Automotive Modal Analysis

Accelerometers; Dynamic Force Sensors; Modally Tuned®, ICP®, Impact Hammers; Electrodynamic Modal Shakers; and Accessories

PCB PIEZOTRONICS INC

Automotive Sensors Division ☎ Toll-Free in USA 888-684-0014 ☎ 716-684-0001 www.pcb.com

Classical vs. Operational Modal Analysis

Classical modal analysis is the process of extracting dynamic characteristics of a vibrating system from measured force inputs and vibratory responses, whereas operational modal analysis extracts the dynamic characteristics of a vibrating system in its operating environment solely from vibratory responses. Both of these methods offer distinct advantages and disadvantages in designing and developing today's automotive structures (e.g., automobiles, trucks, ATV, etc.) and their systems and components (e.g., body, engine, exhaust, etc.)

Why Classical Modal Analysis?

Classical modal analysis is a more mature technique, in comparison to operational modal analysis, and is extremely useful in the design of automotive structures. The understanding and visualization of scaled mode shapes is invaluable in the design process to identify areas of weakness and provide direction on structural improvements. Enhanced computing power and advances in finite element analysis (FEA) techniques have increased the fidelity of today's automotive analytical model and in several cases have reduced the need for classical modal analysis, especially with legacy structures. However, classical testing will continue to be required to give engineers the confidence they need to continue to bring new product into development in today's competitive automotive market. Common applications for classical modal analysis include:

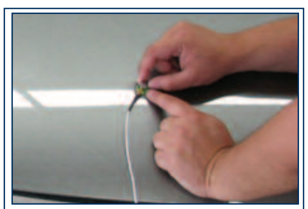
- Modal alignment
- Analytical model correlation
- Design studies
- Force response simulation
- Cascade target setting

Modal alignment is performed early in the design process to mitigate risk of structural resonance issues in the automotive structure. The desired resonant behavior of structures, systems, and components is mapped out prior to design and development and is predominately used as a constraint in the design process. Adherence to this requirement is performed analytically and experimentally with early development prototypes.

Four Primary Assumptions of Classical Modal Analysis

Whether it is quick troubleshooting or full model correlation, successful classical modal analysis relies heavily on adhering to the four primary assumptions: observability, linearity, time invariance and reciprocity.

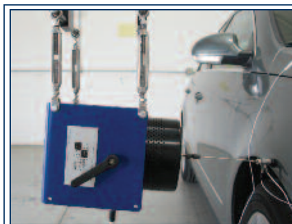
Modes of interest are observable:



PCB® offers a wide range of cost effective modal analysis sensors to accurately depict structural behavior of automotive components and systems.

- Response Degrees of Freedom (DOF) need to have adequate spatial resolution (both sensor location and orientation) to represent the modes of interest
- The input location and forcing function need to adequately excite the modes of interest

Test structure behaves linearly:



Linearity checks can be easily performed with the 100 lb modal shaker from The Modal Shop.

- The input and output characteristics need to remain proportional within the measurement range
- This assumption is best confirmed using precisely controlled inputs from a shaker at a range of input force levels and comparing the resulting Frequency Response Function (FRF) measurements

Test article exhibits time invariance & stationarity:

To reduce test time and minimize errors due to invariance, PCB® offers several solutions to multi-channel data acquisition, including bank switching.

- Modal parameter estimation algorithms need to assume consistent global modal frequencies and vectors
- Modal parameters need to remain consistent throughout the entire data set
- Changes in the test environment (temperature, humidity, etc.) during the data acquisition process need to be minimal

Maxwell's theory of reciprocity must be followed:

To ensure reciprocity PCB® offers an impedance sensor that simultaneously measures both force and acceleration at the input location.

- The FRF matrix is symmetric; meaning the FRF between input A and output B is the same as the FRF between input B and output A
- Excite with shakers and measure response with an array of accelerometers or rove the input with an impact hammer and fix a few reference accelerometers

Why Operational Modal Analysis?

Although the technique is still being refined, many of today's automotive engineers choose operational modal analysis over classical modal analysis because of its simplicity of test, in situ test configuration, and ability to separate closely coupled modes. Unlike classical modal analysis, there is no requirement for instrumented force applicators such as modal shakers or impact hammers, only that the excitation is random in time and that it is spatial. This can be accomplished either from operational forces and/or external inputs. The ability to test the structure in situ allows for efficiency and flexibility. Assuming adequate spatial resolution on the responses, closely coupled modes can be extracted due to the random nature of forces acting on the test structure. When done correctly, this technique will extract the same modal information as a classical modal test including natural frequencies, damping ratios, and mode shapes. Obtaining this real-world data allows automotive engineers to confirm dynamic properties of automotive structures based on true boundary conditions and actual excitation sources and levels.

Automotive Modal Analysis

PCB® manufactures accelerometers, dynamic force sensors, instrumented impact hammers, electrodynamic modal shakers and accessories specifically designed for detection, measurement, motion, shock, and vibration to meet your modal analysis needs. Products are designed and manufactured in our state-of-the-art facilities, and together with our global distribution network and Total Customer Satisfaction guarantee, you can rely on us to deliver products and solutions for your demanding requirements.

Every effort has been made to ensure the information presented in this brochure is accurate at the time of printing. For the most current specifications on all our products, please visit our web site at www.pcb.com. The web site also offers educational and technical information, as well as the latest product releases and tradeshow events.

PCB® prides itself on being able to respond to your needs. Strategic investment in machinery, capabilities, and personnel allow us to design, test, and manufacture products for specialized applications. Please contact one of our highly trained representatives to discuss your unique needs.

