BAY SYSTEMS

Vehicle Pass-By Noise Testing - Using Radio Microphones

Introduction

Pass-by testing noise limits (depending on country the regulations/standards are: - ISO 362, SAE J1470, ISO 13325, SAE J366 and SAE J986.) apply to all vehicles sold within Europe and in many other countries. Testing for pass-by noise is prescriptive and at present it does not mirror actual vehicle usage or commonly found road surfaces, this unsatisfactory situation may well change in the near future. Regardless of the detail of the test the basic format will remain the same, see figure 1. A vehicle's noise will be measured on both sides at a distance of 7.5 metres from a centre line as the vehicle traverses a 20 metre section of road. At present the test requires full acceleration but again this may well change in the future. A max hold sound level metre, or its equivalent is positioned at the mid point of the 20 metre test section and the maximum sound pressure level recorded. Current (2007) Pass-By limit for passenger cars is 74dBA, see tables in Annex 1 for a full list of pass-by levels.

Current approach and instrumentation used

There is some variation dependant upon supplier but there are two approaches used:-

Basic (and what a government inspector will use) a sound level meter either hand held or on a tripod positioned 7.5m from the centre line and set on peak hold. The results of four pass-by runs for each side of the vehicle, noted by hand on paper, with the proviso that the runs foe each side do not differ by more than 2dB.

Advanced (what most automotive companies will use to help them both measure the noise and locate the problem areas of the vehicle) a computer based system comprising two microphones a pair of laser gates to stop and start the acquisition, a radar to measure the vehicles speed and a radio link to the car to gather throttle position and possibly engine rpm. The same restriction on scatter applies as for Basic.

What is there to choose between these approaches?

Basic does the job; is simple to use and pretty much never goes wrong but tells you little about the cars noise signature other than it passes or fails the test; this is fine if it passes but not much help if it fails! The test requires a driver and the tester; two people are all that are needed.

Advanced Depending on the complexity of the software and the competence of the user it tells you everything, probably in colour and if you are lucky it will sound a hooter when your vehicle passes the test! However it is usually made up of a lot of little boxes and long lengths of cable to plug together. There is also a cable-way that needs to be laid under the road to allow the signal from the far side microphone to be gathered. The test requires a driver and tester but in reality most "advanced systems" need at least three people, the third being on the phone to the system supplier trying to sort out the problems with the kit!

What is needed and what this system seeks to deliver is the high quality output but with the ease of use of a basic system. The added value of the BAY Systems' BARS based solution is that the whole pass-by test can be performed by a single person. Logically the only way to achieve this is for the driver to execute the whole procedure; this does not mean that the driver has to be a senior engineer. Once the decision is made to make the driver the only person involved then many other advantages flow in-so-far as there will not be a problem communicating results and instructions to the driver as everything appears on the screen of the micro VAIO computer at the completion of each run in the car next to the driver.

Elements making up the BAY SYSTEMS Vehicle Pass-By Noise System

Component parts:-

1. Radio microphones on either side of test track
2. Radio receivers inside vehicle cabin
3. BARS or Sony EX data acquisition system onboard vehicle ideally inside vehicle cabin.

Optionally - engine rpm sensor, speed sensor, throttle position sensor, engine bay

1. microphone(s), exhaust pipe microphone(s),tyre wheel arch microphone(s), cabin microphone(s)
2. Photocells attached to inside of vehicle side window glass, one on each side.
   Lasers at start, midpoint and end of test strip aimed at where the photocell on the passing vehicle will be. These will signal the start, mid and end point of the test and will help confirm source location.

Channel designation on data acquisition system:

1 = left hand trackside microphone 2 = right hand trackside microphone 3 = left hand photocell 4 = right hand photocell Optionally 5 = engine rpm 6 = speed sensor 7 = Engine bay microphone 8 = Exhaust pipe microphone 9 = Front tyre microphone 10 = Rear tyre microphone 11 = cabin microphone….

Mode of operation.

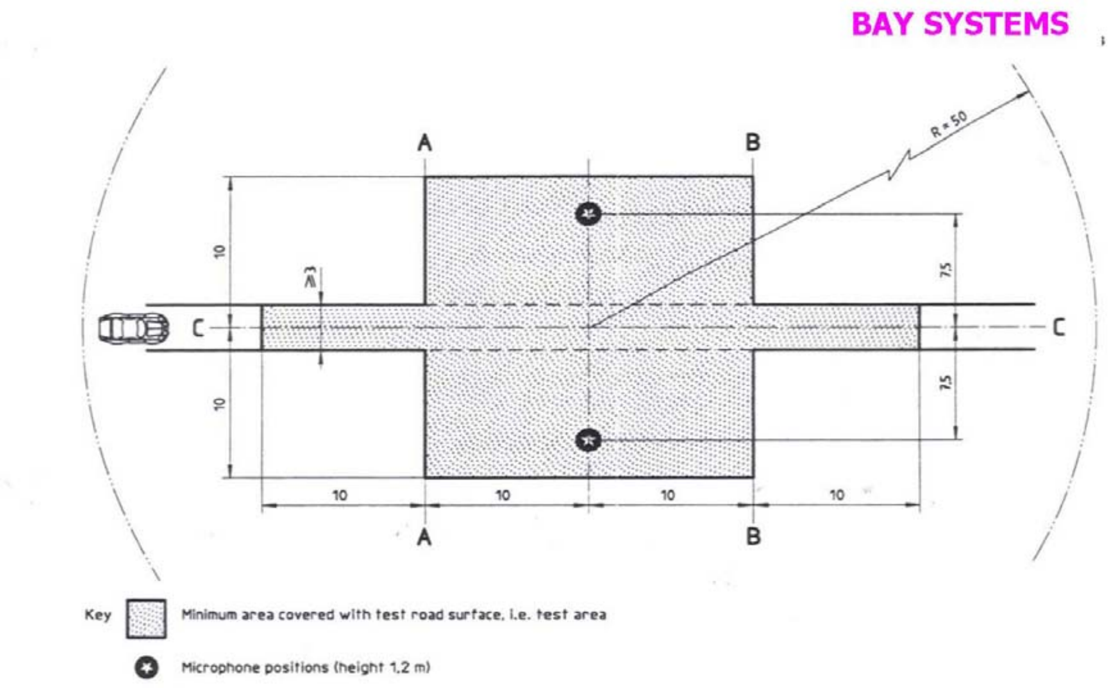
The acquisition system is Armed by the driver touching the trigger button which can be attached to any convenient point, typically clipped to breast pocket. The acquisition is triggered by the first laser with a two second pre- trigger and a total duration recorded of six seconds; alternatively if there are no lasers available the acquisition is simply started on the trigger button and terminates after a set time e.g. 10 seconds. This ensures that all of the run and some additional before and after data is available. Data is gathered from all channels at either any desired sample rate but normally this will be 52kHz or 65kHz. The throughput file is automatically processed between the laser gate pulses and the data presented using the standard displays, some of which are shown later in this document. The optional channels, if present will allow engine speed and other parameters to be plotted against the pass-by noise signatures. If any of the following :- engine, exhaust or tyre noise data was acquired then a correlation between these sources and the pass-by noise signature can be undertaken with source identification.

