

Noise Camera: Automated Detection Technology to Identify Noisy Vehicles

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ABSTRACT

Higher traffic densities and community expectations for a clean environment have resulted in jurisdictions developing and adopting more stringent standards for motor vehicle emissions. This includes motor vehicle drive-by noise and noise generated by heavy vehicle engine brakes. To date, enforcement of in-service motor vehicle noise standards has been limited to stationary noise testing. This method of enforcement is labour intensive, disruptive to conforming motorists and does not correlate well with drive-by noise levels. The South Australian Department for Transport, Energy and Infrastructure has undertaken to develop an automated system called a noise camera to identify noisy vehicles in the traffic stream. The noise camera, believed to be a world first, is capable of recording noisy vehicles based on user programmable sound characteristics. Designed primarily to identify noisy engine brakes in accordance with Engine Brakes Noise Standards, currently being developed by the National Transport Commission, the camera can also identify noise from individual vehicles during acceleration. This paper describes the drivers behind the development of the camera, the design of the technology, its capabilities and data collected to date.

INTRODUCTION

The transport sector is a significant contributor to community noise and transport and environment agencies around Australia receive numerous complaints from individuals about traffic noise in general and about individual vehicle noise. Over the last several years the number of these complaints has been gradually increasing particularly in relation to noise generated by heavy vehicle engine brakes.

Indeed, the Australian road freight task is forecast to continue to grow at an average annual rate of around 4.1% (Apelbaum 2006). This increase is expected to be achieved by more heavy vehicles, carrying more weight and travelling increased average distances per trip and this is likely to exacerbate the noise problem.

Anecdotally, in Australia, the expenditure on traffic noise barriers and other noise treatments such as quiet pavements has been increasing over time as a percentage of road project costs.

Noise barriers are also not as effective in mitigating noise generated by individual vehicles as is control of the noise at its source. In its traditional approach however vehicle enforcement can be resource intensive. The need to pull vehicles over to make stationary noise measurements also inconveniences drivers of compliant vehicles.

Noise generated by heavy vehicle engine brakes is currently unregulated in Australia and its measurement can only be made while the vehicle is in motion. There is also a poor correlation between stationary noise and engine brake noise.

A new approach to enforcement of noise from individual motor vehicles was therefore required to address this growing community concern.

DEVELOPMENT OF THE NOISE CAMERA

The notion of the noise camera technology was conceived within the South Australian Department for Transport, En-

ergy and Infrastructure almost ten years ago and since that time three versions of the system were developed.

The original system was based on "off the shelf" componentry and allowed triggering on the basis of sound pressure level (SPL) only and its setting was performed through a manual potentiometer adjustment. The early trials and experiences proved invaluable in establishing the latest noise camera specification.

The last two versions of the system were developed under a contract by a Sydney based company Acoustic Technologies Pty Ltd (AT) following a tender evaluation that the company won in March 2003. AT's experience in the provision of acoustical systems and instrumentation to military and commercial customers in Australia and around the world contributed in part to their winning formulae.

The first prototype of the camera was delivered in September 2003 and testing and evaluation of the system took place over the next 6 months. The second version of the system was delivered in early 2006 and incorporated improvements relating to the analysis software and night time visibility. Additional features included extra sound analysis functions and a radar input allowing recording and triggering on the basis of vehicle speed and length.

The design of the camera has also been influenced by the development of the National Transport Commission's Engine Brake Noise Standards (NTC 2006) with a view of potentially using the system in the future to enforce the Standards.

MAIN NOISE CAMERA FEATURES

The noise camera system comprises of the three main components namely (Figure 1, Ford Jan & March 2006):

- the Noise Processing Unit (NPU) and microphone
- the Camera Processing Unit (CPU) and two video cameras (for scene and close-up views) and
- the system controller lap top computer.

The NPU can also be fitted with an optional radar system to allow triggering on the basis of vehicle length and/or speed.

