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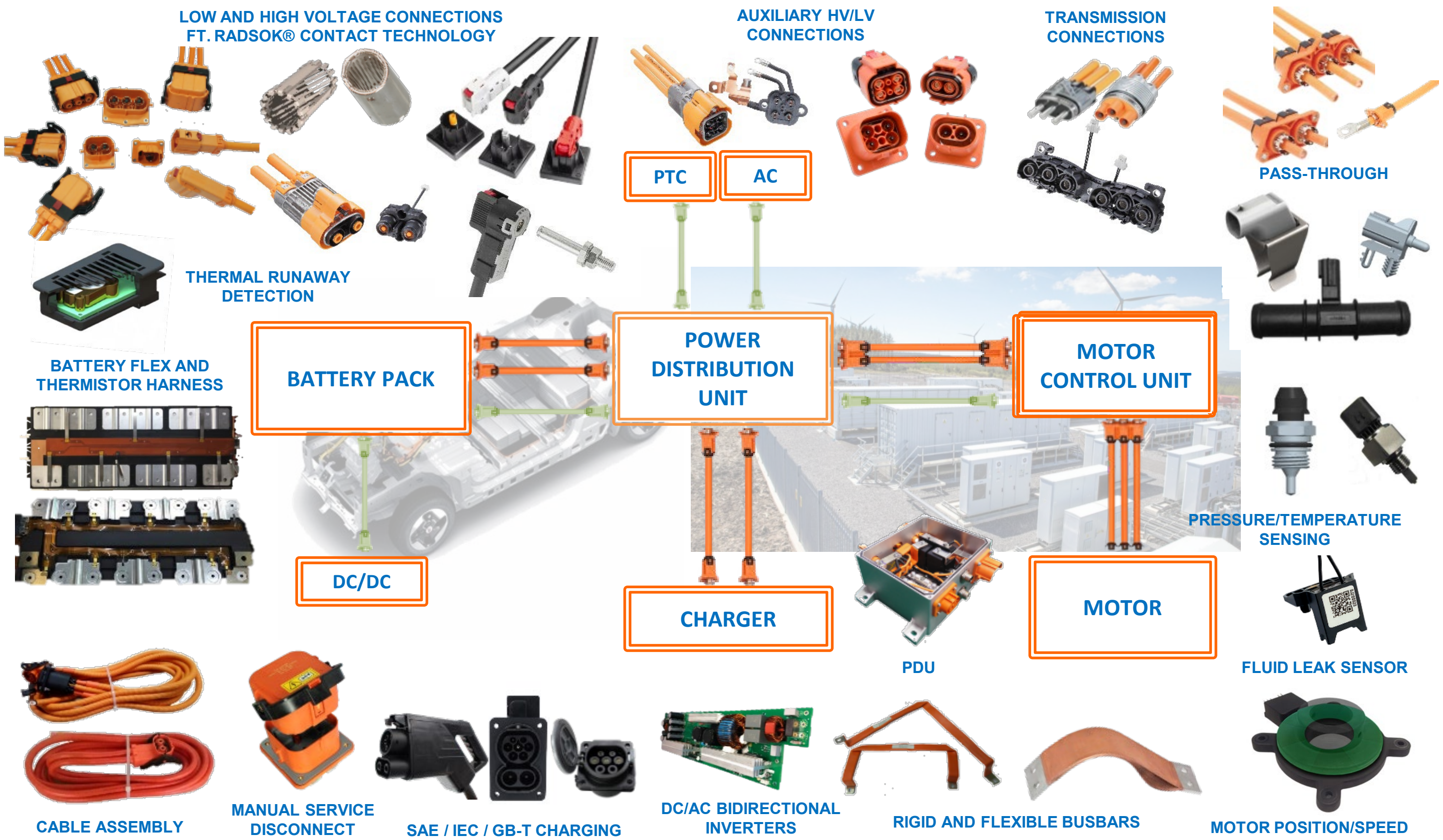
Supporting Mobile and Stationary Sensing & Electrification Solutions



Sensing:

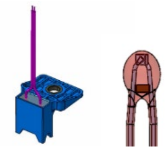
- *Temperature*
- *Pressure*
- *Fluid Level*
- *Concentration*
- *Speed*
- *Current*
- *Rotary/Linear Position*
- *Accoustic /ultrasonics*
- *Vibration / Acceleration*
- *Force*
- *Air Quality*
- *Gas concentration*
- *Particulates / Dust*
- *Moisture / Humidity*
- *Process Controls*
- *Validation Instruments*

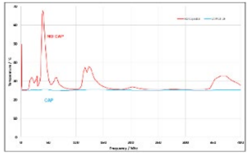
xEV / Battery Portfolio Developments

Working Together to Improve Battery Safety, Diagnostics, & Robustness

Robust Early Detection of Thermal Runaway (REDTR)

- **Mobile and Stationary applications**





- **Cell & Pack Diagnostics**
  - **Coolant breach/water intrusion sensor**
  - **EMC immune Temperature sensors**

1	Sensor type	Assemby method	Main parameters	Sensor view
2	Water temp sensor	Thread M12	R25C=10K/100K/2.08K -40°C to 125°C	
3	Water temp sensor	Quick lock	R25C=10K/100K -40°C to 125°C	
4	Water temp sensor	Pipe surface 12/15 to18	R25C=10K/100K -40°C to 125°C	
5	Coolant medium temp s	Thread M12	R25C=10K/2.828K -40°C to 130/150°C	
6	PT sensor	Tread M14&M12	50-300KPa GE-2098 -1...10bar to - 1...100bar -40°C to 125°C/130°C	

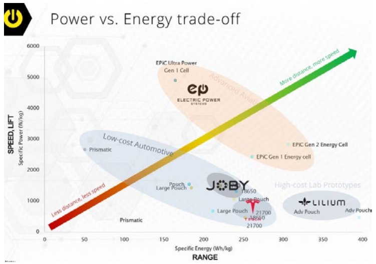
- **Battery / xEV Heat Pump / HX Sensors**
  - **Full suite of thermal management sensors**
  - **Pressure and Temperature**

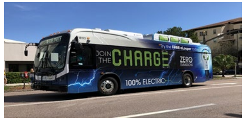
- **Cell Connection Systems**
  - **World's largest supplier of Cell Connection Systems**

Typical Battery Thermal Management design considerations

Thermal management system design - depends on what you are using batteries for:

- What is ambient temperature range?
- System capacity? (Energy or Power application)
- What is the voltage and current?
- What are the charge/discharge profiles?
- What is the expected life? (calendar, charge cycles)
- What are expected State of Health Limits?
- What are other heat sources that need to be managed?
- What is required energy density? (EV = very compact, stationary storage = less space constraints)
- What are weight/volume/cost constraints?
- How can I move heat into/out of the cells?





Influence of temperature on battery health

Li-ion cells perform best ~ 10C and 60C

Charging/discharging generate heat

Charging:

- Dendrites can grow under low temperature charging; PTC Heaters mitigate cold charging issues
- Fast charging improved at higher temperatures, but sacrifices cell life

Most cell internal heat is conducted away from cell core through busbars

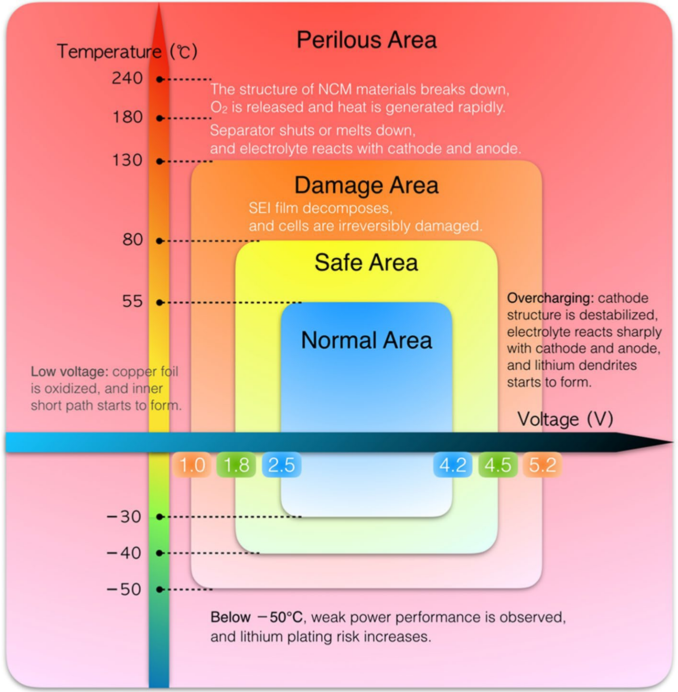
Uniform cell& pack temperatures important; non uniformity / imbalance results in shorter life