Output Format

As with other recent Bay Systems modules the output will be tabulated using html making results viewable using any Web Browser. BARS supports a large number of read and write data formats including ASAM.

The Vehicle Pass-By Noise Test

Layout of the test as defined in the ISO 362, see figure 1.

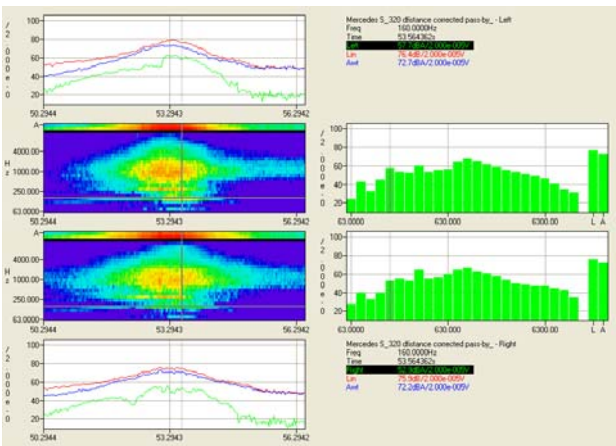


NOTE Shaded area ("test area") is the minimum area to be covered with a surface complying with ISO 10844.

Figure 1 — Test site dimensions

The nVision display of a complete pass-by, reproduced below in Figure 2, is a comprehensive overview of a vehicles pass-by performance showing the overall A weighted sound pressure level, the blue line. The red line is the linear overall level and the green line the level of a 1/3rd octave band selected using the cursor from the colour map or the 1/3rd octave spectra. This flexibility and linking in the display panels helps the engineer identify the high level sources. In this example the high level at the 160Hz third octave is the third order of the engine i.e. the firing rate.

Figure 2. Pass-By Noise for a Mercedes S320 (W140) petrol



Can some Pass-by Noise testing be done without a special track facility?

Regulatory pass-by noise testing occurs at the culmination of the vehicles development but there are likely to be many pass-by and other noise tests needed to check that noise targets will be met. The ability to make measurements quickly and accurately is essential for the development engineers. If these measurements can be economically completed then the system that delivers this result should be a very attractive proposition. It is accepted that the results from an ad-hoc test site are unlikely to be identical to a fully certificated Pass-By noise testing facility. What is a justified aspiration however is that the results from an ad-hoc site should be repeatable and with a known and correctable deviation from those that would have been obtained at a certified site.

The availability of a certified site and the certainty that it will not rain makes gathering pass-by data very difficult for both large and small companies. If the need to get some pass-by results arises then surely the ability to look out the window and providing it is not raining to have the results in front of you in less than an hour has got to be an interesting option for any company.

Calibration of an ad-hoc measurement site near you.
How to find a site; things to consider:

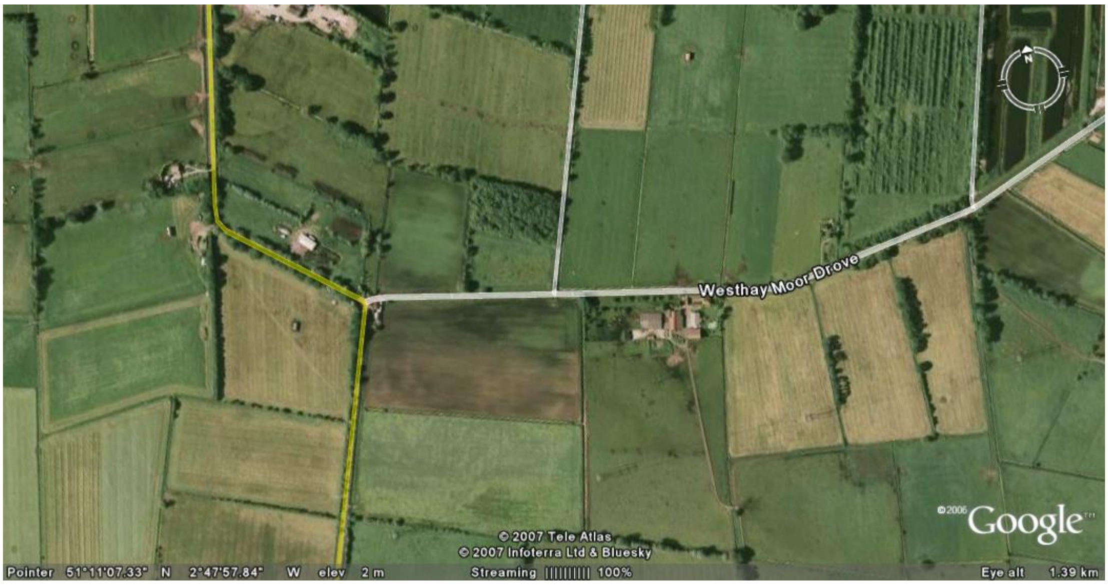
1. Safe operation
2. Low background noise levels
3. Road surface in good condition and unlikely to change
4. Security for the roadside equipment
5. Space to position the microphones

What does this mean in practice?
The obvious solution for a large company is to use the car park, assuming it is suitable, when it is empty either early in the morning, late at night or at the weekends. For a small company or where measurements are needed during the day and it is important not to wait then what is needed is a single track road with at least 800 metres of visibility and safe parking and turning places. This usually equates to a flat and reasonable straight piece of country road not too far from the facility. The positioning of the microphones in field gate ways will allow them to be around 3-4 metres from the centre of the road; if there are two gates opposite then left and right hand signatures can be taken simultaneously. Depending upon the hedging material used the microphones might be set back the full 7.5m but this is unlikely to be the case.

An Example Measurements made on Westhay Moor Drove in Somerset.
The microphones were set up at the cross drove and field gate. The distance from the centre of the road to each microphone was 4 metres on north and 3m to south, see figures 3 and 4.

Figure 3.
Westhay Moore Drove, a flat piece of country road with good viability and low traffic density.

Figure 4. Looking at the immediate area the suitability of the site is clear: the countryside is flat, there are no hedges with viability for at least 800 metres.

