

# Tire Noise Pass-By Testing System Meets Latest Standards

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Automotive pass-by noise is a complex test that requires meeting several different standards with regard to the physical track layout, measurement systems, data acquisition, triggering, processing and analysis. Overview of the pertinent standards for tire and vehicle pass-by testing is provided along with the description of development of an advanced solution to meet specific needs. Key features of the solution are provided along with the lessons learned from operation of the system at a Cooper facility and several other test tracks.

This article describes the solution developed by Cooper Tire and Vehicle Test Center,<sup>1</sup> Pearsall, TX, that meets the requirement of ISO 13325<sup>2</sup> along with providing the latest updates to ISO 362.<sup>3</sup> The goal was to provide a world-class facility with a flexible pass-by noise test solution that allows efficient, accurate and repeatable tire noise testing while maintaining the ability to perform vehicle pass-by noise testing. This article describes the requirements, methods developed to meet the requirements and lessons learned from the development. Figure 1 shows a vehicle passing through the measurement trap of the new pass-by noise system.

## Background and Proposed Solution

Developing a new pass-by noise system was prompted by several factors. The need for quicker test results and improved throughput, which yields more efficient testing, was the primary factor. Updates to the ISO 362 standard also required updating the software and ability to more accurately measure acceleration. Finally, maintenance and support of the legacy system required more labor and costs than desired. A schematic of the legacy system is shown in Figure 2.

The legacy system used optical triggers to determine when to begin and stop measuring the noise from the microphones. These optical triggers were prone to mechanical failure, cumbersome to set up and could not determine forward from reverse runs, requiring the operator to traverse the same direction through the measurement pad. This increased test time and wasted fuel. A radar system was used to measure vehicle speed. The radar system was hard to set up and maintain and not consistent for different sizes and shapes of vehicles. Driver deviation from centerline could not be easily determined from simple radar measurements. Radar dropouts occurred, which resulted in rejected test runs. This system required two persons to operate. A driver had to operate the vehicle and communicate with an observer, who reported the weather station variables and recorded the measurement microphone output. Setup was time consuming and also required two persons.

A new solution was devised to use a global positioning system<sup>4</sup> (GPS) to determine the vehicle location, absolute speed, acceleration and direction. A differential GPS system can provide location resolution within less than 2 centimeters. Merely pushing on a vehicle and slightly rocking it can be seen in the location display. This system also provides an integrated weather station and infrared track probe and communicated all data to the operator – allowing single user operation. Figure 3 is a schematic of this new system.

## Tire Pass-By Noise System Overview

The primary requirement is that the new solution meets the relevant tire pass-by noise regulations and provides for supporting



Figure 1. Vehicle triggering measurement with new pass-by noise system.

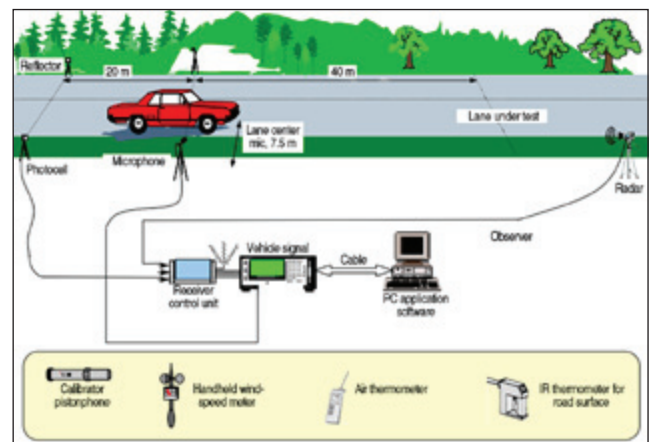


Figure 2. Schematic of legacy optically triggered system.

vehicle pass-by testing based on the latest update to ISO 362:2007 while still maintaining the ability to calculate results in accordance with the ISO 362:1998<sup>5</sup> standard. The specific requirements for tire testing are reviewed here with key differences between tire and vehicle testing documented.