Both cell heating and cooling are required for maximum pack life

Highly thermally conductive materials help remove heat from cells

Pumped fluid /external heat exchangers can improve heat rejection

Battery pack/motor/inverter/HVAC are part of a total system

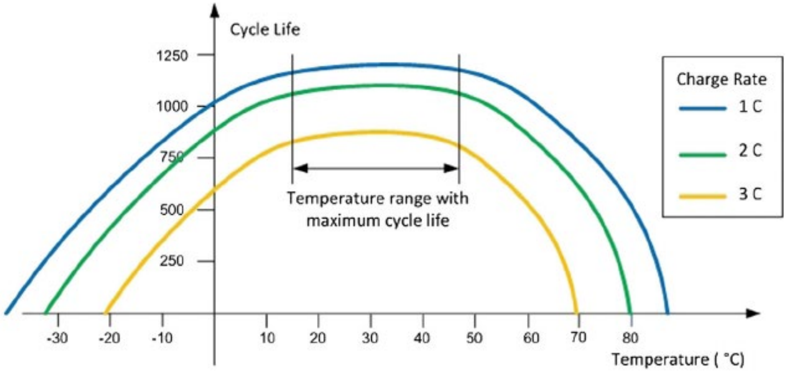


Influence of charge rate and temperature on cycle life

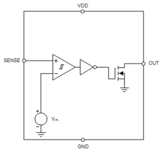
C- Rate:

The C-rate is the unit battery experts use to measure the speed at which a battery is fully charged or discharged. For example, charging at a C-rate of 1C means that the battery is charged from 0-100% in one hour. A C-rate higher than 1C means a faster charge; for example, a 3C rate is three times faster, so a full charge in 20 minutes. Likewise, a lower C-rate means a slower charge: C/5 (or 0.2C) would be five times slower than 1C, amounting to a five-hour charge.

- EV's drive high C-rates (fast charging)
- Higher C-rates shorten cycle life and generate high internal cell temperatures and intercalation swelling
- E-HVOR & e-Aero applications in the MW range charging – has substantial effect on cooing requirements (HX sized for charging event)
- Stationary storage applications can operate at lower c-rates and broader SOC/SOH range



Typical Measurements & Sensors for Battery Control - Voltage



The Battery Voltage Sensor (BVS) provides a more accurate battery charging voltage to the charge controller, which allows for more precise charging stage regulation and increases overall battery performance and life. Battery Voltage can be monitored by the microprocessor of the Battery Management System.

Voltage Monitoring- Over-voltage

One of the most straightforward aspects of a BMS system is monitoring the lithium-ion cell voltage, which must be kept within an upper limit (typically around 4.2 volts) and a lower limit (typically 2.0 volts) to prevent permanent damage to the cell.
During charging, if the voltage increases beyond the recommended upper cell voltage, typically 4.2 Volts, an excessive amount of current can flow through the battery cell. The excess current promotes the deposition of metallic lithium onto the surface of the graphite anode. This reduces the number of free lithium ions available for reaction and so can cause an irreversible reduction of cell capacity. The plating of the lithium can also form spikey, needle-like crystals, called dendrites, that can grow large enough to reach the cathode and short out the cell, potentially causing a fire. Excessive current also causes increased heating of the cell, accompanied by an increase in the temperature of the pack

Voltage Monitoring- Under-voltage

Allowing the cell voltage to fall below about 2 volts, either by over-discharging the pack or by storage for extended periods can result in a progressive breakdown of the anode and cathode electrode materials. If the cells are stored or kept for long periods at voltages below 2 volts, there is a gradual breakdown of the cathode over many cycles. This breakdown can result in the release of oxygen from oxide cathodes, permanently reducing the battery capacity. with the release of Oxygen by the Lithium Cobalt Oxide and Lithium Manganese Oxide cathodes and a consequent permanent capacity loss. With Lithium Iron Phosphate cells this can happen over a few cycles. Low voltages can also cause the thin copper plate, which acts as a current collector for the graphite anode, to partially dissolve into the electrolyte. When the cell voltage again goes above 2 volts, the dissolved copper ions that are now dispersed throughout the electrolyte are precipitated as metallic copper, but not always on the current collector and potentially causing the cell to short out.

Typical Measurements & Sensors for Battery Control - Current

The Battery Current Sensor (BCS) A current sensor is a device that detects electric current in a wire and generates a signal proportional to that current. The generated signal could be analog voltage or current or a digital output. The generated signal can be then used to display the measured current in an ammeter, or can be stored for further analysis in a data acquisition system, or can be used for the purpose of control. In Battery control, current can be measured at cell, module, and pack level.

Various technologies for current sensing can be used. Generally, Fluxgate and Hall Effect based on the Lorentz Force is the most common configuration of current sensor used in BMS applications. Accuracy is a critical metric in current sensor performance

Current monitoring and control are critical for preventing overcharge / overdischarge conditions and is critical to calculating State of Charge (SOC) and cell balancing.

Typical Measurements & Sensors for Battery Control – Cell Charge Balancing

Charge Balancing-General

Battery packs that are required to provide serious amounts of power and energy (like those in EVs or used for power grid support) need to have lots of individual cells. Unfortunately, the more cells that are used, the greater is the opportunity to fail and degrade the pack's reliability.

The potential for failure is even worse due to the possibility of interactions between the cells. Each cell is different and slight variations in manufacturing, ***temperature,*** and aging of the cells can cause slight differences in their fully charged voltage and their ability to discharge the same amounts of electrical energy. During charging a degraded cell with a diminished capacity presents a danger that once it has reached its full charge it will become overcharged while the rest of the cells in the pack reach their full charge. This can cause temperature and pressure build-up within the cell and possible damage. During discharging, the weak cells will have the greatest depth of discharge and will tend to fail before the others.

Charge Balancing-Charging

To prevent premature failure of a pack, various methods of cell balancing exist and are used to equalize the charging and discharging stresses on the cells. One strategy is to balance the individual cells only during charging. A BMS for example only balances the cells during charge mode. It works by looking for the lowest voltage cell and then placing a load on all cells that are more than a maximum difference above that lowest cell. The algorithm continues until all cells are balanced to within the pre-defined maximum difference in voltage and continue even after the BMS has switched off the charger. As a safety feature, there is a minimum balancing voltage threshold at which the BMS is not allowed to remove energy from a cell. While the rest of the cells will continue to balance, the BMS will not place a load on any cell which is below this threshold, even if a cell below this threshold is needing to be balanced. This protects the cells from over-discharge.

Charge Balancing- Discharging

Over time some cells may become weaker than others and during discharging the weak batteries limit the runtime of the system. It is noted by Analog Devices, for example, that a battery mismatch of 5% results in 5% of the total capacity of the pack that will be unused—this can be an excessive amount of energy left unused. Active balancing can be used during discharging to redistribute charge from the stronger cells to the weaker cells, resulting in a fully depleted battery profile at the point at which the battery needs to be recharged.

Typical Measurements & Sensors for Battery Control – SOC & SOH

State of Charge (SOC)

Battery SOC is analogous to a gas gauge and is generally used as a way to quantify the amount of energy left in a battery compared with the energy it had when it was fully charged. It gives a user an indication of how much longer a battery will go before it needs recharging. The easiest way to estimate the SOC is by determining the ratio between the amount of energy stored in the battery and the battery's actual capacity. Typical BMS systems can estimate battery SOC to accuracies of approximately 1 percent.

Battery State of Health (SoH)

A BMS can employ algorithms that use key parameters to estimate the health of the entire battery pack. This would include measured changes in internal & external factors and in all parameters to identify a potential reduction in anticipated battery life. Battery state of health represents the level of degradation of the battery as a result of its environmental and usage history. SoH is calculated from an algorithm. An example is a BMS product called Vigilant produced by Eagle Eye Power solutions. Rather than simply read and display measured parameters, Vigilant uses Artificial Intelligence (AI) to calculate the SoH of the battery. Measurement data and analysis are done via a built-in web server, which can be accessed with any browser and the web-based software eliminates the need for a standalone software package and the results can be viewed on any mobile device.