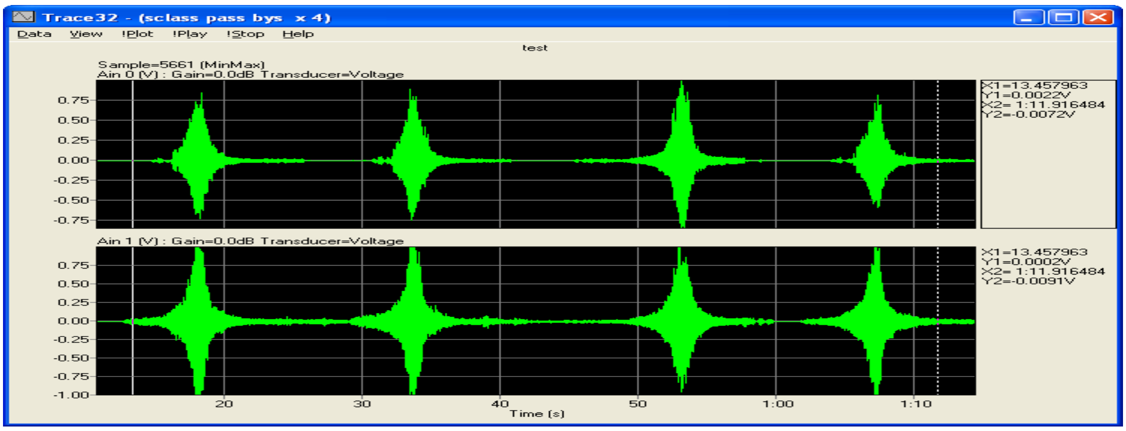


Equipment used.

Two GLM 100 microphone calibrated using Class 1 calibrator
Bay Systems Radio link; three small boxes that fit inside a shoe box.
BARS data acquisition system; total system shown weighs less than 500g
nVision post processing software.
Sony Micro Vaio PC; shown as an integrated package with BARS
Total cost of the all the above equipment < £12,000

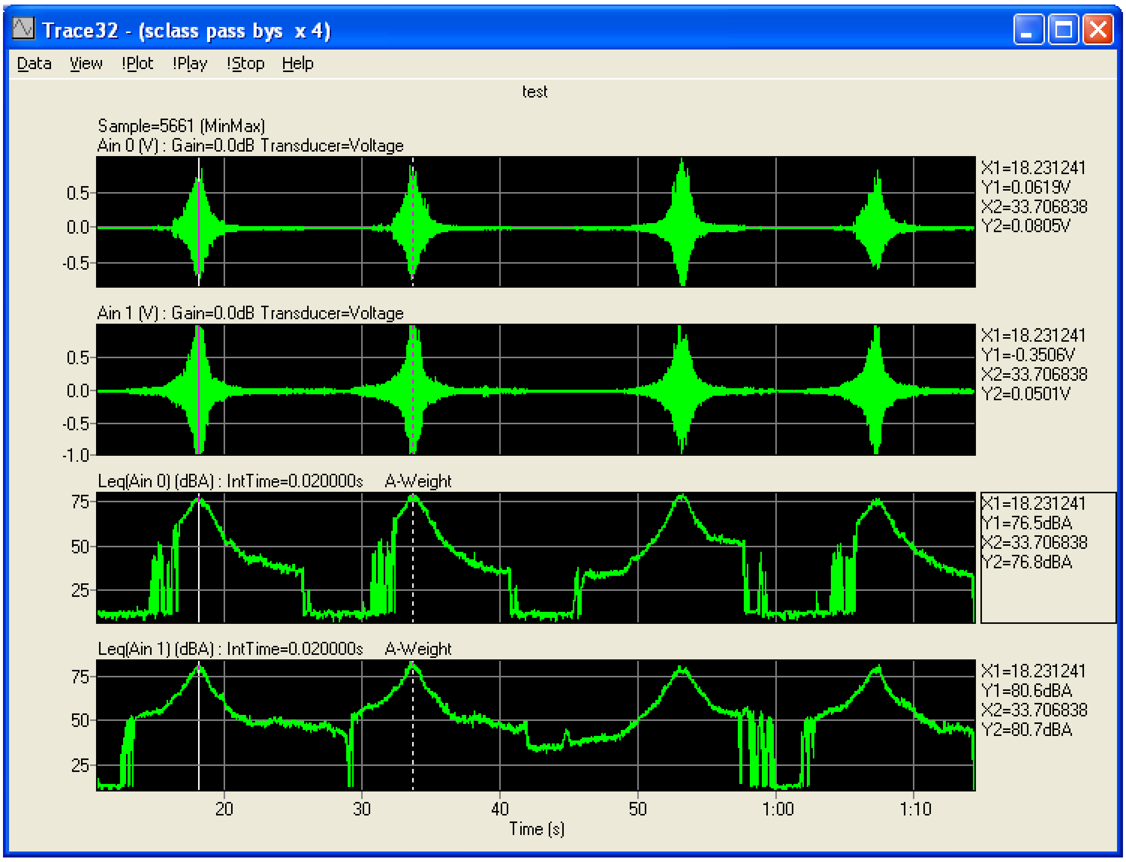
The Throughput Files are shown. nVision has been used to concatenate the 4 runs, see figure 5.

Figure 5. North and south road side microphones time history of 4 separate passes by Mercedes S320 (W140)



Although slightly non standard it is interesting to simply convert the time history into the A weighted level by using a digital filter. The Pass-By Standard calls for an integration time of not more than 30ms. However as we are not now looking at full compliance it is interesting to bend the rules a little and use the best tools available to get a stable and accurate result. In the first example the data is processed with a 20ms integration which in consequence gives a rapidly changing peak level, see figure 6.
The background noise level was less than 50dBA

Figure 6. Processed in A wt Leq third octaves with 20ms integration time. The original time histories appear at the top of the figure. The A weighted overall levels are the bottom two. The cursor readings of the maximum levels can be read from the right hand side.



Extracting the peak levels with integration set on 20ms * see table 1.

