ICSV14
Cairns • Australia
9-12 July, 2007
14th International Congress on Sound & Vibration

DRIVER EXPOSURE TO NOISE FROM AUDIO TACTILE LINE MARKING IN QUEENSLAND

Daniel Naish[1]

[1]Queensland Government, Department of Main Roads
477 Boundary Street, Spring Hill, Brisbane, Queensland, Australia
daniel.a.naish@mainroads.qld.gov.au

Abstract

This study, which was funded by the Queensland Department of Main Roads, conducted various acoustic measurements near a vehicle driver's left and right ear position for a number of different test conditions to determine the change in noise level introduced by Audio Tactile Line Marking (ATLM). ATLM's are the ribbed profiles placed over the edge lines or centrelines of roads with the purpose of raising the awareness and alertness of a vehicle driver that the vehicle is travelling outside the bounds of its carriageway. The ATLM induces an audible and vibratory signal inside the cabin of the vehicle, however only the audible signal is investigated in this study. A site with a recently installed ATLM (250 mm spacing with 5 to 6 mm rib heights) was chosen for this study. Tests were conducted in standard passenger vehicles at 100 km/hr, 90 km/hr and 80 km/hr. The results showed that for parameters L_{A10}, L_{A5}, L_{A1} and L_{Amax}, the ATLM is observed to raise overall levels by 7 dB(A) to 9 dB(A) with little differences due to vehicle speed. Most of the additional acoustic energy is located at the fundamental frequency of the ATLM and up to the 3rd harmonic with the general spread of additional energy being between 50 Hz and 500 Hz. Also it was found that the left ear is subject to slightly higher noise increases than the right ear.

1.0 INTRODUCTION

This paper presents results obtained from the in-cabin acoustic measurements conducted for noise emitted by a vehicle driving over Audio Tactile Line Markings (ATLM) situated near Gatton, Queensland. ATLM's are pavement surface treatments in the form of raised bumps or ribs located on the pavement marking lines. They can be either on the pavement edge line or centre lines. The purpose of ATLM's is to provide an audible and vibratory warning system for driver's when their vehicles stray outside of the carriageway. The noise and vibration is produced by the passage of tyres over the raised bumps, therefore activating the ATLM.

A study was funded by the Queensland Government Department of Main Roads to provide further understanding of the audible signal produced at the driver's ear inside the cabin of a standard passenger car by activation of the ATLM. To do this, site measurements were conducted at a rural location where ATLM had been recently installed. The site is located west of the town of Gatton in south east Queensland. The signposted speed limit at this site was 100 km/hr. The ATLM constructed at this site is at 250 mm centres, each rib being 60 mm width and ranging from 5 mm to 6 mm in height. The pavement surface type is a "chip seal" surface. Figure 1 and Figure 2 show photographs of the test site ATLM and pavement.

This study has been conducted in two parts. Part A investigated the audible noise at the driver's left ear in 1/3 octave bands with a single channel. This part aimed to determine the overall change in noise level with various vehicle speeds, and also review the frequency content of the audible signal. Part B conducted dual channel narrow band measurements near the driver's left and right ear to determine differences in noise level on both sides of the driver's head. These measurements were aimed at providing more detail on the frequency content of the audible signal.