Response Output Measurements

General Purpose, ICP® Accelerometers for Automotive Modal Analysis

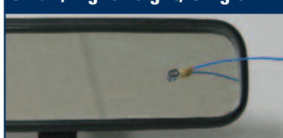
Overall, the optimal accelerometer for automotive modal analysis is one that has high sensitivity with excellent resolution, a wide frequency range and small mass. Trade-offs are usually made since a large sensor's inertial mass is directly proportional to resolution and sensitivity and inversely proportional to frequency range. For very small objects, like brake pads or rearview mirrors, a small, lightweight accelerometer with a wide frequency range is preferred over a larger accelerometer with high sensitivity, in order to minimize errors due to mass loading a small structure. For larger structures, such as body-in-white, a larger accelerometer with better resolution and higher sensitivity is optimal. While the choice of an accelerometer is similar between a classical and operational modal analysis test, there is a significant contrast in the ambient and operating condition in which the measurement is made. An operational modal test is performed in a structure's ambient environment which can be quite harsh, requiring hermetically sealed connectors and good temperature resistivity. The operating inputs can also be quite severe requiring the sensor to have good amplitude range and a robust construction.

PCB® offers a complete line of ICP® single axis and triaxial accelerometers for automotive modal analysis ranging from highly sensitive and lightweight sensors for low level inputs and mild environments to units with high ranges, hermetically sealed connectors, and rugged titanium construction for severe inputs and environments. With a variety of packages, mounting, and output cabling options, these sensors can accommodate virtually any automotive modal analysis testing situation. Optional "TEDS" circuitry offers 'smart sensing' solutions for automating sensor performance bookkeeping and structure coordinate mapping.

Small, Lightweight, ICP® Accelerometers for Automotive Modal Analysis

Specific automotive modal analysis testing can also require small, lightweight accelerometers for high-frequency response, low noise, minimal mass loading, and installation in space restricted locations. PCB® offers a line of ceramic shear ICP® accelerometers housed in lightweight aluminum or robust hermetically sealed titanium. By minimizing the mass of the sensor, mass loading effects are reduced, leading to improved measurement accuracy.

Small, Lightweight, Single Axis, ICP® Accelerometers for Automotive Modal Analysis

					TEDS COMPLIANT 
Model Number	**352C23**	**352C22**	**352B10**	**352A24**	**352A56**
Sensitivity	5 mV/g	10 mV/g	10 mV/g	100 mV/g	100 mV/g
Measurement Range	1000 g pk	500 g pk	500 g pk	50 g pk	50 g pk
Broadband Resolution	0.003 g rms	0.002 g rms	0.003 g rms	0.0002 g rms	0.0006 g rms
Frequency Range (± 10 %)	1.5 to 15k Hz	0.7 to 13k Hz	1.0 to 17k Hz	0.8 to 10k Hz	0.3 to 15k Hz
Temperature Range	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C
Electrical Connector	3-56 Coaxial Jack	3-56 Coaxial Jack	Integral Cable	3-56 Coaxial Jack	5-44 Coaxial Jack
Sealing	Epoxy	Epoxy	Hermetic	Epoxy	Hermetic
Housing Material	Anodized Aluminum	Anodized Aluminum	Titanium	Anodized Aluminum	Titanium
Weight	0.2 gm	0.5 gm	0.7 gm	0.8 gm	1.8 gm
Size	0.11 x 0.34 x 0.16 in 2.8 x 8.6 x 4.1 mm	0.14 x 0.45 x 0.25 in 3.6 x 11.4 x 6.4 mm	0.32 x 0.24 in 8.1 x 6.1 mm	0.19 x 0.48 x 0.28 in 4.8 x 12.2 x 7.1 mm	0.26 x 0.57 x 0.30 in 6.6 x 14.5 x 7.6 mm
Mounting	Adhesive	Adhesive	Adhesive	Adhesive	Adhesive
Supplied Accessories					
Wax/Adhesive	080A109	080A109	080A90	080A109 080A90	080A109
Removal Tool	039A26	039A27	—	039A28	039A31
Cable	030A10	030A10	—	030A10	—
Additional Accessories					
Connector Adaptor	070A02	070A02	070A02	070A02	—
Mating Cable Connectors	EK	EK	AL	EK	AG
Recommended Cables	030	030	—	030	018 Flexible, 003 CE

Small, Lightweight, Single Axis, ICP® Accelerometers for Automotive Modal Analysis

