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The challenge of e-mobility and eVTOLs on measurement technology with vibration and acceleration sensors.

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Abstract

The influences of trouble signals on measurement technology have recently changed significantly due to new technologies. Due to the technology shift to more electric drives and hydrogen technology, sensors should also provide reproducible and reliable data even in this environment. In order to continue to ensure the quality of the measurement results, sensors and cable concepts must be reconsidered, modified and tested. The aim of this presentation is to point out these problems in connection with vibration and acceleration sensors with piezoelectric ICP®- and MEMS-DC technology and to show examples of improvements and solutions. Product improvements will be presented and measurement results from a test series in the field of e-mobility will be shown. Practical suggestions for optimal wiring, cable selection and ground concepts will be discussed. The perspective on the use of placebo sensors to verify measurement results is addressed. The findings and suggestions for improvement are a good help for test and measurement engineers in the development field of E-Mobility as well as eVTOLs for Urban Air Mobility (UAM) in selecting sensors and their use.

Key Words

ICP®-Technology, DC MEMS-Accelerometer, Electric and Magnetic Fields, Pseudo Transducer, Ground and Case Isolation.

The new challenges for NVH sensors in eMobility and eVTOLs applications.

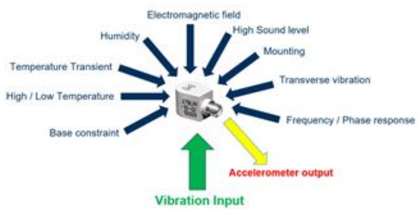
Hybrid and electric vehicles present NVH testing (Noise, Vibration, Harshness) challenges due to vehicle complexity and potential for problems with electrical shielding. NVH issues related to the addition of new electrical devices, gear whine, and vehicle resonances increase the number of NVH areas to be tested.

Our broad line of accelerometers is engineered to meet these challenges, by incorporating ground and case isolation. Electrically isolated accelerometers help avoid measurement errors and poor test data that can result when ground loops and stray electrical signals are present during testing.

The aim of this paper is to point out these problems in connection with acceleration sensors with piezoelectric **ICP® -** and MEMS-DC technology, as they are used in such applications.

External influences on vibration sensors

There are some environmental influences that can affect the output signal of an accelerometer and therefore the accuracy and fidelity of a measurement.



Typical electrical noise sources

Capacitively coupled

the varying electrostatic field between input and ground is electrically coupled by some stray capacitance, ex: power lines, electric motors, adjacent circuitry (multi-channel printed circuit boards without channel isolation/shielding).

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Magnetically coupled

the varying magnetic field around (poorly shielded) cable, ex: changing current in cables found near AC power distribution paths (machinery, transformers, etc.).

Current coupled

current other than the vibration signal is introduced into the measurement system via a common path, where impedance generates extraneous signals, ex: shaker drive circuits providing conduction currents through multiple ground points.

Triboelectric effect

relative motion/separation between the cable dielectric and the outer shield, ex: cable ”whip”

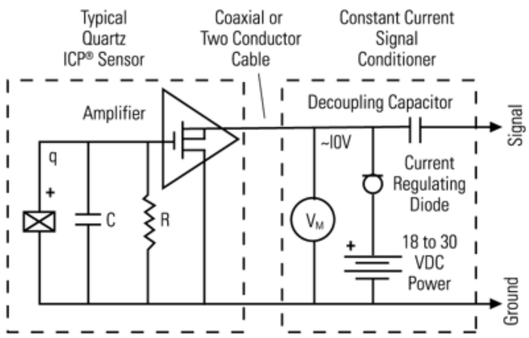
Ground loops/potentials

line frequency and harmonics, ex shaker power systems

The sensor technology for NVH applications

ICP® -Accelerometers (IEPE)

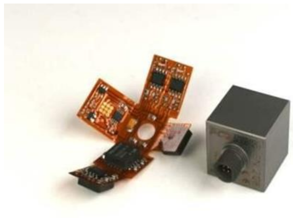
ICP® is a PCB® registered trademark that stands for "Integrated Circuit Piezoelectric" and identifies sensors that incorporate built-in microelectronics. The electronics convert a high-impedance charge signal generated by a piezoelectric sensing element into a usable low-impedance voltage signal that can be readily transmitted, over ordinary two-wire or coaxial cables to any data acquisition system or readout device.