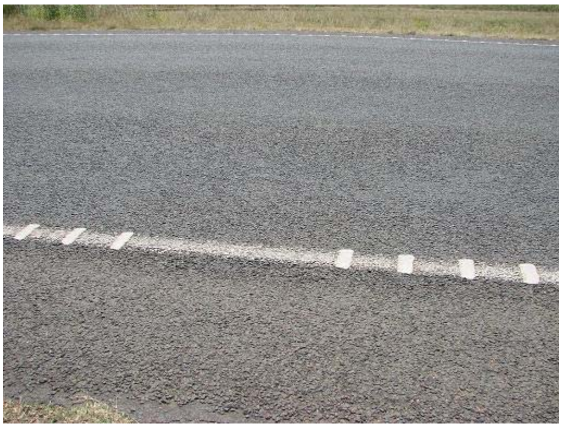


Figure 1: The ALTM at Gatton

Figure 2: ALTM ribs with a 300 mm ruler

2.0 METHODOLOGY

2.1 Part A

In this part, a B&K Type 2250 with a B&K Type 4189 microphone was set to 1 second logging with full 1/3 octave band spectra and overall statistics. The microphone was placed near the driver's left ear (the driver in Australia is seated on the right side of the vehicle). When the vehicle approached the ATLM, the measurement was commenced, and once the left side vehicle tyres activated the ATLM a manual measurement marker was engaged. This allowed the stored data to be later interrogated as to whether the recorded signal was on the ATLM (ATLM-On), or off the ATLM (ATLM-Off). The ATLM-Off situation represents the in-cabin background noise.

Three vehicle speeds were tested, 100 km/hr, 90 km/hr and 80 km/hr. Three passby tests at each speed were conducted. Two control tests at each speed were also made without the ATLM being activated. The vehicle used for Part A was a Mitsubishi Lancer ES sedan. All windows on the vehicle were closed and the air conditioning fan was operated at the slowest speed and was barely audible when the vehicle was idling.

2.2 Part B

In this part, a B&K 3560B PULSE system with FFT analysis software 7700 was used with two B&K Type 4189 microphones located near the left and right ear of the driver's head. Real time measurements were taken from 22 Hz to 10 kHz with 3200 lines resulting in frequency bands of 3.125 Hz width. During the 100 km/hr tests, a simultaneous time recording was made and was later analysed from around 22 Hz to 1 kHz with 3200 lines (0.3125 Hz width frequency bands).

Similar to the tests in Part A, three vehicle speeds were tested, 100 km/hr, 90 km/hr and 80 km/hr and three passby tests at each speed were conducted. Two passby tests were conducted without activating the ATLM thereby capturing the background noise. For these tests a Toyota Camry Altise year 2006 model sedan was used.

3.0 RESULTS PART A

3.1 Overall level results

The effect of the ATLM in overall dB(A) levels for various acoustic parameters is presented in Table 1. The overall results from Part A in Table 1 were analysed by taking the arithmetic mean of the sound pressure level descriptor. For example, if a single test contained 8 seconds of activated ATLM data, the L_{Aeq} data reported is the arithmetic mean of each of those 8 seconds.

Table 1: Effect of ATLM on various A-weighted noise parameters

Vehicle Speed	**ATLM Off/On**	L_{Amin}**	L_{A99}**	L_{A95}**	L_{A90}**	L_{A50}**	L_{Aeq}#	L_{A10}#	L_{A5}#	L_{A1}#	L_{Amax}#
80 km/hr	ATLM-Off	67	67	69	69	71	72	73	74	75	76
80 km/hr	ATLM-On	60	62	64	66	70	75	80	82	84	85
	Difference	-7	-5	-5	-3	-1	**3**	**7**	**8**	**9**	**9**
90 km/hr	ATLM-Off	62	63	64	66	71	71	73	74	75	76
90 km/hr	ATLLM-On	62	64	66	68	72	76	81	82	84	85
	Difference	0	1	2	2	1	**5**	**8**	**8**	**9**	**9**
100 km/hr	ALTM-Off	63	64	66	68	73	73	75	75	77	78
100 km/hr	ATLM-On	61	62	65	67	73	77	82	84	85	87
	Difference	-2	-2	-1	-1	0	**4**	**7**	**9**	**8**	**9**

#A noticeable difference due to the activated ATLM is observed.
**No appreciable difference or significance due to the ATLM. Differences in background noise for this data may be a result of different measurement durations and driving style. The "ALTM-On" data in this table includes a short time period prior to the vehicle activating the ATLM

For parameters L_{A10}, L_{A5}, L_{A1} and L_{Amax}, the ATLM is observed to raise overall dB(A) levels by 7 dB(A) to 9 dB(A). This is to be expected as these parameters represent the acoustic energy levels which are of short duration compared to the whole measurement period. The increase in noise level for these parameters was reasonably constant regardless of the vehicle speed.

