Performance Modeling of Automotive Sensors and Sensor Interface Systems using Simulink

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Abstract: ***Basically*, t*he signal delivery and quality of sensor data is of growing importance for modern automotive control applications. The use of analog signaling, which is the actual state of realization in many cases, is sensitive to the time variant effects mentioned before. This time variance is hard to consider for the control system development. In this paper we will analyze the role of the sensor in the signal supply chain and discuss approaches for digital sensor ECU communication and their potential to establish a link. The increasing legal requirements for safety, emission reduction, fuel economy and onboard diagnosis systems push the market for more innovation solutions with rapidly increasing complexity. Hence, the embedded systems that will have to control the automobiles have been developed at such an extent that they are now equivalent in scale and complexity to the most sophisticated avionics systems. This paper will demonstrate the key elements to provide a powerful, scalable and configurable solution that offers a migration pass to evolution and even revolution of automotive sensors and sensor interfaces. The document will explore different architectures and partitioning.***

Keywords: Sensor, Failure Mode and Effects Analysis (FMEA), Bus Interface, Sensor Channel, Simulink Modeling.

1. Introduction

The increasing legal requirement for safety, emission reduction, fuel economy and onboard diagnosis push the market for more innovative solution with rapidly increasing complexity. System sensing is at the same time rapidly growing. Total signal delivery analysis is becoming a must to demonstrate the relevance of the system choice. The variation of all the parameters should be assessed to design a robust and accurate control loops.

For the growing part of electronic control systems, which are currently overtaking more and more of the former mechanical functions or introducing completely new functionality in motor management, security systems , vehicle stability control and driver assistance, sensors are the required interfaces to get response from the system environment. In parallel to the growing amount of sensors that are required, the functionality of sensors changes from a pure passive detector to an active subsystem. This one has to perform its own signal processing functions like filtering, calibrations temperature compensation and communicate with other systems. For the future this trend to more intelligent sensors will continue and further functions like self-diagnosis and networking capability or even self-calibration will come up. These topics, the advantages and difficulties that are related with them will be discussed in this paper.

The paper will highlight the key element to design cost effective sensor and sensor interfaces. New sensing technologies are creating a paradigm shift in automotive. The inexorable migration from analogue shift to digital sensor communication will be demonstrated. Different sensor presentation will illustrate this trend and will show improvements of signal delivery.

2. Sensor System

The control of modern systems requires most of the time more accuracy, diagnosis, reliability, availability and durability. The values to be sensed should usually be measured as close as possible to the process to be controlled. From an ECU point of view it is possible to be controlled. From an ECU point of view it is possible to classify two types of sensors: the offshore sensors and local sensors.

The offshore sensors must sense the physical vales at a location away from the control unit; this requires an additional complexity coming from the need of power supply and communication with the sensor. In the case of local sensors the power supply and communication link are already embedded inside the ECU. Most of the time the physical valve sensed by local sensors is not strongly related to the sensor location (e.g. Barometric Pressure, Ambient Temperature).

To guaranty the information coming from a sensor the complete loop must be investigated the power-line, the sensor itself, and the communication channel. In case of offshore sensors communication is often combined with the power line to avoid additional wiring. In special cases like tire pressure monitoring, also wireless channels are in use for the communication from the sensor to the ECU. Historically unidirectional communication allowing the transmission of sensor data to the ECU was the only requirement for the data connection to a passive sensor element. With increasing functionality of the sensor systems bi-directional communication will be required. This allows changing the mode of the sensor during operation, in order to allow the variation of operational parameters, the selection of different signal sources or the initiation of even more complex functions.

From ECU point of view it is necessary to be aware of the availability and the status of the sensor thus the following actions are identified to be of increasing relevance for future sensor generations: networking , self –test, self –calibration and even self-repair.

3. Sensor connection

The sensor world is having large varieties of interfaces. For passive sensor the electronic is always required to bridge the sensor to the microcontroller with the basic function of supply and communication. There are several ways to realize this functionality and several functions where it can be implemented:

Option 1: Using discrete component

The first and long-established implementation is performed using discrete components. Resistance Bridge for supplying a sensor resistor, RC filters for anti-aliasing and amplifiers for gain settings. Very quickly the number of component increase when trimming and temperature compensation or even simple self-test has to be performed.

Option 2: Using as integrated companion

The performance and the integration of mixed signal technologies have allowed reducing the number of components on the ECU with a simultaneous increase of signal processing and self-test capability. This is achieved by smart partitioning between software running on high performance microcontrollers and sensor specific hardware companion ICs. Due to investigate a larger spectrum of the signal, which often offers additional information about the observed process and accuracy and the larger spectrum will support an evaluation of redundant information from different sensors without significant increases in costs.

Option 3: Digital communication sensors

By moving towards the smart sensor, it is now possible to shift the signal conditioning, the self-test operation, and the information communication inside the sensor. This changes the functionality of the sensor from the passive device to an independent subsystem. For that subsystem communication requirements are now defined by the application instead of the sensing element, which can significantly reduce the communication overhead because highly over-sampled processing blocks are shifted into the sensors.

The ECU only needs to power and communication with the sensor and its resources can be used more effective for the application. The step allows once more reducing the number of components and offers a new quality of communication between sensor and ECU by using secured protocols including redundant channel coding and acknowledging.

4. Sensor communication

The simple case for the data transmission with a sensor is given by sensor, which measure environment properties in the vicinity of the ECU microcontroller. Temperature sensor or atmospheric pressure sensors are typical examples for those on board sensors. Those sensors are usually connected to the ECUs microcontroller using a simple analog voltage line or a digital serial interface.

These interfaces are usually very low cost solution using a simple analog voltage line or a digital serial interface. These interfaces are usually very low cost solutions using the ADC of the microcontroller or its peripherals interfaces. But they have to be operated under defined condition of supply voltage and the low distortion by external field in order to avoid complex protection circuits for the controller inputs. Of cause local sensors can also be connected to companions ICs or even be integrated into the companion.

