Application note

Evaluation on L9966 fitting requirements of some automotive applications

Introduction

The L9966 is an automotive grade IC designed to be used as sensors interface. Up to 15 channels are available for analog sensing, resistance measurement and digital sensing (e.g. temperature, lambda, pressure, position sensors).

The L9966 allows to replace a number of discrete components and it gives the possibility to change the sensors across different applications without modifying the PCB hardware.

1 L9966 overview

Below a list of the key features of the device:
- 12 V and 24 V systems compatible (operating battery supply voltage 5.5 V - 36 V)
- Programmable interface with 15 total inputs:
  - 12 for connection to external analog loads (with connection to VVAR, VDD5 and clamped battery VPRE, with resistance measurement)
  - 4 with also λ sensor functionality
  - 4 with also SENT functionality
  - 3 for connection to external digital switches (with connection to VPRE)
- Programmable pull-up/down current sources
- Integrated precise resistance measurements
- 12 bit ADC for voltage measurements
- 15 bit ADC for resistance measurements
- Variable reluctance sensor / Hall sensor Interface
- 1 analog output channel + 4 digital output channels
- SPI interface for device configuration and data communication
- Overtemperature protection

The figures below illustrate the application circuits of sensors (lambda sensor, VRS sensor and Hall sensor) typically interfaced by L9966.

Basically, L9966 implements two sigma delta time continuous converters:
- ADC1 (Volt) is a general purpose 1.25 V full scale, 12 bits ΣΔ converter used for input voltage measurement
- ADC2 (RES) is a dedicated 15 bits ΣΔ converter used for resistance measurement function on the 12 analog input pins of L9966.

  The aim of ADC1 is to achieve voltage measurement over all the 12 analog input pins, 3 ECU internal voltage monitors (UBSW, VI5V, VIX), internal junction temperature, internal BandGap and 3 digital input pins. The ADC circuitry implements an input time-continuous filtering structure intended to filter out HF noise and to avoid aliasing effects.

  Regarding the voltage measurement, L9966 also implements different input voltage dividers to adapt the ADC to different input ranges. The input impedance of the channel is strongly dependent on the selected full-scale. There are 4 different input ranges for the ADC conversion of analog inputs and 3 for the digital inputs.

