenuator (0-99 dB adjustable range) and finally a Murray Amplifiers MA 534 power amplifier. The amplified signal was fed to four speakers (Yamaha Professional Series S500) placed inside a reverberation room (150 m^3) located at the National Acoustic Laboratories' facility.

The signals were picked up using a Brüel & Kjær Type 4128C Head And Torso Simulator (HATS) with left and right ears. The output signal from each ear went through a Brüel & Kjær Type 2610 Measuring Amplifier, and was analysed by a Stanford Research Systems SR780 Network Signal Analyser.

3.2. Results

Figures 5-7 illustrate the noise attenuation in third-octave bands provided by the devices when exposed to 90 dB SPL pink noise in the diffuse field. The passive, active and total attenuation is illustrated in

Figures 5 to 7 respectively. Each figure comprises of four plots, one for each device group. The frequency range of the results was restricted to 31.5-10,000 Hz as this was the equalised region in the field response. Apart from the devices that reached their overload limit, there was no change in the device characteristics for each product over the 80-110 dB SPL range (none of the devices were overloaded at 90 dB SPL). More details regarding the overload response can be found in Section 4.

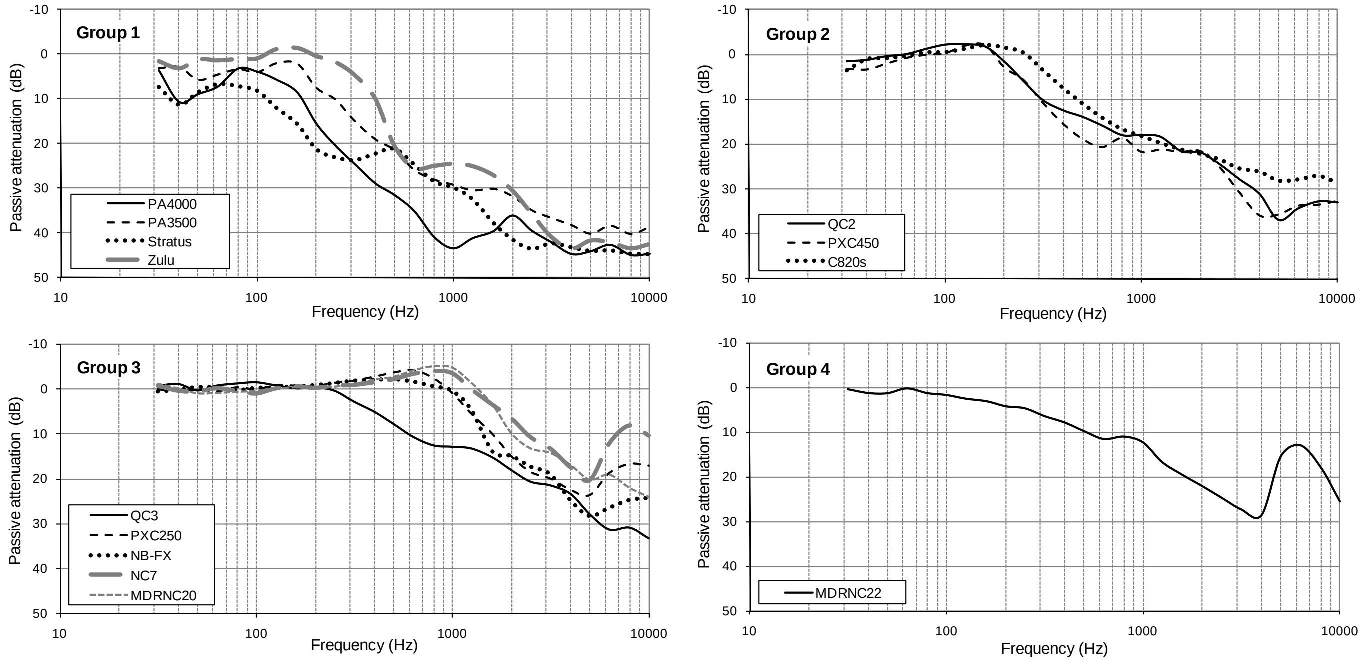

Figure 5. Passive attenuation at 90 dB SPL for groups 1-4

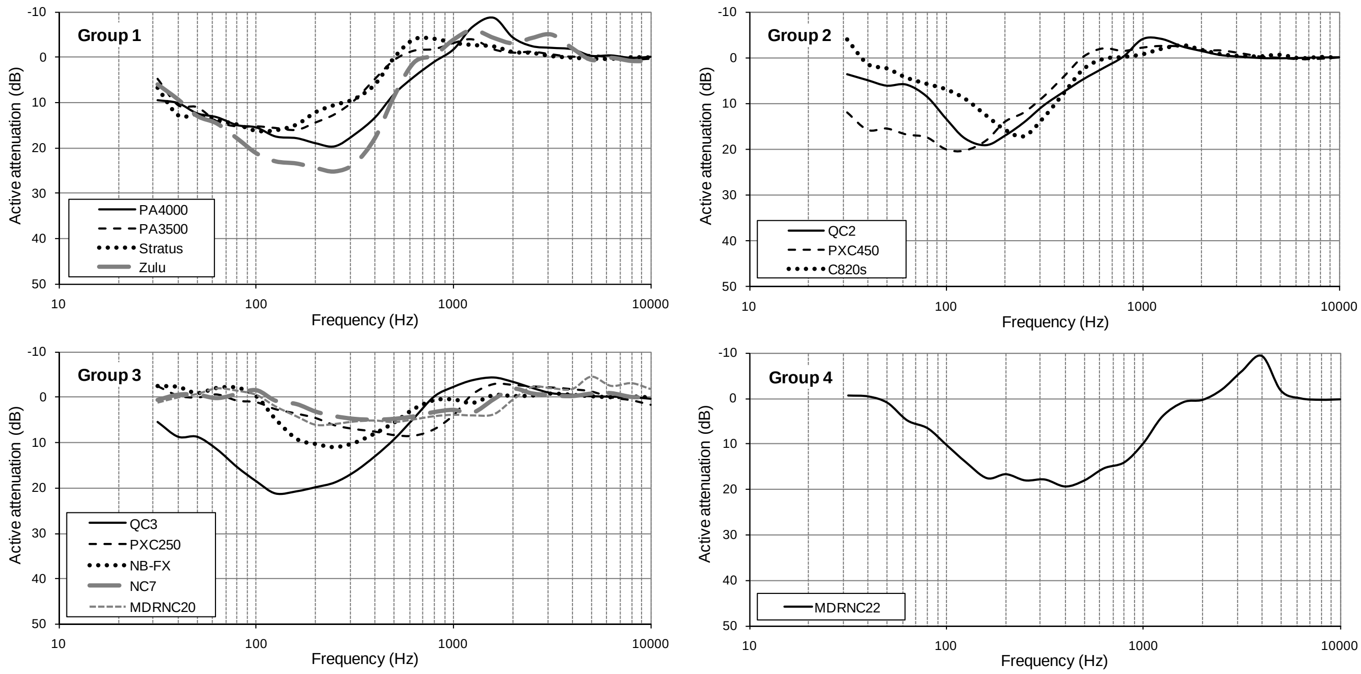

Figure 6. Active attenuation at 90 dB SPL for groups 1-4

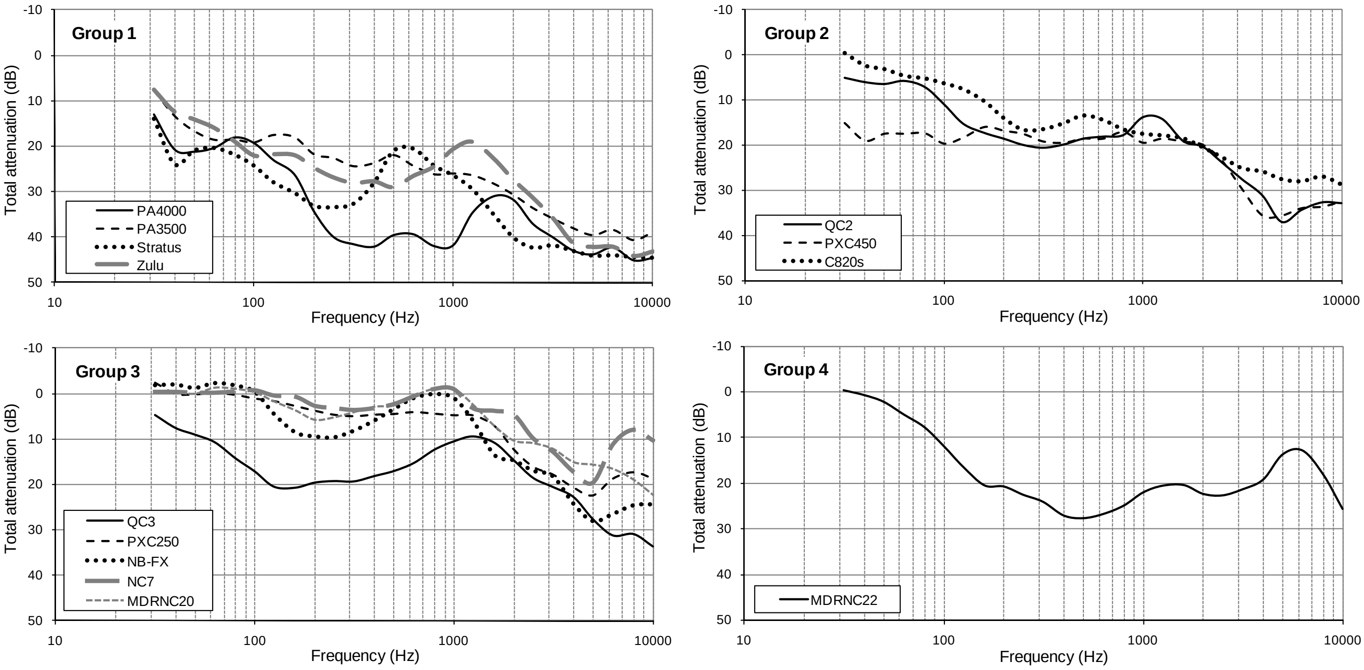

Figure 7. Total attenuation at 90 dB SPL for groups 1-4

3.3. *Discussion*

One of the main goals of testing attenuation of broadband noise was to analyse the effect of the active system in each device, and determine characteristics common within the groups and overall. The following terminology is used to analyse the properties of the active attenuation component:

- Attenuation Depth – the maximum attenuation in dB provided by the device
- Attenuation Frequency – the frequency in Hz at which the attenuation was largest