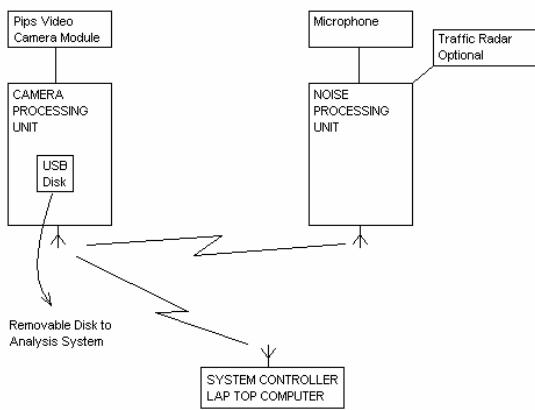


Figure 1. Noise Camera System Schematic

Both the Camera and Noise Processing Units are PC based and able to communicate via a wireless Ethernet connection. The CPU communicates with the System Controller Lap Top and is able to receive commands and settings and send information recorded by the noise camera system.

The CPU and NPU are mounted in double skinned enclosures and intended to be positioned on adjacent roadside poles. In-situ the units are separated so that the scene view camera has a clear view of the microphone locality. This assists in the identification of the vehicle responsible for the noise and allows for the determination of the approximate distance between the noise source and the microphone.

A Rion UC-53A microphone is used by the system and the noise measurement conforms to AS-1259 Type 1 specification.

A PIPS P362 video camera system is used to feed video information to the Camera Processing Unit using 75 ohm standard video output. Designed specifically for automatic plate recognition systems this camera system comprises of a monochrome CCD camera with high infra-red sensitivity and a colour overview camera, surrounded by an illuminator consisting of a ring of eye-safe, infra-red light emitting diodes. The illumination provides an effective viewing range of up to 15 metres. PIPS patented filter and flash techniques assist in the suppression of headlights. Field-by-field control of camera parameters allows the use of PIPS patented 'triple-flash' technique to reduce problems of plate-to-plate variation. The noise camera records front licence plates to identify the prime mover rather than the trailer.

A 250 Gb removable USB hard drive is used to transfer bulk amounts of information captured by the noise camera. Whilst the continuous recording of information (that includes video, audio and analysis data) extinguishes this memory capacity of the system in approximately 24 hours (depending on data resolution selected), the ability of the system to target specific events ensures that it can operate independently for several weeks at a time.

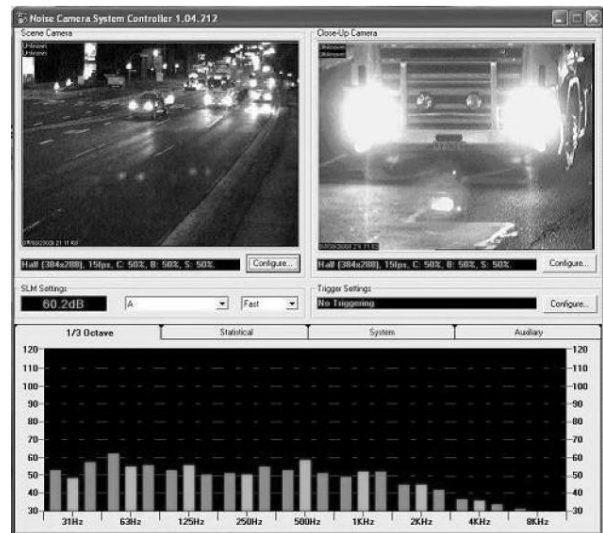
The system is controlled using a lap top computer via a wireless Ethernet connection. The controller and analysis software driving the noise camera system provide a high level of flexibility to the camera operation and post analysis. The controlled software allows the remote setting of all critical elements of the noise camera including trigger configuration, video camera settings and system calibrations. The controller software allows previewing of real time video and sound data. The lap top computer is also able to access the noise camera files through the standard Microsoft Windows operating system so that complete data relating to specific events

can be downloaded remotely without the need to access the Camera Processing Unit and the removable hard drive.

NOISE CAMERA CONTROLLER SOFTWARE

The Controller Software allows for a high degree of operator flexibility in the type and amount of information recorded by the noise camera system. This allows the operator to achieve a balance between the type and detail of the information and the volume of data collected.