Figure 1. Application circuit of L9966 to interface lambda sensor

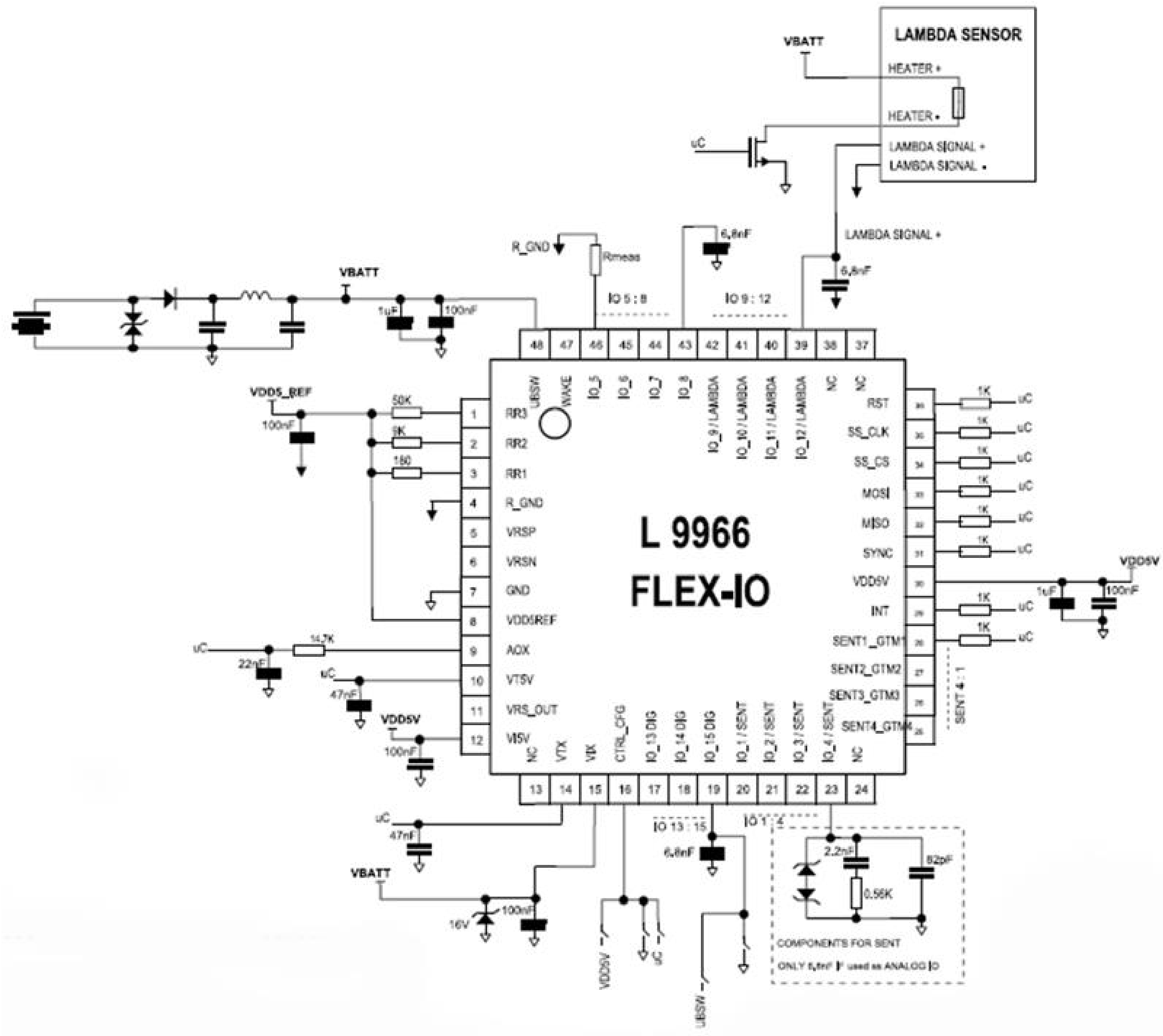


Figure 2. **Application circuit of L9966 to interface VRS sensor**

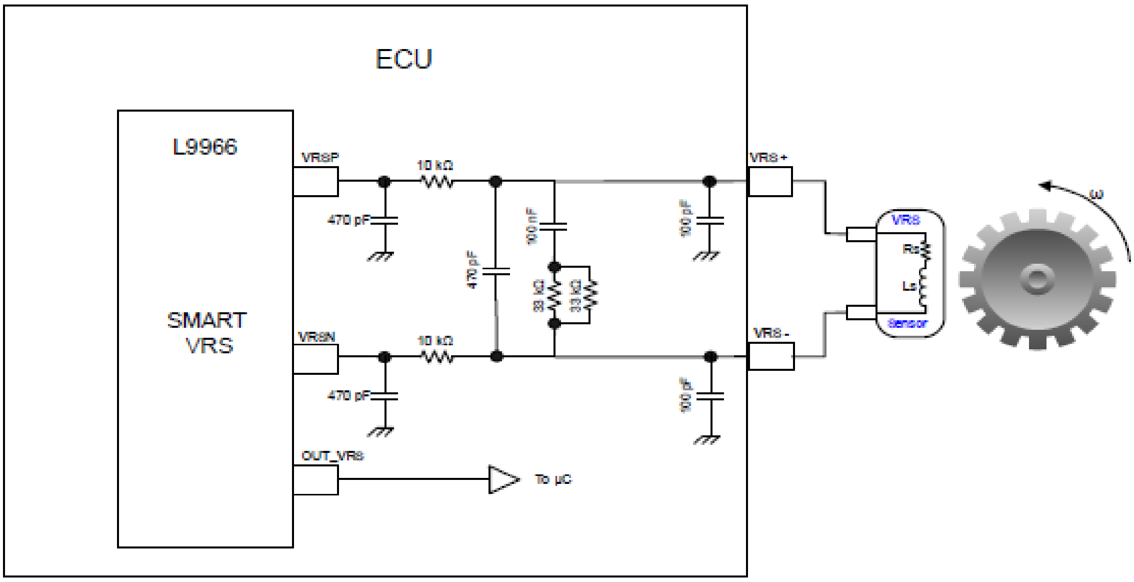
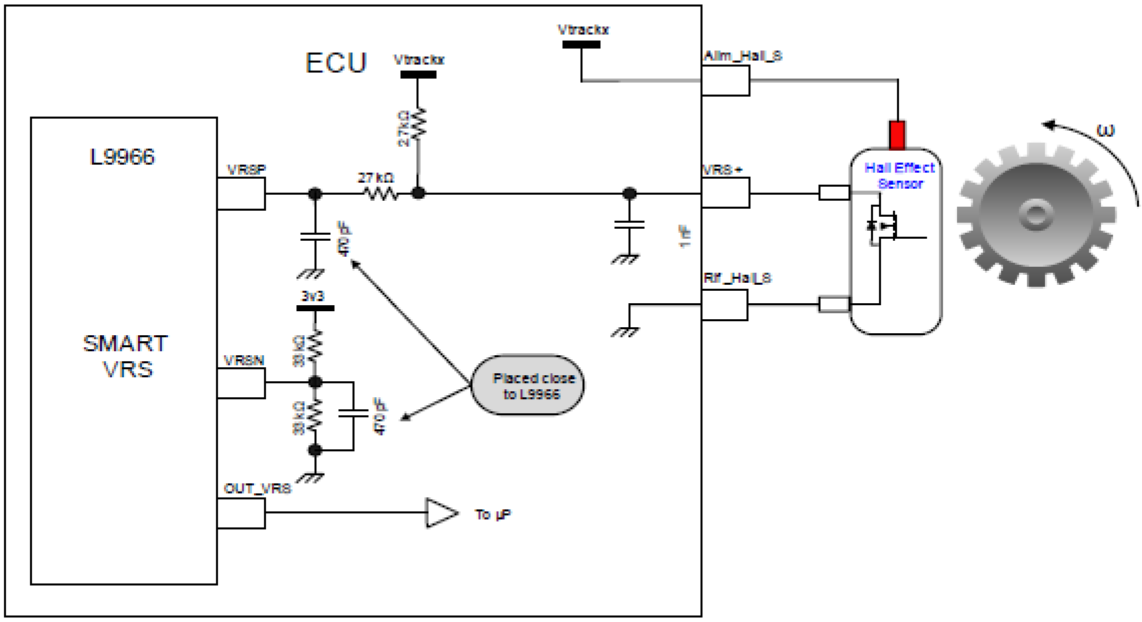


Figure 3. **Application circuit of L9966 to interface hall sensor**

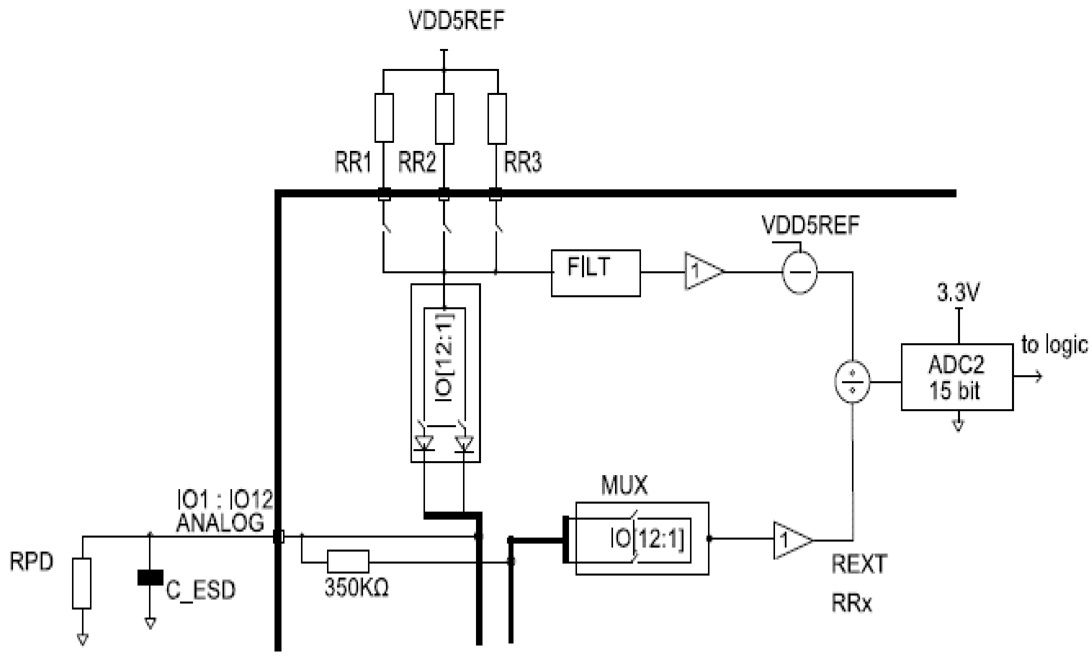


The purpose of ADC2 is to implement a dedicated function to perform high precision resistance measurements connected between analog input pin IO[12:1] and ground of L9966. In the Figure 4 a simplified circuit for resistance measurement is depicted.