- Attenuation Breadth – the bandwidth of the active attenuation in Hz (third-octave), calculated here as the span in which the attenuation exceeded 3 dB
- Boosting – the maximum amplification in dB provided by the active system
- Boosting Frequency – the frequency in Hz (third octave) at which the amplification was largest.

These properties are displayed in Figure 8. Referring back to Figure 6, it is apparent that active attenuation of every device displays the general characteristics shown in Figure 8.

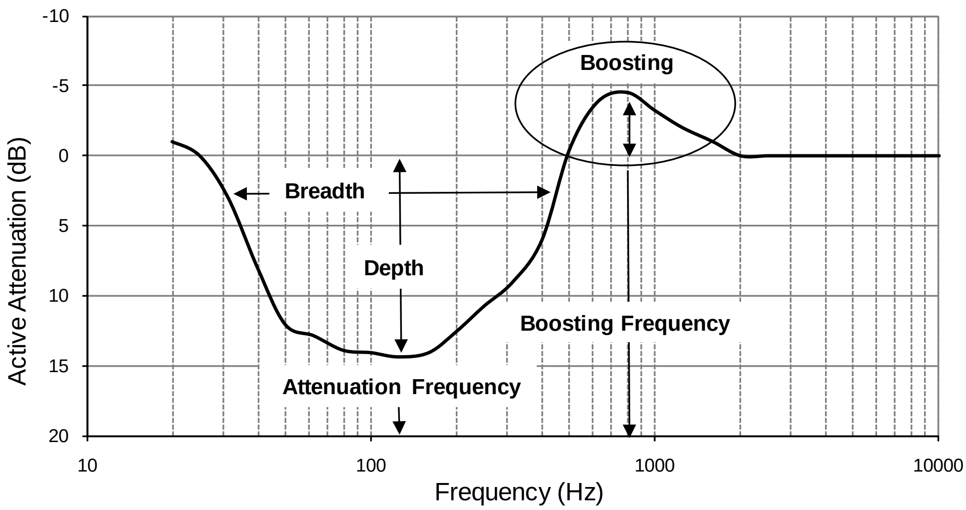

Figure 8. Active attenuation properties

Table 2 summarises the range of values obtained for each group and shows clear differences between the supra-aural and circumaural devices. The supra-aural devices (group 3) had a wider attenuation bandwidth, but the attenuation depth was smaller (8 dB mean) and centred at a higher frequency. In contrast the circumaurals (groups 1 and 2) had a much greater attenuation depth (mean of 19 dB), which was centred at a lower frequency and was not as wide.

