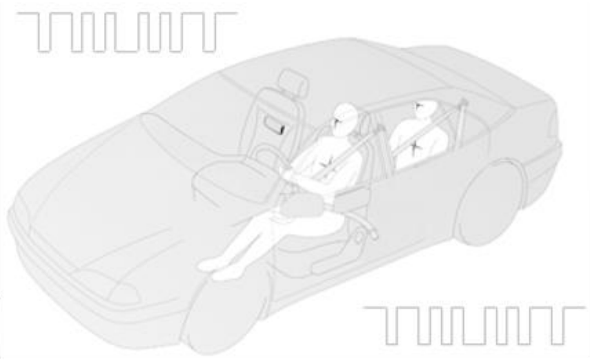
Peripheral Sensor Interface for Automotive Applications



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1 Introduction

1.1 Description

The Peripheral Sensor Interface (PSI5) is an interface for automotive sensor applications. PSI5 is an open standard based on existing sensor interfaces for peripheral airbag sensors, already proven in millions of airbag systems. The technical characteristics, the low implementation overhead as well as the attractive cost make the PSI5 also suitable for many other automotive sensor applications.

Development goal of the PSI5 is a flexible, reliable communication standard for automotive sensor applications that can be used and implemented free of charge.

The PSI5 development and the publication of the PSI5 Technical Specification V2.3, comprised by a Base Standard (this document) and three application specific Substandards (“Airbag”, “Chassis and Safety” and “Powertrain”), are responsibly managed by the “PSI5 Steering Committee”, formed by the companies Autoliv, Bosch, and Continental.

This Base Standard version is a joint development of the companies AB ELEKTRONIK, AMS, Analog Devices, Autoliv, Bosch, Continental, CS Group, Denso, ELMOS, Hella, IHR, Infineon, Melexis, NXP, ON Semiconductor, Renesas, Seskion, ST, TDK and ZF TRW.

1.2 PSI5 Main Features

Main features of the PSI5 are high speed and high reliability data transfer at lowest possible implementation overhead and cost. PSI5 covers the requirements of the low-end segment of digital automotive interfaces and offers a universal and flexible solution for multiple sensor applications. It is characterized by

- Two-wire current interface
- Manchester coded digital data transmission
- High data transmission speed of 125kbps or optional 189kbps
- High EMC robustness and low emission
- Wide range of sensor supply current
- Variable data word length (10 to 28 bit with one bit granularity)
- Asynchronous or synchronous operation and different bus modes
- Bidirectional communication

PSI5 Technical Specification V2.3 provides a new structure in terms of Physical, Data Link and Application Layer in order to ease the application of the PSI5 Interface. Due to backward compatibility established parameters according to PSI5 Technical Specification V1.3 are still valid; the alternative implementations are mainly optional and specifically indicated.

Though, general interface parameters are given within this Base Standard, application specific frameworks and conditions are given in the effective Substandards “Airbag”, “Chassis and Safety” and “Powertrain”.

1.3 Scope

This document describes the interface according to the ISO/OSI reference model and contains the corresponding parameter specifications. PSI5 standardizes the low level communication between peripheral sensors and electronic control units.

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2 Definition of Terms

2.1 Glossary

Table 1: Glossary

Term	Definition
Complex sensor cluster	Single connecting component with integrated microcontroller.
Cycle	Complete instance of the PSI5 communication structure that is periodically repeated. For example, In a synchronous communication scheme a cycle consists of a sync pulse followed by all sensor responses and the necessary idle time
Data Range	Range of values within the payloads data region A allocated for initialization, status & error messages and sensor output signal
Data Region	Part of the payload involved in the transmission of data
Frame	Ensemble of communication bits including: payload, start and error detection bits.
Payload	Part of the data frame involved in the transmission of data, status, frame control or messaging bits
Sensor	Single connecting component with one sensing element.
Sensor cluster	Single connecting component with more than one sensing element.
Serial Channel	Additional messaging option available for sensor to ECU communication by using two optional bits in each data frame, more specifically in each payload.
Serial Data Frame	Ensemble of communication bits for the serial channel comprising data, identification, configuration, cyclic redundancy and reserved bits.
Slot	Time allocation of a frame within a cycle

2.2 Symbols / Parameters

2.2.1 General Parameters

Table 2: Symbol definitions – ECU side

Symbol / Parameter	Definition
V_{CE}	ECU output voltage present at the ECU socket pins under all conditions including dynamic load such as noise or line effects
$V_{CE,BASE}$	ECU mean output voltage present at the ECU socket pins without communication (ΔI_S=0) and without synchronization pulse (static)
V_E	ECU internal supply voltage
V_{t0}	Sync slope reference voltage referenced to $V_{CE,BASE}$
V_{t2}	Sync signal sustain voltage referenced to $V_{CE,BASE}$
$I_{E,Low}$	Interface quiescent current tracking at ECU =$\sum I_{S, LOW}$
$I_{E,LIMIT}$	ECU current limitation
$I_{E,LIMIT,dyn.}$	Dynamic ECU current limitation
$\sum\Delta(I_{S, LOW})$	Total interface quiescent current signal noise limit, i.e. sum of all sensor quiescent current signal noises of all bus participants
$L_{D\ (NEW)}$	Dynamic Load, i.e. time that the ECU should be able to provide the current $I_{E,LIMIT,dyn.}$
R_E	ECU total internal resistance $R_E = R_{E1} + R_{E2}$
C_E	ECU total internal capacitance $C_E = C_{E1} + C_{E2}$
C_{E1}	ECU internal capacitance
C_{E2}	ECU capacitance at ECU socket pins