The L9966 allow a wide range of resistance measurements by selecting the pull-up external reference resistors (for a specific application concerning the lambda sensor interface one can refer to the corresponding application note, i.e. “L9966 lambda sensor interface”). Digital out is RPD/RRx represented over 15 bits fixed point number (4 bits integer, 11 bits fractional). The result from the SPI register needs then to be divided by 2048:

RPD = (ADC2_RESULT/2048)*RRx

Figure 4. Simplified circuit describing resistance measurement of L9966



2 Aim of the application note

The aim of this document is to illustrate a method to do a preliminary evaluation how L9966 could fit requirements of sensor interface IC for different sensors (temperature, pressure, magnetic, capacitance, position and speed, etc…) in automotive applications. The results of this analysis consists of two tables, extracted from the L9966 data sheet (see the following Table 1 and Table 2). These tables allow to understand if the requirements in terms of accuracy of a generic sensor involved into an automotive application could be nominally satisfied by L9966. In order to do this comparison, the user should know the transfer-function of the sensor involved into the automotive application and the requirement in terms of accuracy (e.g. accuracy in terms of pressure or temperature or capacitance).

Examples on how to use the Table 1 and Table 2 to do a preliminary evaluation on how L9966 could fit requirements of sensor interface IC for different automotive applications will be provided into a specific section of this document.

Table 1. Preliminary evaluation of L9966 accuracy in voltage measurements

L9966 accuracy in voltage measurements	Accuracy %
ADC measurement error on analog inputs (full range 1.25 V)	1
ADC measurement error on analog inputs (full range 5 V) with tion	0.25
ADC measurement error on analog inputs (full range 5 V) without calibration	1.6
ADC measurement error on analog inputs (full range 20 V)	2.2
ADC measurement error on analog inputs (full range 40 V)	2.2
ADC measurement error on digital inputs (full range 1.25 V)	2.4
ADC measurement error on digital inputs (full range 20 V)	2.5
ADC measurement error on digital inputs (full range 40 V)	2.5

Table 2. Preliminary evaluation of L9966 accuracy in resistance measurements

L9966 accuracy in resistance measurements in range (50 Ω – 400 KΩ)	Accuracy %
Total resistance measurement accuracy (in range 50 Ω – 2 KΩ) with calibration	1.5
Total resistance measurement accuracy (in range 2 KΩ – 30 KΩ) with calibration	1.5
Total resistance measurement accuracy (in range 30KΩ – 400 KΩ) with calibration	1.5
Total resistance measurement accuracy (in range 50 Ω – 2 KΩ) without calibration	10
Total resistance measurement accuracy (in range 2 KΩ – 30 KΩ) without calibration	10
Total resistance measurement accuracy (in range 30KΩ – 400 KΩ) without calibration	10

Concerning the calibration option on the ADC channels of L9966, it is useful to highlight that at power-up of the device the calibration is disabled. In other words, the "default operating state" of the device is characterized by a disabled calibration, that is CALIB_SEL = '0' in the GEN_STATUS register. In order to reach the best accuracy of the ADC channels the calibration mode has to be activated by setting CALIB_SEL = '1' in the GEN_STATUS register.

When the calibration mode is activated, the ADC output is real-time adjusted by using the calibration codes. These calibration codes are stored in an NVM memory.

3 Sensor based automotive applications

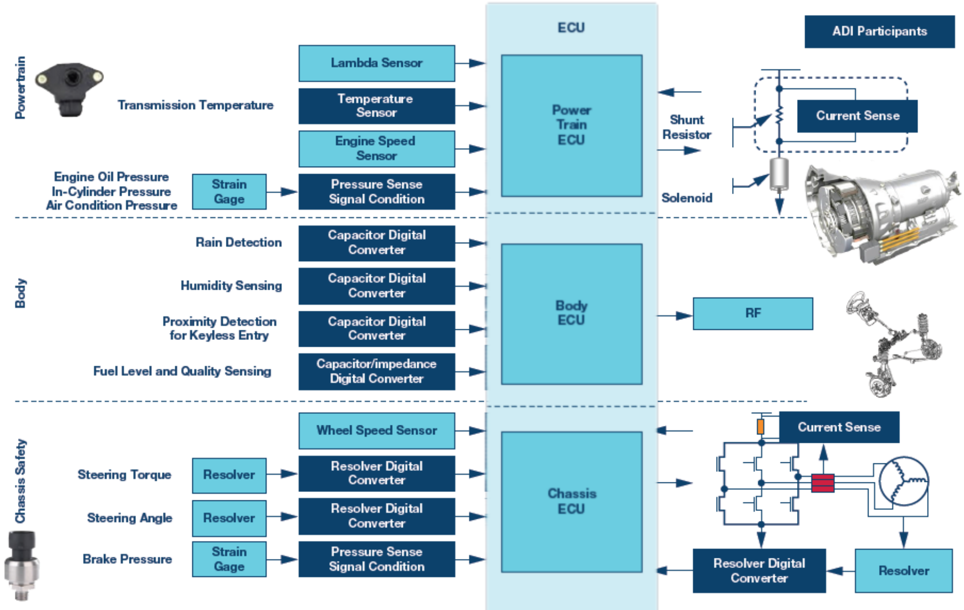
There are typically more than 100 sensors in a vehicle. These sensors can typically be partitioned into six classes, including pressure, current, capacitance, position, speed, and temperature sensors.

Vehicle sensors are used across multiple applications in power-train, chassis/safety, and body systems.

To fit more and more challenged targets in terms of optimization of fuel economy strategies, emission strategies, and vehicle performance it is needful to have sensors conceived to improve performance in areas such as dynamic range, accuracy, diagnostics, and robustness (such as EMC, ESD, and temperature).

The Figure 5 describes some sensor interface signal chains that allow to understand how sensors are and could be used to improve generally the performance of automotive applications.

Figure 5. Automotive sensor and sensor interface signal chain



3.1 Pressure sensors in automotive

In automotive many pressure sensors are required in high pressure and harsh environments to measure air or fluid pressures.