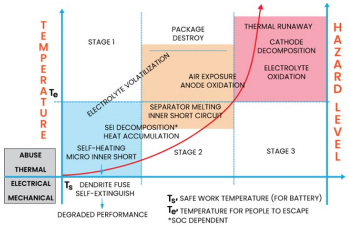
Typical Measurements & Sensors for Battery Control – Thermal Runaway Prevention

Thermal runaway

The thermal runaway of a lithium-ion battery cell progresses through several steps, each of which can progressively cause increasing damage to the cell. An initial step is often the breakdown of part of the thin Solid Electrolyte Interphase (SEI) layer on the surface of the anode. This can occur if the cell overheats, or if the layer is penetrated by a physical object. This breakdown of the SEI layer can occur at 80° C and the result is an uncontrolled exothermic reaction between the electrolyte and the graphite anode, which further increases the cell temperature.

Eventually, between 70°C and 110° C, the organic solvents in the electrolyte begin to break down, releasing flammable hydrocarbon gases like Ethane and Methane. At this stage, no free oxygen is formed, but the formation of the gasses causes a buildup of pressure within the cell. The temperature may increase beyond the flash-point of the flammable gasses, but because of the lack of oxygen, they do not ignite yet. Most lithium-ion battery cells are equipped with a venting system to allow the gases to escape and prevent the buildup of pressure. If the vent fails, or can't vent quickly enough, the cell will explode.

At around 135° C the polymer separator between the anode and cathode melts, allowing the battery cell to short out and greatly increasing the temperature. Eventually, the heat from the uncontrolled reactions and the electrical short circuit raises the temperature high enough (above 200° C) to cause the metal oxide cathode to break down in an exothermic reaction that further increases the temperature and pressure and also releases oxygen. Now, with heat, organic flammable gases, and oxygen, the next step is a catastrophic failure of the battery cell, and potentially the entire pack.



Reference from Sinovoltaics

Passive Thermal Management designs – challenge of moving heat

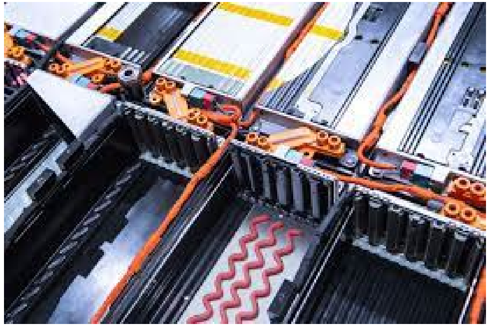
Heat Transfer from cells is a balance between maintaining uniform pack temperature under normal operation and preventing thermal propagation (TP) if a cell undergoes thermal runaway. Normal conditions encourage highly conductive materials, TP events require highly insulative properties.

Normal heat transfer from cells via:

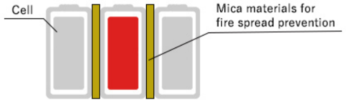
- Conductive and convective cooling of busbars
- Thermally conductive epoxies and resins
- Heat sinks

To prevent thermal propagation during cell thermal runaway, barrier materials used between cells:

- Mica
- Aerogels now used in place of compression foam



Lithium-ion batteries with mica materials for fire spread prevention



Mica materials for fire spread prevention prevent an ignited cell from affecting adjacent cells.

Li-ion pack Thermal Management Evolution – Improving Efficiency / COP with active cooling systems

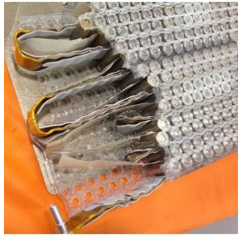
Thermal Management Technology Progression in EV's

- **Early H/EV Batteries**
  - Air cooled packs
  - PTC heaters for cold weather operations
- **First Generation EV's**
  - "Cold plate" cooling with glycol solution
    - Single Loop Cooling with PTC Heat for battery and cabin
    - Heat Pump Systems (Octovalve style) for increased COP
  - Refrigerant Cooling
- **Second Generation EV's:**
  - Immersion cooling with dielectric coolants
    - Esther based or mineral oils
    - Conductive heat transfer and evaporative cooling possible
    - Must maintain high dielectric strength – no contaminants allowed
    - Can still undergo thermal runaway

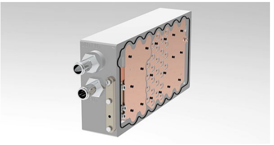
Ford Cmax

Nissan Leaf

Tesla Model 3



Faraday Future



To measure temperature, sensors are critical

Direct Measurement:

- Thermocouple
- Resistance Temperature Device (RTD)
- ***Negative Temperature Coefficient (NTC) Thermistor***

Non-contact:

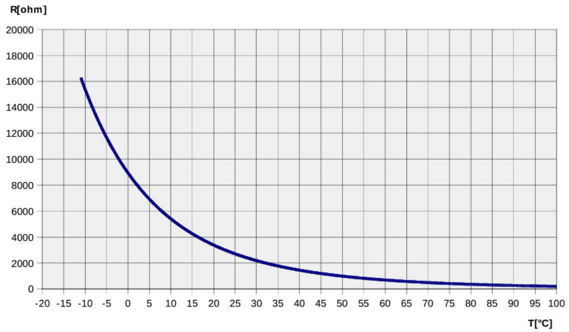
- Infrared sensing (thermopiles and bolometry)

Most industrial and transportation controls utilize thermistor temperature sensing technology. A Negative Temperature Coefficient Thermistor (or NTC Thermistor) is the most common type of thermistor. They are one of many numerous types of highly sensitive temperature sensor and are often small in size. A negative temperature coefficient thermistor alters its resistance characteristics with temperature.

Mechanical package of thermistors can be Surface mount or “lead wire” designs of various sizes and accuracies.

Accuracy requirements for typical battery applications are +/- 1 to 2.5 deg C over measurable range

Sensors can be placed on flex circuits, epoxy potted overmolded, or placed in various probe geometries



Example characteristic of NTC thermistor with the following parameters: R25 = 2.7kΩ i B=3900

RvT Table			
Temp °C (°F)	RES. K OHMS		
	Min. (Ω)	Nom. (Ω)	Max (Ω)
-40 (-40°)	90.688	94.331	98.105
-20 (-4°)	26.565	27.377	28.209
0 (32°)	9.030	9.231	9.434
25 (77°)	2.791	2.828	2.865
60 (140°)	0.687	0.703	0.720
100 (212°)	0.186	0.192	0.198

Protection against EMC

With increasing complexity of electric systems and density of electronic components in modern vehicles conventional NTC sensors are vulnerable to stray electromagnetic interference causing self heating.

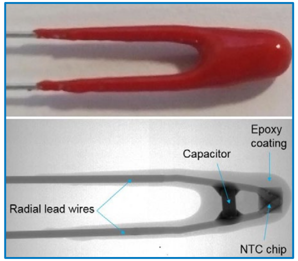
Amphenol Thermometrics UK Ltd have developed a noise-immune NTC thermistor with an integrated RF de-coupling function, providing EMI protection at the component level over a wide frequency range.