### Standards for Tire and Vehicle Pass-By Testing

- Test track layout
- Measurement microphones
- Weather variables
- Tire classifications and temperature correction
- Sound level measurements and process

The solution must provide accurate repeatable results and improve throughput by allowing quick setup and operation with a single operator. To meet this requirement several key areas of operation are reviewed.

### Pass-By Noise Solution Features

- Calibration
- Single operator setup
- Single operator operation
- Immediate results and customer-driven reporting
- Post processing and remote data analysis

Finally, the solution must be open to allow enhancements and

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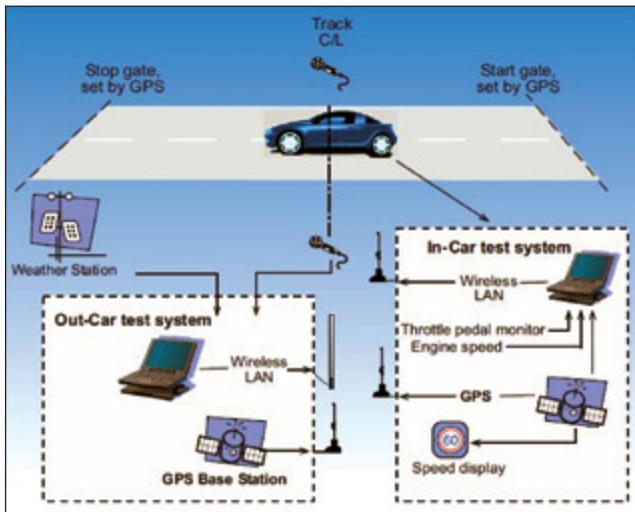


Figure 3. GPS-based pass-by noise system.

improvements as requirements change and technology improves. The following features have proven critical to our continued success and system improvement.

#### Open System and Enhancements

- Flexible software/hardware and customer-available customization
- Standard off-the-shelf wireless communication
- Proven and upgradeable positioning and triggering

#### Standards for Tire and Vehicle Pass-By Testing

Tire noise testing is a subset of the larger group of automotive pass-by noise testing, with many of the requirements the same for vehicle pass-by noise testing. This article will detail the requirements needed for tire testing and indicate differences for vehicle noise testing. The general requirements for the successful operation of pass-by noise of either type are lengthy. They include a suitable test track, calibrated microphones, accurate triggering and measurement of environmental variables. These requirements must be met and be available for inspection by independent auditors.

**Test Track Layout.** Pass-by noise testing starts with the physical layout of the test pad. The test method defines the environment and physical geometry of the site to ensure accuracy and repeatability between test locations. The physical layout of the measurement pad is defined in ISO 10844<sup>6</sup> and shown in Figure 4.

The method requires testing in a wide-open space without interference from structures or other features like a berm or trees for a distance of 50 meters. The asphalt test pad is 20 meters square. The implementation at Cooper Tire & Vehicle Test Center is part of other test facilities including wet and dry test surfaces. The pass-by noise pad is integrated with the 2-mile oval track shown in Figure 5.

**Measurement Microphones.** The microphones must adhere to the ICE 61672-1<sup>7</sup> standard. They must be Type 1 with A-weighting and fast-response time set. They are placed 1.2 meters above the ground facing toward the centerline and 7.5 meters from the centerline of the noise pad. Both a pre- and post-calibration check are performed with a calibrator that meets the IEC 60942<sup>8</sup> standard and stored. Background noise is measured, and if the background noise level is not 10 dB lower than the measured noise, the test is invalid. The measurement interval is the time the noise from each microphone is captured as the vehicle passes through the measurement pad trigger points. This interval must start exactly when the vehicle passes the +10 meter mark and stop when the vehicle passes the -10 meter mark. The vehicle must transverse the test pad along the centerline, and any deviation from the centerline can cause differences between the sound levels at the left and right microphones. When the vehicle passes in the opposite direction through the measurement pad, the left and right microphones are switched to correctly identify which side of the vehicle they are on.