Table 3: Symbol definitions – Sensor side

Symbol / Parameter	Definition
V_{SS}	Sensor input, sensor supply voltage present at the sensor socket pins including dynamic load, such as voltage ripple and noise
$V_{SS,BASE}$	Mean voltage present at sensor socket pins without communication (ΔI_S=0) and without synchronization pulse (static)
V_{TRIG}	Synchronization pulse sensor trigger level threshold referenced to $V_{SS,BASE}$
V_{EMC}	Margin for voltage variations of the signal on the interface line due to EMC effects
I_S	Quiescent current present at the sensor socket pins
$\|dI_S/dt\|$	Sensor quiescent current drift rate
ΔI_S	Sink current $\Delta I_S = I_{S,HIGH} - I_{S,LOW}$ used for sensor to ECU communication
$\Delta(I_{S,LOW})$	Interface quiescent current signal noise limit at single sensor
$I_{S,LOW}$	Current 'low' level ($I_{S,LOW}$) is represented by the quiescent current present at the sensor socket pins.
$I_{S,HIGH}$	Current 'high' level ($I_{S,HIGH}$) generated by the increased current sink at the sensor socket pins ($I_{S,LOW} + \Delta I_S$).
R_S	Sensor equivalent internal resistance at sensor pins
C_S	Sensor equivalent internal capacitance at sensor pins

2.2.2 Communication Parameters

Table 4: Symbol definitions – ECU to sensor communication

Symbol / Parameter	Definition
T_{Sync}	Duration of sync period
t_0	Reference time base; Begin of phase 2 sync slope
t_1	Sync signal earliest start; Delta current less than 2mA; Begin of phase 1 sync start
t_2	Sync signal sustain start @V_{t2}; Begin of phase 3 sync sustain
t^0_3	Sync signal sustain time; For short sync pulse [0]
t^0_4	Discharge time; For short sync pulse [0]
t^1_3	Sync signal sustain time; For long sync pulse [1]
t^1_4	Discharge time; For long sync pulse [1]

Table 5: Symbol definitions – Sensor to ECU communication

Symbol / Parameter	Definition
T_{rise}	Rise time between 20% up to 80% in sink current slope
T_{fall}	Fall time between 80% down to 20% in sink current slope
T_{Bit}	Bit time for a single bit
T_{Gap}	Minimum gap time which must be guaranteed between two successive data frames
t_{TRIG}	Nominal trigger detection time referenced to sensor timebase
T_{TRIG}	Trigger detection window to detect the sync pulse = $t_{TRIG,max} + T_{tol\_detect} + T_{EMC}$
$T_{tol\ detect}$	Tolerance time of internal trigger detection delay at sensor
T_{EMC}	Variation time of the signal on the interface line due to EMC
t^n_{ES}	Earliest start of frame, slot n; this is the earliest time when the transceiver or any other sensor on the bus can expect that the frame no. n begins.
t^n_{NS}	Nominal start of frame, slot n; this is the nominal time when the sender (sensor) transmits data according to its own internal clock. It is the nominal time when the transceiver or any other sensor on the bus can expect that the frame, slot no. n begins.
$t^n_{NS,\ prog}$	Nominal start value of frame, slot n that is programmed to the the sensor. It is derived from t^n_{NS} by rounding up to the next discretisation value.
t^n_{LS}	Latest start of frame, slot n, this is the latest time when the transceiver or any other sensor on the bus can expect that the frame, slot no. n begins.
t^n_{EE}	Earliest end of frame, slot n, this is the earliest time when the transceiver or any other sensor on the bus can expect that the frame, slot no. n is over.
t^n_{NE}	Nominal end of frame, slot n
t^n_{LE}	Latest end of frame, slot n, this is the latest time when the transceiver or any other sensor on the bus can expect that the frame, slot no. n is over.
$t_{Slot\ 1\ Start}$	Earliest start of first sensor data word
$T_{Slot,n}$	Maximum length of frame, slot n.
M^n	No. of bits including start, data and parity or CRC bits of frame, slot n.
N	No. of time slots within one sync cycle
CT^n	Clock tolerance of the transmitter (sensor) sending the frame no. n

2.2.3 Supply Line and Bus Parameters

Table 6: Symbol definitions – Supply Line

Symbol / Parameter	Definition
R_W	Wire resistance (feed & return)
$R_{W/2}$	single wire resistance

Symbol / Parameter	Definition
R_{CE}	ECU connector resistance
R_{CS}	Sensor connector resistance
C_W	Wire capacitance (feed & return)
L_W	Wire inductance (feed & return)
$L_{W/2}$	single wire inductance

Table 7: Symbol definitions – Bus

Symbol / Parameter	Definition
$R_{W,Total}$	Overall line resistance in asynchronous mode or for each wire 'n' in parallel bus mode sum of ECU connector resistance, wire resistance and sensor connector resistances
C_B	Bus capacitance $\sum C_S$
C_{Bus}	Overall capacitive bus load $C_{Bus} = C_E + C_B$; C_W not included
C_L	Bus load capacitance at device under test
$\sum(L_W)$	Bus inductance; sum of all wire inductances
N_S	Number of sensors in bus

2.3 Acronyms, Abbreviations

Table 8: Acronyms, Abbreviations

Symbol / Parameter	Definition
ASIC	Application Specific Integrated Circuit
ECU	Electronic Control Unit
CRC	Cyclic redundancy check
LSB	Least significant bit
MSB	Most significant bit
DUT	Device Under Test

3 Data Link Layer

3.1 Sensor to ECU Communication

3.1.1 Data Frames

The data frames are sent periodically from the sensor to the ECU. A minimum gap time T_{Gap} larger than one maximum bit duration T_{Bit} is required between two data frames. Each data frame consists of *p* bits containing

- two start bits (S1 and S2), always coded as "0"
- one parity bit (P) with even parity or alternatively 3 CRC bits (C0, C1, C2), and
- a payload (D0 … D[k-1]) with *k* = 10.. 28 bit.