Features:

- NTC element-level EMI protection
- Drop-in upgrade for existing applications
- Reduced system cost
- Retro-fit - use existing housing designs
- Eliminate shielded cables and twisted pair protection
  - EMC tested to GMW3097 / IS011452
  - Range of conformal coatings available
- Fast time response

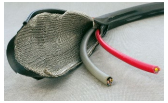
Applications:

- EV/HEV/PHEV markets
- Battery temperature sensing
- HP/HX applications
- eDrive systems
- HVAC



Conventional EMC protection

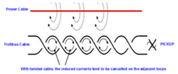
Screening



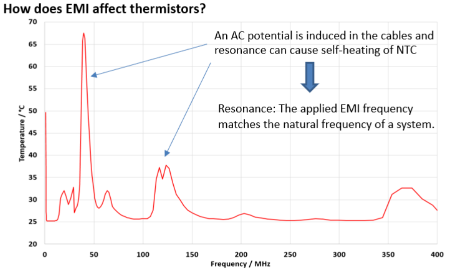
Damping

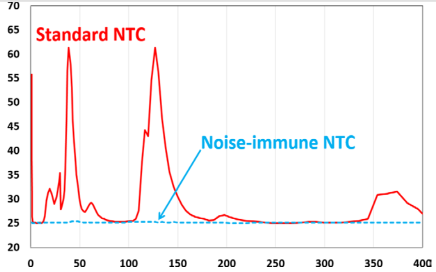
Avoiding

Twisted pair

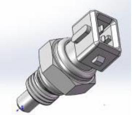
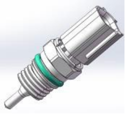
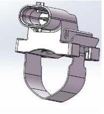
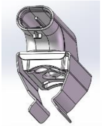
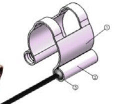
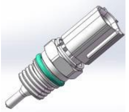


Improved Design



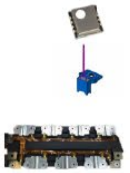


Examples of Heat Pump Pressure and temperature sensor applications

1	**Sensor type**	**Assemby method**	**Main parameters**	**Sensor view**
2	Coolant temp sensor	Thread M12	R25C=10K/100K/2.08K -40°C to 125°C	 
3	Coolant temp sensor	Quick lock	R25C=10K/100K -40°C to 125°C	 
4	Coolant/Refrigerant Pipe temp sensor	Pipe surface 12 to18mm dia	R25C=10K/100K -40°C to 125°C	   
5	Coolant/Refrigerant Probe temp sensor	Thread M12	R25C=10K/2.828K -40°C to 130/150°C	  
6	P/T Refrigerant/Coolant sensor	Tread M14&M12	50-300KPa GE-2098 -1…10bar to -1…100bar -40°C to 125°C/130°C	 

Amphenol sensors utilized throughout xEV, Fuel Cell, and ESS Applications

Battery:



- Busbar Temperature
- Cell Temperature
- Cold plate temperature
- Connector temperature
- Water intrusion/coolant breach
- Early Thermal Runaway Detection (REDTR)
- Cell connection systems

HP/HX:

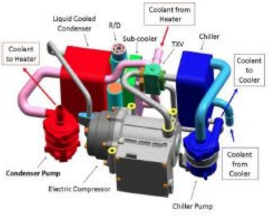
- Coolant Temperature
- Refrigerant Temperture
- Coolant Pressure
- Refrigerant Pressure/Temperature
- Evaporator Temperature
- Position sensors
- Coolant level Sensors

Motor / Inverter:

- Motor coil temperature
- Motor position/speed
- Inverter temperature

Fuel Cell:

- Hydrogen Pressure
- Hydrogen Temperature
- FC Stack Temperature
- Hydrogen leak
- Cathode hydrogen
- Intake Relative humidity / Temperature / Pressure



THERMAL RUNAWAY DETECTION

Temperature Sensors
Measure and monitor battery temperature to detect Thermal Runaway conditions.
- Capable of single or multiple cell detection

THERMOMETRICS

Pressure Sensors
Detect pressure change inside the battery cell that indicates Thermal Runaway conditions.
- Surface mountable
- Simple 3-command I²C interface
- Very low current consumption: <35μA

NOVA SENSOR

Gas Detection Sensors
Detect the out-gassing of Carbon Dioxide (CO_2) to indicate pre-combustion conditions.
- Single and dual channel configurations
- Self-calibration with patented ABC Logic™ Software

TELAIRE

Gas Detection Sensors
Detect the presence of combustible gases that indicate Thermal Runaway conditions.
- Sensitive to multiple gases: H_2 / CH_4 / CO_2
- Fast response time: <10 seconds
- IP6K7 rating

SGX SENSORTECH

BATTERY PACK

Temperature Sensors
Measure and monitor surface temperature of the many batteries within the battery cell, which is critical to preserving the chemistry of the battery.
- Single point temperature sensors
- Rigid and flexible types
- Custom sensor packaging

THERMOMETRICS

CELL CONNECTION SYSTEM (CCS)

Temperature Sensors
Provide temperature and voltage sensing to monitor the state of charge of the battery cells.
- High current circuit for battery cell connectivity
- Available styles:
  Wire Harness and Flexible Printed Circuit (FPC)

THERMOMETRICS

HIGH VOLTAGE CHARGER CONNECTOR

Temperature Sensors
Detect over-temperature conditions during charging.
- Installed within the connector

THERMOMETRICS

BATTERY COOLANT

Temperature Sensors
Measure and monitor fluid temperature of inlet/outlet battery coolant to provide indication of battery cell temperature.
- No leak path - Sensor cavity and tube are one piece
- USCAR sealed connection system
- Many part geometries: Inline tube, flying lead and integral sensor

THERMOMETRICS

Pressure Sensors
Measure the pressure in the cooling system to control pump capacity.
- Internal metal sealing for high media compatibility and no leakage
- Customized calibration for high accuracy

NOVA SENSOR
i2s

Combined Pressure & Temperature Sensors
Measure pressure in the cooling system, while, at the same time, measure temperature of the coolant for optimum thermal management.
- Available versions: R1234yf (up to 35bar) and R744 (up to 200bar)
- Tested LIN 2.1 conformity
- Automatic address assignment within LIN network (Slave Node Position Detection)

i2s

Ultrasonic Level & Temperature Sensors
Continuously monitor fluid level for early detection of coolant leakage.
- Level accuracy: ±2mm
- Temperature accuracy: ±2.5°C
- Output protocol offerings: Analog, PWM, SENT, CAN, LIN
- Input voltage options: 5V / 12V / 48V

SSI

MOTOR COIL

Temperature Sensors
Measure and monitor temperature of the motor coil to provide feedback on the operating conditions of the electric motor.
- Field-proven design
- Variety of lead lengths, terminal and connector options

THERMOMETRICS

POWER INVERTER / E-MOTOR

Temperature Sensors
Measure and monitor operating temperature of the power inverter to provide feedback on unsafe conditions.
- Fast response time
- Pigtail connector

THERMOMETRICS

Inductive Position Sensors
Provide data on the angular position of the rotating motor shaft to optimize control of the motor inverter.
- Inductive eddy-current with weight and size reduction
- Stable output over extended temperature range (-40°C/+160°C) and radial/axial misalignment
- Robust against magnetic flux and external stray fields

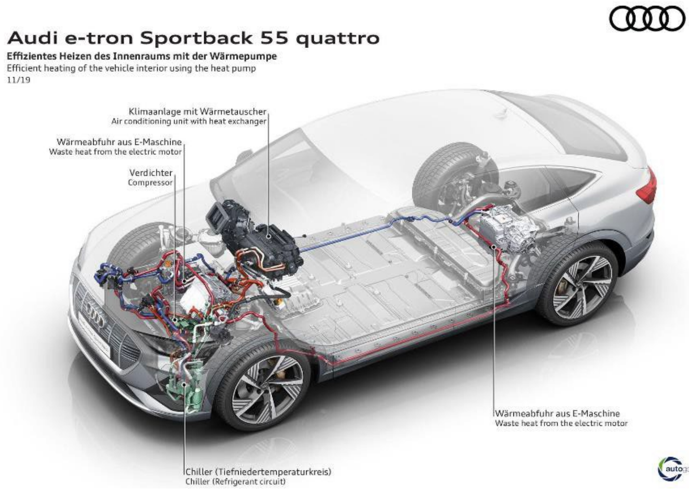
PI-ER sensing systems

3

xEV Efficiency: combining thermal management systems

xEV Thermal Management Systems:

- Systems need to sense and cool/heat battery, motor, inverter, electronics and heat/cool cabin
- Many xEV's utilize a combined HVAC system/powertrain thermal management system
- As shown in the example at right, heat pump systems are replacing single loop refrigerant system to improve efficiency
  - Heat extraction through phase change
  - Continuous temperature feedback of critical components
- Most xEV's use cold plate technology with standard coolant/water mix to cool the battery pack with external heat exchangers, including coolant to refrigerant HX modules
- Some XEV applications utilize refrigerant within the pack to cool the cells
- System control requires many feedback sensors:
  - Powertrain: Battery modules, motor, inverter(s), HX in/out, ambient air, refrigerant temp/pressure
  - HVAC: cabin temp, duct air, evaporator core, sunload, humidity, cabin CO2