The measured increase in L_{Aeq} noise levels ranged between 3 dB(A) and 5 dB(A), with the 5 dB(A) increase measured for a 90 km/hr speed.

3.2 One third octave band frequencies and time history results

The frequency and time history results obtained for the 100 km/hr tests are presented in Figure 3. In Figure 3(a), there are noticeable increases in noise level in the 100 Hz, 200 Hz and 315 Hz frequency bands. This is not surprising as the predicted fundamental frequency for a speed of 100km/hr and an ATLM with 250 mm spacing is 111 Hz as shown in Table 2.

Table 2: Predicted ATLM fundamental frequency and 1st and 2nd order harmonics for 250 mm spacing

	80 km/hr	90 km/hr	100 km/hr
Fundamental Frequency	89	100	111
1st Harmonic	178	200	222
2nd Harmonic	267	300	333

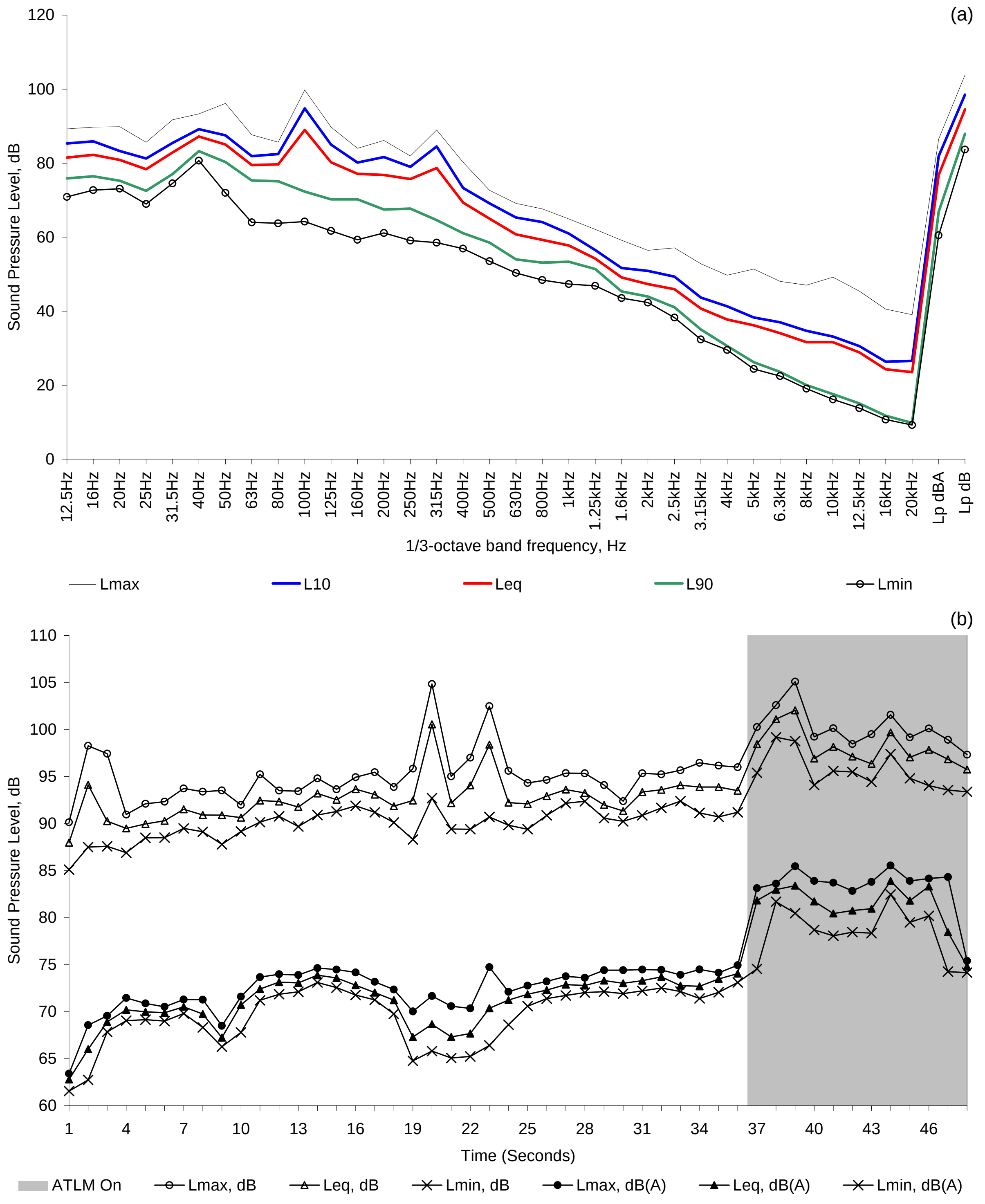


Figure 3: Measured results for speed at 100 km/hr with ATLM-On (a) 1/3 octave band frequency (b) time history.

Similar analysis performed in Figure 3 was applied for the 80 and 90 km/hr tests (data not shown). The analysis of all vehicle speeds measured indicated:

- There is a general broad band increase in acoustic energy across all frequencies. This result was consistent with the results presented in Table 1 which indicates a 7 dB(A) to 9 dB(A) overall increase in noise levels.
- The ATLM introduced tonal characteristics in certain frequency bands, mostly at the fundamental frequency and the 1st and 2nd order harmonic.