Some power-train examples include in-cylinder, transmission oil, diesel common rail, GDI fuel, diesel particulate filter (DPF), and exhaust gas recirculation (EGR) pressure.

Safety applications include brake fluid and occupant detection weight or pressure. High pressure and harsh environment applications require that the sensor element (capacitive or piezoresistive) is separated from the signal conditioning IC.

A piezoresistive (strain gauge) solution can, for instance, measure pressure ranges up to 2800 bar. The strain gauge technology is based on a resistive bridge. Four strain gauges are attached to a diaphragm to form a diaphragm-type pressure transducer. The output signal is as small as 10 mV. The system errors include mechanical output, thermal output, tolerance, and gauge factor errors. The total errors can reach up to 100% FSR. Hence, the conditioning circuit must be highly accurate and have low drift. Multiple variable compensations related to gain, offset, temperature, and linearity are also required.

Pressure sensors are placed mainly in harsh environments. A typical operating temperature range is −40 °C to +125 °C and in some cases up to 150 °C. The sensors also require high EMC capability and diagnostic functions.

Figure 6. Piezoresistive pressure sensor

The Table 3 lists different types of pressure sensors typically involved in automotive applications. For each type of pressure sensor are detailed also the main features.

Table 3. Typical pressure sensor types used in automotive applications

Pressure sensors type	Application in automotive	Main features
Barometric air pressure sensor	• Barometric air pressure sensor family is used to control spark advance to optimize engine efficiency for diesel and gasoline engines	• Ratio metric analog output proportional to the applied pressure • Output signal fully compensated over pressure and temperature • Transfer function voltage min-max = [0,2 – 4,8] V • Detection of broken pressure cells
Pressure sensor for side crash detection	• Side airbag pressure sensors aimed to increase safety requirements for passenger cars	• PSI5 compliant/Multi-Protocol • Synchronous or asynchronous data transmission • two-wire interface with on chip current modulator for Manchester communication • diagnoses for pressure cells
Tire pressure sensors	• Tire pressure info aimed to increase safety requirements for passenger cars	• Versatile pressure ranges for motorcycles, cars and trucks • Temperature sensor for thermal compensation • High sensitive accelerometer for motion detection • Advanced power management for long battery lifetime at low battery weight and cost • Supply voltage range = [2,1 - 3,6] V • Pressure measurements signal range = [2,1 - 3,6] V
Tire pressure sensor in system in package solution	• Ensemble of sensors into the same system (Tire pressure + radial acceleration sensor + battery voltage sensor + temperature sensor)	• Single package IC for Tire Pressure Monitoring Systems (TPMS) with pressure and acceleration sensor, embedded micro controller, LF 125 kHz ASK receiver and FSK/ASK 315/434 MHz transmitter • Supply voltage range = [1,9 - 3,6] V • Pressure measurements signal range = [2,1 - 3,6] V • Temperature measurements signal range = [2,1 - 3,6] V • Radial Acceleration measurements signal range = [2,1 - 3,6] V • Supply voltage measurements signal range = [2,1 - 3,6] V

From the data listed in the Table 3, it comes out the short list of requirements that sensor interface IC must have in order to process the analog output of pressure sensors:

- digitally programmable gain
- output offset correction
- temperature compensation
- sensor non linearity correction

3.2 Current sensors in automotive

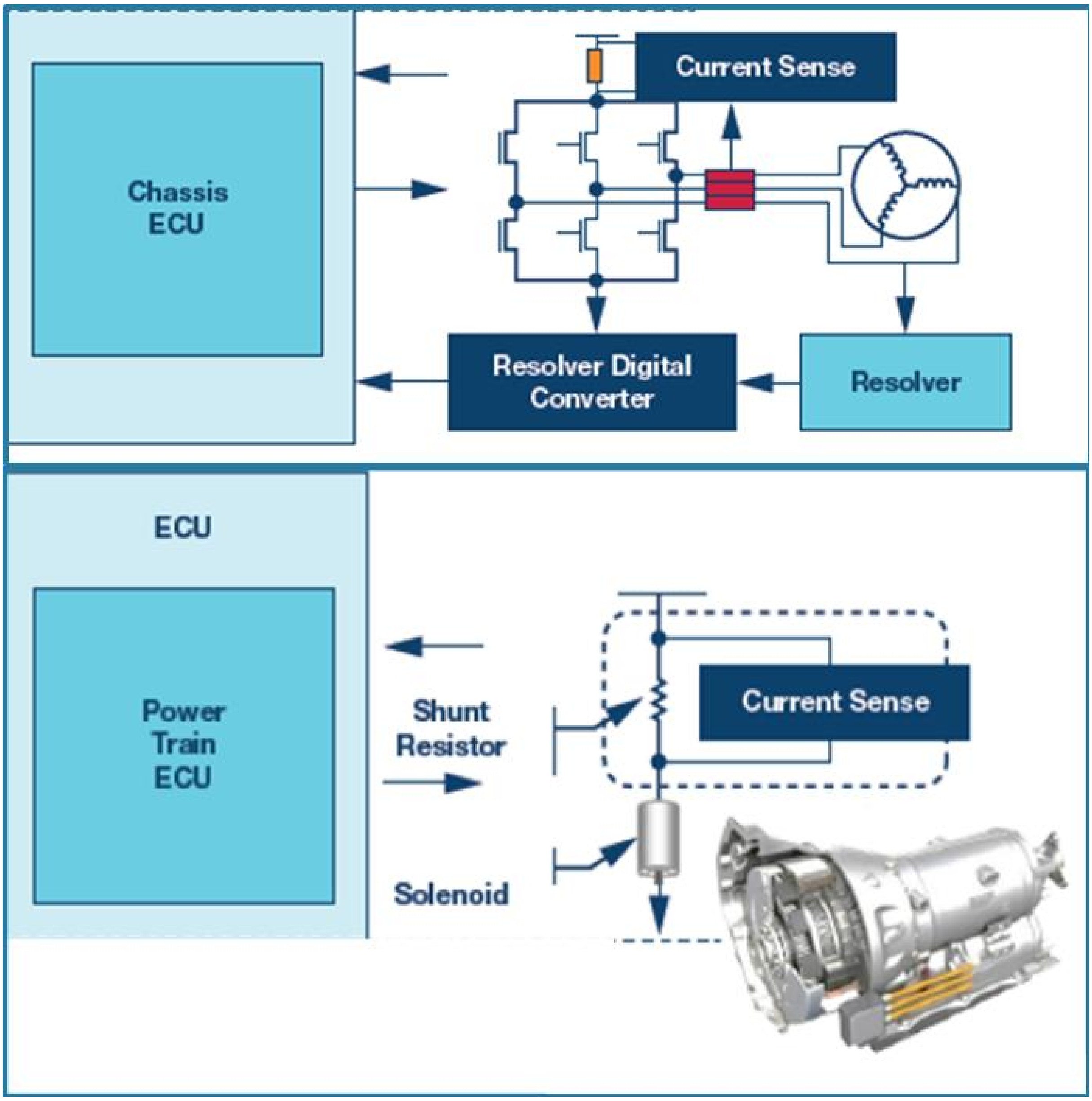
In automotive, in order to optimize fuel economy and energy management, the position of the solenoid valves in the fuel injection system and automatic gearboxes must be accurately controlled.