**Weather Variables.** Several weather variables are measured with accuracy and captured during the testing:

- Air temperature – within 1° C

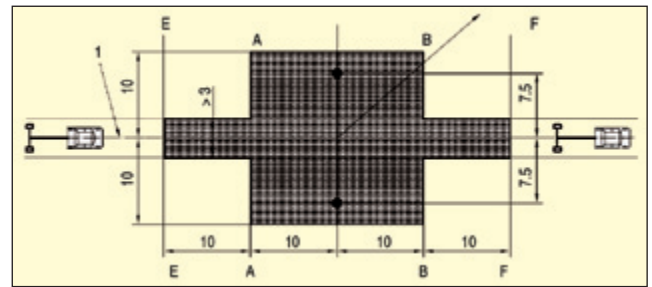


Figure 4. Test track layout. 1 = centerline of travel; • = microphone locations; A-A, B-B, E-E, and F-F are reference lines. Dimensions are in meters.

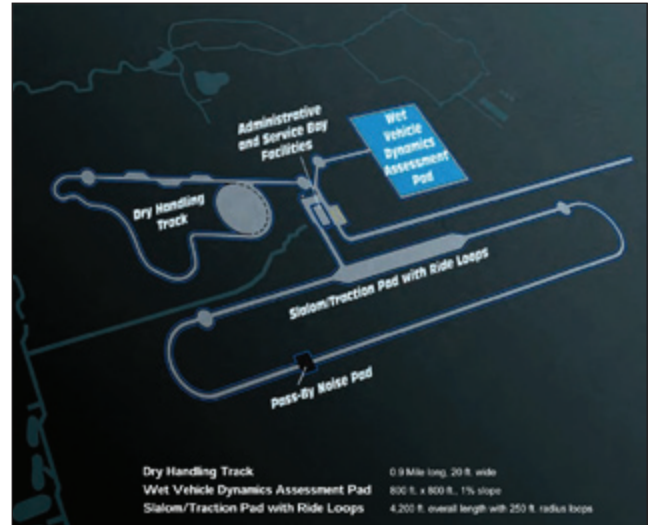


Figure 5. Layout of Cooper Tire & Vehicle test center.

- Wind speed – less than 1 m/s and must be below 5 m/s
- Barometric pressure – between 5 hPa
- Relative humidity – 5%
- Wind direction
- Track temperature –  $\pm 1^\circ$  C

If a radiation thermometer (pyrometer) is used, the height should be chosen to ensure that a measuring spot with a 0.1 m diameter is covered. The weather data are among the keys to successful pass-by runs. The requirements limit the wind speed to 5 m/s. These data must be captured at the same time as the microphone data and be available to the operator in the vehicle to enable him to reject runs if needed. Each of the screens the user can view during the test displays all the weather variables.

**Tire Classifications and Temperature Correction.** For tire testing, several classifications are provided and are needed to determine if temperature corrections are required. The three classifications are:

- C1 – Passenger car tires
- C2 – Commercial vehicle tires with load index in single formation lower or equal to 121 and speed category symbol higher or equal to “N”
- C3 – Commercial vehicle tires with a load index in single formation lower or equal to 121 and speed category symbol “M” and below, or such tires with a load index in single formation 122 and higher

Load Index is a numerical code associated with the maximum load a tire can carry at the speed indicated by its speed symbol under the service conditions specified by the tire manufacturer. In cases where the load index consists of two numbers, reference shall be made to the first number. For tires where the load index is not available, reference shall be made to the maximum load marked on the tire sidewall.