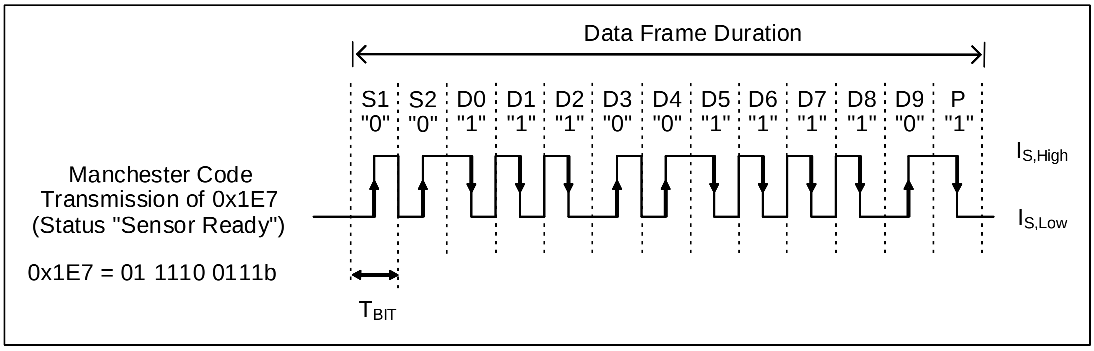

Figure 1: Example of a data frame with 10 data bits (D0-D9), 2 start bits (S1,S2) and one parity bit (P).

It follows that the total length of a data frame is *p* = *k*+3 data bits (in case of frames with parity bit) or *p* = *k*+5 data bits (in case of frames with CRC). Data bits are transmitted LSB first. The parity or CRC check bits cover the bits of the entire payload with a variable length of *k* = 10… 28 bits (with 1-bit granularity).

3.1.2 Data Frame Format

The payload of the data frame may contain one or more fields.
One mandatory:

• Data Region A	A0 … A[*n*-1]
	(scalable *n* = 10…24 with 1-bit granularity)

And additional optional fields:

• Data Region B with data bits	B0 … B[*m*-1]
	(optional 0, or scalable m = 1 … 12 bit with 1-bit granularity)
• Sensor status (error flag)	E0 ... E[*r*-1] (optional 0, 1 or 2 bit)
• Frame control	F0, …F[*q*-1] (optional 0, 1, 2, 3 or 4 bit)
	(denotes type of frame/data content, or identifies the sensor)

- Serial messaging channel   M0, M1 (optional 0 or 2 bit, see also Chapter 3.1.4)

Each optional field can be omitted in total or varied in bit length, but, if applied, the specific hierarchy of the fields must be kept as shown in Figure 2.

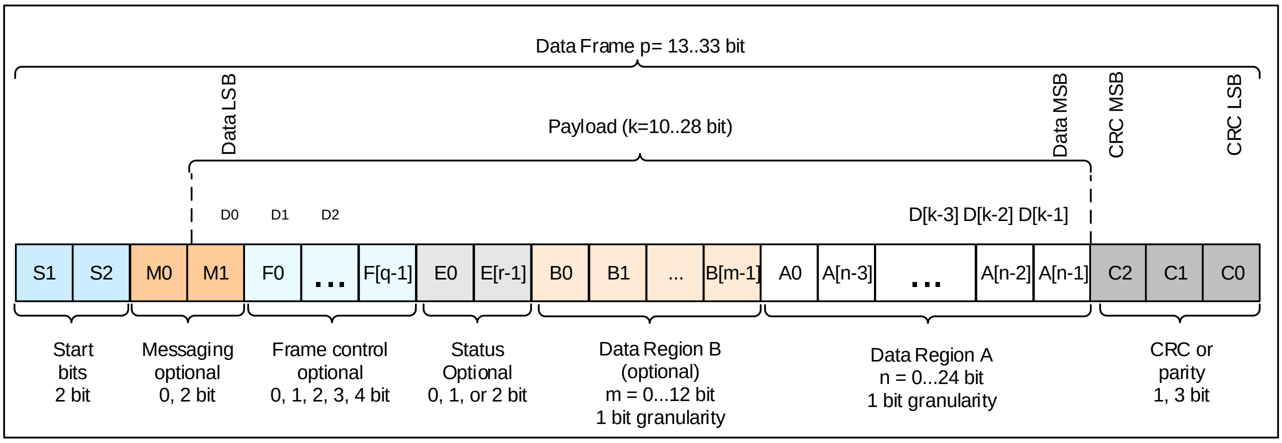

Figure 2: Different parts of the PSI5 data frame

Table 9: Different parts of the payload

Bits	Function	Number of bits	Comment
M0, M1	Messaging	0, 2	Serial messaging channel (optional)
F0 … F[q-1]	Frame control	0, 1, 2, 3, 4	(optional)
E0 … E[r-1]	Status	0, 1, 2	(optional)
B0 … B[m-1]	Data	0, 1, 2, … , 12	Data Region B (optional)
A0 … A[n-1]	**Data**	**10, … , 24**	**Data Region A (mandatory)**