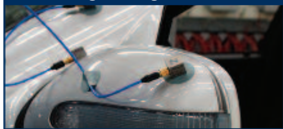
					
Model Number	**352C65**	**352C42**	**352C41**	**352C03**	**352C33**
Sensitivity	100 mV/g	100 mV/g	10 mV/g	10 mV/g	100 mV/g
Measurement Range	50 g pk	50 g pk	500 g pk	500 g pk	50 g pk
Broadband Resolution	0.00016 g rms	0.0005 g rms	0.0008 g rms	0.0005 g rms	0.00015 g rms
Frequency Range (± 10 %)	0.3 to 12k Hz	0.5 to 10k Hz	0.3 to 15k Hz	0.3 to 15k Hz	0.3 to 15k Hz
Temperature Range	-65 to +200 °F -54 to +93 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +200 °F -54 to +93 °C
Electrical Connector	5-44 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Thread	10-32 Coaxial Jack
Sealing	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic
Housing Material	Titanium	Titanium	Titanium	Titanium	Titanium
Weight	2.0 gm	2.8 gm	2.8 gm	5.8 gm	5.8 gm
Size	5/16 x 0.33 in 5/16 in x 8.4 mm	3/8 x 0.38 in 3/8 in x 9.7 mm	3/8 x 0.38 in 3/8 in x 9.7 mm	7/16 x 0.62 in 7/16 in x 15.7 mm	7/16 x 0.62 in 7/16 in x 15.7 mm
Mounting	5-40 Stud	Adhesive	Adhesive	10-32 Thread	10-32 Thread
Supplied Accessories					
Wax/Adhesive	080A109	080A109, 080A90	080A109, 080A90	080A109	080A109
Adhesive Mounting Base	080A15	—	—	080A	080A
Mounting Studs	—	—	—	081B05 M081B05	081B05 M081B05
Additional Versions					
Alternate Connector	352C68 - 10-32 Coaxial Jack	—	—	—	—
Top Connector Position	352C66	—	—	352C04	352C34
Metric Mounting Thread	M352C65	—	—	—	—
Additional Accessories					
Magnetic Mounting Base	080A30	—	—	080A27	080A27
Triaxial Mounting Adaptor	080B16	—	—	080B10	080B10
Mating Cable Connectors	AG	EB	EB	EB	EB
Recommended Cables	018 Flexible, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE

General Purpose, Single Axis, ICP® Accelerometers for Automotive Modal Analysis

						
Model Number	**333B30**	**333B32**	**333B40**	**333B42**	**333B50**	**333B52**
Sensitivity	100 mV/g	100 mV/g	500 mV/g	500 mV/g	1000 mV/g	1000 mV/g
Measurement Range	50 g pk	50 g pk	10 g pk	10 g pk	5 g pk	5 g pk
Broadband Resolution	0.00015 g rms	0.00015 g rms	0.00005 g rms	0.00005 g rms	0.00005 g rms	0.00005 g rms
Frequency Range (± 5 %)	0.5 to 3000 Hz	0.5 to 3000 Hz	0.5 to 3000 Hz	0.5 to 3000 Hz	0.5 to 3000 Hz	0.5 to 3000 Hz
Temperature Range	0 to +150 °F -18 to +66 °C	0 to +150 °F - 18 to +66 °C	0 to +150 °F -18 to +66 °C	0 to +150 °F -18 to +66 °C	0 to +150 °F -18 to +66 °C	0 to +150 °F -18 to +66 °C
Electrical Connector	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack
Sealing	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic
Housing Material	Titanium	Titanium	Titanium	Titanium	Titanium	Titanium
Weight	4.0 gm	4.0 gm	7.5 gm	7.5 gm	7.5 gm	7.5 gm
Size	0.4 in Cube 10.2 mm Cube	0.4 in Cube 10.2 mm Cube	0.45 in Cube 11.4 mm Cube	0.45 in Cube 11.4 mm Cube	0.45 in Cube 11.4 mm Cube	0.45 in Cube 11.4 mm Cube
Mounting	5-40 Thread	Adhesive	5-40 Thread	Adhesive	5-40 Thread	Adhesive
Supplied Accessories						
Wax/Adhesive	080A109, 080A90	080A109, 080A90	080A109, 080A90	080A109, 080A90	080A109, 080A90	080A109, 080A90
Adhesive Mounting Base	080A25	—	080A25	—	080A25	—
Mounting Studs	081A27 M081A27	—	081A27 M081A27	—	081A27 M081A27	—
Additional Accessories						
Removal Tool	039A08	039A08	039A09	039A09	039A09	039A09
Mating Cable Connectors	EB	EB	EB	EB	EB	EB
Recommended Cables	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE

Automotive Modal Analysis

Small, Lightweight, Triaxial, ICP® Accelerometers for Automotive Modal Analysis

					
Model Number	**356A01**	**356A31**	**356A33**	**356A12**	**356A32**
Sensitivity	5 mV/g	10 mV/g	10 mV/g	100 mV/g	100 mV/g
Measurement Range	± 1000 g pk	± 500 g pk	± 500 g pk	± 50 g pk	± 50 g pk
Broadband Resolution	0.003 g rms	0.002 g rms	0.003 g rms	0.0002 g rms	0.0003 g rms
Frequency Range (± 5 %)	1.0 to 8000 Hz	1.0 to 10k Hz	2.0 to 10k Hz	0.4 to 6000 Hz [1]	0.7 to 5000 Hz [1]
Temperature Range	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +170 °F -54 to +77 °C	-65 to +250 °F -54 to +121 °C
Electrical Connector	Integral Cable	8-36 4-Pin Jack	1/4-28 4-Pin Jack	Integral Cable	8-36 4-Pin Jack
Sealing	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic
Housing Material	Titanium	Titanium	Titanium	Titanium	Titanium
Weight	1.0 gm	4.5 gm	5.3 gm	5.4 gm	5.4 gm
Size	0.25 in Cube 6.35 mm Cube	0.45 in Cube 11.4 mm Cube	0.4 in Cube 10.2 mm Cube	0.45 in Cube 11.4 mm Cube	0.45 in Cube 11.4 mm Cube
Mounting	Adhesive	Adhesive	5-40 Thread	5-40 Thread	5-40 Thread
Supplied Accessories					
Wax/Adhesive	080A109, 080A90	080A109	080A109	080A109	080A109
Adhesive Mounting Base	—	—	080A	080A	080A
Mounting Studs/Screws	—	—	081A27, 081A90 M081A27	081A27 M081A27	081A27 M081A27
Cable Assembly	034G05	034K10	034G05	034G05	034K10
Additional Accessories					
Magnetic Mounting Base	—	—	—	080A30	080A30
Removal Tool	—	039A09	039A08	030A09	039A09
Mating Cable Connectors	AY	EH	AY	AY	EH
Recommended Cables	034	034	034	034	034
Note					
[1] Range shown is ± 10 %					