		Group 1	Group 2	Group 3[a]	Group 4
Active attenuation	**Attenuation Depth**	16 - 25 dB (µ: 19 dB)	17 - 20 dB (µ: 19 dB)	5 - 11 dB (µ: 8 dB)	19 dB
	Attenuation Frequency	100 - 250 Hz	125 - 250 Hz	200 - 630 Hz	400 Hz
	Attenuation Breadth (approx)	400 - 600 Hz	340 - 500 Hz	375 - 1450 Hz	1200 Hz
	Boosting	4 - 9 dB (µ: 6 dB)	3 - 4 dB (µ: 4 dB)	2 – 5 dB (µ: 3 dB)	9 dB
	Boosting Frequency	800 – 1600 Hz	< 40 Hz & 1250 - 1600 Hz	≤ 100 Hz & 1600 - 5000 Hz	4000 Hz
Passive attenuation	**Maximum**	40 - 45 dB (µ: 43 dB)	29 - 37 dB (µ: 34 dB)	20 - 28 dB (µ: 24 dB)	29 dB
	Position of resonant peak	≤ 160 Hz	≤ 160 Hz	500 - 800 Hz	-

[a] not including the QC3 data

Table 2: Range and mean (where applicable) of broadband noise attenuation results

The position of the passive resonant peak was also a telling sign in differentiating between the groups. The resonant peak is influenced heavily by acoustic leakage, cavity volume, and the presence of sound absorption material inside the cup [11]. Since supra-aural devices have a reduced cavity volume and shell mass (smaller muff), often contain no absorptive material, and exhibit more acoustic leakage (due to poorer seals with the pinnae than the head surface), it is not surprising that the resonant peak was much higher in these devices than in the circumaural products. The group 1 devices (industrial circumaural) provided the best passive attenuation (43 dB mean) out of the four groups as they provided the largest clamping force, cavity volumes, and padding.

It should be noted that the data for the Bose QC3 has been excluded from Table 2, and the group 3 values are based only on the remaining 4 products in that group. This is because the QC3 displayed the characteristics of a group 2 device and clearly stood out from the other supra-aural devices in terms of performance. This was primarily due to the ear pad design, which formed a superior seal with the ear and greatly reduced its leakage component, as well as providing extra foam padding.

The only active in-ear device tested (group 4) presented attenuation properties similar to the group 2 devices in the lower frequencies but provided the most impressive extension of active attention into the higher frequencies of all the devices. Despite having no cavity volume, the small bud end allowed for a good seal at the end of the ear canal and thus good active and passive attenuation was achieved.

It was found that all groups exhibited some level of boosting (amplification) in the active response. This boosting is attributed to there being positive gain present in the active system at higher frequencies where the active system’s phase shift provides reinforcement of the signal rather than cancellation. The boosting was typically around 5 dB. The frequency at which maximum boosting occurred generally increased with reduced enclosed volume as summarised in Table 2. It was found that a slight boosting also occurred at very low frequencies (100 Hz and below) in some devices.

Note that the Stratus, which is designed for pilots to help remove engine noise, did not achieve its full active attenuation level due to a lack of tonal sounds in the test noise. Further testing found that for tonal noise the Stratus could achieve >40 dB active attenuation at 100 Hz.

All the devices perform ANR using analogue electronics. To achieve good cancellation of non-stationary noise the noise cancelling signal should be close to 180 degrees out of phase with the noise. This is typically achieved by inverting the noise signal and keeping the phase shift due to processing to a minimum within the noise cancelling bandwidth. This phase shift requirement generally makes the use of digital signal processing systems less attractive as the phase shift resulting from sampling and reconstruction will restrict the upper frequency at which noise cancellation can occur - although this upper frequency can be increased by oversampling. The Stratus and Zulu devices contain digital electronics in addition to the analogue electronics. The Stratus uses analogue electronics to provide cancellation of noise in general and digital electronics to provide additional attenuation of tonal sounds, such as those made by aircraft engines.