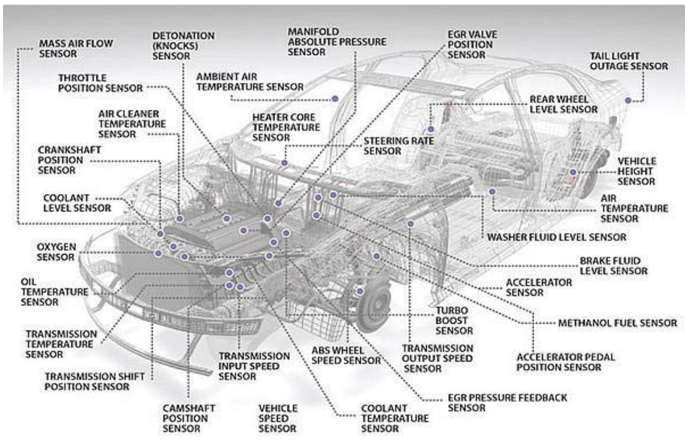

Figure 1: Automotive Sensors in a Car

But as mentioned before the majority of sensors are off-shore sensors, which are not located on the same board as the ECU. For those sensors two typical connection types are used,

- Point to point connection, mostly in combination with a special receiver or companion chip on the ECU side.
- Sensor busses, where a large variety of systems covers a wide range of requirements.

Some randomly selected sensor connections starting with very low complexity point to point interfaces at the bottom and increasing protocol effort to the top of the stack. The choice for the a suitable interface for each application has to be taken in consideration of the following criteria,

- System cost.
- Bandwidth.
- Latency.
- Determinism.
- Safety.
- Recovery actions.
- Physical layer.

5. Failure Mode and Effects Analysis (FMEA)

As it has been shown before there are lots of cost effective requirement besides the pure functionality and those are the more or less quality and safety related.

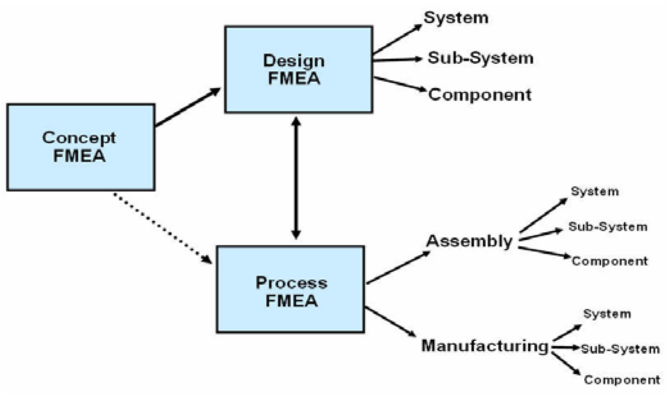

Figure 2: Basic FMEA Process

In order to go deeper into the analysis of those influences an FMEA should be performed to understand the failure modes and analyze their effects in order to weight the relevance for the system. From this analysis a strategy of test, redundancy and repair mechanism will be elaborated and adopted to make the risk acceptable to the user, but limit the effort to the required level.

Finally the FMEA is a standardized way to calculate figures of merit which help to control it measure against an individual failure have to be taken and how complex they have to be.

The growing integration density allows shifting a variety of functions from the ECU into the sensor. The resulting smart sensor now a day's usually include calibration and signal processing functions. The trends to increase the sensor functionality is ongoing and the coming functionality which will migrate into the sensors are bus interfacing and in special cases self test, self calibration and even self repair functions.

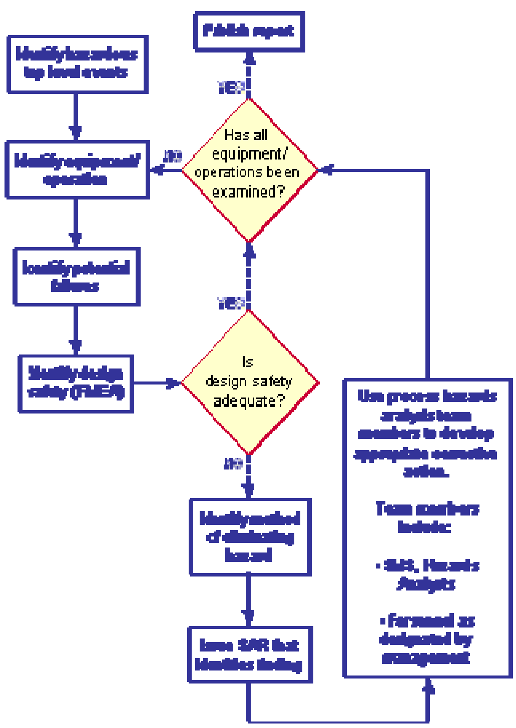

Figure 3: Operational Procedure for FMEA

The reasons, principles and enabling conditions for that additional functionality will be discussed in the following:

- Fault detection.
- Self test.
- Self calibration.
- Self repair.

6. Challenges and Objectives

The control of model systems normally requires more accuracy, diagnosis, reliability, availability and durability. The values being sensed should be closer to the physical value to be controlled. The offshore sensors must sense the physical value at the right location away from the control unit. This requires an additional complexity coming from the need of a power supply and communication channel with the sensor.

The challenge is to guarantee the right physical value will be sensed, transported to control unit without losses and the information will arrive at the right time. The complete loop must be investigated; the power –line, the sensor itself, and the communication channel. In case of offshore sensor the communication channel is often combined with the power line to avoid additional wiring. In special cases (e.g. tire pressure monitoring) wireless channel are used. Historically unidirectional transfer was the only requirement but with the increasing functionality a bi-directional communication is becoming a must. The sensor should now being able to change modes, to provide status and diagnosis information, to run calibration sequences.

7. Bus Interface

Safe-By-Wire

The safe-by-wire protocol gives also a complete definition of possible topologies, bus media, data link and application layer. It is a master/slave oriented bus, where the data communication is done over the two symmetrically modulated supply lines. The data rates are fixed by the master and ranges between 20 and 150 kbps. It also provides the possibility for smart sensor slaves to send special interrupts to signal impact events. Daisy chain slaves are also supported in every combination with parallel slaves. They provide the feature of in bus address programming and bus section isolation for fault recovery.