The Controller Software Interface, shown in Figure 2, allows the user to monitor and control the noise camera through a set of clickable windows and menus.



Source: (Ford January 2006)

Figure 2. Noise Camera Controller Interface

Video Camera System

The video camera control extends to the setting of frame size and rate as well as brightness, contrast and saturation.

Additional video camera settings are available through the PIPS software to control such features as the flash table for the infra red illuminator. The features controlled through this function run locally and autonomously and are typically set once only.

The Controller Software provides a preview of both the scene and close-up cameras. The preview frame rate is fixed and changing the frame rate alters the recording frame rate only. The system is designed to provide a minimum of 24 hours continuous recording when the frame size is set to a maximum resolution (768 x 576) and a frame rate of 12 frames per second for both cameras.

Sound Level Meter

In the Controller Software the Sound Pressure Level (SPL) is displayed numerically. The settings for the Sound Level Meter (SLM) include selection of frequency, band or preset options. Options are provided for each of the 1/3 octave band frequency centres in accordance with 1/3 band filters defined in AS4476. Linear, A and C weightings are also provided as per AS1259 Part 1.

The SLM settings also include selection of time averaging applied to the readings and include options for Fast, Slow, Impulse as per AS1259 Part 1 and 5ms.

1/3 Octave Display

The Controller Software features a 1/3 Octave Display provided in a bar graph format. This data is time averaged using SLM settings (see Figure 4 for a similar display incorporated into the Noise Camera Analysis Software).

Statistical Display

Another standard display of the Controller Software displays statistical information of the most recently acquired background noise statistics. The information can be configured for time weighting options of Fast, Slow, Impulse and 5ms and time intervals of 1, 2, 3, 5, 10, 15, 20, 30 and 60 minutes.

The Statistical Display includes tabulated information of L_{eq} , L_{max} , L_1 , L_5 , L_{10} , L_{50} , L_{90} , L_{95} , L_{99} , L_{min} for each Linear, A and C weighting and each of the 1/3 octave band frequency centres.

Configuring this area of the Controller Software allows the noise camera to generate ".std" files that contain the background noise statistics. These files can be later viewed or exported into Microsoft Windows environment.

System Display

A system display is also provided and includes general information about the system including system ID, remaining storage capacity, system date and time, last calibration time and date and noise camera location, microphone location and offset, view direction and installer name.

This display also allows for updating manually entered information including calibration of the microphone system.

Auxiliary Display

The Auxiliary Display provides outputs of the modulation based algorithms including RMS, Tonal and Harmonic described in the following section under Modulation Detection. The Display provides a current numerical indication, a peak numerical value reached within the cut and a dynamic bar graph. This display is identical to that used in the Analysis Software (see Figure 9) with the addition of reset buttons used to zero peak values.

The Auxiliary Display also indicates Traffic Radar input including detection and receive time and speed and length of the vehicle.

Trigger Settings

The Noise Camera Controller Software provides the user with a range of noise camera triggering options. These can be based on sound characteristics (SPL, SPL statistical variation, and modulation), time (continuous, periodical) or vehicle characteristics (vehicle speed and length).

During operation the noise camera system continuously records audio and video information into a memory buffer. When a trigger is asserted the camera can retrieve up to 30 seconds of this information from the buffer and record a maximum of 60 seconds for each event. Both the pre-trigger time and cut duration are user selectable. This allows the camera to record the complete drive-by of the vehicle including its approach to the microphone site.

For each cut the camera records two video files, one audio file and general information file. This allows the cut to be reanalysed at a later time using different settings.

The following trigger options are provided by the Noise Camera Controller Software:

Sound Pressure Level (SPL)

An instant Sound Pressure Level trigger can be defined by identifying the SPL together with the frequency weighting, time averaging and whether the trigger is based on over or under a set sound pressure level. The SPL values between 40 dB and 120 dB can be entered. The instant SPL function also allows the use of logical operators AND and OR to establish the relationships between the parameters. Up to 8 "AND'd" parameters on each of the 4 "OR'd" sets are permissible. The SPL level can also be set over time on the same basis as the instant SPL but with the addition of a time element where the desired SPL level must be sustained for a period of time ranging from 1 to 99 seconds before the trigger is asserted.