Most of the devices contain a single microphone that is located within the enclosure and achieve ANR using negative feedback. The exceptions to this are the NB-FX, NC7, MDRNC20 domestic supra-aural devices and the MDRNC22 domestic in-ear device. These four devices all employ an external microphone. The PCX450 also contains an external microphone, but its purpose is only to provide talk through. The MDRNC20 and MDRNC22 achieve ANR using purely feed-forward techniques while the NC7 uses an internal microphone signal in combination with the feed-forward signal from the external microphone. The NB-FX also contains an internal microphone and uses a combination of feedback and feed-forward techniques. Generally, the devices employing feedback techniques provide greater active attenuation than those employing feed-forward techniques. This advantage, however, is at the expense of producing a greater boost in the noise level at frequencies just above the attenuation band. Of the devices employing feed-forward techniques, the MDRNC22 in-ear device was the best performer. Being an in-ear device, its receiver is presented with a higher acoustic impedance than is presented to the supra-aural feed-forward devices, resulting in better low frequency cancellation despite having a smaller receiver. Its deep and wide active attenuation reflects a good match of the feed-forward path with that of the acoustic leakage path over a wide range of frequencies.

4. Overload response

4.1. Method

The overload response of each device to continuous noise was measured using the method described in Section 3 with a few exceptions. Firstly, the external noise levels ranged from 100-125 dB SPL in 5 dB steps. Secondly, the tests were performed in an anechoic chamber with the noise source at 90 degrees to the median plane of HATS. Thirdly, sine waves at third octave frequencies swept over a range of 80 Hz to 2,000 Hz were used instead of pink noise.

The external noise signal was again produced by a Stanford Research Systems SR780 Network Signal Analyser; this was fed through a Behringer Ultra Curve Pro DSP 8024 equaliser, and a NAL remote control attenuator (0-99 dB adjustable range). The signal was then fed into two powered speakers (JBL EON15) that were placed inside an anechoic room (9 x 11 x 6.5 m) also located at the same facility. The speakers were placed side by side and positioned so HATS median plane was perpendicular to the direction of the sound.

The signals were analysed using the same setup as in Section 3.

4.2. Results

Figure 9 is an example of a typical overload response for a device that was not able to maintain its ANR for high level external noises. This figure shows the progressive reduction in the active attenuation with increasing noise level. When overloaded, none of the devices exhibited any instability or unexpected noise spikes. Instead the devices that overloaded simply produced less active attenuation until the benefit provided by the active system was negligible.

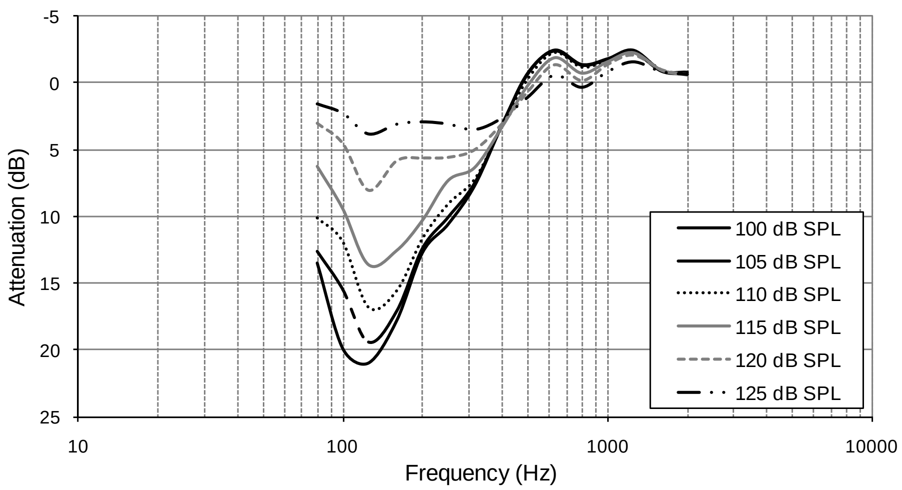

Figure 9. Overload response for the PXC450 (average of left and right devices)

Table 3 lists the highest external noise (tone) level (over a range of 80 Hz to 2 kHz) reached before each device began to overload. Overload was defined as the level where the active attenuation deviated more than 2 dB from its maximum. Table 3 also lists the frequency of the tone that first causes overload.