Temperature correction shall be applied only for C1 and C2 tires. Each measured sound pressure level  $L_m$  shall be corrected using the following formula:

$$L = L_m + K\Delta T \quad (1)$$

where  $L$  is the corrected sound pressure level and  $K$  is the coef-

ficient that:

- For C1 tires, the correction is equal to  $-0.03 \text{ dBA}/^\circ \text{C}$  when the measured test surface temperature is  $>20^\circ \text{C}$  and  $-0.06 \text{ dBA}/^\circ \text{C}$  when the measured test surface temperature is less than  $20^\circ \text{C}$ .
  - For C2 tires, the correction is equal to  $-0.02 \text{ dBA}/^\circ \text{C}$ .
- $\Delta T$  is the difference between the reference surface temperature,  $20^\circ \text{C}$ , and the surface temperature  $t$  at the time of the sound recording:

$$\Delta T = (20 - t)^\circ \text{C} \quad (2)$$

Tires need to be conditioned (broken in) prior to testing over a distance 62 miles (100 km) with normal on-road operation. The tires should have full tread depth minus any change caused by the conditioning driving. C1 and C2 test tires need to be run 10 minutes at 62 mph (100 km/hr) immediately prior to testing.

**Sound Level Measurement Procedure.** Tire pass-by noise testing differs from vehicle pass-by testing in several key areas. The primary difference is the need to measure the noise from the tires instead of the vehicle noise. This requires the engine to be off during the pass through the microphone measurement pad. The procedure is for the driver to first line up the vehicle with the centerline and accelerate to the correct speed. Before entering the measurement pad, the vehicle must be placed in neutral and the ignition switched off. An audible tone is heard as the first trigger position is reached. When the second trigger location is reached, the second audible tone plays, indicating that it is safe to turn the vehicle on and return the transmission to drive.

The maximum sound pressure level for each microphone must be captured during the pass through the trap, lines A-A and B-B in Figure 4. The speed during the capture must vary, with four measurements lower and four measurements higher than the reference speed. The one-third-octave spectrum should also be captured when the A-weighted sound pressure level reaches its peak. If peaks occur that are not repeatable then that measurement must be discarded.

## Pass-By Noise Measurement System

**Calibration.** The system must be able to be calibrated and to pass audits for adherence to standards. Each of the components must be calibrated and be able to be integrated with existing facility systems such as the site weather station. The front end of the data acquisition system must be calibrated for accuracy along with the measurement microphones and calibrator. The weather station must be calibrated, and in our case, the pass-by noise weather station must be able to be calibrated to match the reference on-site weather station. This ability is provided in the setup screen shown in Figure 6 under the information field for the weather station.

The user can review the weather station information and perform the microphone calibration, which is required from the left-hand menu bar. This provides the system with the new sensitivity, while the user applies the reference calibrator to each microphone and then measures the background sound level. All data are stored in a calibration run and available for immediate review.

**Single-Operator Setup.** Single-operator setup and operation is a broad requirement but is addressed with the new solution by providing compact packaging of components for both the in-car and out-of-car systems. The weather station sensors are permanently mounted and connected with a single cable. The communication system is off-the-shelf wireless, and the outside wireless antenna is easily attached to the permanently mounted pole. The GPS antenna is also simply attached to a permanently fixed pole. The track temperature probe is connected with USB<sup>9</sup> cable and positioned in a fixed location. The measurement microphones use retractable tripods – with tape indicating the correct height and a sandbag to hold it securely in place. The far-side microphone cable is run underground, and the cables are connected to the out-of-car system.

The in-car system consists of mounting the wireless communication antenna on the roof along with the mobile GPS antenna. The cables are connected to the in-car system along with providing a heads-up speed display and direct power connection to the battery. This is required, since the vehicle power will be turned off automatically through the traps and then powered back on. This cycle of

power can also affect power outlets in the vehicle, so the direct to battery is the best choice. For this configuration, four additional measurement channels are available for the in-car system. This allows connection of the throttle, CAN bus or even accelerometers or microphones in the vehicle to be measured. The setup can be accomplished in minutes by a single operator.

**Single-User Operation.** This is again another very broad requirement that encompasses several features. The first need is to provide the user with accurate start and endpoints for triggering the measurement. The user first measures from the required trigger point back to the GPS mobile antenna. This is entered in the setup screen shown in Figure 7 in the test parameters under the GPS antenna-to-front distance.