Statistical Variation

The statistical variation function allows the user to set up trigger conditions on the basis of a difference between two statistical values. The operator is able to stipulate frequency weighting, time averaging, measurement type and duration for each statistical value. The trigger is asserted if the difference between the two values is either greater or lesser than a stipulated level. The measurement types available to the user include logarithmic mean, L_{eq} , L_{max} , L_1 , L_5 , L_{10} , L_{50} , L_{90} , L_{95} , L_{99} and L_{min} .

Time Based Triggering

The system can be configured to record information on a time basis. This includes recording information:

- continuously
- hourly by setting start and finish times past the hour and
- daily by setting start and finish times

One minute segments can also be recorded every set number of minutes.

Modulation Detection

Evaluation of available literature has found that the annoyance associated with engine brake noise was the result of spectral characteristics of the noise rather than due to a high A-weighted peak noise level (Vipac 1991). Furthermore, Fidell and Horonjeff (1981) report on psychoacoustic experiments that measured the relative annoyance of engine brake recordings. Whilst maximum A-weighted SPL was sufficient for occupational health and safety purposes related to engine brake noise, a correction to this SPL based on peak RMS ratios improved the annoyance correlation.

The Noise Camera software therefore incorporates a number of modulation based algorithms that were specifically developed for the identification of engine brake noise.

The modulation based algorithms incorporated within the noise camera include Rises and Falls, Tonal, Harmonic and RMS. All were evaluated as potential engine brake noise indicators during the development of the National Transport Commission's Engine Brake Noise Standard (NTC 2006).

The Rises and Falls algorithm triggers the camera on the basis of a number of modulations above a preset level measured over a selectable time period.

The Tonal algorithm converts 5ms time averaged SPL data into a spectral form. The magnitude of the peak tonal, refined by altering the search bandwidth and the resolution of the

spectral data, is used as the basis of the output source (Keeley 2004).

The Harmonic algorithm expands the Tonal algorithm by incorporating the harmonics of the peak tonal into the output score (Keeley 2004).

The RMS algorithm provides a quantitative indication of the intensity of short term variations in the noise signal compared to the long term average.

Radar

Developed for the purpose of collecting complete noise data sets about specific vehicle classes defined on the basis of vehicle length and to allow evaluation of the impact of vehicle speed on noise, the Radar information triggers the noise camera on the basis of preset vehicle lengths and speeds or a combination thereof. The lengths and speeds can be defined as a range of acceptable values.

NOISE CAMERA ANALYSIS SOFTWARE

The Noise Camera Analysis Software resembles in appearance the Controller Interface and displays scene and close-up camera views in the upper portion of the screen and cut information in the lower portion. Figure 3 shows an example of the Analysis Software displaying a vehicle captured by Vic Roads in Melbourne's CityLink Domain Tunnel.

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Figure 3. Noise Camera Analysis Interface

The recorded information (cut information and noise statistics) is accessed through the File Menu located on the top left hand corner of the screen.

Once loaded, the recorded events can be replayed using control icons positioned below the scene and close-up camera displays (see Figure 4). These icons allow the operator to play the recording or view it one frame at a time or move between recorded events.

This window also contains SPL meter settings where the operator can set 1/3 octave frequency or linear, A and C weightings as well as time averaging options. These settings are then used to display SPL in a graphical format as described below.

Another important feature of the analysis software is the Lateral Estimation function. The program assumes a hemispherical noise dissipation pattern to arrive at a corrected SPL reading once the system is calibrated and the scene camera view used to estimate the distance from the microphone to the noise source.

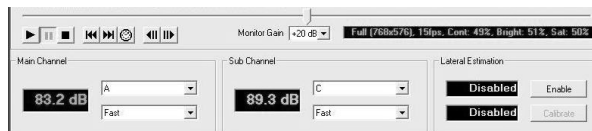


Figure 4. Camera, SPL and Lateral Estimation Control

The lower portion of the analysis screen provides access to cut information by clicking one of the seven tabs provided including cuts list, general cut information, noise statistics, SPL graph, narrowband, 1/3 octave and auxiliary for RMS, tonal, harmonic and radar data.