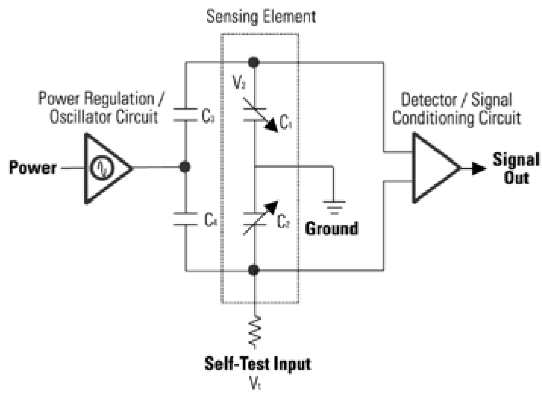


ICP® System Schematic

Capacitive Accelerometers

MEMS stands for micro electro mechanical system and applies to any sensor manufactured using microelectronic fabrication techniques. These techniques create mechanical sensing structures of microscopic size, typically on silicon. When coupled with microelectronic circuits, MEMS sensors can be used to measure physical parameters such as acceleration. Unlike ICP® sensors, MEMS sensors measure frequencies down to 0 Hz (static or DC acceleration). PCB® manufactures two types of MEMS accelerometers: variable capacitive and piezoresistive. Variable capacitive (VC) MEMS accelerometers are lower range, high sensitivity devices used for structural monitoring and constant acceleration measurements. Piezoresistive (PR) MEMS accelerometers are higher range, low sensitivity devices used in shock and blast applications.





DC MEMS System Schematic

Study 1:

Influence of Electric Vehicle High Voltage Electromagnetic Fields on NVH Sensors

(Test Paper WPL 84)

The development of NVH sensors for automotive applications, in the past, has been without regard for HV EM Fields that are now present with EVs and HEVs. Consequently, there are concerns about what influence or effects HV EM Fields impose on microphone and accelerometer signals when implemented for operational testing of EVs or

HEVs. To address and understand the influences of EV HV EM Fields on microphone and accelerometer signals a study was performed to asses these effects on an EV. Ten different models of PCB NVH sensors, including several cable types for some of the sensors, were evaluated local to various HV EM Field sources on an EV. The microphone and accelerometer signals were recorded along with signals from adjacent transducers that measure the EM Field strength. Assessment of the influence of the HV EM Fields is based on the coherence function between the NVH sensor signal and the corresponding EM Field transducer signal – where higher coherence values indicate a higher influence of HV EM Fields on the NVH sensor signals.present during testing.

Ten types of PCB Piezotronics NVH Sensors were evaluated at nine different HV EM Field sources on an EV. Six of the NVH sensors, all of which were an ICP type, were evaluated with two different cables.