3.1.3 Scaling of Sensor Output (for data words longer than 10 bit)

The sensor output signal range scales with the data word length *n*, whereas status and initialization data words for frames with a payload data region of more than 10 bits still are sent in 10 bit codes of data range 2 and 3. Hence, during Initialization with the data range method, the first 10 MSB bits of data are always used for signaling as defined in Chapter 5.2. The remaining data bits of the payload (either A[0]…A[*n*-10] or an optional Data Region B) are free to use.
The following parts of the payload are not affected by signaling range definition:

- Remaining bits above 10 of Data Region A (A[0]...A[*n*-10])
- Data Region B (optional)
- Serial messaging Channels (optional)
- Frame control (optional)
- Status (optional)

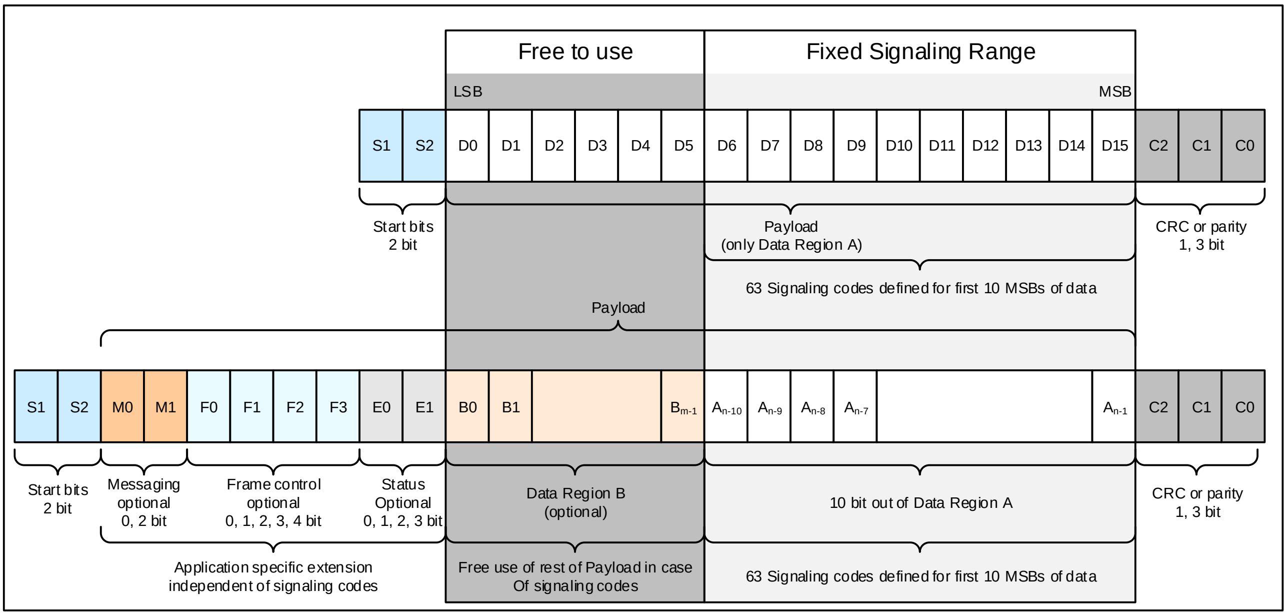

Figure 3: Scaling of data range

3.1.4 Serial Channel

In addition to Data Regions A and B, information can be sent via a serial channel. In this case, the serial message frame stretches over 18 consecutive PSI5 data messages from the transmitter as shown below. All 18 frames must be successfully transmitted for the serial value to be received. The messaging bit M1 of sensor frame No. 8 determines the serial format (12bit data field with 8bit ID or 16bit data field with 4bit ID). In synchronous operation the serial data frame, or its constituent messaging bits, respectively, is assigned to the related time slot of the corresponding data frame.