The S-frames are used to fast data pulling of a certain preprogrammed numbers of sensor slaves, whereas the D-frames are used to addressing a single slave for diagnosis, writing, reading of deploying purpose. The data in the D-frames is protected by an 8 bit CRC. In the S-frames the data is from every slave is secured by a 3 bit CEC. The failure recovery possibility from shorts is the same as for the BST bus.

LIN

The LIN (local interconnect network) bus falls into category A of the SAE busses. Its maximal data rate of 20kbps is not suited for high speed transmission or time critical applications. But it's cheap solution and high availability gives it a big market share in diagnosis and general purpose communication. LIN is a single master multi slave protocol. All participants are connected in a "wired AND" fashion to the single communication line. In this way they can pulled down to the recessive high level (='1') down to the dominant ground level (='0'). Every communication frame is initiated from the master. The master part of the frame contains synchronization and the identifier field. The synchronization field is used by the slaves so that the cheap on chip oscillators can be used to fulfill the timing accuracy.

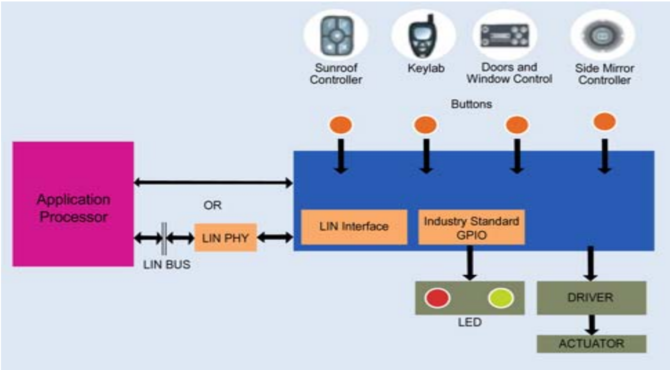

Figure 4: Working with LIN Protocol

The following six bit long identifier is secured by two parity bits. The data after the master task can be sent by a slave or by the master itself. It contains up to eight data types and one checksum byte. If an error in the identifier parity or the checksum is detected then the slave sets an internal error flag, which can be retrieved by the master for fault confinement. When a sending unit is detecting an error with its read back logic it aborts the transmission. The master can send the bus into the sleep mode by broadcasting the sleep command. The sleep mode can be interrupted by any bus participant by sending 8 bit of dominant '0'.

CAN

The CAN (Controller Area Network) is a very flexible serial multi master bus protocol. The basic specification covers only the data link layer, where as the physical layers is generally left open to be optimized in the application. But there exist specification for hardware layers with different application in mind, like that the ISO 11898-2 for high speed CAN or the ISO 11898-3 for low speed fault tolerant CAN or the SAE J2411 for low speed single wire can.

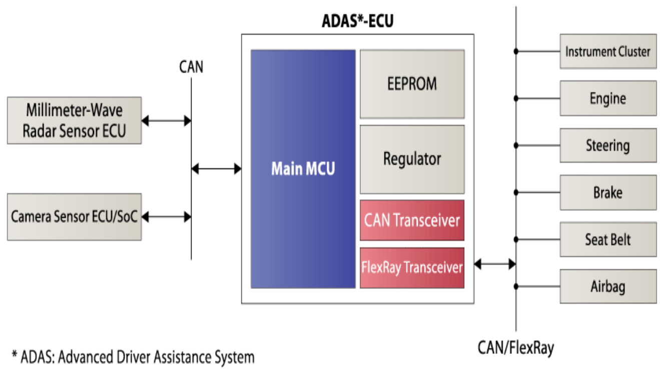

Figure 5: ECU Interface with CAN

The common part of all CAN hardware layers is need for a recessive and dominant bit. For example, in case of a wired-AND implementation of the bus, the 'dominant' level would be represented by a logical '0'and the 'recessive' level by a logical '1'. CAN is a synchronous interface, so the clocks of the nodes have to be resynchronized continuously and a stable time base has to be used.

Every node can initialize a data frame if it detects a bus state. It two or more stations are competing; the one with the highest priority is selected during the sending during the sending of the identifier (arbitration field). This is made possible by the recessive and dominant bit definition. The last bit in the arbitration field is the remote transmission request. It follows the control field for the data length, the data field itself (only in data frames), the CRC field (15 bit +1 delimiter), the acknowledge field and the end of the frame. Every frame has to be divided by a certain inter-frame space.

If an error in the CRC, Frame composition, acknowledge, transmitter monitoring or bit stuffing is detected an error frame is sent immediately. This prevents other station to accept the message. The sender tries to resend the message immediately after the error frame (competing with other station for priority). Fault tolerance of the hardware layer can be achieved with the two wire symmetrical modulation at low speeds (up to 125kbps for ISO 11898-3). If line wire has a failure the data can be transmitted asymmetrically over the second line.

8. Strength and limits of sensors

Sensor channel

Using a classical model from information theory a communication system consists of a source, a channel and a sink. The source sends information into the channel and the sink receives information from the channel. The difference between the received information and the transmitted information is the loss of the original information due to the transportation and the additional noise that is added in the channel due to electromagnetic interference. In our case the source and sink are obviously the sensor and the ECU.

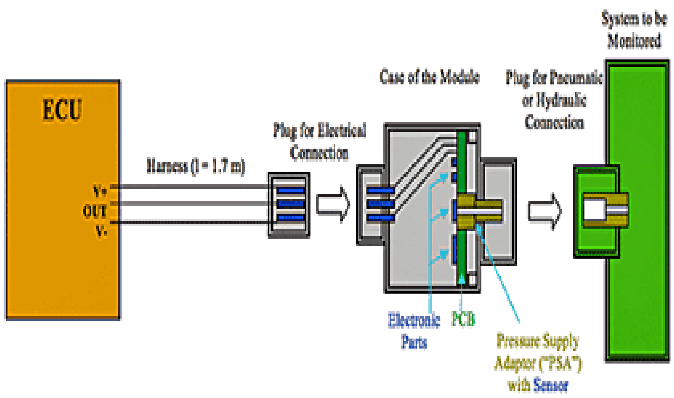

Figure 6: Sensor module design improves automotive electrical integration, functionality

The characteristics that has to be assumed for the source and sink of information is ideal, which meals that the data is available at the sensor side with a defined precision that is sufficient for the application running on the ECU side. The delivery of this ideal information has to be carried out by use of the channel.