- The increase in level due to the ATLM in the fundamental frequency band is approximately 16 dB(A) for both the 100 km/hr and 90 km/hr tests and 20 dB(A) for the 80 km/hr test. Increases in noise level of these magnitudes are clearly noticeable to an alert driver however more review is needed to determine if these increases are sufficient to wake a person with low levels of alertness.

Figure 3(b) shows the time history of a particular test at 100 km/hr. It is observed there is a sudden increase in all noise level descriptors from L_{min} to L_{max} when the ATLM is activated.

4.0 RESULTS PART B

With the measurements conducted in Part B it was possible to see the overall and narrowband differences between the driver's left and right ear. The results in Table 3 are based on the measured overall levels and averaged for each speed configuration. The results suggest that the difference in sound pressured level in background noise conditions was around 0.8 dB with the right ear being subject to slightly higher noise levels. When the ATLM was activated, the right ear was also subjected to higher noise levels than the left ear, but the difference is around 1.3 dB. With overall levels and a linear scale, the measured differences were almost negligible.

Table 3: Average level differences between driver’s left and right ear, dB (linear)

Speed	80 km/hr		90 km/hr		100 km/hr	
ATLM	Off	On	Off	On	Off	On
Left Ear	95.4	97.2	96.3	97.9	95.0	96.2
Right Ear	96.1	98.7	97.1	99.2	95.9	97.6
Difference (Right to Left Ear)	-0.7	-1.5	-0.8	-1.3	-0.9	-1.4