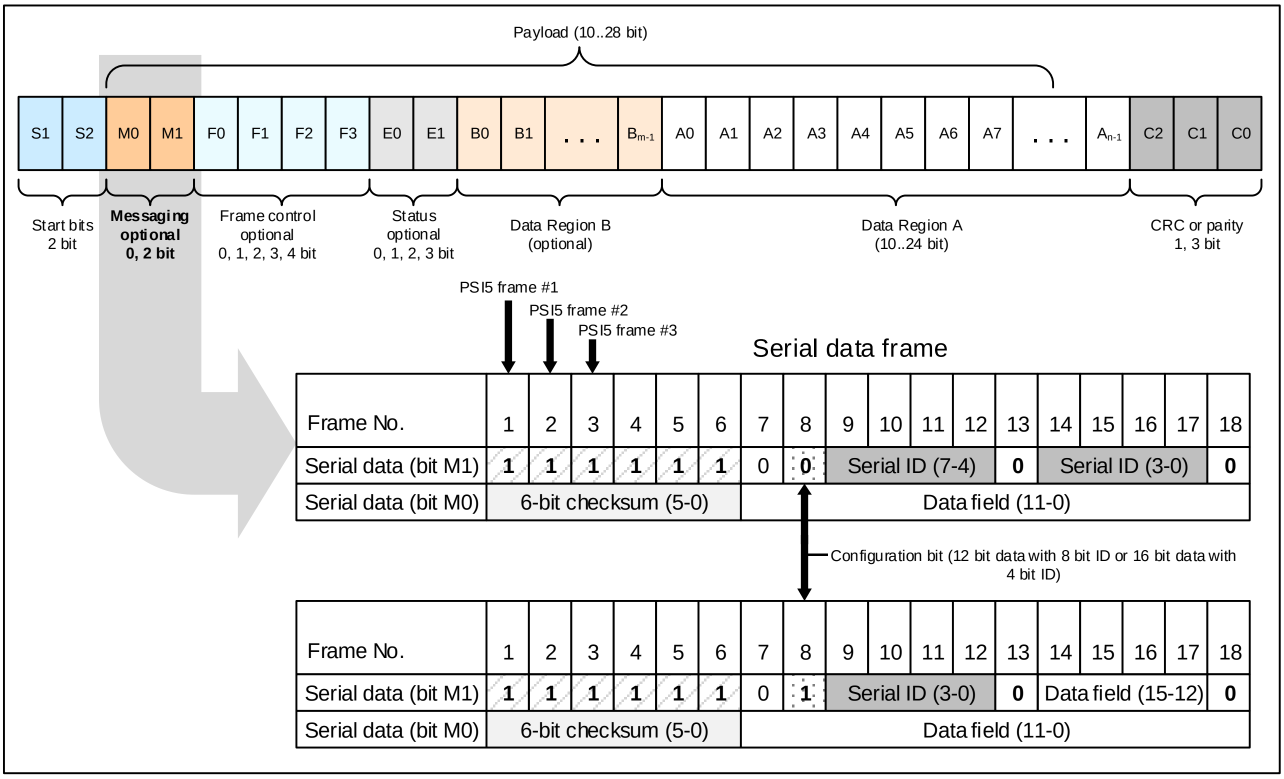

Figure 4: Serial data frame generated by the two messaging bits of the sensor data frame (messaging channel)

3.2 ECU to Sensor Communication

3.2.1 Data Frames

The frames for the ECU to sensor communication are composed by

- A specific start condition, enabling secure detection of the frame start even after loss of synchronization
- A data field
- A checksum to ensure data integrity

Transmission of a correct ECU to Sensor data frame does not have to be acknowledged in general. However, if required by the application, the sensor may send an optional response to the ECU by either transmitting a return code and return data out of the reserved data range area or via the serial channel's messaging bits. ECU to Sensor data frames are structured as described in following chapters. They are applied in different ways for the two different bit coding method in use (Tooth Gap or Pulse Width method). A combined usage of bit coding method and their respective frame types is not allowed in order to ensure safe data recognition. Specific regulations must be given in the corresponding Substandards or specific product specifications.

3.2.2 Frame Formats - Tooth Gap method

The Tooth Gap method is limited to usage of data frame formats 1-3. Frame formats 1-3 are composed by three start bits, a data field containing the sensor address, function code and data and a three bit CRC. Sensor response may be sent in data range format within the following two or three sync periods. Three data field lengths are available, "short", "long" and "xlong".

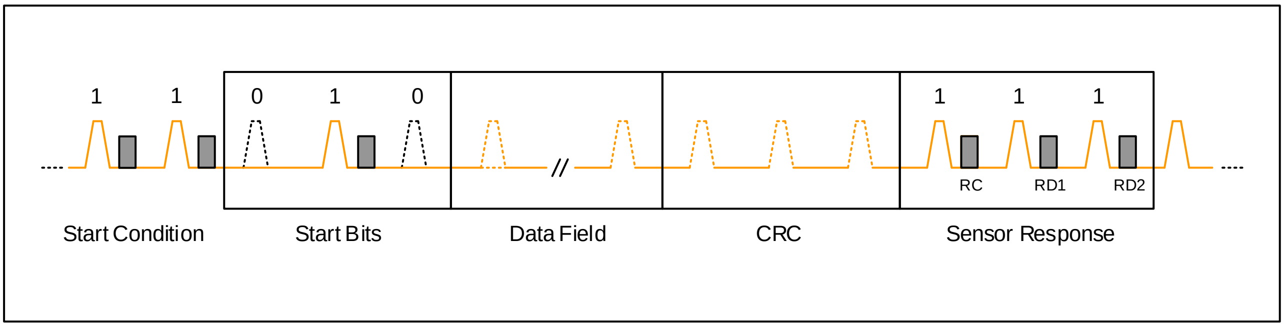

Figure 5: ECU to sensor communication with Tooth Gap method

The start condition for an ECU to sensor communication consists of either at least five consecutive logical zeros or at least 31 consecutive logical ones. The sensor responds with the standard sensor to ECU current communication in its corresponding time slot. “Sync Bits” (logical “1”) are introduced at each fourth bit position in order to ensure a differentiation between data content and start condition and to enable sensor synchronization when using the tooth gap method. The data frame length is defined by the content of the Sensor Address (SAdr) and the function Codes (FC) as shown in Figure 6. The calculation of the three bit checksum is given in Chapter 3.3.2.