PCB Piezotronics SENSOR DESCRIPTION					PCB Piezotronics CABLE DESCRIPTION			
					CABLE A		CABLE B	
TYPE	MODE	FEATURES	AXES	M/N	M/N	VARIANTS	M/N	VARIANTS
Microphone	ICP	pre polarized	uniaxial	378B02	003D20	Low Noise Coax	024AC015AC	Twisted Pair
Accelerometer	charge	charge converter	triaxial	356A70	003G10	Low Noise Coax	n/a	n/a
Accelerometer	ICP	standard	triaxial	356A02	010AY015NF	Grounded Shield	010S10	Non-grounded Shield
Accelerometer	ICP	filtered	triaxial	HT356A63	010AY015NF	Grounded Shield	010S10	Non-grounded Shield
Accelerometer	ICP	TEDS	triaxial	TLD356A16	010AY015NF	Grounded Shield	078G10	Non-grounded Shield
Accelerometer	ICP	case isolated	triaxial	354A04	010AY015NF	Grounded Shield	036G20	Non-grounded Shield
Accelerometer	ICP	ground isolated	triaxial	J356A43	010AY015NF	Grounded Shield	036G20	Non-grounded Shield
Accelerometer	DC	single ended	triaxial	3713B11200G	037M29	Multi Conductor	n/a	n/a
Accelerometer	DC	differential	uniaxial	3741F12100G	integral	Multi Conductor	n/a	n/a
Accelerometer	CVLD	case isolated	uniaxial	355M87A	integral	Coax	n/a	n/a

Table 1 – Sensor and Cables subject to EV HV EM Field evaluation

Measuring Points on the eMobile

Each PCB sensor/cable is evaluated at 9 different HV EM Field locations on the EV (the EV was a BMW i3)

EV HV EM FIELD LOCATIONS FOR SENSOR EVALUATION	
LABEL	DESCRIPTION
EME TOP	Power electronics module with HV inverter, HV converter, DC-DC converter, top surface
ELEC HEAT CABLE	Cable for high voltage heat system
KLE SIDE	Charging electronics module, side surface
KLE TOP	Charging electronics module, top surface
EME KLE CABLE	Cable connecting power electronics module to charging electronics module
LOCAL HV BAT CABLE	Local to high voltage battery cable, offset to one side of the parallel cables
HV BAT CABLE	Immediately adjacent to high voltage battery cable, above but centered between the parallel cables
EKK BOTTOM	Air conditioner compressor motor, bottom surface
EM BOTTOM	Vehicle electric motor, bottom surface

Table 2 – EV HV EM Field locations implemented for NVH sensors/cables

Test Conditions

Operating measurements were obtained for EV conditions that yield a high or maximized EM Field to assess a maximum influence on the NVH sensors / cables.

VEHICLE OPERATING CONDITIONS FOR HV EM FIELD INFLUENCE ASSESSMENT		
OPERATING CONDITION DESCRIPTION / PARAMETERS	OBJECTIVE	ACTIVE SYSTEMS
vehicle power off	Baseline EM Field Levels (reference zero)	none
accelerate up-hill	Max Load - DC and AC systems	HV BAT, EME, EM, EKK
air. cond. max		
windows down		
constant speed	Max Load - AC heat system	EME, ELEC HEAT CABLE
max heat		
windows down		

Table 3 – Vehicle operating conditions

Data Analysis – Coherence Function

Assessment of the influence of HV EM Fields on the NVH sensors/cables is accomplished using the coherence function between the NVH sensor signal (system output) and the locally measured EM Field transducer signal (system input) – where the NVH sensor / cable and the corresponding EM Field transducer define a single system.

The coherence function has values that range from 0 (zero) to 1 where a value of 0 indicates no causality between the system output signal and the system input signal, and where a value of 1 indicates causality between the system output signal and the system input signal. As related to the NVH sensor/cable coherence data, frequencies with low coherence indicate less susceptibility of the sensor/cable to the

local EV EM Field and frequencies with high coherence indicate more susceptibility of the sensor/cable to the local EV EM Field.

In an ideal situation the coherence function between the sensor signal and the EM Field will be 0 (zero) – no causality. This means the sensor signal only contains information about the desired measured phenomena (acceleration / acoustic pressure) and is not influenced by the EM Field (electrical noise).

Comparison of coherence functions of NVH-Sensors

The coherence spectrum is useful for assessing the performance characteristics of the NVH sensors/ cables at the various EM Field locations or for comparing performance between sensors/cables at the same EM Field location.