The channel is much more complex to define than the source and sink of information, physically it obviously consist of the connecting elements, which may be a twisted of wires for example and a connector. But it also has to include functional block like coders' modulators, converters and drovers that convert the ideal information into electrical signals for the transmission. These blocks are located at the input side of the channel. Evidently the opposite operations like filter, receivers, comparators and decoders on the receiver side also have to be taken into account. These elements are mainly responsible for the loss of information in the channel which is caused by damping and delay of the transmitted signals.

Quantization is a heterogeneous topic that can be modeled as loss or as additional noise that is added to the signal. For our discussion of the channel we will model it as quantization noise source, which is the common approach in electronic design. The "noise" injection from the environment into the channel can be divided into two main parts, the short range crosstalk from adjacent wires in a bundle of cables and the interference caused by radiated electromagnetic field form distant sources.

However the definition of the interference effects in the channel is complex and would lead to different results depending on individual configurations of sensor applications in different cars. Electromagnetic fields that have to be expected in the surrounding of a sensor cable depend on the neighborhood of the sensor cable and are individual for each application and each car type.

Analog Voltage Interface

The analog voltage interface in one of the most common types of sensor connections. It is usually specifies as a so-called radiometric signal, which means that the signal is varied within a defined ratio with respect to the supply voltage. Usually there are upper and lower clamping limits in a distance of few percent from each supply rail, which allow simple fault detection if a signal is shorted to the supply. The covered faults are shorted wires and faults that are detected by the test mechanism on the sensor and pull the output voltage actively to one of the supply voltages.

However the signaling capability to transmit additional information from the sensor to the ECU is very limited. Only two different states which are pulling up and pull down are available and the detectable faults have to be clustered into two groups that are assigned to these two error signals. Typical representatives of sensors using analog voltage interfaces have been shown with the MAP sensor and the linear hall sensor.

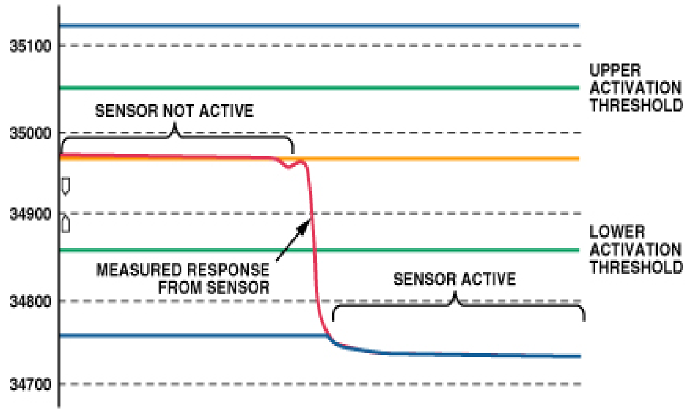

Figure 7: Waveforms showing Reduction in Sensor Efficiency

The transmitter in an analog interface is usually a buffer amplifier that is used to drive the signal over the transmission line. Hence as actual sensor mostly employ digital signal processing as actual digital to analog converter often has to be considered prior to the buffer. The last effect that is not directly related to data transmission, but has a significance influence, is the EMC protection of the analog output of the sensor and the analog input of the ECU. For the purpose the minimum protection for the sensor is a capacitor between the output voltage and ground. At the receiver side the external elements are typically passive low pass filters minimally in form of a serial resistor and a capacitor. This has two main functions which are attenuation of out of band noise and EMC protection of the receiver.

The ECU usually needs the measured values in a digital representation again which requires an analog to digital converter at the input. The ADC's reference is the supply voltage which is used for the sensor. This will cancel out the ratiometricity of the sensor signal. The need for the same signal as sensor supply and references voltage for the receiver requires a third wire to be included into the sensor channel. The reference input should see the same filter as the signal input in order to avoid coupling through the reference input.

Finally we can summarize that all measures to improve the delivery quality of analog signals except the detection of voltages above and below defined clamping limits are of physical nature.

Time based interfaces

Two possible variants of time based interfaces are the frequencies interface and the PWM interface. The frequency interface directly transmits the zero crossing of a measured AC signal and is especially important for incremental speed and position sensors. Theoretically it would also be possible to convert measured values into a frequency and transmit them in the same manner, but this would require as stable time base. For transmission of non binary measurement results on a time base the PWM is the established solution. It offers the advantage to transmit the actual time base together with the time codes values in the same protocol.

PWM is still an analog interface type; hence the signal is transmitted by a continuous change of the pulse width of the signal. Each sample is coded in the relation between the duration of the high state to the duration of the signal period, the so called duty cycle. This means compared to the voltage interface the PWM transmits discrete time samples and the rate of transmitted values is defined by the period of the PWM carrier. The advantage of the PWM is the use of two discrete voltage levels.

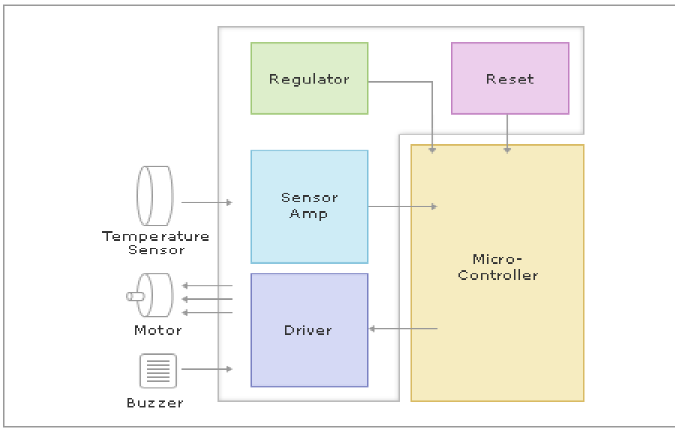

Figure 8: Interfacing Sensor with Micro-controller

Looking onto the physical level of the interface we have to consider two different types of connections which are two wires current modulated and three wires open drain configuration. For the two wire interface the current consumption of the device is modulated using levels of e.g. 7mA for low and 14mA for high. For the PWM we have to add a converter into the signal path that translates the measured values into the signal path that translates the measured values into the PWM timing information. Added noise in the PWM signal is visible in form of jitter and is generated by the clock that is used to operate those timers for the PWM signal. The last component that belongs to the transmitter is the modulated current sink that adjusts the current consumption of the sensor until the selected current level is reached.