Group	Device	Maximum noise (tone) level before overload (dB SPL)	Frequency of the tone that first causes overload (Hz)
1	PA4000	>125	-
	PA3500	>125	-
	Stratus	>125	-
	Zulu	>125	-
2	QC2	115	80
	PXC450	100	100
	C820s	110	125
3	QC3	>125	-
	PXC250	100	200
	NB-FX	115	500
	NC7	115	500
	MDRNC20	105	200
4	MDRNC22	105	500

Table 3: Highest noise (tone) level reached before overload (>2 dB decrease in active attenuation) and the frequency of the tone that first causes overload. Test range: third-octave tones from 80 Hz to 2 kHz with levels from 100 to 125 dB SPL in 5 dB steps.

4.3. Discussion

The goal of testing the overload response of each device was to examine how well the active systems coped with high external noise levels. The results highlight some significant differences between devices as the external noise increased to 125 dB SPL. All of the group 1 devices and the QC3 were able to maintain consistent active attenuation up to an external noise level of at least 125 dB SPL, while some devices were unable to maintain this much above 100 dB SPL.

Major factors that affect the ability of a device to maintain consistent active attenuation at high external SPL levels are: the passive attenuation, as this determines the sound level needed to be generated within the occluded ear for noise cancellation purposes; the acoustic impedance presented to the receiver; the receiver performance when presented with this acoustic impedance and the maximum drive level to the receiver. The supra-aural group of devices (excluding the QC3) which provide no passive attenuation at low frequencies and exhibit a resonance in the mid frequency region overloaded at low external noise levels. They initially overloaded in the low-mid frequency (200-500 Hz) region. The poorer seal of the supra-aural devices results in both a high external noise level within the occluded ear and a low acoustic impedance presented to the receiver, meaning that for high level external noises the active systems were at their limit to produce a strong enough inverse sound pressure to cancel the noise. In contrast, the superior acoustic seal provided by the industrial circumaural devices meant that the active system did not have to work as hard to counteract the noise within the occluded ear, thus increasing the potential external noise range before the active systems reached their output limit. The domestic circumaural devices contained less padding, had lighter less voluminous shells and a lower clamping force than the group 1 devices, and thus did not perform as well (i.e. less passive protection led to a poorer overload response). They initially overloaded in the low frequency (80-125 Hz) region where there was no passive attenuation and the acoustic impedance was presented to the receiver was low. The maximum drive voltages were not directly measured. However with the exception of the PA4000 all the devices that maintained active attenuation consistently up to an external noise level of 125 dB SPL had battery supplies of at least 3 volts. The remaining devices except for the PCX250 had battery supplies of only 1.5 volts.

5. Internal noise

5.1. Method

The internal noise of each device was measured on a HATS located within the large anechoic room described in Section 4. Other than HATS, all the test equipment was located outside the anechoic room.

The signals were analysed using the same setup as in Section 3. The left and right ear measurements were averaged to produce the internal noise levels at third-octave frequencies.

5.2. Results

Table 4 summarises the broadband internal noise levels for each device produced by the active electronics. The frequency range for these measurements was 31.5-8,000 Hz, but in some cases the range was reduced to ensure the noise floor of the test system was at least 3 dB below the active noise level in all the third octave analysis bands. The diffuse field values in dBA were obtained by converting the third-octave real-ear SPL values using the inverse diffuse field frequency response of HATS given in ITU-T recommendation P58 [10] and then applying the third-octave A weighting values given in IEC 60651 [12]. The internal noise of the devices was around 25 dBA on average with a spread from 19 dBA to 32 dBA. Figure 10 shows an example of the third-octave noise levels for one of the devices. This particular device exhibited a high noise level within a narrow region of its active attenuation band.

Group	Device	Internal noise (dB SPL real ear)	Internal noise (dBA diffuse field)
1	PA4000	35	26
	PA3500	29	21
	Stratus	39	32
	Zulu	34	25
2	QC2	27	19
	PXC450	31	21
	C820s	37	27
3	QC3	28	19
	PXC250	36	28
	NB-FX	37	30
	NC7	37	28
	MDRNC20	32	24
4	MDRNC22	36	25