Frame 1 „Short“

Start				Sadr				FC				CRC			Resp	
0	1	0	S	A0	A1	A2	S	F0	F1	F2	S	C2	C1	C0	RC	RD1

S	Synchronisation Bit [1]

N° Bits: 15+2 (8.5ms @ 500µs)

Frame 2a „Long“ (4-Bit Data Nibbles)

Start				SAdr				FC				RAdr								Data					CRC				Resp		
0	1	0	S	A0	A1	A2	S	F0	F1	F2	S	X0	X1	X2	S	X3	X4	X5	S	D0	D1	D2	S	D3	C2	C1	S	C0	RC	RD1	RD2

N° Bits: 29+3 (16ms @ 500µs); Address / Data Range: 64 x 4 Bit

Frame 2b „Long“ (8-Bit Data Word)

Start				SAdr				FC				RAdr		Data											CRC				Resp		
0	1	0	S	A0	A1	A2	S	F0	F1	F2	S	X0	X1	D0	S	D1	D2	D3	S	D4	D5	D6	S	D7	C2	C1	S	C0	RC	RD1	RD2

N° Bits: 29+3 (16ms @ 500µs); Address / Data Range: 4 x 8 Bit

Frame 3 „XLong“

Start				SAdr				FC				RAdr	Data	CRC				Resp		
0	1	0	S	A0	A1	A2	S	F0	F1	F2	S	X0-X7 + Sync Bits	D0-D7 + Sync Bits	C2	C1	S	C0	RC	RD1	RD2

N° Bits: 37+3 (20ms @ 500µs); Address / Data Range: 256 x 8 Bit

Figure 6: Data frames 1-3 for ECU to sensor communication with Tooth Gap method

3.2.3 Frame Formats – Pulse Width method

Pulse Width method uses frame format 4. Data frame 4 is composed by nine start bits, a three bit sensor address field, a configuration bit, a 20-bit data field containing application specific data and a six bit CRC. “Stuffing Bits” (logical “0”) are introduced at each seventh bit position (eight bit position for start region) in order to ensure a differentiation between data content and frame start. Transmission of a correct ECU to Sensor data frame does not have to be acknowledged in general. However, if required by the application, the sensor may send a response to the ECU by either transmitting a return code and return data out of the reserved data range area or via the serial channel’s messaging bits. All function codes and frame data content of frame formats 1-3 can also be transmitted with frame format 4 and Pulse Width method, as describes in the next section.

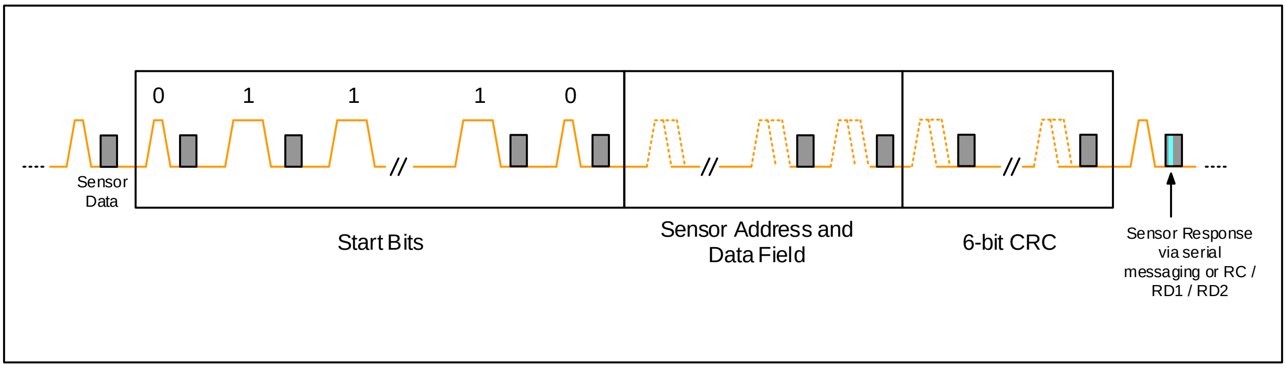

Figure 7: ECU to sensor communication with Pulse Width method

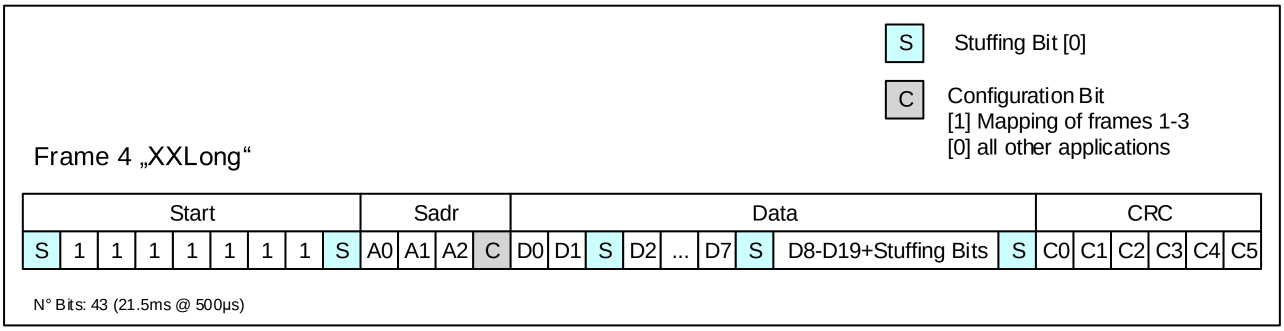

Figure 8: Data frame 4 for ECU to sensor communication with Pulse Width method

3.2.4 Mapping of Data frames for Pulse Width method

In case the function codes as defined in Chapter 5.3 shall be used in combination with frame 4 and Pulse Width method, they shall be mapped as shown below.