At the receivers side we have a shunt resistor that converts the modulated currents onto a voltage together with an EMC protection capacitor that crates a low pass character in the current to voltage conversion. The comparator that is responsible for level decision and the counter that are used to evaluate the duty cycle are summarized in an additional jitter source. The open drain version of the PWM channel is similar except that the modulated current source is replaced by a switch and that the shunt resistor operates as pull up. Sensors using current modulation or open drain interfaces have been shown by the ABS wheel speed sensor and the camshaft sensor.

The hardware complexity of the current modulation interface can be estimated from the chip plot. The highlighted region is the area used for the modulated current sources, the digital control for the protocol is a minor part included in the digital area above. The ABS sensor uses only a few different pulse widths in order to transmit additional status information attached to the pulses that are used for incremental speed measurement, however the needed digital part for a PWM that transmit measured values consist only of a counter and it is not significant for the chip area. For comparison reasons it should be mentioned that the ABS sensor is roughly half the size of the previously shown MAP sensor.

Digital interface

For the digital signal in general the same facts as for analog ones are true and the signal to noise ratio SNR is still the dominant fact that describes the signal quality. But as the signal can only have 2 defined levels additional noise does not matter as long as the switching level between the digital states in not exceeded. Thus we have to convert the SNR into a property that describes the probability that a transmitted bit is received as the inverse state due to added noise.

The common definition that describes the quality of the digital transmission is the bit error rate BER. The BER is defined as the number of errors divided by the number of transmitted bits. Besides its obvious dependence on the SNR of the received signal there is a significant influence of the characteristics of noise and interference and the according protection measures that can be taken to correct the data at the receiver side. Thus differently coded message will achieve different BERs passing the same channel with a fixed SNR. The penalty paid for this coding gain is an increased count of transmitted bits for the same information.

For the physical channel properties we can assume the same configuration as for time based signal. With the different that there is no jitter source, due to the fact that the information is not coded in the timing of the protocol. For the timing in a digital interface we find the same is true as for the time based ones. It offers a high safety margin and may be varied without any effects on the transmitted information unless the decoder on the receiver side fails. Of course, the filtering of short pulses is also applicable for digital transmissions that use a defined minimum pulse length.

Failures may occur if strong interferences disturb the transmission and exceed the detection level of the logic state which is opposite to the original transmission. In case of a digital interface this is not the point at which faulty information is forwarded to the controller. In a digital protocol various protection mechanisms can be applied on protocol level. At the low level the bits are coded using a so called line code. This can be a Manchester code.

At the high level of protocol can include redundant information, which allows verification that the transmitted data is consistent. These redundant codes are known as channel codes and a wide variety for different application conditions have been developed. The simplest case of a redundant code is the well known parity bit, which is the EXOR product of all transmitted bits. It allows checking to detect if an odd number of bits in the transmitted message has been toggled. But the simple parity fails if an even number of bits has been inverted. For a better protection more complex coding schemes use different principles to generate a code alphabet out of the incoming data.

The goal of this code alphabet is to extend the number of bits that may be changed until one allowed code symbol is changes into another. This characteristics parameter of a code is called hamming distance. For sensor protocols CRCs (cyclic redundancy checking) are widely used and seems to be an appropriate choice due to the extremely hardware efficient coder and decoder structure. Depending on the length of the code in relation to the number of data bits to are transmitted the detectable number of error bits can be increased. If the distance between the allowed words into the same forbidden word, this number of bit shift is not only detectable but even correctable.

Finally it should be mentioned that there are special codes that have been optimized for the corrections of different errors. Codes that are optimal for arbitrary single bit errors are not as valuables if the typical failure is a burst error, which means that the transmission of a number of adjacent bits is disturbed. The selection of an optimum channel code requires an exact knowledge of the interference characteristics for the given channel. A typical current modulated digital interface has been used in the side airbag sensor.

9. Simulink Modeling

Simulink provides an environment for simulation and model-based design for dynamic & embedded systems. Simulink is integrated with MATLAB, providing immediate access to an extensive range of tools that help to develop algorithms, analyze and visualize simulations. The modeled system can be tested using simulation, reducing the number of hardware versions required to design the system.

A similar principle is also applicable for designing the vehicle simulator used to test automotive electronic controller units (ECU). The vehicle simulators used to simulate an automotive environment that can be designed using Simulink®. The simulated model can be auto coded using real rime workshop and then built into an executable using C compiler to run on real time operating system.

It also provides the most effective way to implement a model-based approach to design a vehicle simulation. MATLAB-Simulink will allow us to quickly create real-time simulations of dynamic systems and use them throughout the design cycle – from initial concepts, to controller design, test and validation using hardware-in-loop (HIL) testing. The target system is a PC or cluster of PCs where the simulation runs. The real-time requires a real-time operating system (RTOS). The target system allows us to perform model compilation and real-time execution, as well as scheduling any signal I/O hardware for HIL applications.

MATLAB model is running on a standard PC motherboard and controls the simulator via base module. Power moding is done by the base module. This guarantees consistency of the rising & falling edge of the power moded signals across all modules. All modules are updates at each frame of the model execution and the changes are clocked in at the end of the models frame. These modules are,

Base Module (Controller and Power Moding for the Simulator) – It provides Power moding for the ECU as well as being the digital controller interfacing to all of the modules.

- Analog Sensor Module – It provides analog voltages that are ratio metric to the ECUs power signals. Typically used to simulate sensors such as manifold air pressure, tank pressure and so on.
- Resistive Sensor Module (Sensor simulation) – It provides an adjustable termination resistor to one of the ECUs power rails. Typically used to simulate thermistor applications such as manifold air temperature, oil temperature, and so on.
- Switch Module (Sensor simulation) – It provides discrete and rotary switches terminated to the ECU power rails. Typically used to simulate door, AC, and other such switches.
- Pulsed Output Module (Sensor simulation) – It provides pulse trains to the ECU in which the user can control frequency, duty cycle and termination voltage. Often used to simulate magnetic and optical speed sensors, mass air flow sensors and so on.
- Pulse Driven Load Module (ECU Command Capture) – It allows the user to measure voltage, frequency and duty cycles of ECU outputs.
- Reference Pulse Generation Module (Engine-Specific Sensor Simulation and ECU Command Capture) – It provides synchronous pulse trains for signals such as cam and crankshaft position as well as other rotational signals.