In addition electric motor current for "on demand" power must be monitored more and more accurately.

Typical design challenges for current sensors consist of high accuracy, low offset (an offset needs < 5 mV and an offset drift needs < 20 µV), high bandwidth (some cases require up to 500 kHz), a wide common-mode voltage range, and wide operating temperature range (up to 125 °C) in a harsh environment.

The Figure 7 depicts some automotive applications involving current sensors. In both block schemes, current sensors are used to optimize the control of underlying application.

Figure 7. **Current sensors used to optimize the control in some automotive applications**



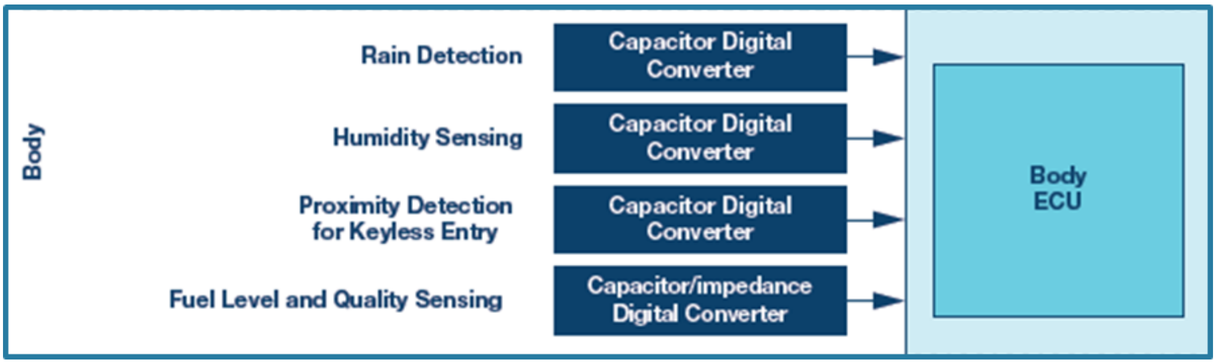
From the analysis of the current sensors used in automotive, it comes out the short list of requirements that sensor interface IC must have in order to process the analog output of currents sensors:

- current sense amplifiers supporting shunt-based precise current sensors on both the high and low sides
- zero-drift function (offset drift < 1 μV/°C)
- maximum offset < 0.5 mV
- current threshold monitor solution
- overcurrent protection

3.3 Capacitance sensors in automotive

In automotive, capacitance sensors take advantages from their low system cost, different shape feasibilities, and low power consumption. They are typically applied as proximity detectors in a keyless entry system, rain detectors, humidity sensors, and fuel level/quality sensors. Capacitance sensors are sensitive to environmental changes and thus require a high resolution, accuracy, adjustable common-mode capacitance, and EMI immunity.

Figure 8. Capacitance sensors used in some automotive applications



From the analysis of the capacitance sensors used in several automotive applications, it comes out the short list of requirements that sensor interface IC must have in order to process the analog output of capacitance sensors:

- sigma-delta (Σ-Δ) architecture capacitance-to-digital converter (CDC). The Σ-Δ modulator uses charge balancing techniques to help customers get capacitance value more easily and more accurately;

In some applications it is useful to combine an on-board frequency generator with a 12-bit, an on-board MSPS ADC and on-chip DSP engine processing a DFT (discrete Fourier transform) of a signal. It can be used in fuel level and quality sensors. It also can measure the mixing ratio of the gasoline and ethanol in the flex-fuel application.

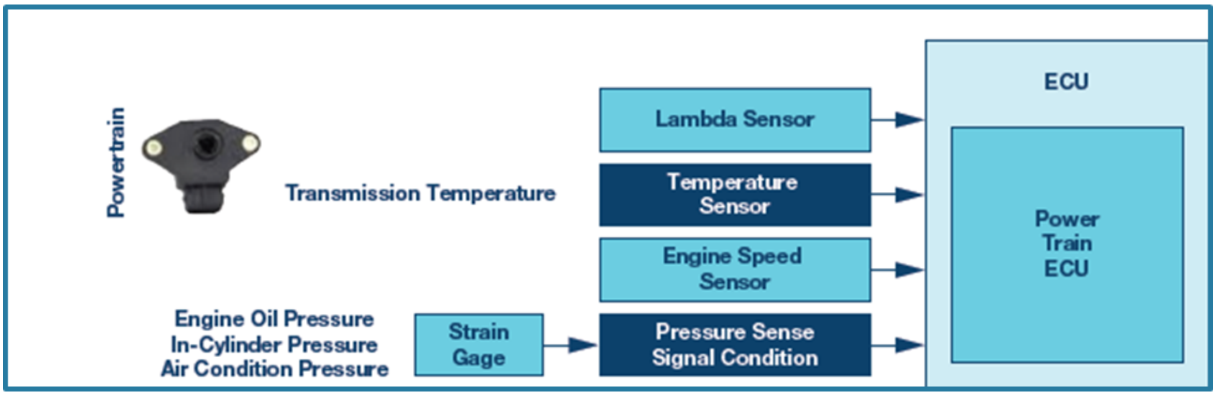
3.4 Temperature sensors in automotive

Wide temperature ranges and high accuracies are required in some high temperature applications such as transmission control.

A typical temperature range is − 40 °C to + 150 °C and in some cases up to 175 °C.

Further, an accuracy of ± 2 °C or ± 1 °C is required.