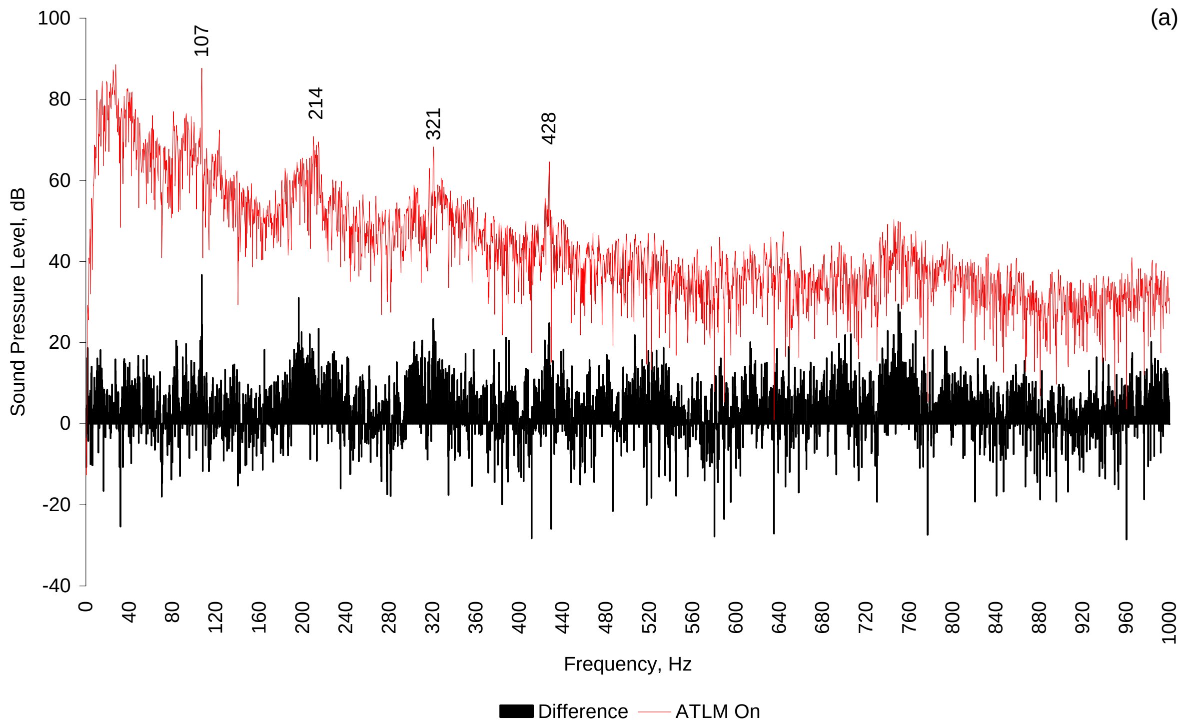
To compare the effect of A-weighting the results, the results of the time recorded 100 km/hr test was analysed into 1/3 octave band frequencies and the overall levels calculated. The ATLM-On and ATLM-Off results were analysed both as linear and A-weighted noise levels. Table 4 presents the results, which show that by A-weighting the noise levels, calculated differences were significantly higher. Interestingly, the difference in A-weighted noise levels was higher for the left ear than for the right ear, and conversely for linear noise levels.

Table 4: Difference in the total level at the ear, ATLM On to ATLM Off, linear or A-weighted

	Left Ear (Difference ATLM-On to ATLM-Off)	Right Ear (Difference ATLM-On to ATLM-Off)	Difference (Right to Left Ear)
Linear	0.4	1.4	1.0
A-weighted	4.9	3.6	-1.2

In 1/3 octave bands, there was little difference between the background noise and the activated ATLM beyond around 800 Hz. Almost all of the additional energy due the ATLM was observed to be between 50 Hz and 500 Hz.

The recorded test at 100 km/hr was analysed in narrow bands up to 1 kHz for both left and right ears and with ATLM–On and ATLM-Off. The results in Figure 4 demonstrate that the fundamental frequency occurs at 107 Hz with up to the 3rd order harmonic frequency clearly noticeable as containing significant additional energy.