10. Case study

1. Modeling of Temperature Sensor

A temperature sensor is a device that gathers data concerning the temperature from a source and converts it to a form that can be understood either by an observer or another device. Temperature sensors come in many different forms and are used for a wide variety of purposes, from simple home use to extremely accurate and precise scientific use.

Sensors represent the interfaces between the ECU, as a processing unit, and the vehicle, with its complex drive, braking, chassis and bodywork functions. The field of mechatronics, in which mechanical, electronic and data processing components are interlinked and cooperate closely with each other, is rapidly gaining in importance in the field of sensor engineering. Since their output signals directly affect not only the engines power output, torque and emissions, but also vehicle handling and safety, sensors, although becoming smaller and smaller, must also fulfill demands that they be faster and more precise.

Here, in this modeling we are using three different relays, as we have only three types of relay faults in automotive sensor application. These are,

- Short_to_gnd
- Short_to_Vbatt
- Open fault.

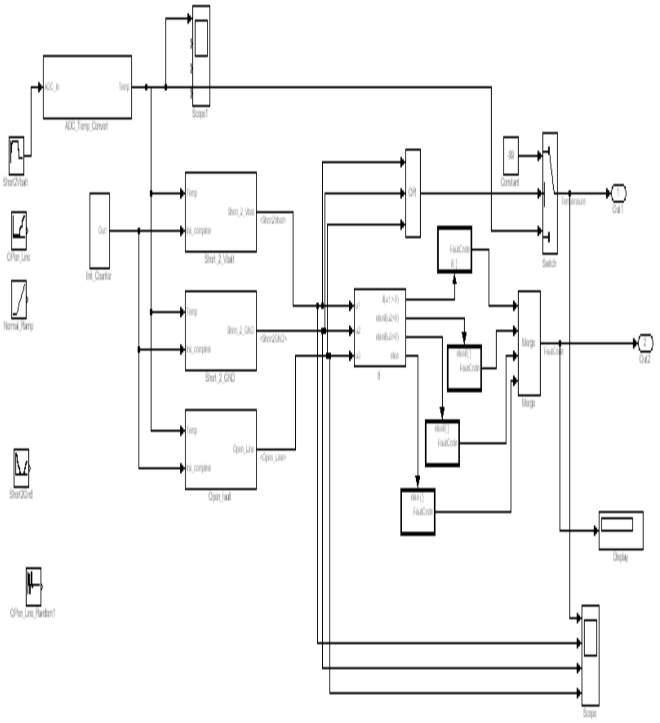

Figure 9: Simulink Modeling of Temperature Sensor

In this case study, we are considering only short_to_Vbatt fault. The following diagram gives the details about modeling.

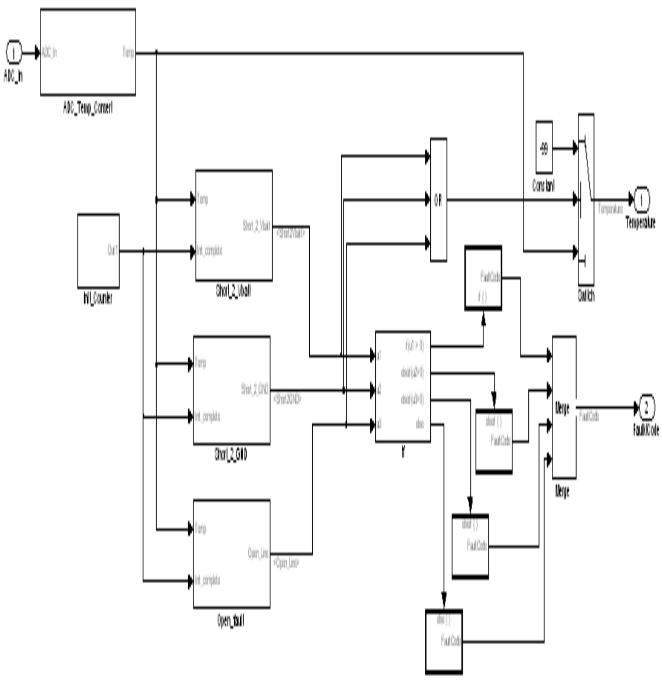

Figure 10: Modeling when relay short_to_Vbatt in process

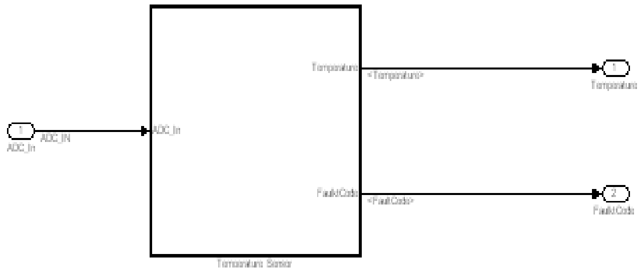

Figure 11: Temperature Sensor

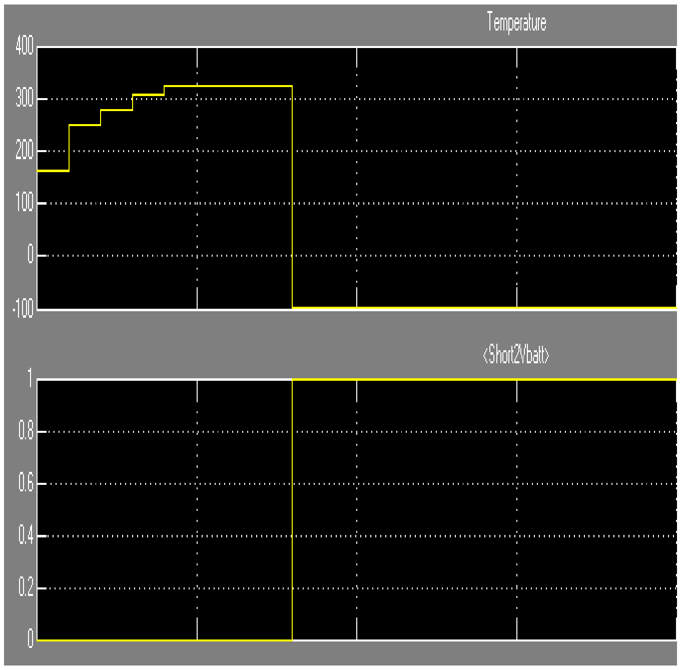

Figure 12: Output Waveform for Temperature Sensor

As seen above, the short_to_Vbatt signal will be initiated when the temperature falls to its minimum.