General Purpose, Triaxial, ICP® Accelerometers for Automotive Modal Analysis

					
Model Number	**356A16**	**356A02**	**356A25**	**356A15**	**356B18**
Sensitivity	100 mV/g	10 mV/g	25 mV/g	100 mV/g	1000 mV/g
Measurement Range	± 50 g pk	± 500 g pk	± 200 g pk	± 50 g pk	± 5 g pk
Broadband Resolution	0.0001 g rms	0.0005 g rms	0.0002 grms	0.0002 g rms	0.00005 g rms
Frequency Range (± 10%)	0.3 to 6000 Hz	0.5 to 6500 Hz	0.5 to 6500 Hz	1.4 to 6500 Hz	0.3 to 5000 Hz
Temperature Range	-65 to +176 °F -54 to +80 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-20 to +170 °F -29 to +77 °C
Electrical Connector	1/4 - 28 4-Pin Jack	1/4-28 4-Pin Jack	1/4-28 4-Pin Jack	1/4 - 28 4-Pin Jack	1/4 - 28 4-Pin Jack
Sealing	Epoxy	Hermetic	Hermetic	Hermetic	Epoxy
Housing Material	Anodized Aluminum	Titanium	Titanium	Titanium	Anodized Aluminum
Weight	7.4 gm	10.5 gm	10.5 gm	10.5 gm	25.0 gm
Size	0.55 in Cube 14.0 mm Cube	0.55 in Cube 14.0 mm Cube	0.55 in Cube 14.0 mm Cube	0.55 in Cube 14.0 mm Cube	0.8 in Cube 20.3 mm Cube
Mounting	10-32 Thread	10-32 Thread	10-32 Thread	10-32 Thread	10-32 Thread
Supplied Accessories					
Wax/Adhesive	080A109	080A90, 080A109	080A109	080A90, 080A109	080A109
Adhesive Mounting Base	080A12	080A12	080A12	080A12	080A68
Mounting Studs	081B05 M081B05	081B05 M081B05	081B05 M081B05	081B05 M081B05	081B05 M081B05
Additional Accessories					
Magnetic Mounting Base	080A27	080A27	080A27	080A27	080A27
Removal Tool	039A10	039A10	039A10	039A10	—
Mating Cable Connectors	AY	AY	AY	AY	AY
Recommended Cables	034	034	034	034	034

Filtered and High Temperature, ICP® Accelerometers for Operational Modal Analysis

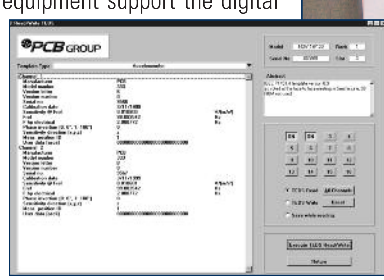
Filtered, ICP®, triaxial accelerometers prevent overloads due to excessive high frequency excitation commonly encountered with powertrain testing. High temperature ICP® accelerometers are specially designed and tested to survive temperature extremes beyond the range of standard ICP® accelerometers. These accelerometers are ideal for use in engine, turbo, exhaust and other automotive high temperature testing environments.

Filtered and High Temperature, ICP® Accelerometers

						
	Filtered Triaxial Accelerometers		Filtered and High Temperature, Triaxial, ICP® Accelerometers	High Temperature, Single Axis, ICP® Accelerometers [1]		
Model Number	**356A63**	**356A66**	**339A30**	**320C18**	**320C15**	**320C03**
Sensitivity	10 mV/g	10 mV/g	10 mV/g	10 mV/g	10 mV/g	10 mV/g
Measurement Range	± 500 g pk	± 500 g pk	± 500 g pk	500 g pk	500 g pk	500 g pk
Broadband Resolution	0.008 g rms	0.002 g rms	0.008 g rms	0.005 g rms	0.005 g rms	0.005 g rms
Frequency Range (± 10 %)	2.0 to 4000 Hz	2.0 to 4000 Hz [2]	2 to 10k Hz [2]	1.5 to 18k Hz	1.5 to 18k Hz	0.7 to 9000 Hz
Temperature Range	-65 to +250 °F -54 to +121 °C	-65 to +250 °F -54 to +121 °C	-65 to +325 °F -54 to +163 °C	-100 to +325 °F -73 to +163 °C	-100 to +325 °F -73 to +163 °C	-100 to +325 °F -73 to +163 °C
Electrical Connector	1/4-28 4-Pin Jack	1/4-28 4-Pin Jack	8-36 4-Pin Jack	10-32 Coaxial Jack	5-44 Coaxial Jack	10-32 Coaxial Jack
Sealing	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic
Housing Material	Titanium	Titanium	Titanium	Titanium	Titanium	Titanium
Weight	5.3 gm	9.0 gm	4.0 gm	1.7 gm	2.0 gm	10.5 gm
Size	0.4 in Cube 10.2 mm Cube	0.55 in Cube 14.0 mm Cube	0.4 in Cube 10.2 mm Cube	9/32 x 0.74 in 9/32 in x 18.8 mm	5/16 x 0.43 in 5/16 in x 10.9 mm	1/2 x 0.81 in 1/2 in x 20.6 mm
Mounting	5-40 Thread	10-32 Thread	Adhesive	5-40 Stud	5-40 Stud	10-32 Thread
Supplied Accessories						
Wax/Adhesive	080A109	080A109, 080A90	080A109	080A109	080A109	080A109
Adhesive Mounting Base	080A	080A12	—	080A15	080A15	—
Mounting Studs	081A27 M081A27 081A90	081B05 M081B05	—	—	—	081B05 M081B05
Additional Versions						
Alternate Mounting	—	—	339A31 - 5-40 Stud	M320C18 - Metric	M320C15 - Metric	—
Additional Accessories						
Magnetic Mounting Base	080A30	080A27	—	080A30	080A30	080A27
Triaxial Mounting Adaptor	—	—	—	080B16 080A196	080B16 080A196	080B10
Removal Tool	039A08	039A10	039A08	—	—	—
Mating Cable Connectors	AY	AY	EH	EB	AF, AG	EB
Recommended Cables	034	034	034	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE
Notes						
[1] See also the high temperature (HT) versions of Models 356A01, 356A02, and 356A33 – each have a temperature range of -100 to +325 °F (-73 to +163 °C) [2] Range shown is ± 5 %						