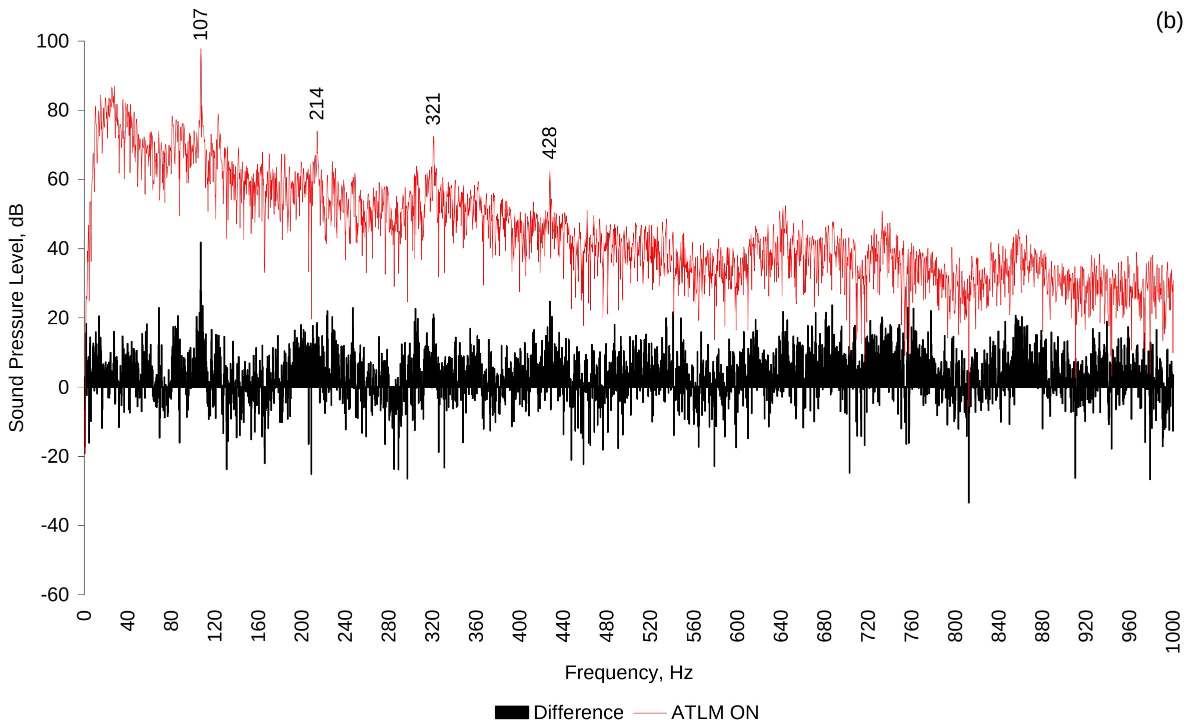


Figure 4: Results at 100 km/hr for ATLM-On and the difference with ATLM-Off
(a) left ear (b) right ear

Upon closer inspection of Figure 4 it was observed that the left ear is subject to considerably more broad band reductions around the 1st and 2nd harmonic than the right ear. It is also noticed that the activated ATLM results in lower in-cabin noise in some frequencies compared to the background level.

The exact cause for this remains unexplored but it is possible that the left wheels were not in continuous contact with the normal pavement surface which may result in less energy in some frequencies transmitted to the cabin. Another possible cause is the right wheels of the vehicle will be close to the centre of the carriageway and not travelling in the normal track of the pavement surface, where the normal track is likely to be more worn and fatigued than the centre of the carriageway. This could also result in different acoustic energy in different frequency bands for the ATLM-On and ATLM-Off scenarios.

A histogram of the differences shown in Figure 4(a) and (b) for 5 dB intervals from -35 dB to 45 dB was generated and is shown in Figure 5. As the analysis was from 0 Hz to 1000 Hz at 3200 lines, the number of frequency bands is 3200. The results in Figure 5 show that for the left ear, 902 of these frequency bands demonstrated increased noise levels between 5 and 10 dB. Figure 5 shows that the left ear is generally subjected to a higher number frequency bands with 5 to 10 dB increases due to the activation of the ATLM than the right ear. Compared to the left ear, the right ear was subject to more frequencies with -5 dB differences, which means more frequency bands had higher background levels than with the activated ATLM.