Active HVAC heating/cooling represents parasitic drain on battery; therefore, recirculating cabin air reduces HVAC losses

Heating and Cooling xEV applications

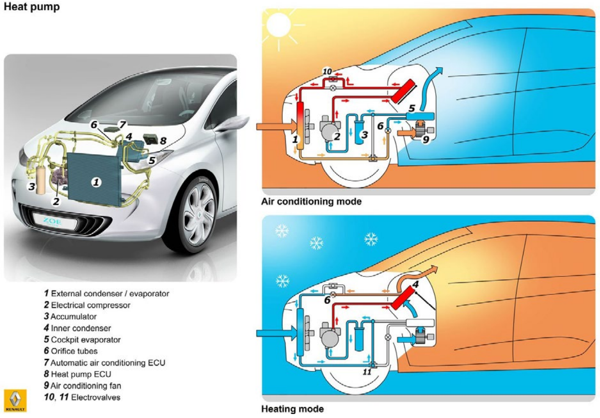
"Using waste energy is smart, wasting energy is not"

Moving the baseline from ICE: Heating

- First generation EV's used conventional heated coolant or electric PTC heaters to warm the cabin
- Gen 1 Nissan Leaf : a gallon of coolant warmed by PTC heater pumped into heater core
  - Consumed approximately 7 kW
  - Reduced driving range by 30 to 40 percent
- Gen II Leaf: Adopted Heat Pump Technology
  - Consumed approximately 2 kW to warm cabin under same conditions

Moving baseline: Cooling

- Similar performance improvements of approximately 5 kW saved



Heat pump system application Main OEMS

Brand	Vehicle type
VW	e-Golf
Audi	R8 Q7e-tron
Renault	Zoe
BMW	I3
Nissan	Leaf
Jaguar	I-Pace(SUV)
Kia	Soul
SAIC	Ei5 Marvel-X
ChangAn	CS75-PHEV

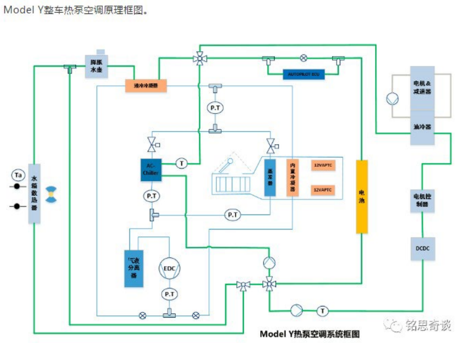
Model Y Octovalve HP System increased vehicle range by 10 percent!

Use cases drive a variety of heat pump configurations

Heat pump scheme of Model Y shown:

- 2 expansion valves
- 3 way and 4 way valves
- 3 refrigerant pressure/temperature sensors
- 2 temperature sensors

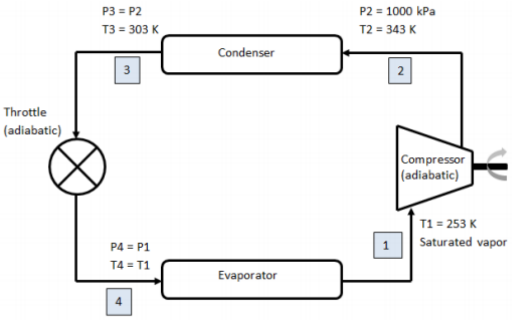
4PTs 1T

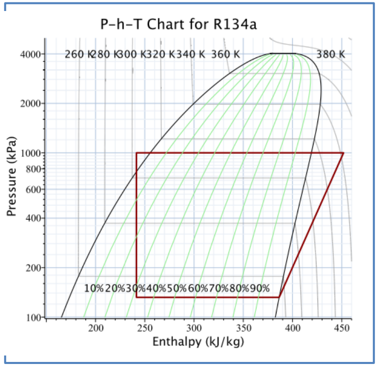


Variations can contain up to 5 PT sensors or 3 PT sensors and up to 5 temperature sensors throughout the refrigerant system, with additional temperature sensors in the cooling system

Sensors used for feedback control of compressor, expansion valves, and flow control valves.

- Temp and pressure of the refrigerant needed at various points of the PhT map
- Controlling for highest CoP /minimum parasitic loss

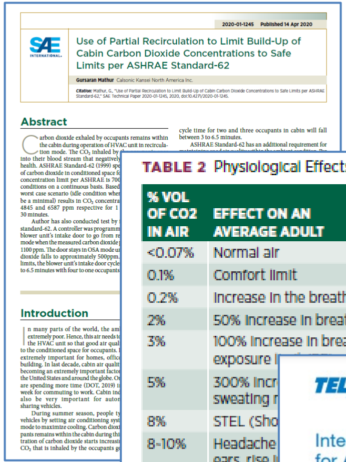




Recirculation of cabin air to reduce parasitic loss and its limits

Recirculation:

- Recirculation heating and cooling of the cabin air reduces power consumption
- Recirculation builds up water vapor and carbon dioxide in the passenger cabin
- Normal CO2 levels are 400 to 1,000 ppm
- ASHRAE Standard-62 targets 1100ppm maximum in cabin
    - 3000ppm is Permissible Exposure Limit
    - 8000ppm is Short Term Exposure Limit
- Testing has shown early generation EV's can generate CO2 levels in excess of ASHRAE control limits
- OEM's are now deploying CO2 sensor feedback for controlling recirculation/refresh events
    - Amphenol providing high accuracy, long life Non dispersive infrared co2 sensor for automotive applications


2020-01-1245 Published 14 Apr 2020

Use of Partial Recirculation to Limit Build-Up of Cabin Carbon Dioxide Concentrations to Safe Limits per ASHRAE Standard-62

Gursaran Mathur Calsonic Kansei North America Inc.

Abstract

Introduction

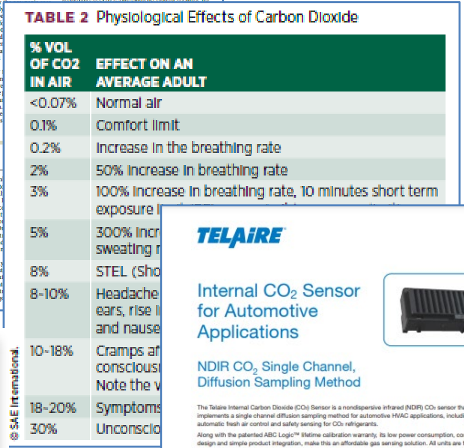
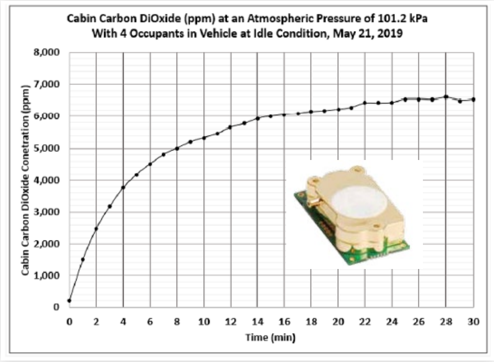


TABLE 2 Physiological Effects of Carbon Dioxide

% VOL OF CO2 IN AIR	EFFECT ON AN AVERAGE ADULT
<0.07%	Normal air
0.1%	Comfort limit
0.2%	Increase in the breathing rate
2%	50% increase in breathing rate
3%	100% increase in breathing rate, 10 minutes short term exposure [illegible]
5%	300% incr[illegible] sweating [illegible]
8%	STEL (Sho[illegible]
8-10%	Headache[illegible] ears, rise [illegible] and nause[illegible]
10-18%	Cramps af[illegible] conscious[illegible] Note the v[illegible]
18-20%	Symptoms[illegible]
30%	Unconscio[illegible]

© SAE International.



© SAE International.