Transducer Electronic Data Sheet (TEDS)

A sensor incorporating a Transducer Electronic Data Sheet (TEDS) is a mixed-mode (analog/digital) sensor with a built-in read/write memory that contains information about the sensor and its use. A TEDS sensor has an internal memory that includes information about the manufacturer, specifications and calibration, defined by IEEE standard 1451.4, effectively giving it the ability of "plug-and-play" self-identification within a measurement system. Using the same two-wire design of traditional piezoelectric with internal charge amplifier transducers, the TEDS sensor can flip between analog and digital modes, functioning with either a typical analog output, or with a digital bit stream output. Although a TEDS sensor can be connected to any ICP® sensor signal conditioner, only a TEDS-capable ICP® signal conditioner and data acquisition equipment support the digital communication mode.



Most PCB® accelerometers are available to order with TEDS functionality by specifying the unit's model number with a "T" prefix. Model 400B76 TEDS sensor interface kit provides users with full access to support both reading and writing information to the TEDS sensor. Its Windows® GUI supports both IEEE and LMS templates, communicating with a TEDS sensor over a USB port. Model 400B76-T includes an adaptor that allows reading and writing to triaxial accelerometers with one mouse click.

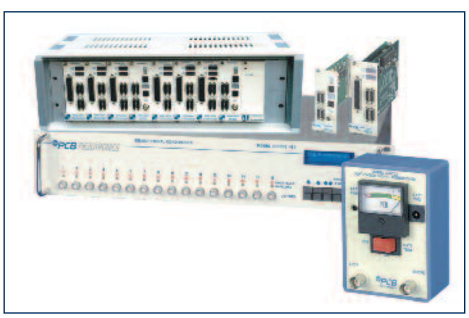
Charge Output Accelerometers for Automotive Modal Analysis

PCB® charge output accelerometers utilize piezoceramic sensing elements, in shear mode configurations, to directly output an electrostatic charge signal that is proportional to applied acceleration. These sensors do not contain built-in signal conditioning electronics. As a result, external signal conditioning is required to interface their generated measurement signals to readout or recording instruments. The sensors' charge output signals can be conditioned with either a laboratory-style, adjustable charge amplifier or an in-line fixed charge converter.

Charge Output Accelerometers for Automotive Modal Analysis

						
	Single Axis				Triaxial	
Model Number	**357A08**	**357A09**	**357B11**	**357B03**	**356A70**	**356A71**
Sensitivity	0.35 pC/g	1.7 pC/g	3.0 pC/g	10.0 pC/g	2.7 pC/g	10.0 pC/g
Measurement Range	± 1000 g pk	± 2000 g pk	± 2300 g pk	± 2000 g pk	± 500 g pk	± 500 g pk
Frequency Range (+10 %) [1]	20k Hz	13k Hz	16k Hz	12k Hz	7000 Hz	7000 Hz
Temperature Range	-100 to +350 °F -73 to +177 °C	-100 to +350 °F -73 to +177 °C	-95 to +500 °F -71 to +260 °C	-95 to +500 °F -71 to +260 °C	-95 to +490 °F -70 to +254 °C	-95 to +490 °F -70 to +254 °C
Electrical Connector	3-56 Coaxial Jack	3-56 Coaxial Jack	5-44 Coaxial Jack	10-32 Coaxial Jack	5-44 Coaxial Jack	10-32 Coaxial Jack
Sealing	Epoxy	Epoxy	Hermetic	Hermetic	Hermetic	Hermetic
Housing Material	Anodized Aluminum	Titanium	Titanium	Titanium	Titanium	Titanium
Weight	0.16 gm	0.6 gm	2.0 gm	11 gm	7.9 gm	22.7 gm
Size (Length x Width x Height)	0.11 x 0.16 x 0.27 in 2.8 x 4.1 x 6.9 mm	0.14 x 0.45 x 0.25 in 3.6 x 11.4 x 6.4 mm	5/16 x 0.33 in 5/16 in x 8.4 mm	1/2 x 0.81 in 1/2 in x 20.6 mm	0.73 x 0.90 x 0.40 in 18.5 x 22.9 x 10.2 mm	0.96 x 1.00 x 0.50 in 24.4 x 25.4 x 12.7 mm
Mounting	Adhesive	Adhesive	5-40 Stud	10-32 Thread	Through Hole	Through Hole
Supplied Accessories						
Cable Assembly	030A10	030A10	—	—	—	—
Wax/Adhesive	080A109	080A109	—	080A109	—	—
Quick Bonding Gel	—	—	—	—	080A90	080A90
Adhesive Mounting Base	—	—	—	—	—	080A170
Removal Tool	039A29	039A27	—	—	—	—
Mounting Studs	—	—	—	081B05 M081B05	081A46	081A94
Additional Versions						
Alternate Electrical Connector	—	—	357B14 10-32 Coaxial Jack	—	—	—
Top Connector Position	—	—	357B14	357B04	—	—
Additional Accessories						
Adhesive Mounting Base	—	—	080A15	080A	—	080A170
Magnetic Mounting Base	—	—	080A30	080A27	—	—
Triaxial Mounting Adaptor	080A194	—	080B16, 080A196	080B10	—	—
Connector Adaptor	0709A02	0709A02	—	—	—	—
Mating Cable Connectors	EK	EK	AG	EB	AF, AG	EB
Recommended Cables	030	030	018 Flexible, 003	003	003	003
Notes						
[1] Dependant on charge amplifier (signal conditioner)						