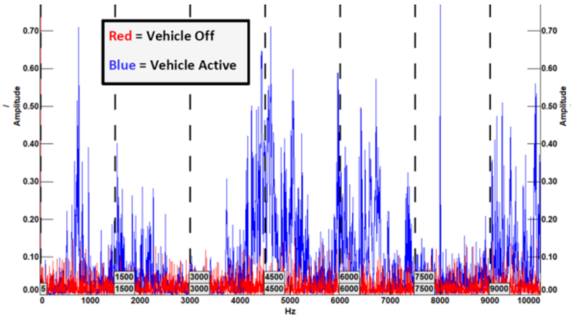


Figure 4 – Coherence functions comparing NVH sensor performance characteristics between an active EV HV EM Field (blue) and the same EV HV EM Field switched off (red) and Frequency bands for average coherence.

Results – Normalized Average Coherence

The relative ranking of NVH sensor/cable performance at different EM Field locations is not easily assessed with average coherence data given the sensors are not identical (differences include; circuitry, sensitivity, shielding, housing, power source, etc.) and the EM Field sources are not identical (differences include; circuitry, power levels, power functions, switching and duty cycles, etc.). Therefore, the average coherence data for the 5 Hz to 9 kHz frequency bands are normalized to determine a relative ranking performance for the sensors/ cables.

The normalized average coherence is determined from ratios between each sensor's average coherence at each EM Field location (for the 5 Hz to 9 kHz band) and the EM Field location with the maximum average coherence for that sensor (one of the nine EM Field locations). Thus, the normalized average coherence values will theoretically range between 0 (zero) and 1. A further consequence of the normalized average coherence process is each sensor / cable will have one EM Field location with a maximum value of 1 (corresponding to the EM Field location that is most influential on a particular sensor/cable).

Consolidating the normalized average coherence values into tables provides an overview for assessing sensor / cable performance at different EM Field locations and for sensor to sensor comparisons. The normalized average coherence data are organized into two tables; Table 5 for the sensors with Cable A and Table 6 for the sensors with Cable B.

A color scale is superimposed on the normalized average coherence values to distinguish between low, moderate, and high values. The color scale fades from green to yellow to orange to red which corresponds to low, low-moderate, moderate-high, and high coherence values, respectively. The color scale applies across the table rows (per sensor performance at each EM Field location), as well as down the table columns (sensor to sensor comparison at each EM Field location), and between the Cable A data and the Cable B data.

PCB SENSOR DESCRIPTION				EM FIELD LOCATION									
TYPE and M/N	MODE and AXES	FEATURES	REF. AXIS	EME TOP	ELEC HEAT CABLE	KLE SIDE	KLE TOP	EME KLE CABLE	LOCAL HV BAT CABLE	HV BAT CABLE	EKK BOTTOM	EM BOTTOM	AVERAGE PER SENSOR
MIC 378B02	ICP UNIAX	pre-polarized	X Y Z	0.806	0.325	0.854	0.581	0.611	0.683	0.940	0.368	0.853	0.669
ACCEL 356A70	CHARGE TRIAX	charge converter	X Y Z	0.398	0.167	0.314	0.719	0.393	0.676	0.483	0.336	1.000	0.498
ACCEL 356A02	ICP TRIAX	standard	X Y Z	0.276	0.232	0.592	0.530	0.366	0.517	0.379	0.348	0.996	0.471
ACCEL HT356A63	ICP TRIAX	filtered	X Y Z	0.539	0.253	0.708	0.473	0.457	0.645	0.572	0.408	0.911	0.552
ACCEL TLD356A16	ICP TRIAX	TEDS	X Y Z	0.339	0.284	0.799	0.496	0.375	0.675	0.630	0.409	0.787	0.533
ACCEL 354A04	ICP TRIAX	case isolated	X Y Z	0.250	0.215	0.295	0.425	0.293	0.535	0.577	0.315	1.000	0.434
ACCEL J356A43	ICP TRIAX	ground isolated	X Y Z	0.373	0.270	0.416	0.425	0.485	0.573	0.320	0.376	1.000	0.471
ACCEL 3713B11200G	DC TRIAX	single ended	X Y Z	0.266	0.248	0.279	0.254	0.273	0.362	0.308	0.320	1.000	0.368
ACCEL 3741F12100G	DC UNIAX	differential	X Y Z	0.202	0.120	0.202	0.188	0.167	0.275	0.218	0.145	1.000	0.280
ACCEL 355M87A	CVLD UNIAX	case isolated	X Y Z	0.318	0.472	0.518	0.403	0.436	0.445	0.284	0.296	1.000	0.464
AVERAGE PER EM FIELD LOCATION				0.377	0.258	0.498	0.450	0.385	0.539	0.471	0.332	0.955	