Sensor Package locations:

Sensor locations are distributed throughout the system depending on hardware design and control strategy:

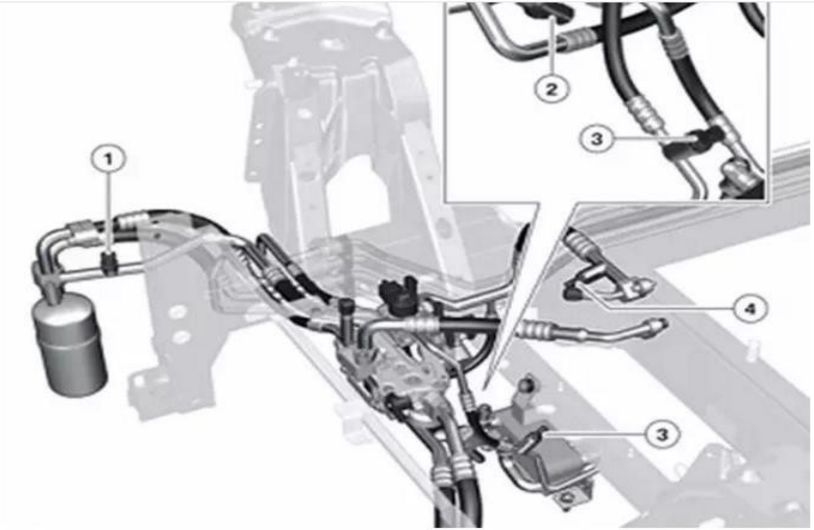
- Compressor outlet
- Condensor in/outlet
- Evaporator in/outlet
- Expansion valve in/outlets
- Flow Reverser in/outlet
- Liquid to liquid HX in/outlets

General Requirements include:

- Sealed connectors
- LIN communications for P, P/T sensors
- Water and corrosion resistance
- Pressure ranges as low as 5 bar and as high as 100 bar
- Temperature range from -20 to 150C
- EMC protection
- Attachment:
  - Threaded
  - Press fit/O ring / retention clip
  - Pipe clip

Heat pump scheme of BMW IX3

- 2 Pressure/Temperature sensors
- 2 Temperature sensors



1 制冷剂压力-温度传感器1 2 制冷剂压力传感器(不带热泵也配置)

3 制冷剂温度传感器1 4 制冷剂温度传感器3

Typical Coolant Loop Sensor designs

Metal Body Threaded Probe Sensors:

- Used when installation of probe is directly into a metal manifold or heat exchanger
  - Aluminum cooling plate
  - Coolant pump
  - HX flange
- Advantages of this traditional design are:
  - Robust sealing through axial O ring
  - Standard sealed USCAR connectors
  - Good resistance to moisture intrusion
  - Damage and corrosion resistant
- These sensors are generally not for use in plastic without a metal insert
- Larger metal bodies act as heat sink and can influence measurement

Plastic Probe sensors with "snap clip" installation:

- Used when interface is into plastic manifold or housing
  - Distribution manifold or port
  - Custom plastic tubing
- Advantages of this design are:
  - Robust O ring sealing
  - Standard USCAR connector
  - Excellent resistance to moisture intrusion
- Less effective at sealing in high vibration, or high pressure environments

HP application coolant side sensors


THERMOMETRICS
A COMMITMENT TO EXCELLENCE

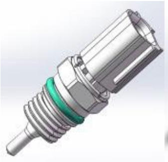
HVAC Refrigerant Temperature Sensor GE-1920
for Automotive Applications

The refrigeration temperature sensor measures the refrigerant temperature both at the high pressure side and at the low pressure side of the line. The control module uses this information to maximize the performance of the HVAC system.

Applications
- High pressure line temperature of the condenser and receiver/drier unit side
- Low pressure refrigeration line temperature measurement of the evaporator side
- Battery coolant temperature

Features
- High accuracy and long term stability
- Fast response time
- Integral connector
- Existing field proven design
- Alternate RvT curves available
- 100°C Max operating temperature
- Plated steel body
- Other resistance and beta values available

Amphenol
Advanced Sensors




THERMOMETRICS
A COMMITMENT TO EXCELLENCE

GE-2133
General Fluid Temperature Sensors

Thermometrics GE-2133 Series of General Fluid Temperature Sensors measures and monitors the temperature of a variety of fluids. The spring clip design secures the sensor in place and provides a quick means for installation and removal.

Applications
- Battery Coolant Temperature
- Refrigerant Temperature
- Outside Air Temperature
- Engine Coolant Temperature

Features
- Low price
- High sensitivity
- Wide application range
- Compact design
- Easy installation
- Validated to ISO 16750-Z-A-O-D-A IPK69K

Amphenol
Advanced Sensors

Coolant Loop Sensor designs

Sensor locations vary:

- Inline/ embedded in tubing assemblies
- Pack cold plate in/outlet
- HX in/outlet

Inline Sensors:

- Inline sensors are used whenever the optimum sense point for coolant is within a plastic tube or rubber hose. This is often used in the line near the inlet or outlet of a heat exchanger or cold plate
- Advantage of integrated inline sensors is that because they can be implemented into a hose assembly, there is no need to drill/tap/ and seal the metal HX.
- Further advantage of the integrated inline approach is that the probe is formed as part of the plastic tube, such that there is no fastener or seal required for the tubing, eliminating potential leak paths and added assembly operations

HP application coolant side sensors


THERMOMETRICS
A COMMITMENT TO EXCELLENCE
Product Spotlight

Flow-Through Temperature Sensors

Thermometrics Inline Flow-Through Temperature Sensors monitor the temperature of a fluid that passes through it where a system control module receives this temperature reading and uses a control loop to control the overall system temperature. This could be engine temperature, heater temperature, industrial supply temperature, etc.

In addition to our existing range of Flow-Through Temperature Sensors, Thermometrics is introducing an additional configuration - CTTS-302651-F01 - that employs barbed sensor tubes for securing the mating pipe to the sensor.

GE-2103
GE-1935
GE-2102

NEW Configuration
CTTS-302651-F01

Features
- Operating Temperature Range: -40°C ~ 120°C
- R @ 25°C: 10KΩ±1.5%
- Housing Material: Polyamide 6/6
- USCAR sealed connection system
- Response Time: <15 seconds in flowing water
- Alternate RvT curves available upon request
- Designed for mating with polyamide tube with 14mm ID

Applications
- EV/HEV Battery Pack Coolant Line Temperature
- Industrial Process Flow Measurement
- Engine Coolant Temperature
- HVAC Water Management
- Home Appliances

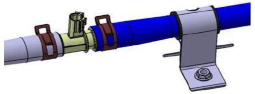
Ordering Options

Part Number	Hose Size
GE-2102	0.50 in. (12.70 mm)
GE-1935	0.75 in. (19.05 mm)
GE-2103	1.25 in. (31.75 mm)
CTTS-302651-F01	0.55 in. (14.00 mm)

Amphenol
Advanced Sensors

www.amphenol-sensors.com

AAS-930-235A - 04/2019



Integration of sensor core into injection molded manifolds

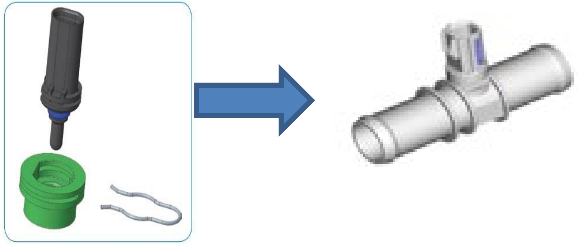
Sensor Integration into molded Assemblies:

For injection molded Plastic coolant manifolds and connectors

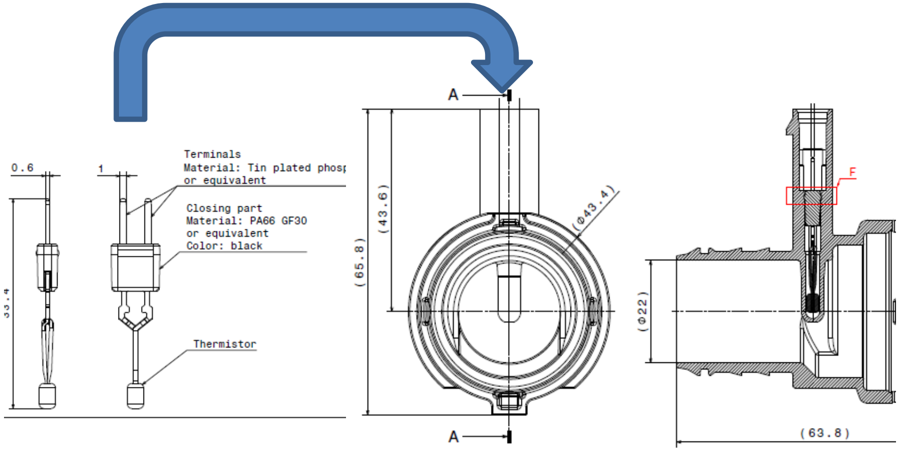
- **Benefits:**
  - Reduced components in BOM
    - No O ring
    - No retention clip
  - Lower cost
  - Lower risk of leak
  - Better DFMEA
  - Improved performance due to optimum probe placement
  - Easy Assembly/test

- **Requirements:**
  - Design needs to allow for molding of probe (or half probe) feature
  - Electrical connector molded as part of fluid feature

- **Assembly Process:**
  - Mold fluid carrying component
  - Inject thermally conductive medium through electrical connector to probe tip
  - Snap lead frame sensor assly through electrical connector
  - Functional test
  - Complete!