Recommended Signal Conditioning Systems Solutions for Large, Multi-channel Automotive Modal Analysis



The third primary assumption of classical modal analysis is the time invariance of the test article. This assumption essentially requires that the modal properties of a structure do not change over time. As a result, the consistency of the data set is critical to accurate parameter estimation. The best way to ensure data consistency is to acquire all data simultaneously, a single "snapshot" in time eliminating any variance due to changing environmental or boundary conditions. Although this is the optimal solution it is often not economically feasible to purchase all the required channels of sensors, signal conditioning and data acquisition.

Traditionally, when a completely simultaneous measurement system is not realizable, the test engineer has had to resort to roving accelerometers in order to capture all necessary response data. This approach distresses the assumption of time invariance and can cause significant complications. First, it takes time to acquire the complete data set and the structure may indeed change throughout the testing over the course of hours or days. Second, roving a set of accelerometers actually produces an inconsistent mass distribution on the test article.

Bank Switching is a very effective means to acquire high quality consistent data sets while minimizing financial investment. Fully instrumenting the test structure with a complete set of accelerometers, and bank-switching signals from groups of accelerometers into a smaller, more affordable multi-channel simultaneous data acquisition system is an ideal compromise. Using the computer controlled automation of PCB® Series 440 signal conditioner, multiple data sets are acquired in just minutes, nominally longer than a full simultaneous acquisition, but substantially shorter than the hours or days of testing when roving accelerometers.

Modally Tuned®, ICP®, Impact Hammers for Automotive Modal Analysis

Modally Tuned®, ICP®, impact hammers are easy-to-use solutions for delivering impulse forces into automotive test structures. "Modal tuning" is a technology that ensures the structural characteristics of the hammer do not affect measurement results. This is accomplished by eliminating hammer resonances in the frequency range of interest from corrupting the test data, resulting in more accurate and consistent outcomes.

Modally Tuned®, ICP®, impact hammers are also available in convenient kits which include the response accelerometers, signal conditioners, cables, and accessories needed for automotive component structural testing. Consult the PCB® web site at www.pcb.com for further details.

Model Number	GK291E80	GK291D	GK291D20
Supplied Kit Components	**Model**	**Model**	**Model**
Impact Hammer	086E80	086C03	086D20
Accelerometer #1	352B10	352B10	353B33
Accelerometer #2	352C68	352C68	352B
Signal Conditioner (2 ea.)	480E09	480E09	480E09
Hammer Cable	Integral	003D10	003D20
Accelerometer Cable (2 ea.)	003C10	003C10	003C20
Cable Adaptor	070A02 (2 ea.)	070A02	--
Output Cable (2 ea.)	003D03	003D03	003D03

Modally Tuned®, ICP®, Impact Hammers for Automotive Modal Analysis

				
Application	Rearview Mirrors, Printed Circuit Boards for ECMs, Lightly Damped Door Panels	Body-in-white Structures, Engine Components, Steering Columns	Light-Duty Truck Frames, Engines, Exhaust Systems	Heavy-Duty Truck Frames, Suspensions, Bus Structures
Model Number	**086E80**	**086C03**	**086D05**	**086D20**
Sensitivity	100 mV/lbf 22.5 mV/N	10 mV/lbf 2.25 mV/N	1 mV/lbf 0.23 mV/N	1 mV/lbf 0.23 mV/N
Measurement Range	±50 lbf pk ±220 N pk	±500 lbf pk ±2200 N pk	±5000 lbf pk ±22,000 N pk	±5000 lbf pk ±22,000 N pk
Resonant Frequency	≥ 100 kHz	≥ 22 kHz	≥ 22 kHz	≥ 22 kHz
Hammer Mass	4.8 gm	0.16 kg	0.32 kg	1.1 kg
Tip Diameter	0.10 in 2.5 mm	0.25 in 6.3 mm	0.25 in 6.3 mm	2.0 in 50.8 mm
Hammer Length	4.2 in 106.7 mm	8.5 in 215.9 mm	9.0 in 228.6 mm	14.5 in 368.3 mm
Electrical Connection	5-44 Coaxial Jack	BNC Jack	BNC Jack	BNC Jack
Extender Mass Weight	1.25 gm	75 gm	200 gm	-
Supplied Accessories				
Miniature Coaxial Cable	018G10	—	—	—
Wax	080A109	—	—	—
Extender Mass	084A13	—	084A09	—
Plastic Handle	084A14	—	—	—
Aluminum Handle	084A17	—	—	—
Tip Cover	084A28	—	—	—
Mounting Studs	—	081B05	081B05	—
Aluminum Extender	—	084A08	—	—
Hard Tip	—	084B03	084B03	084A63
Medium Tip	—	084B04	084B04	084A62
Soft Tip	—	084C05	084C05	084A61
Super Soft Tip	—	084C11	084A50	084A60
Tip Cover (4 each)	—	085A10	085A10	—