Features of temperature sensor

- Calibrated directly in ° Celsius (Centigrade).
- Linear + 10.0 mV/°C scale factor.
- 0.5°C accuracy guarantee able (at +25°C).
- Rated for full -55° to +150°C range.
- Suitable for remote applications.
- Low cost due to wafer-level trimming.
- Operates from 4 to 30 volts.
- Less than 60 µA current drain.
- Low self-heating, 0.08°C in still air.
- Nonlinearity only ±¼°C typical.
- Low impedance output, 0.1 Ohm for 1 mA load.

Applications

Engine temperature sensor - This sensor is installed in the coolant circuit. The engine management system uses its signal when calculating the engine temperature. The measuring range is usually from -40° to + 130°C.

Air temperature sensor - This sensor is installed in the air intake tract. Together with the signal from the manifold absolute pressure sensor, its signal is applied in calculating the intake air mass. Apart from this, desired values for the various control loops can be adapted to the air temperature. The measuring range is usually from -40° to + 120°C.

Engine oil temperature sensor - The signal from this sensor is used in calculating the service interval. The measuring range is usually from -40° to + 170°C.

Exhaust gas temperature sensor - This sensor is mounted on the exhaust system at a point which is particularly critical regarding temperature. It is applied in the closed loop control of the systems used for exhaust gas treatment. A platinum measuring resistor is usually used. The measuring range is usually from -40° to + 1000°C.

11. Modeling of RPM Sensor

A sensor is necessary to sense shaft speed. Typical devices used for this purpose are shaft encoders (rotary pulse generators), proximity sensors, and photoelectric sensors. Each of these devices sends speed data in the form of pulses. Two factors affect the quality of this data,

- Number of pulses per revolution of the shaft (referred to as PPR). Higher PPR values result in better resolution.
- Symmetry of pulses. The symmetry of one pulse to the next can play a role in consistency the RPM readings. Symmetrical pulses give more accurate data.

High Pulses per Revolution (PPR) Solutions Using the Frequency Measurement Method

For this discussion, high PPR is considered to be at least 60 PPR. When using high PPR sensors, such as shaft encoders or proximity sensors sensing gear teeth, the easiest way to determine RPM is to monitor the pulse frequency from the sensor using a digital input module and the Get Frequency command in PAC Control Professional.

When using frequency measurement as a method of monitoring RPM, the key factor is the number of pulses being sensed per revolution, or the PPR. This method works well with high PPR sensors and works poorly for low PPR sensors.

• At a pulse frequency of 1 Hz, the shaft speed is 0.1 RPM.
• At a pulse frequency of 2 Hz, the shaft speed is 0.2 RPM.
• At a pulse frequency of 3 Hz, the shaft speed is 0.3 RPM.
This means that for each increment of 1 Hz, the RPM indication will change by 0.1 RPM. With a 600 PPR sensor, the shaft speed resolution is 0.1 RPM, which meets most application requirements.

Low Pulses per Revolution (PPR) Solutions Using the Period Measurement Method

For this discussion, low PPR is considered to be anything less than 60 PPR. Because it can be measured with higher resolution (0.1 ms), measuring the pulse period is the best method of measuring RPM when using low PPR sensors, such as proximity sensors sensing a bolt head or photoelectric sensors. Period is the time from the start of one pulse to the start of the next pulse.

The main issue when using Period measurements occurs when the PPR is greater than 1 and the pulses are not symmetrical. For example, when shaft speed is constant and you are sensing two bolt heads per revolution, if the bolts are not exactly evenly spaced, the periods will be different, causing the RPM indication to be erratic.

When using the Period method, we configure the digital input with the Period feature. Use the following PAC Control Pro commands:

• Get Period Measurement Complete Status.
• Get & Restart Period.