COLOR SCALE for NORMALIZED AVERAGE COHERENCE DATA

NO DATA	low	low - mid	mid	mid - high	high

Table 5 – Averages of normalized average coherence data (5 Hz to 9 kHz) for sensors with Cable A.

PCB SENSOR DESCRIPTION				EM FIELD LOCATION									
TYPE and M/N	MODE and AXES	FEATURES	REF. AXIS	EME TOP	ELEC HEAT CABLE	KLE SIDE	KLE TOP	EME KLE CABLE	LOCAL HV BAT CABLE	HV BAT CABLE	EKK BOTTOM	EM BOTTOM	AVERAGE PER SENSOR
MIC 378B02	ICP UNIAX	pre-polarized	X Y Z	0.854	0.344	0.886	0.575	0.494	0.760	0.959	0.399	0.755	0.670
ACCEL 356A70	CHARGE TRIAX	charge converter	X Y Z	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ACCEL 356A02	ICP TRIAX	standard	X Y Z	0.316	0.328	0.610	0.393	0.395	0.567	0.505	0.372	0.933	0.491
ACCEL HT356A63	ICP TRIAX	filtered	X Y Z	0.448	0.295	0.689	0.596	0.455	0.525	0.402	0.479	1.000	0.543
ACCEL TLD356A16	ICP TRIAX	TEDS	X Y Z	0.397	0.319	0.600	0.596	0.487	0.749	0.533	0.465	0.969	0.568
ACCEL 354A04	ICP TRIAX	case isolated	X Y Z	0.393	0.365	0.540	0.654	0.503	0.765	0.434	0.488	0.918	0.562
ACCEL J356A43	ICP TRIAX	ground isolated	X Y Z	0.379	0.355	0.503	0.548	0.495	0.769	0.483	0.488	0.985	0.556
ACCEL 3713B11200G	DC TRIAX	single ended	X Y Z	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ACCEL 3741F12100G	DC UNIAX	differential	X Y Z	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
ACCEL 355M87A	CVLD UNIAX	case isolated	X Y Z	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AVERAGE PER EM FIELD LOCATION				0.464	0.334	0.638	0.560	0.471	0.689	0.553	0.448	0.927	

COLOR SCALE for NORMALIZED AVERAGE COHERENCE DATA

NO DATA	low	low - mid	mid	mid - high	high

Table 6 - Averages of normalized average coherence data (5 Hz to 9 kHz) for sensors with Cable B.

Summary of the WPL 84 test (Study 1)

Influence of electromagnetic radiation from electric and magnetic fields on the measurement chains of acceleration sensors using different connection cables (A & B) in electric vehicles.

ICP® sensors

- Largest influence at the measuring point on the electric motor.
- Benefits of NF-cable (Grounded Shield) version.
- The model Triax 354A04 with the best result. (case isolated sensor model!)

DC MEMS sensors

- The sensors with the least influence on the electric and magnetic fields.
- Differential output with the best result.