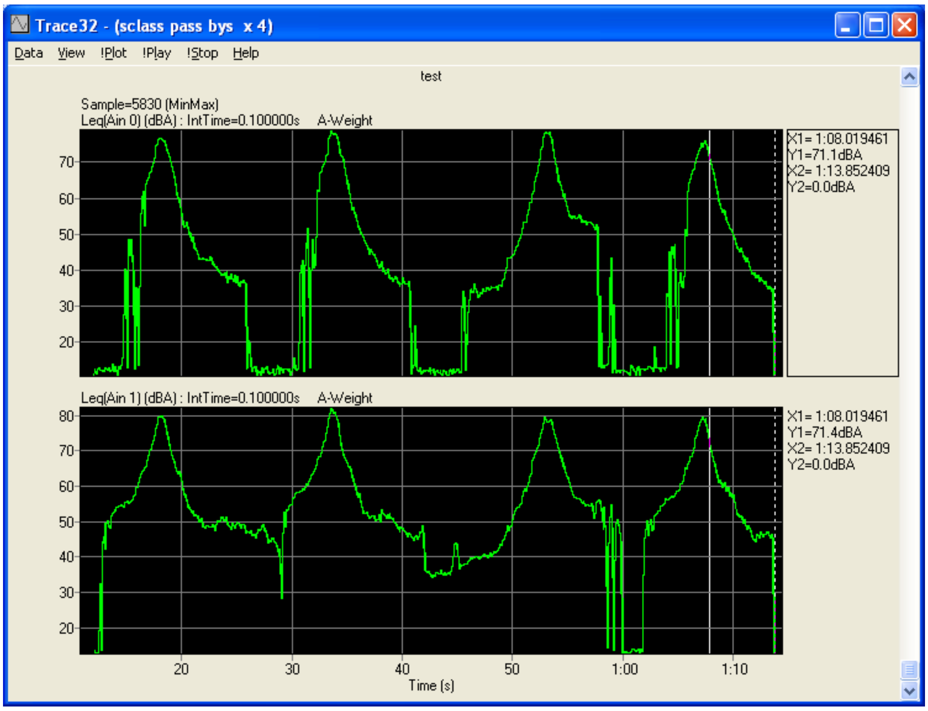
Table 1. Mercedes S320 W140 pass-by with 20msec integration.

	Run 1	Run 2	Run 3	Run4	Average
North microphone	77.1	79.4	79	76.9	78.1
South microphone	80.5	83	79.4	77.9	80.2

N.B. These are levels uncorrected for distance the North microphone was 4 metres from the centre line and the South microphone 3 metres from the road centre line.

The integration time was then set at 100ms. The consequent result was a much smoother profile with a level reduction in the average of 0.4dB, see figure 7.

Figure 4. Processed in A wt and using Leq third octaves with 100ms integration time :-



Extracting the peak levels with integration set on 100ms and then applying the distance corrections needed to translate the results from 3 and 4 metre to the regulation 7.5metres*;see table 2.

(* The distance correction is only valid if we assume that the Maximum level occurs at the closest point of approach; for all other locations the correction factor is too high. Clearly the best solution is to get the microphones position the microphones at 7.5 Metres from the centre line of the road)

Table 2. Result of 4 pass-by runs

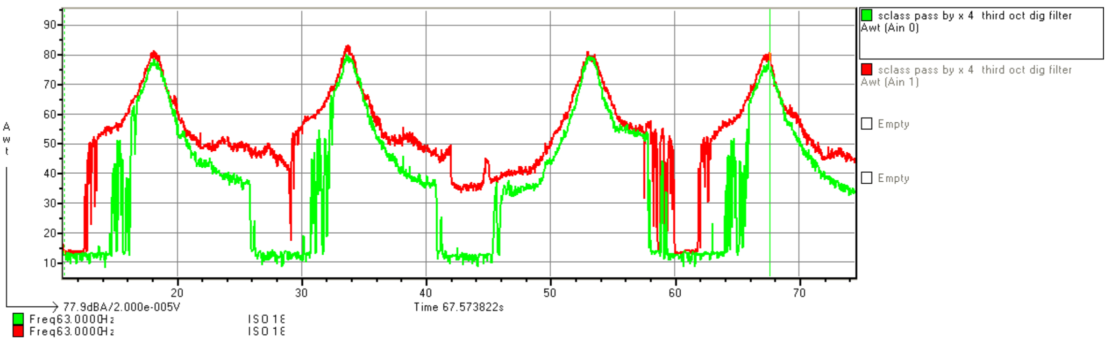
road	Run 1	Run 2	Run 3	Run4	average	
north at 4m	77.0	78.9	78.9	76.1	77.8	
North Corrected for range - 5.5dB	71.5	73.4	73.4	71.6	72.5	
south at 3m	80.4	82.2	80	79.7	80.6	
South corrected for range - 8dB	70.7	72.5	71.5	69.9	71.2	
Highest intermediate					72.5	
Overall average					71.9	

From table 2. the official Pass-By result for the Mercedes S320 would be the highest intermediate result i.e. 72.5dBA. The actual result for this particular car, in this configuration, is not known but from the table of published Pass-By results, reproduced at Annex 1, it should be of order 72dBA. The data at Annex 1. is for the model W220 rather than W140 i.e. it is for the next generation car. It is therefore likely that the W140 was a little noisier than the 71dBA quoted for the W220.

Investigation into the validity of using Leq

Quality check on the Leq technique using standard digital filter to transform to the frequency domain, third octaves, then compute A wt overall level. Figure 8 shows the overall Awt result for the two microphones extracted from a traditional digital 1/3rd Octave approach.

Figure 8. Overall Awt from digital third octaves with 20msec integration time,



These raw data levels shown in figure 8 with peak levels extracted and shown in table 3. below are not corrected for distance.

Table 3. Comparison of Leq and standard Awt pass-by levels

	Run 1	Run 2	Run 3	Run4	Average
North Leq 20ms	77.1	79.4	79	76.9	78.1
SouthLeq 20ms	80.5	83	79.4	77.9	80.2
North third Oct	78.4	80.0	79.5	77.9	78.95
South third Oct	81.1	83	81	80.8	81.4

The difference in the values obtained by the two techniques is at worst 0.8dB and at best 0.2dB.

Conclusions.

Using the GLM100 microphones, Bay Systems radio link and BARS data acquisition system it is possible to get consistent and reliable results with only one person involved in the testing. The total test time including setting up the microphones was less than 1 hour. Five runs in total were completed; the entry speed was of 50kph was measured using the speedometer. There was no light beam or radar positioning equipment used.

Pass-By levels.

Maximum permitted noise levels for motor vehicles in type approval tests according to 81/334/EC. Based on directive 92/97 EC			
			dB(A)
Passenger Transport			
	Less then 9 seats, driver included		**74**
	MORE then 9 seats, driver included:		
	less then 2000 kg		**76**
	more then 2000 kg but less then 3500 kg		**77**
	more then 3500 kg		
		<150 kW	**78**
all types within 2 dB of test level		>150 kW	**80**
goods transport			
	< 2000 kg		**76**
	>2000; <3500 kg		**77**
	> 3500 kg		
		< 75 kW	**77**
		>75,<150 kW	**78**
all types within 2 dB of test level		>150 kW	**80**

Cars and four wheel drives

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Cars                          74dBA
Lower power 4x4s              75dBA
Lower power DI Diesel 4x4s    76dBA
High power 4x4s               76dBA
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Motor Cycles.