SPL Graph and 1/3 Octave

Figure 3 shows SPL graphs over the duration of the cut and 1/3 Octave data in a real time mode.

The SPL graph displays two channels with SPL data based on user selectable weighting and time averaging. As the information is recorded in an audio file the display of SPL can be recalculated using different weighting and time averaging than used to capture the original data.

Cut List

The Cut List tab provides access to a list of cuts contained in the directory currently loaded into the Analysis Software.

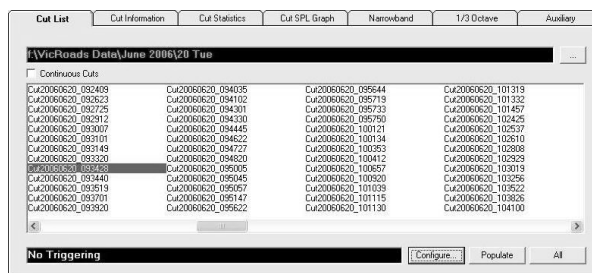


Figure 5. Cut List Display

From this display, cuts can be accessed individually or on a folder basis. The information contained in a folder can also be subjected to a trigger simulation using all trigger settings, except time based, available in the Noise Camera Controller Software. This is particularly useful in analysing the effectiveness of a new trigger on data recorded continuously.

This function can also be used to develop a subset of triggers to fine tune the original trigger used to collect the data. In the future both trigger parameters could be used in combination to minimise post analysis of information.

Cut Information

Clicking the cut information tab displays the general information window related to this particular cut. The information contained in this window is largely manually entered by the operator at the time of configuring the system but also includes file information and cut time and date.

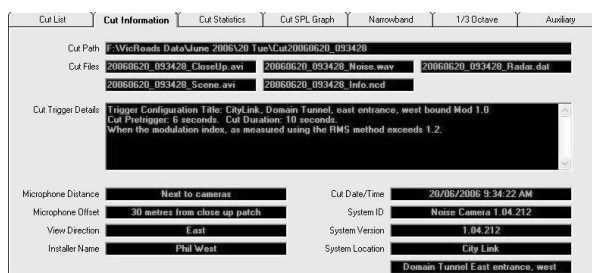


Figure 6. Cut Information Display

Cut Statistics

The cut statistics information is accessed by clicking the cut statistics tab. This window displays statistical data associated with this cut and indicates L_{eq} , L_{max} , L_1 , L_5 , L_{10} , L_{50} , L_{90} , L_{95} , L_{99} , L_{min} for each Linear, A and C weighting and each of the 1/3 octave band frequency centres.

Cut List	Cut Information	Cut Statistics	Cut SPL Graph	Narrowband	1/3 Octave	Auxiliary																																							
		<table border="1"> <thead> <tr> <th>Leq</th> <th>Lmax</th> <th>L1</th> <th>L5</th> <th>L10</th> <th>L50</th> <th>L90</th> <th>L95</th> <th>L99</th> <th>Lmin</th> </tr> </thead> <tr> <td>Lin</td> <td>90.0dB</td> <td>99.4dB</td> <td>98.6dB</td> <td>96.3dB</td> <td>93.5dB</td> <td>86.6dB</td> <td>83.4dB</td> <td>82.7dB</td> <td>81.8dB</td> </tr> <tr> <td>A</td> <td>82.3dB</td> <td>93.1dB</td> <td>92.0dB</td> <td>88.8dB</td> <td>86.0dB</td> <td>79.4dB</td> <td>76.4dB</td> <td>76.0dB</td> <td>75.6dB</td> </tr> <tr> <td>C</td> <td>89.4dB</td> <td>99.1dB</td> <td>98.3dB</td> <td>96.5dB</td> <td>93.2dB</td> <td>85.0dB</td> <td>81.7dB</td> <td>81.2dB</td> <td>80.2dB</td> </tr> </table>	Leq	Lmax	L1	L5	L10	L50	L90	L95	L99	Lmin	Lin	90.0dB	99.4dB	98.6dB	96.3dB	93.5dB	86.6dB	83.4dB	82.7dB	81.8dB	A	82.3dB	93.1dB	92.0dB	88.8dB	86.0dB	79.4dB	76.4dB	76.0dB	75.6dB	C	89.4dB	99.1dB	98.3dB	96.5dB	93.2dB	85.0dB	81.7dB	81.2dB	80.2dB			
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160Hz	74.7dB	83.3dB	83.0dB	81.3dB	79.7dB	69.8dB	65.1dB	63.1dB	61.1dB																																				
200Hz	78.1dB	88.3dB	87.7dB	85.5dB	83.2dB	72.1dB	66.4dB	65.4dB	63.9dB																																				
250Hz	79.6dB	90.4dB	89.6dB	86.3dB	84.7dB	73.7dB	69.3dB	67.9dB	66.1dB																																				
315Hz	81.9dB	93.2dB	92.0dB	88.7dB	86.0dB	75.3dB	69.8dB	68.8dB	67.3dB																																				