Figure 9. Temperature sensors used in some automotive applications



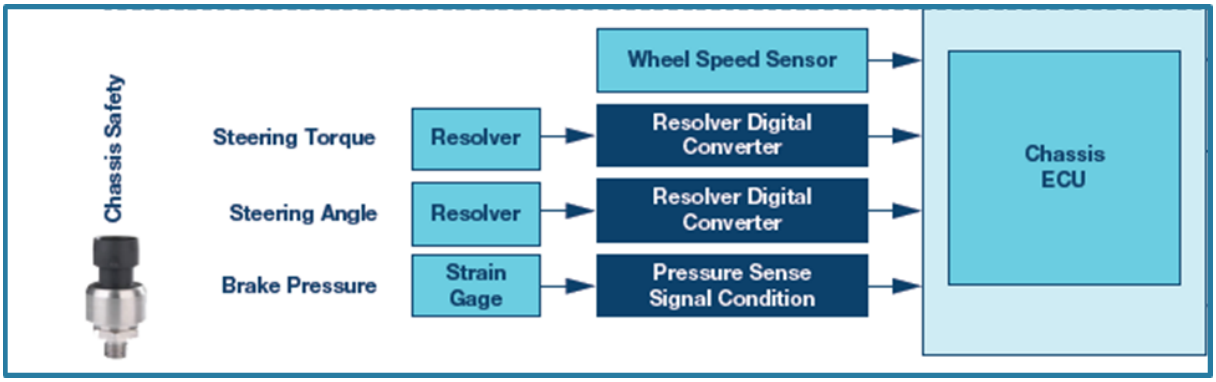
From the analysis of the temperature sensors typically used in automotive applications, it comes out the short list of requirements that sensor interface IC must have in order to process the analog output of temperature sensors:

- accuracy of ± 1 °C on the full scale with a temperature range of − 40 °C to + 150 °C
- digital SPI output

3.5 Speed and position sensors in automotive

Position and Speed Sensors are widely used in EPS and BLDC/PMSM motor control applications. Basically position/speed measurement requires a fast response, good accuracy up to 2.5 arc minutes, robustness, and low drift. Diagnostic functions are also needed into the design of a dedicated IC.

Figure 10. Position/Speed sensors used in some automotive applications



Position sensing is a key element for improving system performance in some automotive applications. For this purpose, solutions based on Hall-effect switches and/or linear Hall-effect sensors have been developed. Both types of sensors use the well-known Hall-effect to transform the position information into an electrical signal. This allows a very robust system design, plus a strong resistance against wear, tear, dust and particles.

Table 4. Typical hall-sensor types used in automotive applications

Hall sensor type	Application in automotive	Main features
Uni- and bipolar hall IC switches	• Position/proximity indicator • Rotational indexing • Brush-less DC motor control	• Temperature-compensated magnetic performance • Digital output signal • Output protection against electrical disturbances
Chopped uni- and bipolar hall IC switches	• position detection systems (e.g. seat position, gear stick position, buckle switch state) • Brush-less DC motor commutation • Index counting	• High jitter performance • High resistance to mechanical stress due to active error compensation • Low supply voltage capability • Two-wire current interface output
Linear hall ICs	• Linear and angular position sensing • Pedal & throttle position • Suspension control • Steering angle • Torque sensing • Gear stick/lever position • Liquid level sensing, e.g. in fuel tanks • Headlight leveling • Seat position or occupation detection • High current sensing • Battery management • Motor control	Analog • Linear ratio-metric output • Programmable in sensitivity (gain), offset and clamping • High voltage capability (24 V) • OBD (e.g. broken supply lines) Digital • 20-bit digital signal processing • 12-bit overall resolution • Low drift of output signal over temperature and lifetime • Digital temperature compensation • Programmable transfer function (gain, offset), clamping, bandwidth and temperature characteristic • The interface options include Pulse Width Modulation (PWM), Single Edge Nibble Transmission (SENT) as well as Short PWM Codes (SPC) • Single supply voltage 4.5 – 5.5 V (4.1 – 16 V in extended range) • On-board diagnostics (over-voltage, EEPROM error)

Differential hall ICs are especially designed for rotational speed measurement such as ABS, cam/crankshaft and automatic transmissions, as well as for position sensing of power steering system. The rotational speed sensors support both gear tooth and magnetic pole wheels.

These sensors are available in different configurations: voltage and current interfaces, with or without direction detection or vibration suppression, with or without integrated capacitors (-C types) for EMC robustness.

Table 5. Typical magnetic sensors used in safety and power-train applications

Magnetic sensors type	Application in automotive	Main features
Wheel speed sensing family	• Anti-lock Braking System (ABS) • Vehicle Stability Control (VSC) • General Speed Sensing • Crankshaft speed and position • Three-wire low-end automatic transmission applications	• Two-wire current interface • Two-wire PWM current interface (with smart features such as Direction detection, Air gap warning and Assembly position diagnosis) • Dynamic self-calibration algorithm (compensates magnetic off sets) • Fast start-up time • Short circuit and over temperature protection of output • Adaptive hysteresis
Wheel speed sensing family	• Low-end automatic transmissions	• Two-wire and three wire configuration • Short circuit and over temperature protection of output • Fast start-up time • Dynamic self-calibration algorithm (compensates magnetic off sets)
Wheel speed sensing family	• High-end automatic transmissions	• Two-wire PWM current interface • Detection of rotation direction • Vibration suppression algorithm • Adaptive hysteresis • Dynamic self-calibration algorithm (compensates magnetic off sets) • Broad operating temperature range • For fine and coarse transmission target wheels • From zero speed up to 12 kHz
Wheel speed sensing family	• Camshaft position	• High phase accuracy for best fuel injection time • Dynamic self-calibration algorithm with programmable power-on and dynamic switching point • over temperature protection

From the analysis of the speed and position sensors typically used in automotive applications, it comes out the short list of requirements that sensor interface IC must have in order to process the output of these sensors:

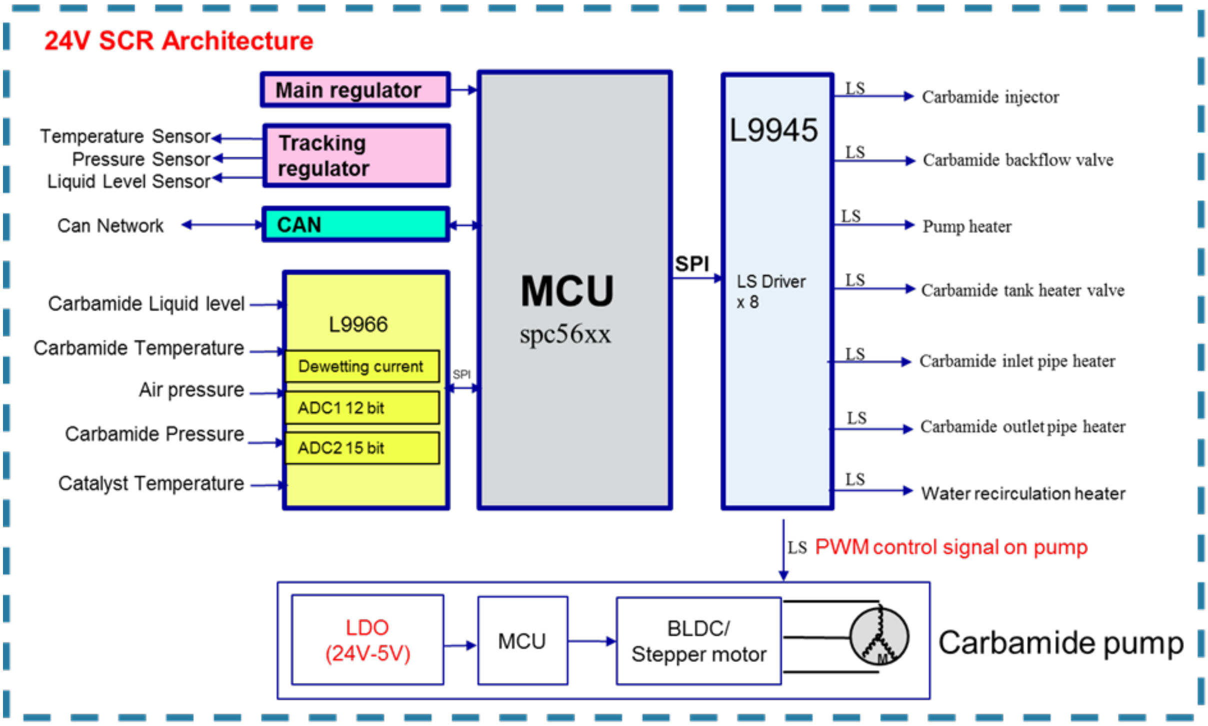
- for Resolver sensor (application motor shaft angle and speed measurements in transmission, EPS, and HEV/EV motors), IC has to be able to track rates at up to 3000 - 3500 RPS with an accuracy of 2.5 arc minutes (at least);
- IC must have programmable fault detection thresholds.

4 Some evaluations on L9966 fitting automotive application requirements

In this section, the use of L9966 in three automotive applications (i.e. Selective Catalytic Reduction, Diesel EMS, VCU/BMS) has been evaluated. Table 1 and Table 2, derived from L9966 datasheet, have been used to evaluate the use of L9966 in the three considered automotive applications.

Figures Figure 11, Figure 12 and Figure 13 depict the block diagrams concerning the three automotive applications involving the potential use of L9966.

Figure 11. Selective catalytic reduction application: block diagram



*(Selective Catalytic Reduction). Diesel after-treatment application for reducing NOx.

Regarding the potential use of the L9966 in the block diagram of the SCR application (see Figure 11 for more details) the Table 6, Table 7, Table 8 and Table 9 analyze the feasibility.

The last column of these tables shows if L9966 fits or not the specifications, in terms of accuracy, of the considered sensor.

Table 6. Feasibility analysis on L9966 fitting SPECS of carbamide temperature sensors conventionally used in SCR application

Carbamide temperature sensor	L9966 accuracy in resistance measurements in range (50 Ω – 400 KΩ)	L9966 fits specs YES / NO
(application accuracy request)*(sensor transfer function) = ± 1 °C * sensor transfer-function = [2,6-6,8] %	1,5 %	YES
Sensor resistance range = [350 Ω - 350 KΩ]		

In the analysis depicted in the table Table 11, the accuracy required for the Carbamide Temperature Sensor is ± 1 °C.

Table 7. Feasibility analysis on L9966 fitting SPECS of carbamide liquid Level sensors conventionally used in SCR application

Carbamide liquid level sensor	L9966 accuracy in resistance measurements in range (50 Ω – 2 KΩ)	L9966 fits specs YES / NO
(application accuracy request)*(sensor transfer-function) = 7 %	1,5 %	YES
Sensor resistance range = [0 Ω - 200 Ω]		

In the analysis depicted in the Table 7, the accuracy required for the Carbamide Liquid Level Sensor is about 7 %.

Table 8. Feasibility analysis on L9966 fitting SPECS of carbamide pressure sensors conventionally used in SCR application

Carbamide pressure sensor	L9966 accuracy in voltage measurements (full range 5 V)	L9966 fits specs YES / NO
Accuracy = ± 0,5 %	0,25 %	YES
Output/Span 0,5 – 4,5 V		

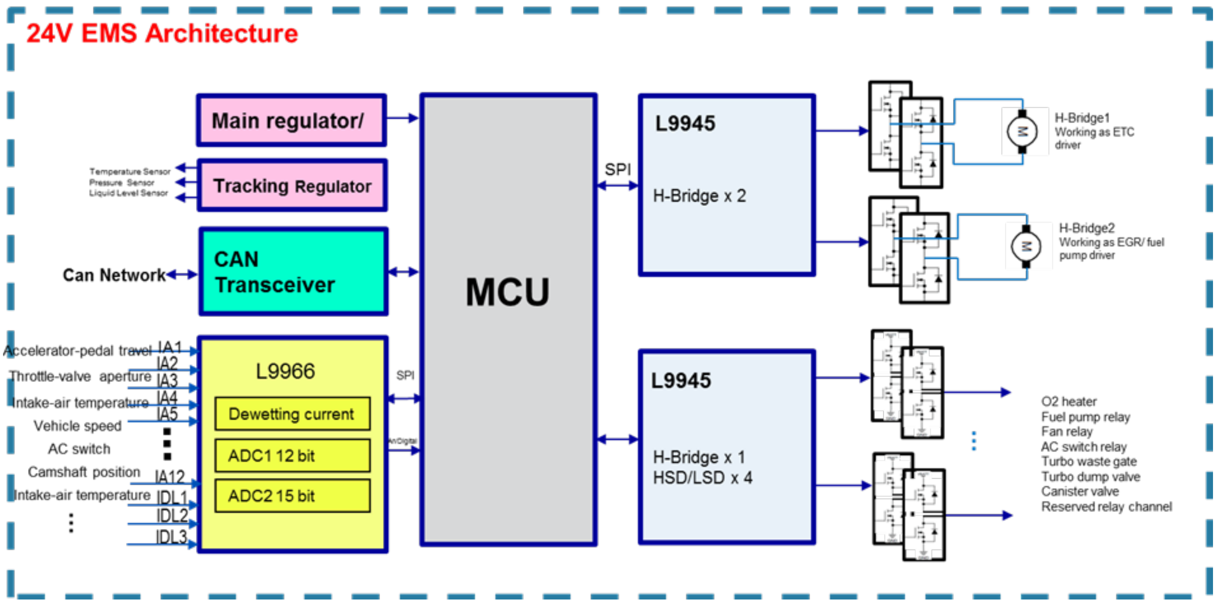
In the analysis depicted in the table 8, the accuracy required for the Carbamide Pressure Sensor is ± 0,5%.