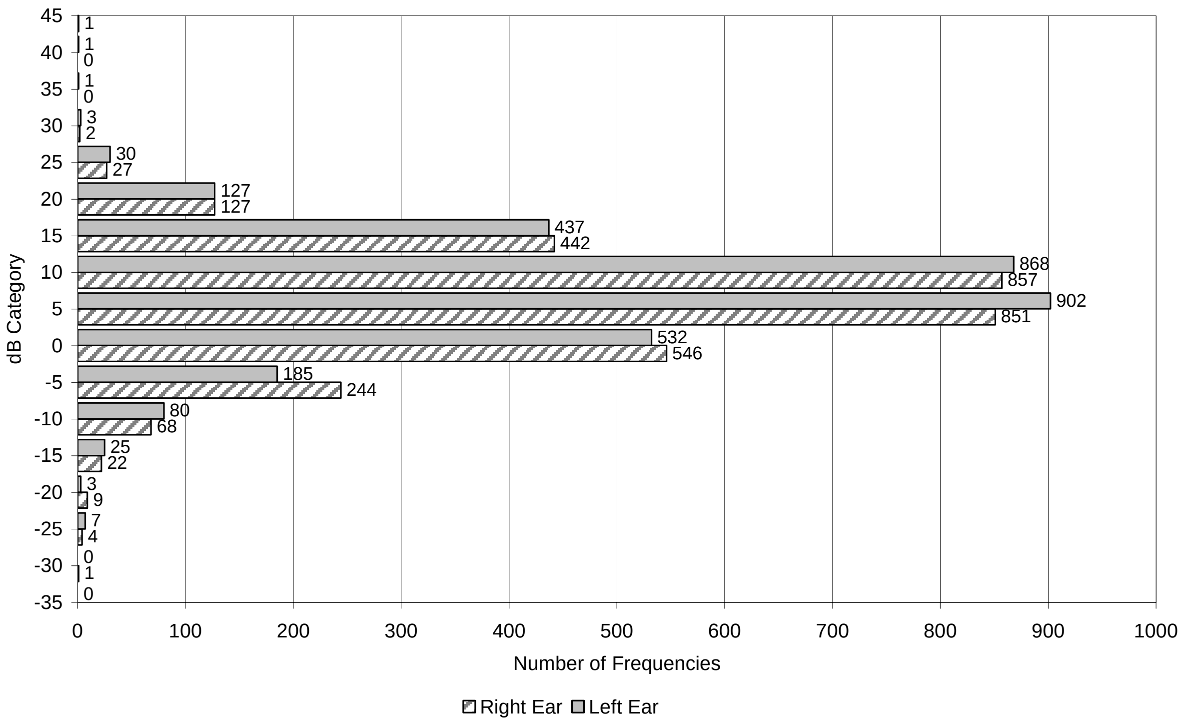


Figure 5: Histogram of the calculated differences from Figure 4(a) and (b)

Table 5 shows some broad statistics obtained from the histogram in Figure 5. This shows that across all frequencies up to 1 kHz, the ATLM increased a driver's exposure to in-cabin noise levels by an average of 4.0 dB with peak increases up to 40 dB in the fundamental frequency band. The 25% quartile was close to 0 dB suggesting that 75% of the frequencies experience an increase in noise due to the activated ATLM. This was consistent with the conclusions from 1/3 octave band frequency results from Part A of this study.

Table 5: Statistics from the histogram data from Figure 5, based on calculated differences ATLM-On and ATLM-Off

Statistic	Left Ear	Right Ear
Average	4.0	3.8
Standard Deviation	7.2	7.3
Max	36.7	41.8
75% Quartile	8.5	8.7
50% Quartile	4.3	4.4
25% Quartile	-0.2	-0.7
Min	-28.6	-33.4

The magnitude of in-cabin noise reductions due to the activated ATLM was around 30 dB. This is an interesting result and warrants further investigation in an extended study, however it is unlikely to be of significant importance as increases constituted 75% of the frequencies while reductions constituted only 25% of the frequencies.

5.0 CONCLUSIONS

This brief study into the acoustic attributes of ATLM's has found that most of the in-cabin noise level with an activated ATLM will be centered around the fundamental frequency and up to the 3rd order harmonic. On average overall in-cabin noise levels increase by around 4 dB and 7 to 9 dB(A), however increases are unlikely to be significant above 800 Hz. The additional acoustic energy in the fundamental frequency is up to 40 dB which should be very noticeable to a driver. There does not appear to be a significant difference between the vehicle speeds tested.

It has been determined that there is little difference between the noise level at the left and right ear for overall linear levels, but differences become significant on an A-weighted scale. The left ear was demonstrated to be subject to higher changes in noise level due to the activated ATLM than the right ear. Based on the results of this study, it is acceptable to conduct future tests with a single microphone located at the driver's left ear only.

It is intended that this study be further extended and improved to include measurement of vibration on the steering wheel of the vehicle and also review the available research on combined acoustic and vibratory energy levels required to raise driver alertness. The effect of various pavement surface types on in-cabin noise levels in Queensland needs to be considered, along with tests conducted at other existing ATLM sites in Queensland. It is intended that this data may be used to determine a refined construction specification for ATLM's in Queensland.

Disclaimer