Discrete sensor **Integrated Sensor**



Typical Refrigerant Loop Temperature Sensor designs

Metal Body Threaded Probe Sensors:

- Used when installation of probe is directly into a metal tube or heat exchanger
  - Tube boss
  - Compressor
  - Liquid/liquid HX
- Advantages of this traditional design are:
  - Robust sealing through axial O ring
  - Standard sealed USCAR connectors
  - Good resistance to moisture intrusion
  - Damage and corrosion resistant
- Larger metal bodies act as heat sink and can influence measurement
- Not for use in CO_2 refrigerant systems
- Installation costs include brazed boss, piercing, threading, torqueing sensor
- Caution should be used to prevent galling of aluminum threads

"Pipe Clip" designs for metal tubes:

- Used when interface is aluminum tube
  - Accommodates various diameters
- Advantages of this design are:
  - No risk of refrigerant leak
  - Robust positioning
  - Standard USCAR connector or flying lead
  - Excellent resistance to moisture intrusion
  - Eliminates brazing/piercing/threading costs
- Ideal for CO_2 refrigerant lines

HP application Refrigerant side sensors


THERMOMETRICS
A COMMITMENT TO EXCELLENCE

HVAC Refrigerant Temperature Sensor GE-1920
for Automotive Applications

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- High pressure line temperature of the condenser and receiver/drier unit side
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- Battery coolant temperature

Features
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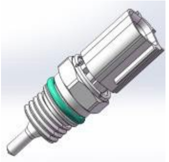
- Fast response time
- Integral connector
- Existing field proven design
- Alternate RvT curves available
- 100°C Max operating temperature
- Plated steel body
- Other resistance and beta values available

Amphenol
Advanced Sensors




THERMOMETRICS
A COMMITMENT TO EXCELLENCE
Product Spotlight

Fluid Temperature Sensor - Pipe Clip

Thermometrics JS8846 Integrated Pipe Clip Surface Temperature Sensor monitors the temperature of a fluid that passes through a pipe or tubing circulation system. A system control module receives this temperature reading and uses a control loop to control the overall system temperature.

Features
- Easy-mount spring clip of galvanized spring steel
- High sensitivity
- Compact design
- Connector Position Assurance (CPA)
- VW75174 approved connector system
- IP67 Ingression Protection Rating
- Operating Temperature: -40°C to +125°C
- Suitable for Pipe Diameters: 16mm to 18mm
- Amphenol FEP Connector - 428 313 000

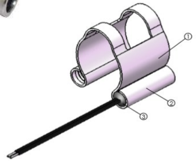
Applications
- Engine Coolant Temperature
- Battery Pack Coolant Line Temperature
- HVAC Water and Refrigeration
- Home Appliances
- Industrial Process Flow Management

Ordering Options	
Part Number	Resistance @ 25°C
JS8846A	2.7 kΩ ±5%
JS8846B	10.0 kΩ ±5%
JS8846C	30.0kΩ ±5%

Tested to AEC Q200 and ISO 16750 for:
electrical / mechanical / vibration and climatic loading.
Contact Amphenol Advanced Sensors for details.

Amphenol
Advanced Sensors

www.amphenol-sensors.com



Typical Refrigerant Loop Pressure Sensor designs

CCT Pressure Sensor

- **Pressure sensing element:** stainless steel, resistive, thin film technology
- **Housing:** aluminum, HEX24
- **Connector:** automotive connector (RD-connector)
- **Measuring range:** -1...10bar (145 PSI) to -1...100bar (1,450 PSI)
- **Pressure type:** gauge
- **Output signals:** LIN, PWM, analog voltage
- **Temperature range:** -40°C...125 °C (150 °C)

CCT Pressure / Temperature Sensor

- For electric vehicles and next generation CO2 climate control units (R744)
- High temperature accuracy and fast response time
- **Sensing elements:** stainless steel (p) and Pt1000 (T)
- **Housing:** aluminum, HEX24
- **Connector:** automotive connector (RD-connector)
- **Measuring range:** -1...10bar (145 PSI) to -1...100bar (1,450 PSI)
- **Pressure type:** gauge
- **Output signal:** LIN (for both p & T measurement)

HP application Refrigerant side sensors

High Voltage devices – non-contacting Temperature Sensing

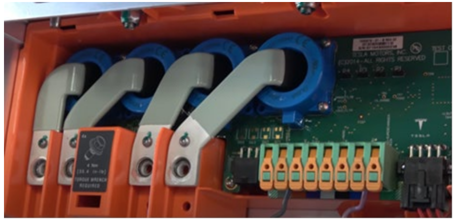
Meet IEC 60664 Clearance requirements with a non-contact temperature monitoring approach

Infrared temperature sensing for fast and accurate monitoring of HV components

Typical applications:

- HV connections, such as charger-to-wire and interconnects
- HV bus temperature
- HV MOSFETs and other inverter components

Parameter	Limits			Units	Condition
	Min	Typ	Max		
Chip Size		1.8 x 1.8		mm^2	
Diaphragm Size		1.0 x 1.0		mm^2	
Active Area		0.5 x 0.5		mm^2	
Internal Resistance	35	50	65	kΩ	25°C
Resistance T.C			0.15	%/°C	
Responsivity	42	60	78	V/W	500K, 1 Hz
Responsivity T.C		-0.10		%/°C	
Noise Voltage		30		nV rms	R.M.S., 25°C
NEP		0.50		$nW/Hz^{1/2}$	500K, 1 Hz
Detectivity		1.00 E08		$cmHz^{1/2}/W$	500K, 1 Hz
Time Constant		20		ms	



Battery Electric Stationary Storage (ESS)

Small scale residential and large scale “behind the meter” storage market is growing

Consumer/Residential Storage:

Passive cooling, convection cooling, and liquid cooling used

- Temperature sensor feedback on cell surfaces and coolant temperature

Large Scale ESS:

Forced air convection cooling and liquid cooling used

- Enclosure air temperature
- Battery busbar temperature
- Cell temperature sensors
- Humidity, water/coolant detection
- Thermal runaway detection
- Ambient air temperature, humidity, rain sensors (on site weather stations)

Electric Vehicle Servicing Equipment (EVSE)

Typical DC Fast Charging system temperature sensor deployment

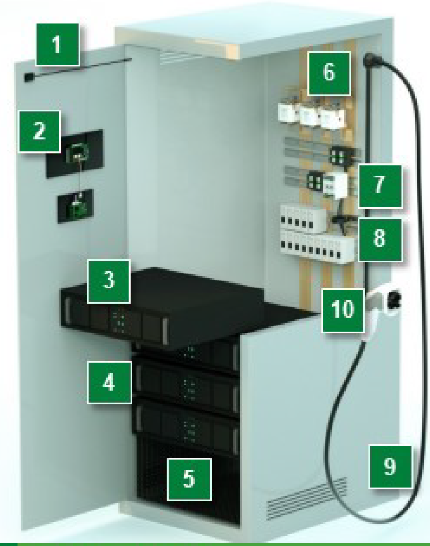
1 Service Access Panel
- Reed Sensor

2 User Interface
- TVS Diode Array
- Polymer ESD Suppressor

3 Communication
- TVS Diode Array

4 Rectification & PFC
- SiC/Si MOSFET
- Rectifier Diode/Module
- Gate Driver
- Temperature Sensor

5 DC-DC Conversion
- SiC/Si MOSFET
- Rectifier Diode/Module
- Gate Driver
- Temperature Sensor



10 Charging Plug
- Temperature Sensor
- Reed Sensor

6 Power Distribution Unit
- Fuse

7 Input Protection
- Fuse
- Surge Protection Device
- TVS Diode
- Current Transformer
- AC Earth Fault Relay

8 DC Output Protection
- DC Fuse
- HVDC Contactor
- Earth Fault Relay
- Current Sensor

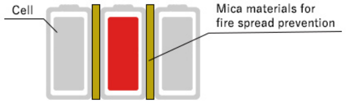
9 Auxiliary Power Supply
- Fuse
- MOV, GDT, SIDACtor® + MOV
- Si MOSFET
- Rectifier Diode