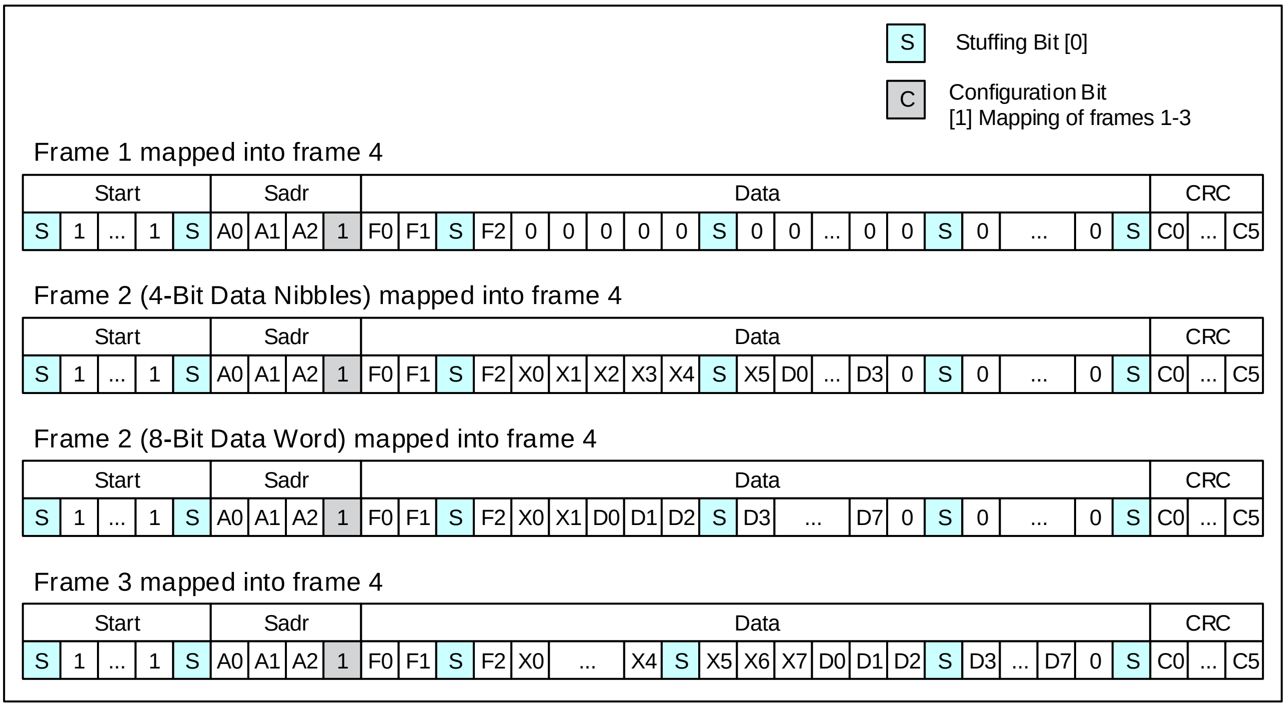

Figure 9: Mapping of frames 1-3 into frame 4

3.3 Error Detection

Error detection is embedded into all messaging schemes within PSI5. For sensor to ECU communication a single bit even parity (for example for 10 bit data words) or a 3 bit CRC (intended for longer data words) is used. In this case the 3 bit CRC comprises all payload bits (D[0] … D[*k*-1], see Figure 10). In addition the 3 bit CRC is also used for ECU to sensor communication for those frames using tooth-gap method. For both the serial channel in sensor to ECU communication and the pulse width method in ECU to sensor communication a 6 bit CRC is used.

3.3.1 Parity Bit

One error detection alternative is the use of a parity bit to verify the payload content. Here, even parity is used. It is intended for use in shorter data words, i.e. 10 bit data words, and excludes the start bits.

3.3.2 3 bit CRC

The generator polynomial of the CRC is $g(x)= x^3+x+1$ with a binary CRC initialization value “111” (MSB first) and the data bits extended by three zeros (as MSBs). This augmented data word shall be fed (LSB first) into the shift registers of the CRC check. Start bits are ignored in this check. When the last zero of the augmentation is pending on the input adder, the shift registers contain the CRC checksum. These three check bits shall be transmitted in reverse order (MSB first: C2, C1, C0).

Example: 16-bit data word „0xAD2C“ with 3-bit CRC

S1	S2	D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	C2	C1	C0
0	0	0	0	1	1	0	1	0	0	1	0	1	1	0	1	0	1	1	0	0
		C="1100"				2="0010"				D="1101"				A="1010"						

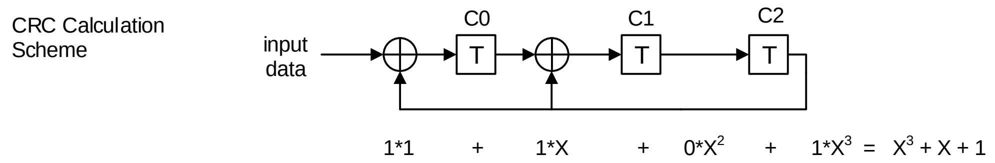

Figure 10: Bit Data word example with 3-Bit CRC

3.3.3 6 bit CRC

The generator polynomial of the 6bit checksum is $g(x)= x^6+x^4+ x^3+1$ with a binary initialization value “010101” (MSB first). In the case of sensor to ECU serial communication the CRC value is derived from the serial messaging contents of sensor frame 7 to 18, the bits are read into a newly generated message data word starting with the serial Data bit M0 of sensor frame 7 and ending with the serial data bit M1 of sensor frame 18. The reading order is illustrated in Figure 11. For ECU to sensor communication the start bits and stuffing bits are ignored in this check.