Table 4: Broadband internal noise due to active component

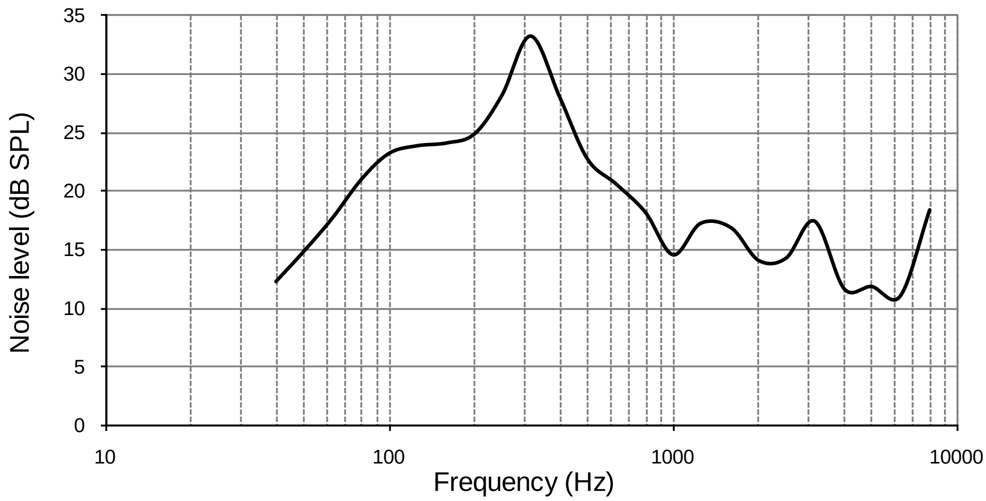

Figure 10. Average third-octave internal noise levels for the NB-FX (average of left and right devices)

5.3. Discussion

This test was useful in examining the noise produced by the electronics in each device. No patterns emerged that aided in comparing groups of devices. However, it should be noted that while there was only a 13 dB spread in the A-weighted total noise of the devices tested, a third-octave examination identified a 23.5 dB spread between the highest and lowest noise levels from all of the devices.

Despite the internal noise level of each device being audible in low noise environments, it is unlikely that the products tested would prove distracting or uncomfortable during long term usage. In most applications (e.g. in an airplane cabin or cockpit, factory or office environment) the internally generated noise is very likely to be considerably lower than the reduced external noise present in the ear canal and therefore is likely to be masked. Furthermore, if an audio/communication signal is reproduced by these devices then the internal noise will be further masked. Thus the measured internal noise levels of these devices are likely to be acceptable to the user when used in the field.

6. Attenuation of impulse noise

6.1. Method

Measurements of impulse noise attenuation were conducted using the following steps:

(a) Setup a reference microphone (FF) and a Head And Torso Simulator's (HATS) right ear equidistant from an impulse noise source at a distance of 1.1 metres to produce an SPL at the FF microphone of approximately 155 dB SPL peak
(b) Generate an impulse noise and record the time domain waveform from HATS (open ear response) and from the FF microphone
(c) Place the test device on HATS and determine passive response (PR) with ANR off (same recording regime as for step (b))
(d) Turn ANR system on and determine total response (TR) of device (same recording regime as for step (b))
(e) Normalise HATS results for comparison using reference microphone as the basis
(f) Repeat the above procedure with an impulse noise source located 8.5 metres equidistant from the HATS' right ear and the FF microphone to produce an SPL at the FF microphone of approximately 135 dB SPL peak.

The tests were conducted in a large anechoic room (9 x 11 x 6.5 m). The impulse noise was generated with a Jex 202 starting pistol. The output signal from the right ear of a Brüel & Kjær Type 4128C Head And Torso Simulator (HATS) and from a Brüel & Kjær Type 4136 ¼" microphone in the field were passed through a pair of Brüel & Kjær Type 2610 Measuring Amplifiers to be digitised by an MAudio MobilePre USB audio interface and finally recorded on a laptop computer using SpectraPlus version 5.0.

6.2. Results

Table 5 shows the attenuation of impulse noise for each device in passive and active mode. The attenuation figures are the averages of the attenuations obtained with the impulse noise source located nearby HATS (at a distance of 1.1 metres) and far from HATS (at a distance of 8.5 metres).

Group	**Device**	**Attenuation (dB)**	
		Passive	**Total**
1	PA4000	42	40
	PA3500	38	37
	Stratus	32	30
	Zulu	34	30
2	QC2	29	27
	PXC450	29	28
	C820s	28	27
3	QC3	18	17
	PXC250	16	17
	NB-FX	13	11
	NC7	12	13
	MDRNC20	11	12
4	MDRNC22	20	21

Table 5: Peak attenuation of impulse noise (average of the peak impulse noise attenuation for noise source locations near and far from ear)

6.3. *Discussion*

The main goal of testing the impulse noise response of the devices was to determine the peak attenuation provided by the four device groups, and to determine if the addition of an ANR system increased protection to impulses.