Then the vehicle is driven to the start of the trigger location A-A with the wheel aligned at the trigger line. Then the start trigger button is selected. For vehicle testing, it would be the front of the vehicle. Additional parameters would be entered as well to provide the target acceleration, run group, reference point, kilowatt and kilogram rating of the vehicle. The vehicle is simply driven forward to the end of trigger location B-B and the set stop button is selected. The user gets a readout of the distance between the two points that can be used when auditors review the ability of the system to set the correct distance with accuracy. Now the user is free to arm the system and proceed through the trap. Approach from either direction is allowed, and the system automatically logs the direction.

**Immediate Results and Customer-Driven Reporting.** The user arms the system with a simple space bar tap, receives an audible cue that the system is ready, and then monitors the speed on the heads-up display and drives through the trap without further need to look down at the system. This triggers the system and provides another audible cue when the system first triggers and then completes measuring at the exit of the trap. This allows the operator to focus on driving with the correct cues to aid meeting the performance requirements. For vehicle noise testing, a pre-trigger tone can be set to allow the operator to apply wide-open throttle to meet the acceleration in the trap. This tone can be set by entering a distance shown in Figure 8 – the WOT on/off pre-trigger value.

The system automatically transfers the data from the out-of-car measurement system to the operator in the vehicle. This allows the operator to have immediate feedback on the run and be able to accept or reject the run. The screen in the vehicle displays the entry, mid and exit speed as well as a graphical display of the path of the vehicle along the test track centerline (see Figure 9).

This allows the operator to adjust the entry speed and make another pass immediately. If the results are ok, the operator continues to make passes until the number of averages needed are completed. The operator can switch to the list summary view and have this summary available, which lists the results of each run in a tabular format and allows him to see visually his number of runs. The ability to see a summary listing of the current results in table format has been key to speeding up the test process. It is easy to identify each run's performance compared to the other runs and decide if additional runs are required. This is available in the

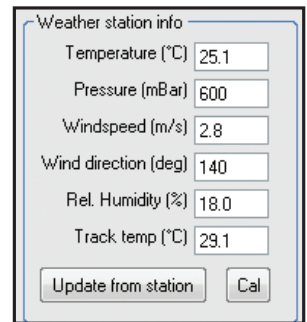


Figure 6. Weather station setup screen allows calibration to site reference.



Figure 7. Simple setup of start and end points for triggering.

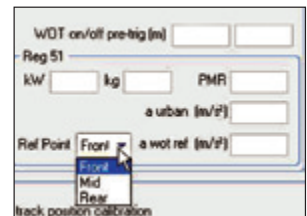


Figure 8. WOT pre-trigger value and updated ISO 362 Regulation 51 variables.



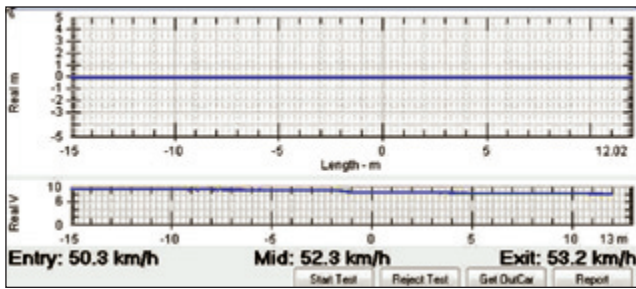


Figure 9. Immediate-results display indicates speed and position along centerline.

Tools	Title	SCPLName	ValidMid	ReverseRun	WindSpeed	WindDirection	Temperature	TrackTemp
<input checked="" type="checkbox"/>	Title 1	001021-111501 SDP	74.0	False	2.8	140	25.1	29.1
<input checked="" type="checkbox"/>	Mastercell	100395-144123 SDP	80.5	True	1.5	119	17.1	0
<input checked="" type="checkbox"/>	Title 1	001222-103643 SDP	84.6	False	3	95	4.1	9.0
<input checked="" type="checkbox"/>	Title 1	vg-110310-151531 SD	74.0	False	2.8	140	25.1	29.1
<input checked="" type="checkbox"/>	Title 1	vg-110312-072743 SD	74.0	False	2.8	140	25.1	29.1

Figure 10. List of run raw data summary view allowing operator to select runs for averaging.