Figure 7. Cut Statistics Display

This statistical information can be reconfigured using a different time weighting.

Narrowband

The narrowband display provides the operator with a graphical display of frequency against signal amplitude in real time. The frequency scale is linear and continuous, with a display resolution of approximately 23.4 Hz. To assist the operator in estimating frequency and amplitude data from this display a mouse pointer is provided and its position on the screen relates to the frequency and amplitude data displayed in the top centre text box.

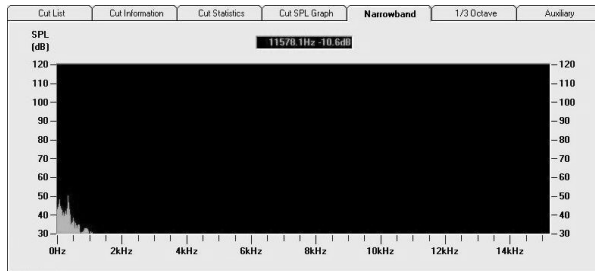


Figure 8. Narrowband Display

Auxiliary Information

The auxiliary display provides identical information to that of the Noise Camera Controller Software except that the Controller Software includes peak values reset function. The reset function is necessary in the Controller Software as the data is analysed on a continuous basis as it is received by the Noise Camera. In the Analysis Software the modulation indexes are recalculated for each cut.

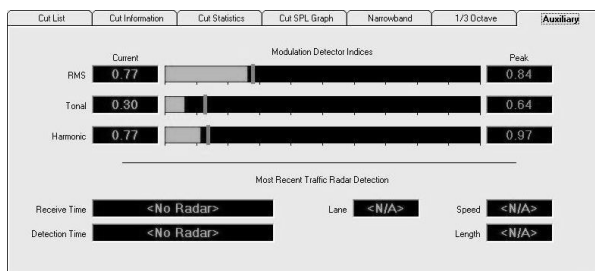


Figure 9. Auxiliary Display

The auxiliary display also includes Traffic Radar information including detection and receive time, vehicle speed and length.

PRELIMINARY DATA

At the time of writing this paper, Vic Roads is in the process of using the Noise Camera system to collect data with the aim of developing a better understanding about engine brake noise. To date, data has been collected at a number of sites and over 20,000 recordings were made over a period of 40 days and this includes approximately 10,000 engine brake events. Ten different noise camera trigger settings were evaluated.

Whilst this work is still in progress, it is included in this paper to demonstrate the capability of the noise camera to collect large volumes of relevant information relating to individual vehicles. It must be stressed however that this data is not quality controlled and should be treated as preliminary data only.

The following data comes from Melbourne’s CityLink Domain Tunnel and represents 577 engine brake events. Each event recorded the RMS (as per RMS algorithm described under Trigger Settings – Modulation Detection) and L_{max} value emitted by the vehicle driving by.