As expected, there was a clear difference in the passive attenuation performance between the product groups. The average peak attenuation was 37 dB for group 1, 29 dB for group 2, 14 dB for group 3 and 20 dB for group 4. The QC3 device, which had performed on the broadband noise tests like a group 2 device performed like a group 3 device with impulse noise. The dominant resonance in the impulse noise response in many cases was around 2 to 3 kHz. There was some variation in the peak attenuation of the impulse noise with a change in the noise source position (near or far). This variation most likely results from changes in the leakage path lengths when the noise source is moved, resulting in changes to the phase of the components at the resonance frequency and hence the peak value of the summed components.

There was no significant improvement seen in the peak attenuation with the active system engaged on any of the devices. For most of the devices that employed feedback based ANR techniques, the impulse protection was slightly reduced when the active system was running. Presumably at the dominant resonance frequency of the impulse response the phase response of the active system was more reinforcing than cancelling of the acoustic leakage path resulting in an increase in the peak impulse noise level.

7. Stability

7.1. *Method*

The stability of each device was measured subjectively by standing inside a diffuse pink noise field and then moving the ANR device around on the subject’s head. This included turning the system on and off, removing and replacing the device over the ears, and completely removing the device from the head and replacing it.

An equalised field of 80 dB SPL was used, generated in the same way as in Section 3.

7.2. *Results*

All of the devices were stable when being moved around (i.e. no audible instability) except the PA3500, which squealed when the ear cups were brought close together while the active system was engaged.

8. Conclusion

This report presents the results of a battery of tests performed on 13 personal ANR devices. Testing using an acoustic test fixture identified a wide variability in responses across devices in regards to broadband noise attenuation, continuous noise overload response, internal noise levels and impulse noise attenuation. The tests provide useful properties for the comparison of devices and groupings. ANR properties include attenuation depth, attenuation frequency, attenuation breadth, boosting, and boosting frequency. The active mechanism in all the devices tested provided attenuation of low frequency external noise and amplification of external noise at frequencies above the attenuation region. In some cases amplification also occurred at frequencies below the attenuation region. Distinctive differences in the performance of the industrial circumaural, domestic circumaural, domestic supra-aural, and domestic in-ear product groups were found for both the passive and active properties.

The active mechanism in effective devices provided a large amount of low frequency attenuation (maximum attenuation depth of 19 dB on average) and was able to maintain this attenuation even at high external noise levels (at least to 125 dB SPL). The poorer devices provided only minimal active attenuation and failed to maintain this attenuation as the external noise was increased. The industrial circumaural devices were the most effective at providing active and passive attenuation, and maintaining it up to at least 125 dB SPL. The domestic circumaural devices provided less passive attenuation and while they provided the same maximum active attenuation depth (19 dB on average) as the industrial circumaural devices they provided reduced active attenuation bandwidth with less effect on the very low frequencies and were more easily overloaded. With the exception of the Bose QC3 (which generally performed more like a domestic circumaural device), the domestic supra-aural devices provided considerably less maximum active attenuation depth (8 dB on average) and overloaded at lower levels. The domestic in-ear device displayed a deep and broad active attenuation (19 dB maximum).

It was found that the active noise reduction component in all the devices exhibited a degree of external noise boosting at some frequencies. The boosting was typically around 5 dB and tended to occur around 1.25 kHz in the case of the circumaural devices and at higher frequencies in the cases of the supra-aural and in-ear devices. A slight boosting of external noise also occurred at frequencies at or below 100 Hz in some devices.

The internal noise of the devices was around 25 dBA on average with a spread from 19 dBA to 32 dBA. The noise generated by the devices is dependent on the electronics within the devices and appeared independent of group type.

Distinctive differences were found in the passive attenuation of impulse noise between the device groups, ranging from an average peak attenuation of 37 dB for industrial circumaural devices down to 14 dB for the domestic supra-aural devices. The ANR system in each device provided no significant peak impulse noise protection. When the ANR was activated a slight increase in the peak impulse noise level resulted for most devices employing feedback based ANR techniques. All of the devices were stable when being moved around except the PA3500, which squealed while the ear cups were brought close together.

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