Figure 11. Run summary view allowing operator to compute results using choice of standards.

PbN_RunGroup	Count	Spread Left	Spread Right	Avg Left	Avg Right	Max
2A	8	0.8 dBA	0.7 dBA	92.9 dBA	92.9 dBA	0
3A	7	15.7 dBA	15.6 dBA	90.8 dBA	90.8 dBA	1.39
2C	4	0.2 dBA	0.2 dBA	93.2 dBA	93.2 dBA	-0.05
3C	4	0.2 dBA	0.2 dBA	93.4 dBA	93.4 dBA	-0.05
Lowest				75.4 dBA		
Lowest				94.9 dBA		

Figure 12. Run summary view allowing operator to compute results using choice of standards.

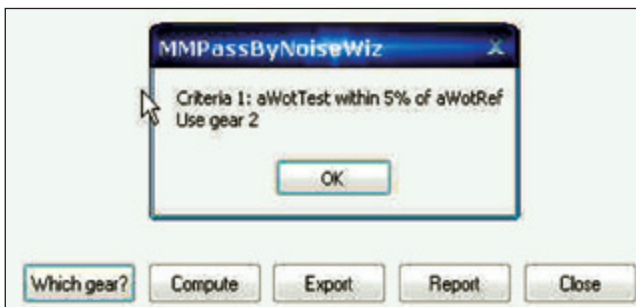


Figure 13. Which gear? Compares averaged runs wide-open throttle vs. reference.

left-hand menu and shown in Figure 10.

Besides visual inspection of the results, the summary also allows the operator the option of computing several results from selected data. That allows quick computation of the average of several runs, and the results are immediately available. Vehicle testing requires comparison to legacy ISO-362-1998 calculations as well as providing the latest Reg. 51 ISO-362-1:2007 calculations. This allows quick comparison in the vehicle as soon as the data of the averaged results are available. The user simply selects the standard desired (see Figure 11), and the results are computed based on the selected rows or runs.

“Field Chooser” can provide customer-desired columns to be displayed. This allows the operator to reduce the fields shown. In Figure 10, for example, the run group and acceleration values are not needed for tire pass-by noise and have been removed. The computation is provided below the list summary in the results box shown in Figure 12.

In addition, the computation of ISO 362-1:2007 requires several runs in different gears with averaged runs in each gear. The calcu-

Run	Vehicle		Wind		Temperature		Uncorrected SL		Corrected SL	
	Speed (kph)	Direction (L/R)	Speed (m/s)	Direction	Air (°C)	Surface (°C)	MIC 1 (dBA)	MIC 2 (dBA)	MIC 1 (dBA)	MIC 2 (dBA)
1	72	R	3.6	88	6	11	74.0	73.4	73.4488	72.9488
2	75	L	3.4	70	5	10	74.7	73.5	74.1488	72.9488
3	77	R	3	70	5	11	72.7	73.5	72.1488	72.9488
4	78	L	2.6	77	6	11	74.5	73.7	73.9488	73.1488
5	82	R	2.8	88	6	11	73.4	73.6	72.8488	73.0488
6	85	L	2.2	80	6	11	74.4	73.9	73.8488	73.3488
7	84	R	2.6	83	6	11	73.4	73.8	72.8488	73.2488
8	89	L	3.4	87	6	11	75.7	73.8	75.1488	73.2488

Temperature Measuring Sensor Type:  
 Air Temperature:  Thermocouple  
 Surface Temperature:  Infrared pyrometer

Figure 14. Sample of custom Excel report with automatic raw data export from list summary; ECE 30 / ISO 13325 coast-by noise test, individual results.