Maximum permitted noise levels for motor bikes in type approval tests according to 81/334/EC. Based on directive 87/56 EC			
		Cylinder	dB(A)
All types within 2 dB of demand		less then 80 cm3	75
		between 80 and 175 cm3	77
		more then 175 cm3	78
Additonal requirements noise levels for small motor bikes (under 50 cm3) in type approval tests according to Decree 108/1986 Dutch Noise Abatement Act.			
Category I			
	Pass by	less then 50 cm3	72
	Stand still test max power	less then 50 cm3	95
Category II max speed <25 km/hr			
	Pass by	less then 50 cm3	66
	Stand still test max power	less then 50 cm3	88

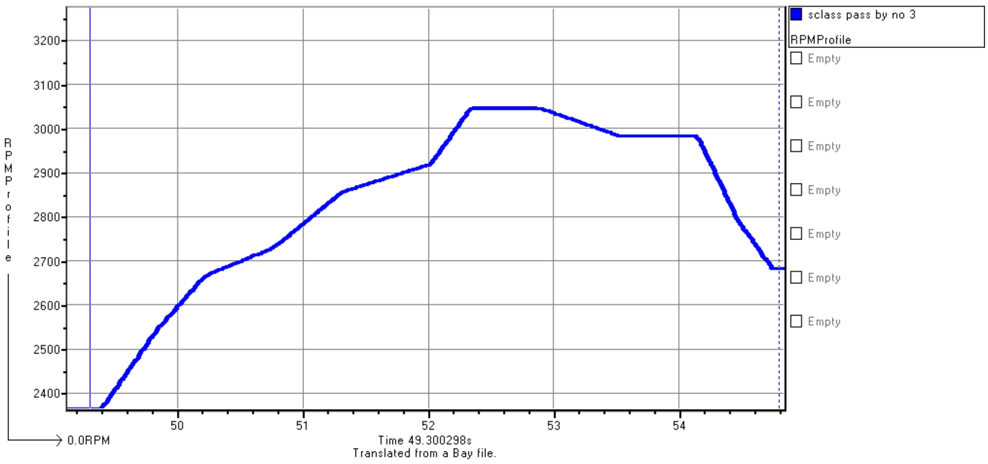
Mercedes S class data from public source.

MERCEDES-BENZ	S-Class (W/V220) Saloon and Limousine Petrol and Diesel	S 320 Saloon	A5	3199	Petrol	71

Extracting order information from Pass-By data without a tacho

The Tacho-Gen module of nVision can extract the rpm profile from a pass-by run in about 5 minutes i.e. considerably less time than is needed to connect up a tacho sensor to the car.
The result of synthesised rpm profile; for the Mercedes S320 (W140), using data from pass-by run 3, is shown below in figure 9.

Figure 9. Extracted rpm profile from pass-by run 3.



Once a synthesised tacho pulse train exists and a rpm profile is derived then the spectral data can be resolved into order and none order related components. If the time history or the subsequent processing adds A weighting then our orders will be A weighted, see figure 10. If each A weighted order is compared with the overall A weighted level then the significance of the power train noise to the pass-by can be judged, see figure 11.

Figure 10. Mercedes S-Class (W140) 320 petrol. Colour contour plot of A wt orders. With solid cursor on order 3 and dotted cursor on order 6.

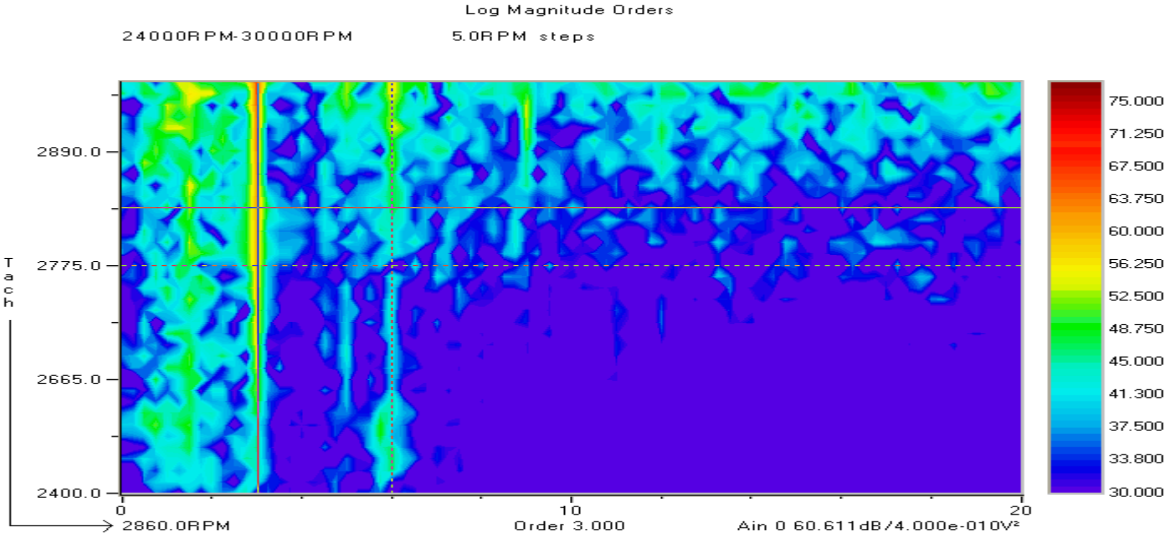
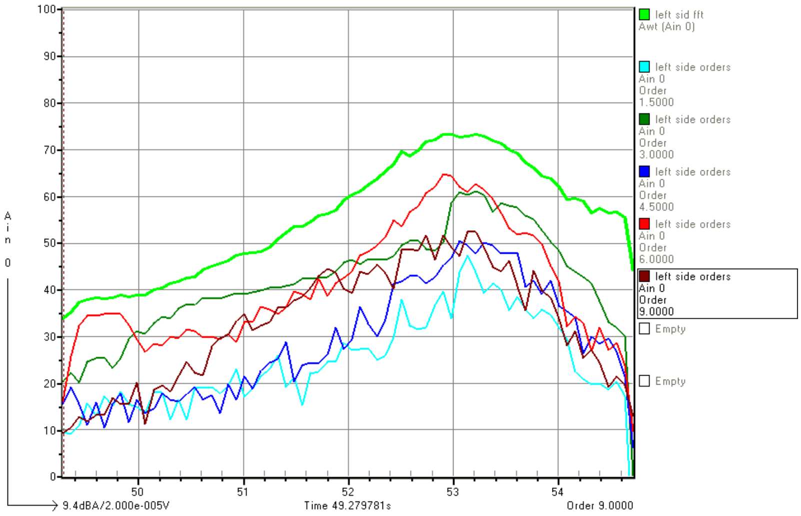