Dynamic Force Sensors for Automotive Modal Analysis

Model Number	288D01		208C01	208C02	208C03
	Acceleration	Force			
Sensitivity	100 mV/g 10.2 mV/(m/s²)	100 mV/lb 22.4 mV/N	500 mV/lb 112 mV/N	50 mV/lb 11 mV/N	10 mV/lb 2.2 mV/N
Measurement Range	± 50 g pk	± 50 lbf pk ± 222.4 N pk	10 lb 44 N	100 lb 445 N	500 lb 2224 N
Broadband Resolution	0.002 g rms	0.002 lb 0.0089 N	0.0001 lb rms 0.00045 N rms	0.001lb rms 0.004 N rms	0.005 lb rms 0.02 N rms
Upper Frequency Limit	7000 Hz	—	36 kHz	36 kHz	36 kHz
Electrical Connector	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack	10-32 Coaxial Jack
Housing Material	Titanium	Titanium	Stainless Steel	Stainless Steel	Stainless Steel
Sealing	Hermetic	Hermetic	Hermetic	Hermetic	Hermetic
Weight	19.2 gm	19.2 gm	22.7 gm	22.7 gm	22.7 gm
Size	11/16 x 0.82 in 11/16 in x 20.83 mm	11/16 x 0.82 in 11/16 in x 20.83 mm	5/8 x 0.625 in 5/8 in x 15.88 mm	5/8 x 0.625 in 5/8 in x 15.88 mm	5/8 x 0.625 in 5/8 in x 15.88 mm
Mounting	10-32 Thread	10-32 Thread	10-32 Thread	10-32 Thread	10-32 Thread
Supplied Accessories					
Mounting Stud	081B08 M081B08	081B08 M081B08	081B05 M081A62	081B05 M081A62	081B05 M081A62
Adhesive Mounting Base	080A	080A	—	—	—
Thread Locker	—	—	080A81	080A81	080A81
Impact Cap	—	—	084A03	084A03	084A03
Additional Accessories					
Mating Cable Connectors	EB	EB	EB, EJ	EB, EJ	EB, EJ
Recommended Cables	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE	002 Low Cost, 003 CE

PCB® recommends the use of Model 288D01 impedance sensor for all automotive modal testing applications. This sensor simultaneously measures an applied, driving point force and response acceleration in a single location. This is extremely important for multiple input test techniques to satisfy Maxwell's theory of reciprocity. In cases where it is not possible to use the impedance sensor, use of Series 208 force sensor is recommended.

Handheld Calibrator and Mounting Accessories

Model 394C06 handheld shaker is a small, self-contained, battery powered, vibration exciter specifically designed to conveniently verify accelerometer and vibration system performance. It accepts sensors weighting up to 210 grams in weight and delivers a controlled, 1 g mechanical excitation.

Adhesive Mounting Bases
Models 080A, 080A12, 080A15, 080A25, 080A68, 080A70

Removal Tools
Models 039A08, 039A09, 039A10, 039A26, 039A27, 039A28, 039A29, 039A31

Adhesive
Model 080A90
Note: A debonder should always be used to avoid sensor damage.

Magnetic Mounting Bases
Models 080A27, 080A30

Triaxial Mounting Adapters
Models 080B10, 080B16

Petro Wax
Model 080A109

Recommended Electrodynamic Modal Shaker System & Accessories from The Modal Shop

Modal Shaker

For many modal test applications, an electrodynamic shaker system is best suited for creating an appropriate input forcing function. Distributing adequate input force energy across the test structure and obtaining accurate and reliable input force measurements is critical for successful modal testing. This often requires a shaker that is highly portable, rugged, and easy to setup in order to facilitate the best exciter location (relative to the test structure) while minimizing any unwanted interaction between the exciter and test structure. Model 2100E11 Modal Shaker, a lightweight electrodynamic modal exciter, is capable of providing 100 lbf (440 N) of peak force excitation in a small footprint weighing just 33 pounds (15 kg). With a 1" stroke and frequency range up to 3000 Hz, Model 2100E11 is suitable for a multitude of automotive modal analysis applications.

Recommended Modal Shaker


Model Number	2100E11
Output Force, sine pk	100 lb 445 N
Output Force, random RMS	70 lb 311 N
Stroke Length, pk - pk	1.0 in 25.4 mm
Frequency Range	2 to 3000 Hz
First Resonance Frequency, nominal	> 3600 Hz
Maximum Acceleration	102 g
Maximum Velocity	5.2 ft/s
Protection Features	Over-travel Over-current (10A fuse)
Maximum Current	10A
DC Resistance, armature, nominal	3.8 Ω
Armature Suspension System	8 pieces composite beam flexures
Effective Armature Mass	0.45 kg
Weight	15.0 kg
Size	12.0 x 12.0 x 8.0 in 30.5 x 30.5 x 20.3 cm
Temperature Range (< 85% RH)	+ 41 to +95 °F + 5 to + 35 °C
Continuous Operation	8 hours
Included	2150G, 2155G, K2160G Stinger Kits

AirRide Mounts

AirRides provide excellent isolation and support of heavy structures during modal testing. They meet the modal challenge of keeping the mounting (rigid body) frequencies well below the frequency of the first deflection mode. Used exclusively for body-in-white vehicle modal tests, they offer a typical mounting frequency of 1.35 Hz for a 310 lb. mass (Model 8030S) or 2.88 Hz for a 650 lb. mass (Model 8032S). Since the natural frequency does not vary appreciably with load, several mounts may be used to support a structure at various loading points with good agreement on overall system mounting frequencies. AirRides offer the highest degree of isolation of any type of vibration isolator.