Good News: State of the Industry for Thermal Propagation countermeasures

- **On vehicle:**
  - "Livestream" data to secure server
  - Aggressive HX
    - Coolant
    - refrigerant
  - load dump from affected modules (as with MegaPack)
  - Phase change materials that absorb heat
  - Disable regen braking contribution to pack charging
  - Disable charging
  - Thermal isolation (Mica, aerogels)
  - On board extinguishing agents (busses)
  - Dielectric coolant
  - Access port

- **Off vehicle**:
  - ISO bath (ISO 17840 / SAE J2990)
  - E lance
  - Lots of water
  - See First Responder Survey Recommendations

Lithium-ion batteries with mica materials for fire spread prevention



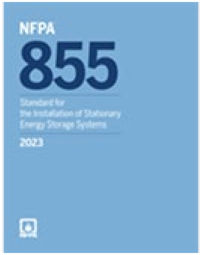
Mica materials for fire spread prevention prevent an ignited cell from affecting adjacent cells.

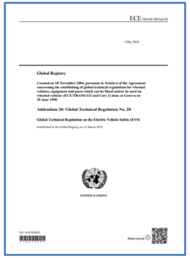
Background

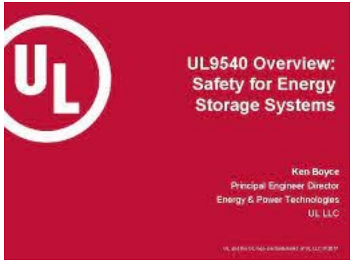
Regulations and Standards

Battery Regulations & Standards:

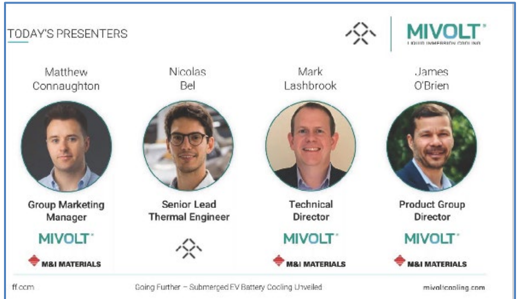
- NFPA 855: Standard for the Installation of Stationary Energy Storage Systems
- IFC: 2024; Chapter 3: Section 321 Rechargeable Battery Storage
- GTR-20: Electric Vehicle Safety
- UL 1973: Batteries for use in Stationary, Vehicle Aux Power and light rail apps
- UL9540: Safety for Energy Storage Systems
- NFPA 70: Electrical Safety
- ISO-17840: Road vehicles — Information for first and second responders
- SAE J2990: Hybrid and Electric Vehicle Safety Systems Information Report
- SAE 3235 (Draft) BEST- PRACTICES FOR THE STORAGE OF LITHIUM-ION BATTERIES







Benchmarks: Immersion Cooling

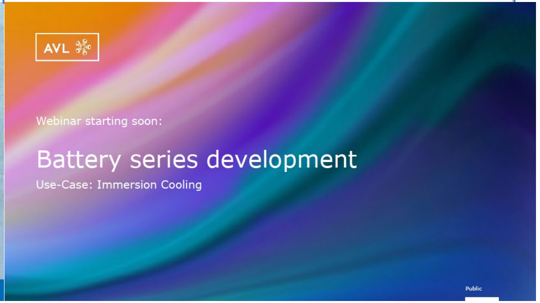


Faraday Future, new xEV Co.

- Dielectric immersion cooling

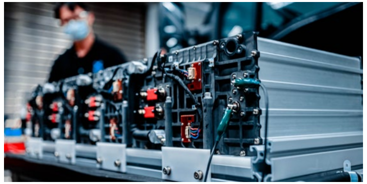
Investigations by:

- AVL
- Ricardo
- University of Warwick
- M&I Materials/ MiVolt



- ✓ Current data shows substantial promise for improved, more uniform cooling, especially in high c rate charging
- ✓ Ricardo data cites improvement in system weight due to direct cooling of busbars, elimination of convective cooling h'ware
- ✓ Reduced risk / containment of TR
- × Current price of mineral oils, esters based on existing market requires improvement for passenger car use

Benchmarks: Immersion Cooling



Jul 11, 2022 - 02:00 pm

Xing Mobility shows battery immersion cooling system for heavy utility vehicles

Xing Mobility, a Taiwanese supplier of electric vehicle technologies, has introduced a new battery system with immersion cooling at the Battery Show Europe in Stuttgart. According to Xing, the Immersio XM25 is particularly well suited for heavy electrified vehicles used in logistics, construction, agriculture and mining.

The Immersio XM25 combines a battery pack with a battery management system and an active safety module, according to the company. The new product builds on Xing Mobility's Immersio 1.0 battery system, which debuted in 2019.

Immersio, or immersion cooling technology, involves the battery cells being completely surrounded by coolant. Cooling plates or channels that only touch one or two sides of a battery cell are otherwise common – the heat transfer takes place over a significantly smaller area than with immersion cooling. As an advantage of its own solution, Xing claims a more even distribution of the temperature in the battery cell and the efficiency of the cooling. This is supposed to enable "super-fast" charging and double the service life of the cells.

The C-rate shows that the system is primarily designed for commercial vehicles with correspondingly large batteries: charging is possible with 1C, discharging with 1.67C. System voltages of up to 800 volts are possible, and Xing states a service life of over 3,000 cycles.

According to Xing Mobility, it has already found an initial customer for the new system: The Immersio XM25 is currently being integrated by an unnamed Asian commercial vehicle manufacturer in a model whose production is scheduled to start at the end of 2022.

Surface vehicle standard practice to supress fire and relieve stranded energy

Response vehicles typically only have ~500 to 1500 gallons of water available on board

Current
"Water Immersion"
& "Large amounts of water"

New Development:
AVL Water "spike" into pack substantially reduced water usage

New field Tools for First Responders:
"Spike" systems from Murer, Rosenbauer

First Application Example

- Renault Zoe Q210
  - Nominal power: 46 kW
  - Max. power: 65 kW
  - Battery capacity: 22kWh
  - Pouch Zellen
- Battery ignited by penetration
- Max temperature after penetration: >600°C
- Water consumption: approx. 300l
- Extinguishing time: 20min
  ->15l/min water
- Temperature after extinguishing: <90°C
- After extinguishing the vehicle was transferred in a container with water

Press release

rosenbauer

October 7, 2021

New extinguishing system for burning traction batteries in electric vehicles

- **Safe deployment due to short deployment time on the burning vehicle and system activation with sufficient distance**
- **Efficient firefighting by cooling the modules and cells in the battery housing**
- **Lead users confirm the efficiency and ergonomics of the system**

Rosenbauer launches a new extinguishing system for burning traction batteries in electric vehicles. The system can be used to safely and efficiently extinguish lithium-ion based high-voltage batteries. It enables direct cooling of the battery modules, or the cells within the modules, and thus a quick stop to the propagation of the thermal runaway of the cells.

The safety of the firefighter was the top priority during the development and is achieved by the fact that the firefighter only being in the vicinity of the burning vehicle for a very short time and the system is activated from a safe distance. The extinguishing system applies the water exactly where it is needed: to cool the cells and modules in the battery housing. Extinguishing thus takes place in a very resource-efficient way and reduces the spread of flue gases to a minimum.

5,000 to 30,000 gallons → **80 gallons**

- "Spike systems" need identified locations for piercing to avoid striking HV bussing & cables
- Pouch cells will self discharge when exposed to water, CID's in prismatic and cylindrical cells may prevent discharge

Stranded Energy and Second Responder safety need to be addressed