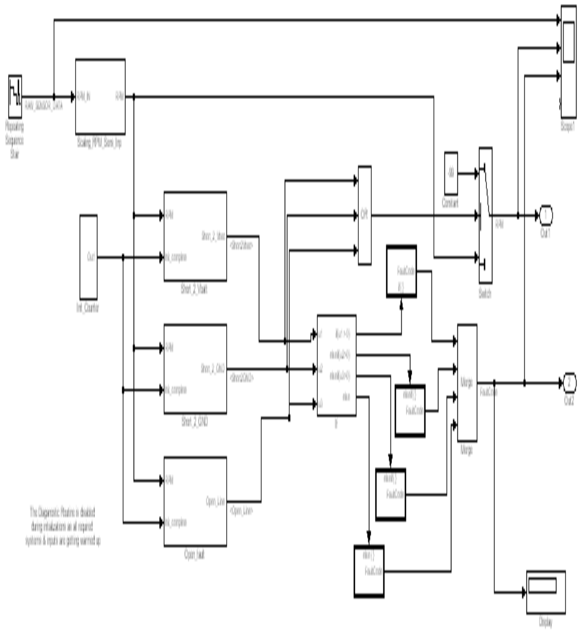

Figure 13: Simulink Modeling of RPM Sensor

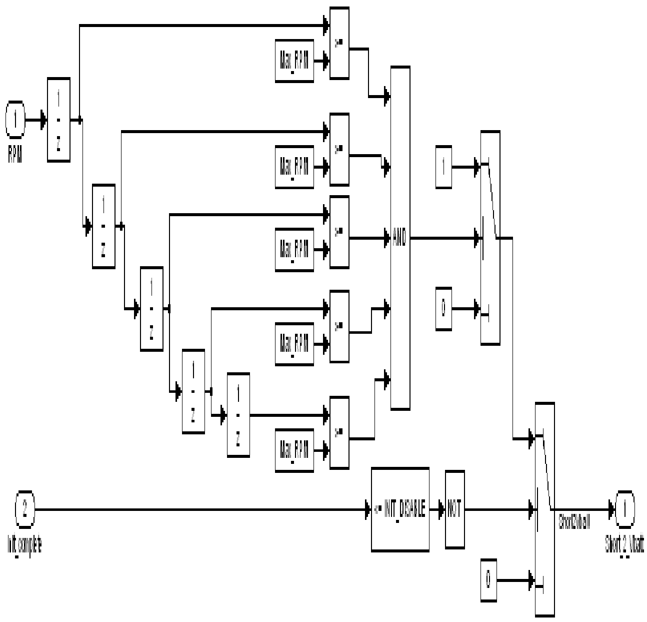

Figure 14: Delay Model for short_to_Vbatt fault

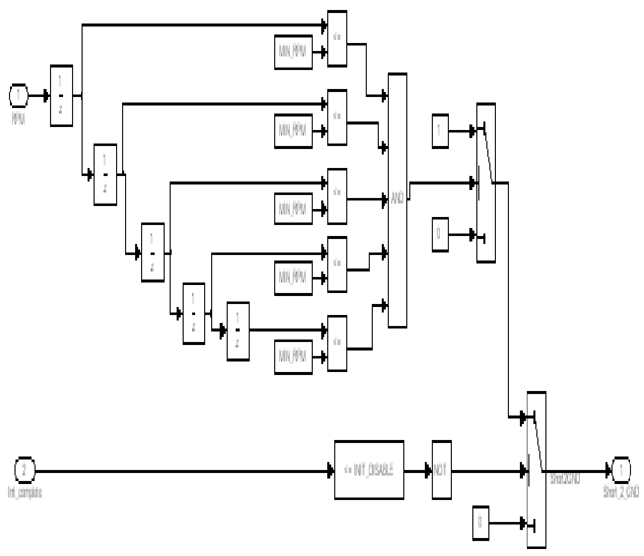

Figure 15: Delay Model for short_to_gnd fault

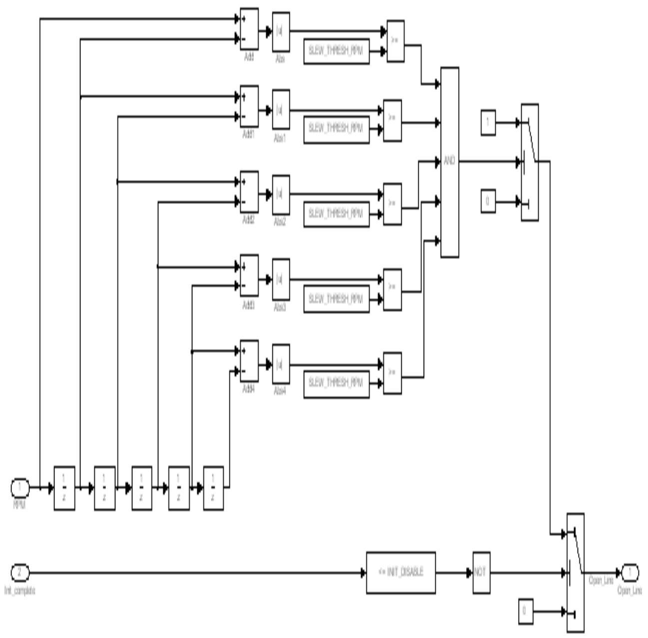

Figure 16: Delay Model for open fault

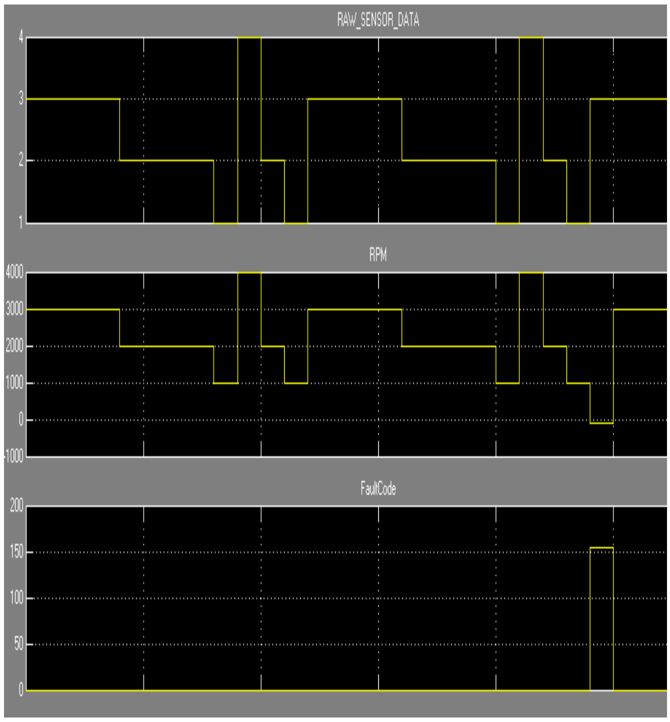

Figure 17: Output waveform for RPM Sensor

As shown above, first window shows raw sensor data value, while RPM output is given by second window.

The fault is generated when RPM signal goes to lower signal value.

12. Conclusion

In this paper we discussed the chances and challenges sensor systems may be faced with in the future. There is requirement on the ECUs side where sensor data is collected and processed has been discussed and scenarios for the coming ECU generation, which will use supply voltages below those of the sensors, have been developed.

Looking into the future we expect that each new generation of sensors will become more and more autonomous and cover functions previously done in the ECU. This sensor will preprocess the data they measure and provide their information into a sensor network, where ECUs and other sensors can receive them and make use of a more global sight on the processes that are running in the car.

We discussed that it is often required to take advantage to the knowledge about the application and the measurement principle of the sensor on order in order to allow different kinds of self-test. The same finding is true for self-calibration, which is actually restricted to very special cases of sensor systems and will not be possible in a more general way until the described networking is available.

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