Recommended AirRide Mounts



Model Number	8030S	8032S
Maximum Load	680 lb 309 kg	1790 lb 814 kg
Maximum Pressure	80 PSIG 552 kPa	100 PSIG 690 kPa
Mounting Frequency	1.35 Hz for 310 lb mass	2.88 Hz for 650 lb mass
Mounting Pillar	1/2 - 13 UNC 2B x 1 in depth	1/2 - 13 UNC 2B x 1 in depth
Mounting Base	8 15/16 in mounting holes	8 15/16 in mounting holes
Size	7.5 x 8.5 in 190.5 x 215.9 mm	7.5 x 7.5 in 190.5 x 190.5 mm

Lateral Excitation Stand

Model 2050A lateral excitation stand provides a versatile means of adapting a modal shaker for horizontal input. Vehicles often require a means of inputting lateral force. The stand facilitates excitation with a tensioned piano wire stinger, which significantly reduces force measurement errors from unmeasured transverse forces. Combining both lateral and vertical excitation more evenly distributes input energy for better signal-to-noise, and helps to excite uncoupled lateral structural modes. Model 2050A allows the shaker to be precisely located in both the horizontal and vertical directions.

2050A

Recommended Lateral Excitation Stand

Model Number	2050A
Vertical Adjustment Range	4 to 49 in 102 to 1245 mm
Horizontal Adjustment Range	0 to 13.5 in 0 to 343 mm
Maximum Support Load	160 lb 72.7 kg
Weight	120 lb 54.5 kg
Size	39.0 x 49.5 x 75.0 in 990 x 1260 x 1910 mm
Included	K2160G Piano Wire Stinger Kit

Recommended Modal Accessories from The Modal Shop

3D Optical Digitizer

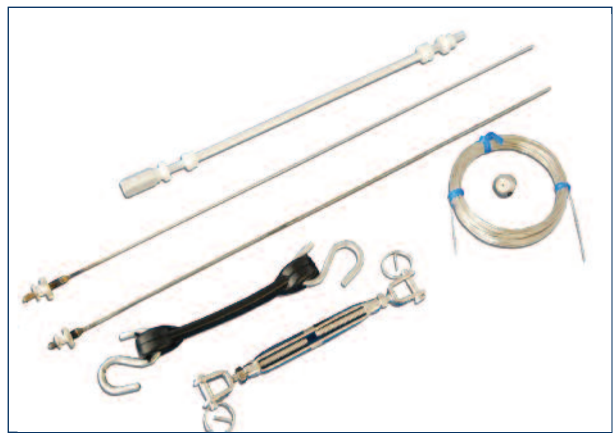
Model 5240 3D Optical Digitizer is ideal for locating modal analysis measurement points, up to 80% faster than manual geometry definition, with a tape measure, with accuracy of better than ± 0.01 in (± 0.25 mm) across a 1 m sphere. The 5240 system's wireless, handheld probe provides the ability to measure accurate coordinates without mechanical restrictions. The probe's locator tip accurately measures the coordinates of remote, or obscured, test points.

- 7 lb (3.2 kg) array weight
- Lightweight, small, rugged and portable
- Automatic digitization with wireless handheld flexibility
- Continuous self-calibration and data validation guarantees system accuracy
- Audible feedback informs user of accepted data points
- Easy repositioning of array and dynamic reference frame (DRF) for increased working volume

Excitation Stingers

Series 2100 Excitation Stinger consists of thin, flexible rods with attachment means at both ends. The stinger transmits force in the stiff axial direction and flexes laterally to reduce input side loads to the structure. This uniaxial force delivered by the flexible stinger increases the accuracy of the measurement. The stinger also helps isolate the exciter armature from the structure, lessening inadvertent shocks, and possibly preventing damage to a fragile exciter armature. Likewise, the stinger can protect a fragile structure from large, inadvertent excitations.

- Provides convenient excitation connection
- Alleviates need for alignment accuracy
- Reduces force sensor measurement error
- Isolates fragile exciter armatures
- Adapts to different mounting threads



For complete specifications on Modal Shakers and Accessories, please visit www.modalshop.com

Based in Cincinnati, Ohio, USA, PCB Piezotronics' sister company, The Modal Shop, specializes in sound and vibration sensing systems for the multichannel, acoustics, modal, and NVH markets. In addition to sensors, calibration systems, and applications engineering support, a variety of modal testing equipment is available as part of the rental program, and an experienced team of in-house experts is available to both perform and provide advice on both classical and operating automotive modal analysis applications.

THE MODAL SHOP INC.
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PCB® Automotive Sensors is a dedicated technical sales and support facility, located in Farmington Hills, Michigan, USA, devoted to the testing needs of the global transportation market. This team is focused on development and application of sensors and related instrumentation for specific vehicle development test programs, including modal analysis; driveability; ride & handling; component & system performance; durability; road load data acquisition; vehicle and powertrain NVH; legislative testing; quality control; powertrain development; and motorsport. PCB® offers exceptional customer service, 24-hour technical assistance, and a **Total Customer Satisfaction** guarantee.

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