Table 9. Feasibility analysis on L9966 fitting SPECS of air pressure sensors conventionally used in SCR application

Air pressure sensor	L9966 accuracy in voltage measurements (full range 5 V)	L9966 fits specs YES / NO
Accuracy < 1 %	0,25 %	YES
Output/Span 0,5 – 4,5 V		

In the analysis depicted in the Table 9, the accuracy required for the Air Pressure Sensor is < 1 %.

Figure 12. Diesel EMS: block diagram



Regarding the potential use of the L9966 in the block diagram of the Diesel EMS application (see Figure 12 for more details) the following Table 10 analyzes the feasibility.

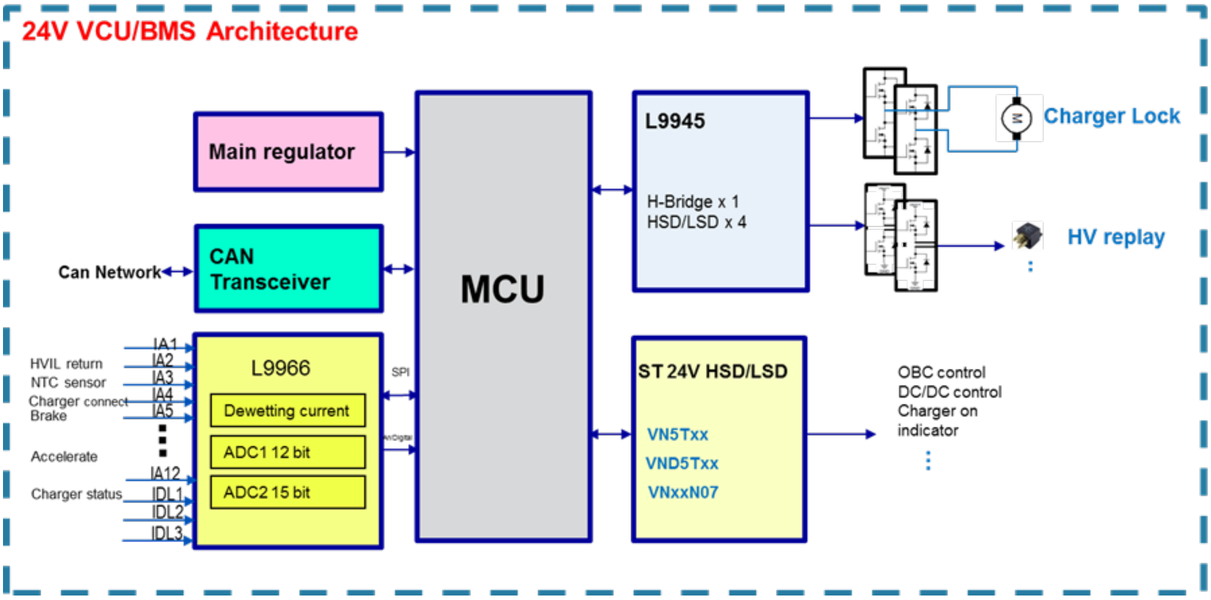
The last column of these tables shows if L9966 fits or not the specifications, in terms of accuracy, of the considered sensor.

Table 10. **Feasibility analysis on L9966 fitting SPECS of Intake-Air temperature sensors conventionally used in diesel EMS application**

Intake-Air temperature sensor	L9966 accuracy in resistance measurements in range (100 Ω – 100 KΩ)	L9966 fits specs YES / NO
(application accuracy request)*(sensor transfer-function) = ± 1 °C * [0,8-1,6] Ω/°C = [0,8-1,6]%	1,5 %	YES
Sensor resistance range = [100 Ω - 100 KΩ]		

In the analysis described in the Table 10, the accuracy required for the Intake-Air Temperature Sensor is of ±1 °C. The result of this analysis shows that L9966 fits the requirements in terms of accuracy of Intake-Air Temperature Sensors conventionally used in Diesel EMS application.

Figure 13. **Vehicle Control Unit and Battery Management System: block diagram**



Regarding the potential use of the L9966 in the block diagram of VCU/BMS application (seeFigure 13 for more details) the following Table 11 and Table 12 analyze the feasibility. The last column of these tables shows if L9966 fits or not the specifications, in terms of accuracy, of the considered sensor.

Table 11. **Feasibility analysis on L9966 fitting SPECS of charger status monitoring sensors conventionally used in VCU/BMS applications**

Charger status	L9966 accuracy in voltage measurements (full range 5 V)	L9966 fits specs YES / NO
Accuracy = ± 0,1 (%)	0,25 %	YES
Output/Span 0 – 4 V		

In the analysis described in the Table 11, the accuracy required for the Charger Status Monitoring Sensor is of ± 0,3 %. The result of this analysis shows that L9966 fits the requirements in terms of accuracy of Charger Status Monitoring Sensors conventionally used in VCU/BMS applications.

Table 12. **Feasibility analysis on L9966 fitting SPECS of NTC sensors conventionally used in VCU/BMS applications.**

NTC sensor (thermistor of 10 kΩ at 25 °C)	L9966 accuracy in resistance measurements in range (100 Ω – 100 KΩ)	L9966 fits specs YES / NO
(application accuracy request)*(sensor transfer-function) = ± 2 %	1,5 %	YES
Sensor resìstance range = [100 Ω - 100 KΩ]		

In the analysis described in the Table 12, the accuracy required for the NTC Sensor is of ± 2 %. The result of this analysis shows that L9966 fits the requirements in terms of accuracy of the NTC Sensors conventionally used in VCU/BMS applications.

Revision history

Table 13. **Document revision history**

Date	Version	Changes
03-Feb-2021	1	Initial release.

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