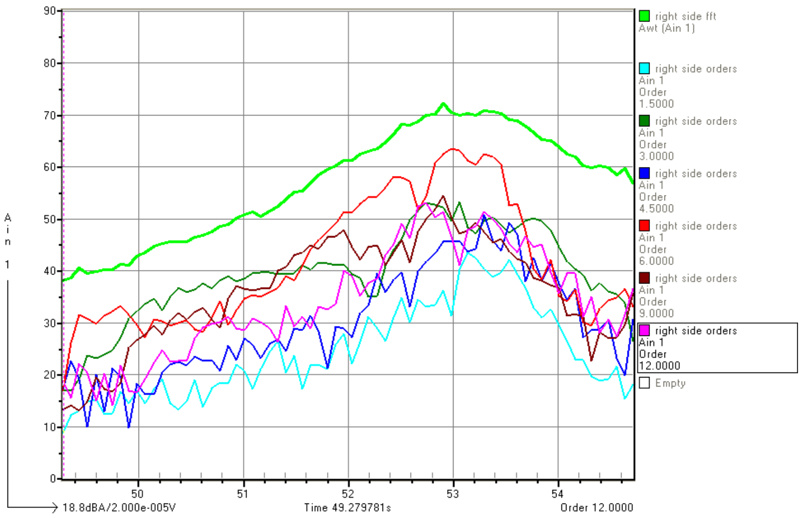
Figure 11. Mercedes S-Class (W140) 320 petrol.



Overall A wt pass-by noise with A wt orders from left (North) side. The red and dark green traces are orders 6 and 3 respectively; these two orders do not however dominate the pass-by noise as their level is at least 6dB lower than the total.

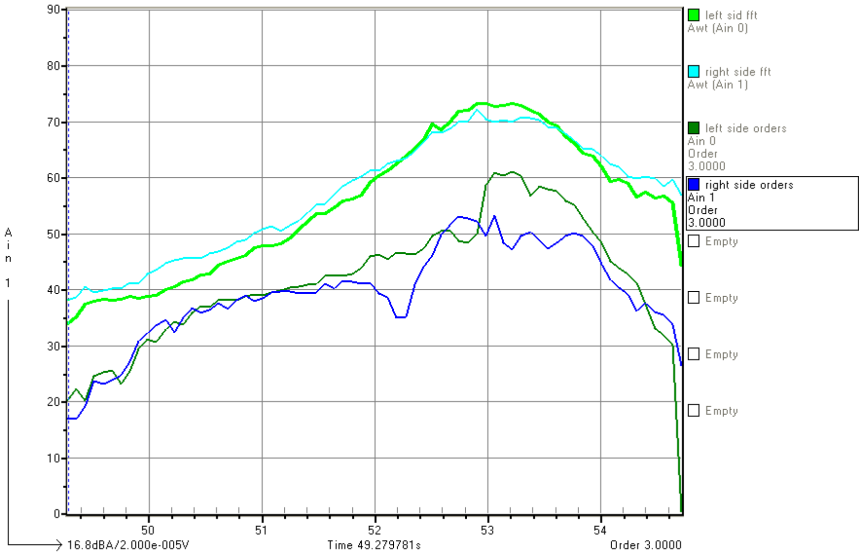
The pass-by level taken on the right (South) side is shown in figure 12.

Figure 12. Mercedes S-Class (W140) 320 petrol.
Overall A wt pass-by noise with A wt orders right (South) side.



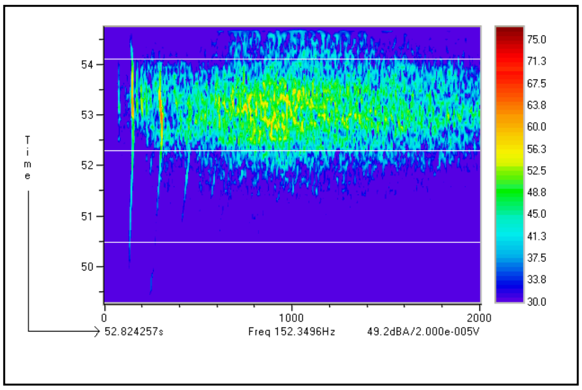
The south side microphone shows a similar result to the north side.
Comparing the two sides of the vehicle, see figure 13.

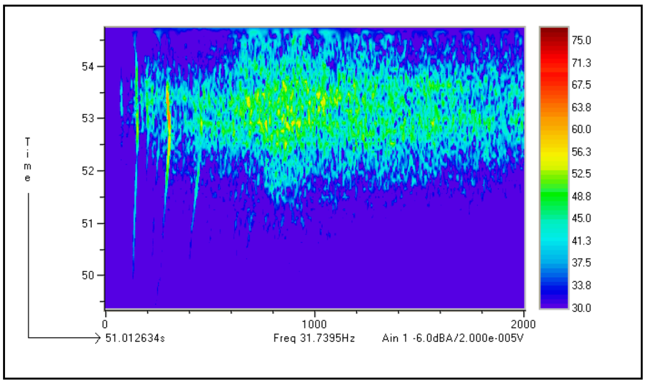
Figure 13. Mercedes S320 right and left overall levels and 3rd order compared.
The overall Awt level is colour keyed to their respective 3rd orders.



Based upon this brief analysis it might be concluded that the pass-by noise peak level was due by approximately 50% to the power train. This statement is based upon the observation that when the SPL of order 3 drops by 10dB the overall level dips by approximately 2dB. The full spectrum is shown in figures 14

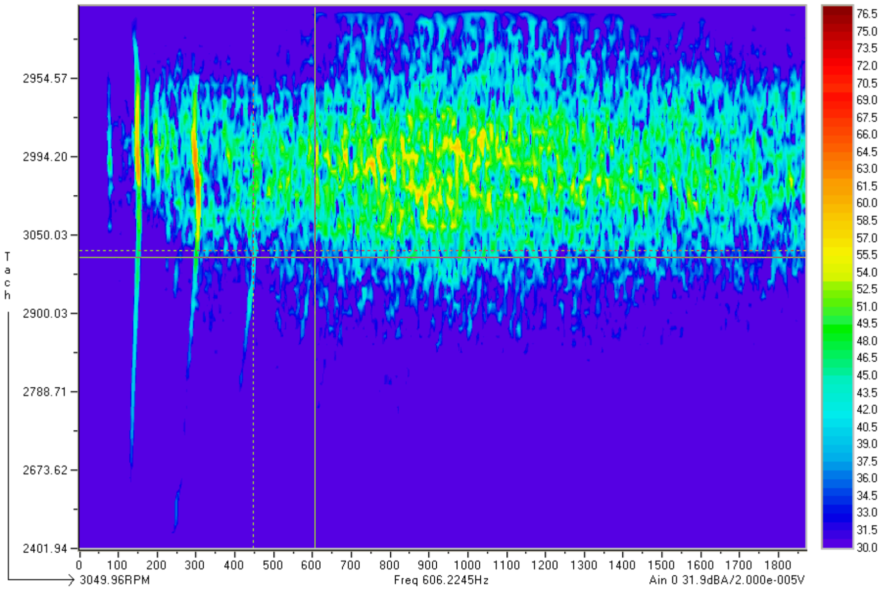
Figure 14. Left (North) and right (South) side colour maps of the S320 pass-by





The spectrum above 600Hz and below 2000Hz does not appear to be dominated by power train orders, an expanded view is shown in figure 15.