Figure 10 represents all 577 pairs of RMS and L_{max} readings plotted from the lowest RMS value of 0.7 dBA on the left in ascending order to the highest RMS value of 3.1 dBA on the right. This graph indicates that the majority (95%) of trucks recorded in this sample fall below RMS of 1.7 dBA. As the RMS value provides a good measure of modulation intensity and this is closely related to the community annoyance about engine brake noise, the RMS algorithm could be used in setting a standard for heavy vehicle engine brake modulation.

This graph also indicates a poor level of correlation between L_{max} values and RMS although this is exacerbated by the L_{max} values not being corrected for distance.

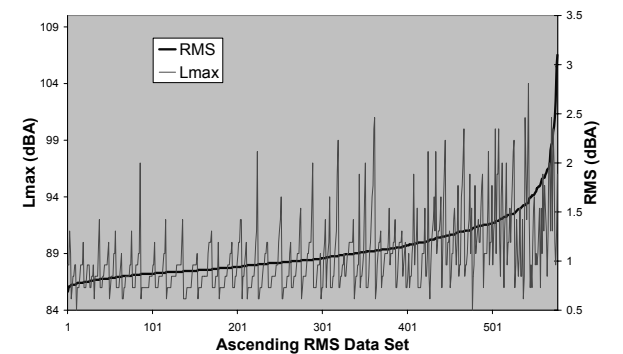


Figure 10. L_{max} and RMS data set

This information was collected using an L_{max} trigger set at 85 dBA and the highest reading recorded at 104 dBA. Figure 11 indicates the frequency distribution associated with this variable. The mean for this distribution was calculated at 88.6 dBA.

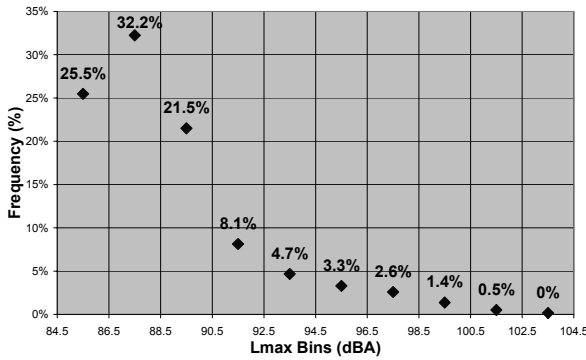


Figure 11. Frequency Distribution L_{max}

Figure 12 shows a frequency distribution for the RMS data with a mean calculated at approximately 1.1 dBA.

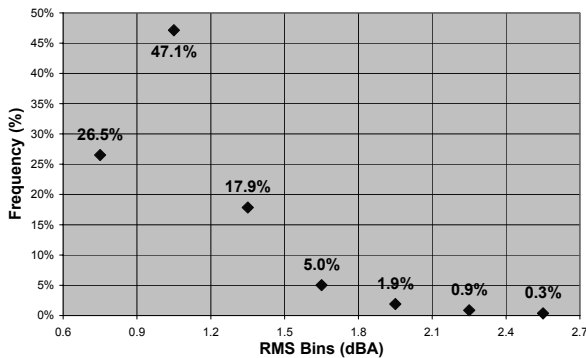


Figure 12. Frequency Distribution RMS

CONCLUSIONS

The development of the Noise Camera system has provided an opportunity for legislators and researchers to learn more about the condition of the in-service motor vehicle fleet. This includes information about both the condition of light vehicles and heavy vehicles, especially those incorporating engine brakes.

The collection of data about individual vehicle performance will inform future policy direction in relation to motor vehicle noise enforcement. Indeed, information collected to date, is being used to assist in the development of the National Transport Commission's Engine Brake Noise Standards.

In the future, the Noise Camera technology may also assist legislators in enforcing the motor vehicle noise standards. The Noise Camera has already proven its ability to effectively identified noisy engine brakes and could be used to enforce the proposed Engine Brake Noise Standards if they are accepted and introduced into legislation.

The Camera could also be used to identify excessively noisy vehicles on the basis of L_{max} levels for possible follow up by enforcement authorities and testing of vehicles in accordance with established stationary noise standards.

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