Study 2:

EMI issue on vibrational ICP-Sensors (Lab Test)

Test bench:

- Test of electro magnetic interference onto ICP® - vibrational sensors.
- Evaluation of different sensor designs, cable configurations and DAQ front end grounding set ups.
- Test bench consist of an electric motor, driving a shaft for RMA test (running mode analysis).
- Motor speed about 20 Hz.
- Magnetic interference EMI measured with magnetic field probe (h-probe).

Sensors

J356A45	ground isolation ICP
356A15	Standard ICP
M354A05	case isolation ICP
639A91	case isolation IMI ICP

Cable

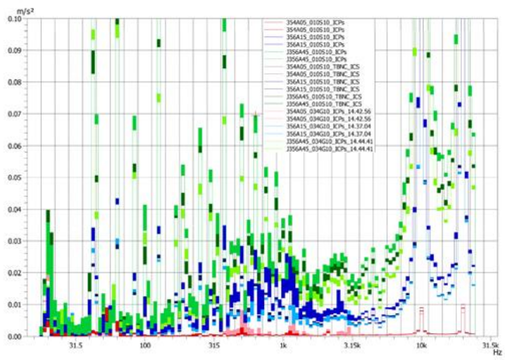
Shield and Ground **NOT** connected:

034G10	BNC plug **JW option**
010S10	BNC plug **JW option**

Shield and Ground connected:

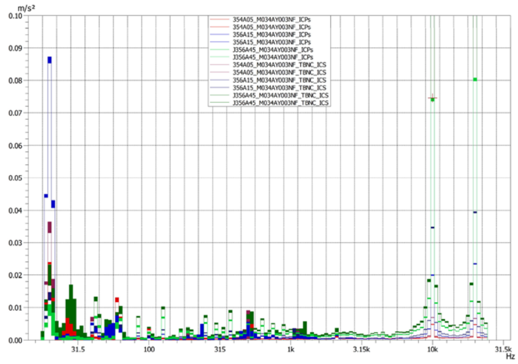
034AY003NF	BNC plug **NF option** (non-standard)
034RB-LEMO-9M	

<u>Result with JW cable (ground/shield splice not connected)</u>



- All <u>not case isolated sensors</u> show a significant noise signal and/or EMI interference at certain singular frequencies (harmonic(s) of rotating frequency
- The case isolated models shows quite low noise level, no predominance of any EMI issue!

<u>Result with NF cable (ground/shield splice connected)</u>



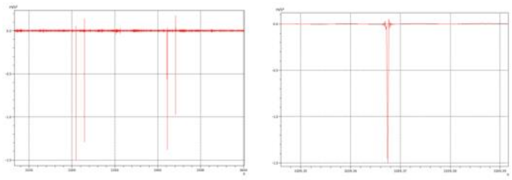
- Case isolated model and not case isolated sensors show quite similar low noise level, no predominance of any EMI issue.

Example Nr. 1:

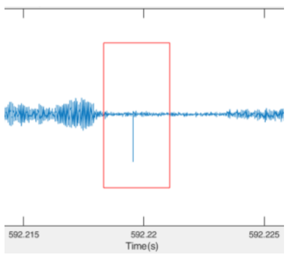
Modal Test at machine tool

Spikes on Triaxial ICP® -Accelerometer

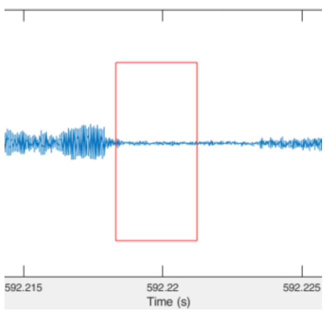
Bad noise effects:



Standard Cable "JW"
Shield & Ground NOT connected



No-Standard Cable "NF"
Shield & Ground connected



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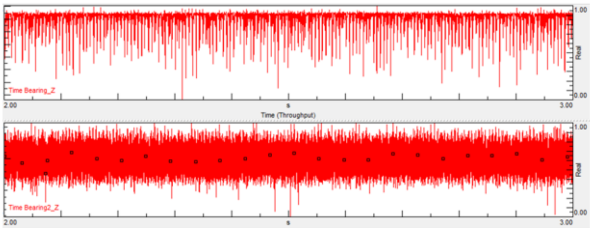
Example Nr. 2