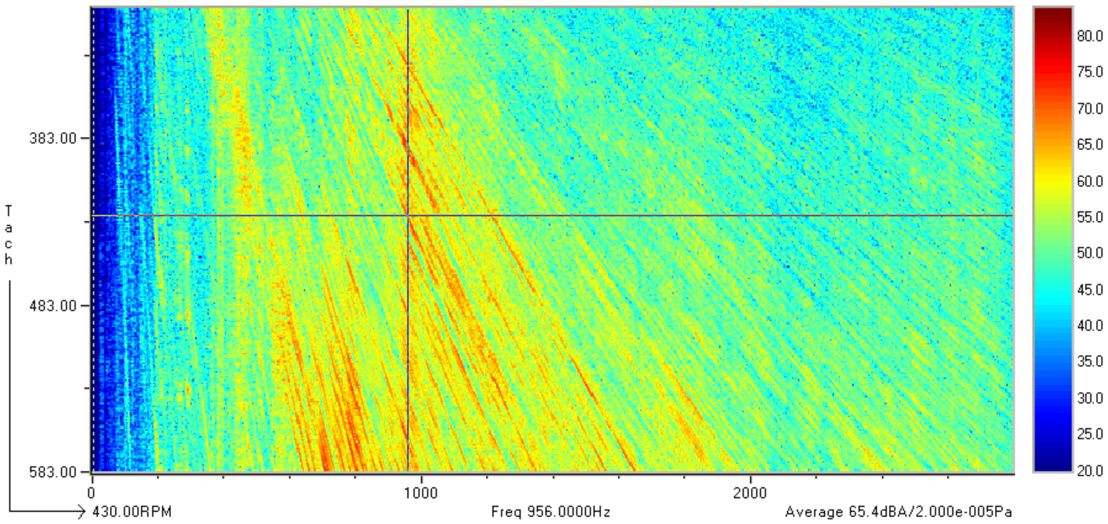
Figure 15. Expanded view of the North Side spectrum.



NB. The engine orders are plain to see at: 160, 300, 450, but are faint to the point of invisible above 600Hz.

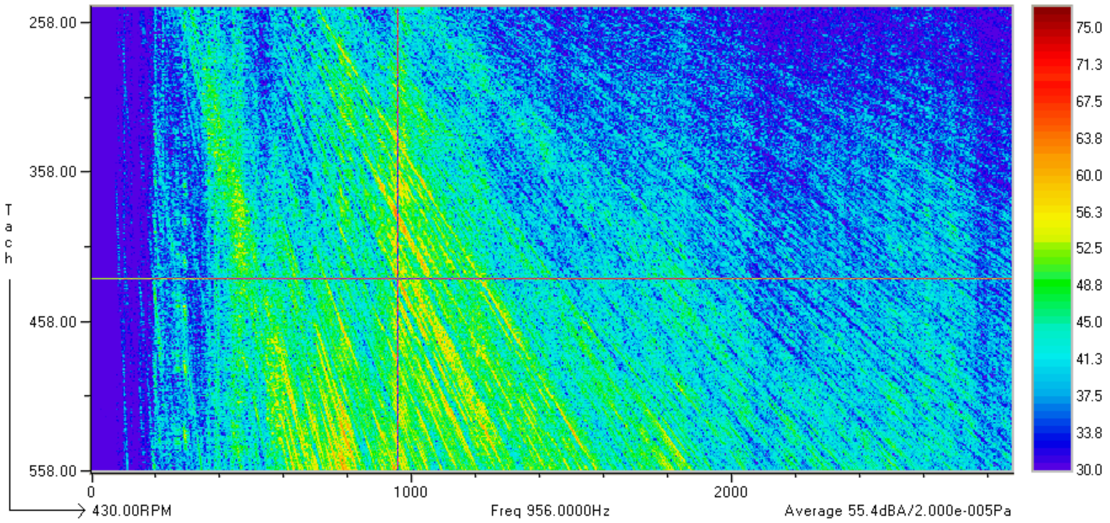
The tyres in use on S320 are summer tyres of section 235, the spectra from these tyres measured at a distance of 1metre on a steel test wheel in the laboratory is shown in figure 16.

Figure 16. Tyre measured at 1 metre in laboratory
The cursor is at approximately 60kph – at 430 rpm.



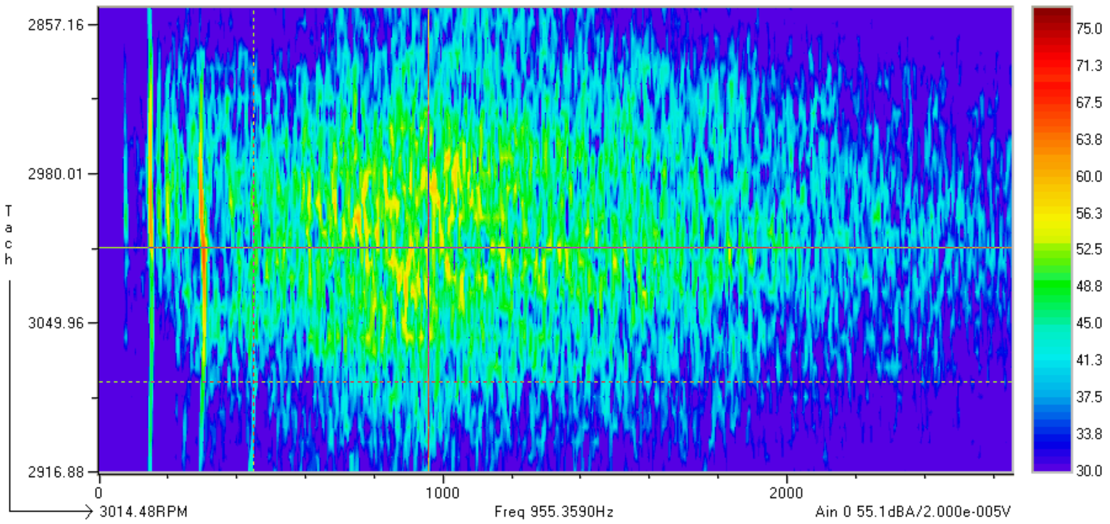
If these levels shown in figure 16 are corrected for pass-by distance i.e. 7.5 metres and for the fact that we have 4 tyres on the vehicle the spectrum at the pass-by microphone for the tyres alone should be as shown in figure 17; the level should be approximately 10dB less than that measured on the steel wheel, shown in figure 16.