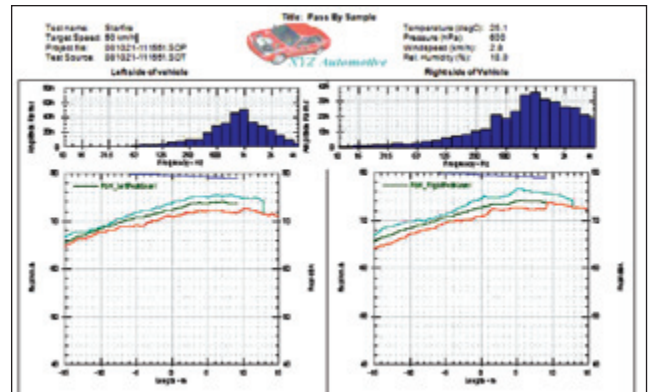


Figure 15. Sample report of results from averaged runs.

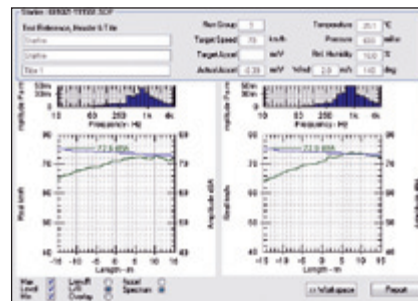


Figure 16. Postprocessing displays additional results from each run.

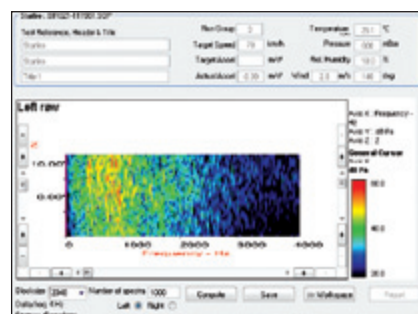


Figure 17. Waterfall analyses available with user-selectable variables.

lation automatically reviews the run data and indicates which gear is within the wide-open throttle specification as shown in Figure 13.

Reporting is available immediately with a button push. Selecting the export button provides export of the pre-selected data in the list summary to be exported to a standard Cooper Tire Excel spreadsheet. This allows the standard spreadsheet, which contains the additional calculations for temperature compensation and tire class, to be used. A sample of a portion of this standard Cooper report is shown

in Figure 14.

The report button can also be selected as shown in Figure 13. This allows the user to define a template and layout as required by the customer. The system merges the data into the template and generates a Microsoft Word document directly from the test data. A sample of a standard Word report is shown in Figure 15.

These reports in Microsoft Word can be active plots, which allow the Word viewer: to add a cursor; change the axes and scaling of measured values; and even perform octave computations from the spectrum displays. This allows the customer receiving the report, to change the scaling or add a cursor to better analyze the results. Spectrum data can be easily converted to one-third-octave results. This feature is also valuable when sharing standard report data

with internal engineering groups. This allows engineering analysis of data without requiring the engineering program to be installed; only a simple viewer plug-in is required.<sup>10</sup> The engineering group or customers can download the viewer plug-in from the web or from internal file servers.

**Postprocessing and Remote Data Analysis.** Some cases require immediate postprocessing and analysis. This can be to ensure that that peak levels are being captured during a trap or to compare the peak levels from each microphone vs. distance. The user can select postprocessing and display the graphs shown in Figure 16.

The postprocessing screen allows the user to display the data from left and right microphones in several ways. This allows the user to see the max levels vs. distance and overlay the left and right results. The upper displays can be used to see the measured spectrum at peak level in one-third-octave format, as suggested by the regulations. This screen also provides the same automated reporting from a single button selection. Postprocessing is available immediately to the operator, allowing quick troubleshooting of the run just completed.

Waterfall analysis is useful for viewing the entire measurement segment in 3D format. Selecting the waterfall icon on the left-hand menu displays the results shown in Figure 17.