Aerospace Customer

Spikes on Triaxial ICP® **-Accelerometer**

Electric Motor / Electromagnetic interference (EMI)

Problem:



Standard Cable „JW“
Shield & Ground NOT connected
034G20

Solution:

No-Standard Cable „NF“
Shield & Ground connected
034G20

No-Standard Cable „LEMO“
Shield & Ground connected
FRE-078-AY-LEMO-3M (9-pin)

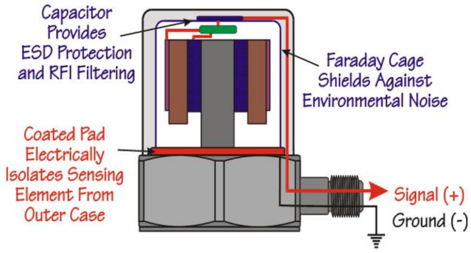
Ground isolated

Sensor Improvements

Case isolated triaxial ICP® **accelerometer**

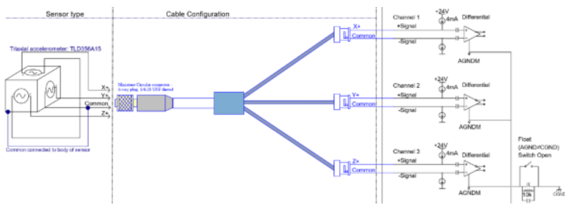
Model 354B04 / 354B05 / TEDS

- Case Isolation
- No need for special isolation bases, coatings and insulated mounting screws



Schematic case isolation

DAQ Improvements



DAQ with differential input best solution.

Placebo Transducer a Tool for Data Validation

For any testing in which the environmental operating conditions of a transducer vary with time and/or location, several requirements must be fulfilled before measurement uncertainty analysis is justified. Included among the requirements are good measurement system design practices, such as adequate low- and high-frequency response and data-sampling rates, appropriate anti-aliasing filter selection, proper grounding and shielding and much more.

In addition to these requirements, data validation must be performed to establish that each transducer responds only to the environmental stimulus for which it is intended. For piezoelectric and piezoresistive transducers, “placebo” (IEST-RP-DTE011.1) transducers enable data validation to be accomplished. The referenced IEST standard defines a placebo transducer as ‘identical to a “live” unit in every parameter except for mechanical sensitivities.’ The placebo transducer should respond only to extraneous “environmental factors.” Ideally, its output would be zero. Any signal output from it would indicate that signals from the “live” transducers could be corrupted.

Placebo Sensors

Summary

- eMobility and eVTOLS have increased the requirements for NVH acceleration sensors due to magnetic influences.
- PCB has conducted studies with users on an e-mobile and a test bench to verify NVH triax sensors and various cable designs.
- For the sensors, isolated mounting or versions with isolated signal output are recommended.
- With triax NVH sensors, attention must be paid to the grounding in the cable and to the grounding concept of the measurement chain.
- The input circuit of the ICP® -signal conditioning can influence the quality of the measurement (single-ended/differential).
- In special cases, placebo sensors are a possibility for validation.
- DC MEMS capacitive accelerometers with true differential output are the most stable.

References

[1] Electric & Hybrid Vehicle Testing & Development (PCB Piezotronics).

[2] TN-16 Placebo Transducers: A Tool for Data Validation (PCB Piezotronics).

[3] Influence of Electric Vehicle High Voltage Electromagnetic Fields on NVH Sensors (PCB Piezotronics).

[4] TP323 Understanding the Endevco variable capacitance accelerometer electrical characteristics (Endevco),