Figure 17. Tyre noise measured in the laboratory and corrected for range and number of tyres so as to simulate pass-by noise testing.



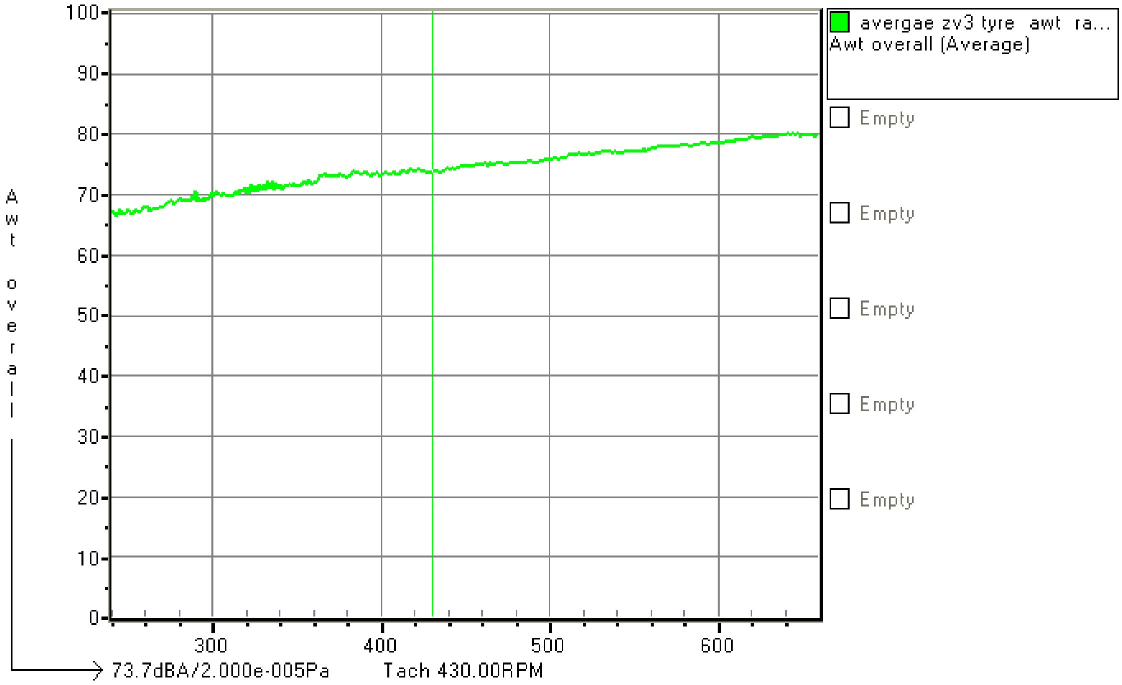
The value at the cursor at 60kph (430rpm) is now 55.4 dBA at 956Hz If we look at the level of this frequency at the point of closest approach on the pass-by the result is in good agreement at 55.1dBA, see figure 18.

Figure 18 Pass by noise at the centre point of the run and at 955Hz the level is 55.1 dBA



The overall Awt fully corrected tyre noise pass-by level calculated from a single tyre laboratory tests for a car with 4 off Tyres is 73.7 dBA, shown in figure 19. This correction from the laboratory to the road is empirical and is based upon a number of assumptions such as that adding a second tyre on the same side of the vehicle will add 6dB and that the two tyres on the other side of the vehicle contribute another 2dB to the overall level. An equally valid assumption would be that the second tyre would add 3dB and the tyres on the other side of the vehicle 1dB. The choice depends, at least to some extent, on the degree of coherence of the noise. If the lower correction factor (4dBA) were chosen then the tyre contribution in this example would drop from 73.7dBA read from the cursor position in figure 19. would reduce to 69.7dBA

Figure 19. Awt overall level for the tyre corrected for 7.5metre and for 4 tyres on the vehicle.
(Tyre number correction used = 8dB an equally valid correction would be 4dB)



The total pass-by noise level will therefore be composed primarily of power train noise and tyre noise. The power train noise is calculated by simply summing the sound pressure levels in the highest orders, taken in this case directly from the pass-by data, see the table 4. The two summations are produced by using the simple multi-source dB addition method and the more reliable method of returning to linear and then add and log. In this case they prove to be equivalent.

Table 4. The summed sound pressure level from the engine orders : -

Orders l	Max level in dBA	Linear level		
1.5	48	0.005		
3	61	0.022		
6	65	0.03556		
7.5	54	0.01		
total	71.25	0.0725		
Total dB	71.25	71.19		

As already discussed the total contribution from the tyres cannot so easily be taken from the raw pass-by data primarily as there is no straightforward way of knowing what the tyre noise is. The way this has been tackled is to use the laboratory measurement of tyre noise. For this test the contributing tyre noise level is taken at the tyre rpm equal to a road speed of 60kph.

Adding the lower of the two possible predictions for tyre overall level (69.7dBA) to the summed engine order level engine (71.2dBA) gives:

69.7 + 71.2 = 72.5dBA

The peak Awt SPL measured was for run 3 was 73.4 dBA and 71.5 dBA when averaged this equates to 72.5dBA

Conclusion

Although empirical in nature the correction factors used have resulted in a high degree of correlation between the actual measured level and the tyre and power train inputs. The tyre noise measured in the laboratory when translated for tyre number and range are certainly reasonable. The engine order levels extracted from the pass-by run using the Tacho-Gen module when added to the tyre noise return a predicted SPL that is identical to the average SPL measured for Run 3.

The diagnosis of at least the principle components of a vehicles noise sources would seem possible without recourse to a full ISO standard pass-by test facility.

For any location the need to calibrate the test site using a vehicle that has been measured on a certified test surface is clearly important. However it would seem likely, from the work done so far, that a good correlation will be achieved once this has been done. Furthermore, based entirely upon this work, there would seem a very good likely hood that even an uncalibrated site will be capable of reliably evaluating the changes in a product being developed. The absolute accuracy of the ad-hoc pass-by levels recorded may well be within 1 dBA of the correct value. Additional measurements are planned to confirm this.

For additional information and to arrange a demonstration please contact:
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Acknowledgements:
Layout of the pass-by test track - BS ISO 362:1998
Pass-by noise levels - http://www.xs4all.nl/~rigolett/ENGELS/typetest/typfr.htm