The user can toggle the display between left and right microphone. This allows viewing in spectral or sonogram type displays of the noise level vs. frequency over the entire measurement period. If captured in the vehicle, additional channels can be analyzed in the same way. The operator can select the block size and number of spectra to provide the resolution required. The data can be exported and analyzed in a remote location, where these screens are available. This feature has been used to share results with analysis groups in different locations.

## System Design

**Flexible Software Customization and Modular Design.** A key to any successful system is the ability to provide updates as the standards change as well as features in the product software and hardware to match how the operator and customer need to use it. This can be as simple as integrating with a reference weather station or as complicated as adding data acquisition channels or matching specific reporting outputs with automated scripting. In this case, we were able to customize the standard product to work with our existing Excel results files. Automated export of the data into predefined fields allowed all previous work to be retained while reducing the export of data to a single button click. This preserved the results format in our customers view as well as speeding their testing.

The challenge to operating any electronic equipment in the high temperatures found in the test track location are great. Failures are inevitable, but with the modular design that was implemented, quick repairs can be made along with upgrades. Power supplies are especially sensitive to the high temperatures, and active cooling has been implemented for the outside system to limit the high temperatures when not actually running the system.

**Standard Off-the-Shelf Wireless Communication and Hardware.** This has proven to be an important feature as wireless standards advance in both speed and range. The ability to upgrade system routers with newer versions provides a low-cost and high-performance increase. Using standard off-the-shelf antennas for the communication system results in low-cost upgrades as newer higher gain units become available. Legacy telemetry systems do not offer the same flexibility in upgrade and performance increases. Test tracks usually cover large distances as shown in Figure 5. We recently moved the location of the noise pad, which necessitated longer distances to the turnaround. Simple upgrades to the out-of-car wireless antenna provided the desired range increase. Future enhancements include the possibility of adding wireless range extenders to our garage area and thereby including the entire driving path with wireless coverage.

A key requirement was that the solution use off-the-shelf data acquisition hardware and drivers. This reduces maintenance cost and ensures future upgrades will be available. The vendor chosen in this case was National Instruments.<sup>11</sup> The wide range of avail-

able hardware in compact form factors allowed us to minimize the in-car enclosure while still being able to have additional channels to meet future needs. The use of off-the-shelf hardware also ensures we can upgrade our input channels when desired – adding additional channels or higher performance modules as new units become available. This also reduces the cost when replacement hardware is required.

**Proven Positioning, Speed, Acceleration and Triggering.** GPS systems have proven reliable and accurate enough for the most demanding pass-by noise testing requirements. The system that was selected allows accurate triggering, speed, acceleration along with providing exact positioning. This allows quicker setup and more flexible testing. Challenges with different size and type of vehicles, including tire trailers, require flexibility in setting the trigger points. With GPS triggering, the distance from the GPS antenna to the trigger point is easy to adjust to get repeatable and accurate results. Using optical triggers would not be as simple to adjust and would require multiple passes and postprocessing to verify triggering.

Time history editing can be required for using tire trailers when the sound level with the tow vehicle is not at least 10 dB below the level without the tow vehicle. When this is required, measurement data are already synchronized with embedded distance, and this allows editing to be done immediately. This eliminates the need for capturing additional triggers to the data and complicated post processing.

The vehicle noise standard update requires specific acceleration targets, accurate measurements, and immediate feedback to the operator to complete the testing with less trial and error. The wide-open throttle pre-trigger is a key feature to help the operator focus on vehicle handling by providing an audible tone to apply full throttle.

## Summary

Meeting complicated standards and running complex systems are a challenge to any organization. This new system developed for pass-by noise supports the primary requirement of tire noise testing but also supports vehicle testing. The improvements support single operator usage, increased accuracy and throughput. The reduced cost of support and simple operation provide relief from a legacy system. System flexibility and capability allows future requirements to be supported. Recent opportunities to travel to several different test tracks and operate successfully when managed by a single operator illustrated the flexibility and portability of the new system. Within minutes – instead of hours – we were able to run pass-by noise tests in a new location.

## Acknowledgments

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