For CRC generation the transmitter extends the message data by six zeros. This augmented data word shall be fed (LSB first) into the shift registers of the CRC check. When the last zero of the augmentation is pending on the input adder, the shift registers contain the CRC checksum. For sensor to ECU serial communication these six check bits shall be transmitted MSB first [C5, C4, ... C0]. An example is given in Figure 12. In the case of ECU to sensor communication via pulse width method these six check bits shall be transmitted LSB first [C0, C1 .. C5].

Messaging bits for checksum calculation (frames 7–18)

Sensor Frame Frame No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Serial Data (bit M1)							*1*	*3*	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*	*23*
Serial Data (bit M0)							*0*	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*22*

Figure 11: Reading order for checksum generation in sensor to ECU serial communication

ID = 0x23	Data = 0x2E5

Bit receive No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Serial Data (bit M1)	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	1	1	0
Serial Data (bit M0)	C5 1	C4 0	C3 0	C2 1	C1 1	C0 1	0	0	1	0	1	1	1	0	0	1	0	1

Shift data:

D0	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23
0	0	0	0	1	0	0	0	1	1	1	0	1	0	0	0	0	0	1	1	0	1	1	0

CRC Calculation Scheme:

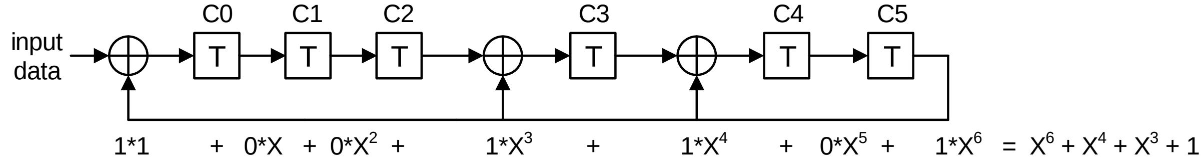

Figure 12: Example for checksum generation, 12-Bit data field, 8-Bit message ID and 6-Bit CRC for sensor to ECU serial communication channel

4 Physical Layer

4.1 General

The sensors are connected to the ECU by just two wires, using the same lines for power supply and data transmission. The ECU integrated transceiver provides a pre-regulated voltage to the sensors and reads in the transmitted sensor data. The transmission of sensor data to the ECU is done by the means of current modulation. An optional pulse modulation on the supply voltage from the ECU to the sensors can be used to synchronize sensor data transmission and to transmit data from the ECU to the sensor. For 125kbps all maximum and minimum values are specified. Implementations at other data rates, such as 189 Kbps are however possible but have to be validated on system level. Large cable lengths / inductances may require appropriate selection of sensor and ECU capacitance values and / or additional damping measures.

4.2 Supply Line Model

PSI5 usually uses twisted pair lines which are modeled as shown in Figure 13. Parameter specification is done separately for the different system configurations. All parameters are based on a maximum supply line length of 12m under assumption of standard CAN cable with a maximum inductance of 0.72µH/m and maximum capacitance of 50 pF/m. This maximum length, however, is only an indication. Depending on the wiring harness and system configuration the maximum length might vary.

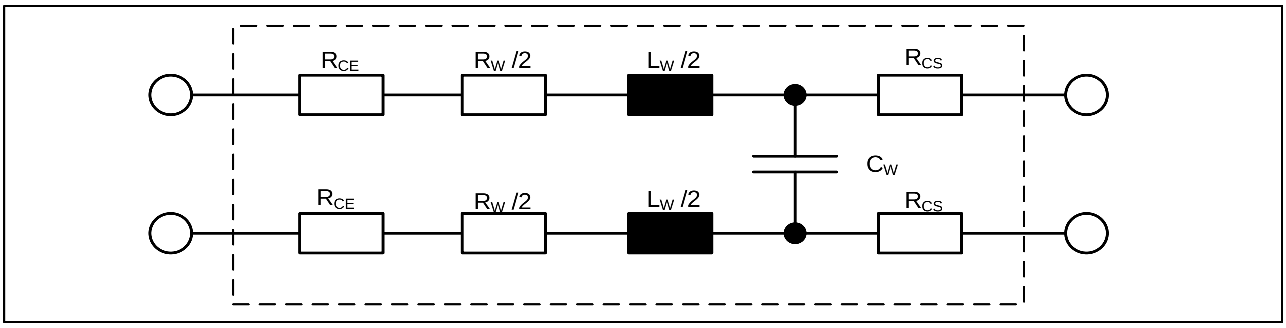

Figure 13: Supply line model for PSI5

Table 10: Parameter specification for supply line model

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1	ECU Connector resistance	R_{CE}			(0.2)		Ω
2	Sensor Connector resistance	R_{CS}			(0.2)		Ω
3	Single wire resistance	$R_{W/2}$			(0.5)		Ω
4	Overall line resistance incl. wire & connector	$R_{W,Total}$	2 * (R_{CE} +$R_{W/2}$+R_{CS})	0.1		2.5	Ω
5	Wire inductance	L_W	2 * (L_W / 2)			8.7	µH
6	Wire capacitance	C_W				600.0	pF

4.3 Single Sensor, Point to Point Topologies

4.3.1 Single Sensor, Point to Point Asynchronous Topologies (PSI5-A)

PSI5-A describes a point-to-point connection for unidirectional, asynchronous data transmission.
Each sensor is connected to the ECU by two wires to a dedicated interface of the transceiver. After switching on the power supply, the sensor starts transmitting data to the ECU periodically. Timing and repetition rate of the data transmission are controlled by the sensor.

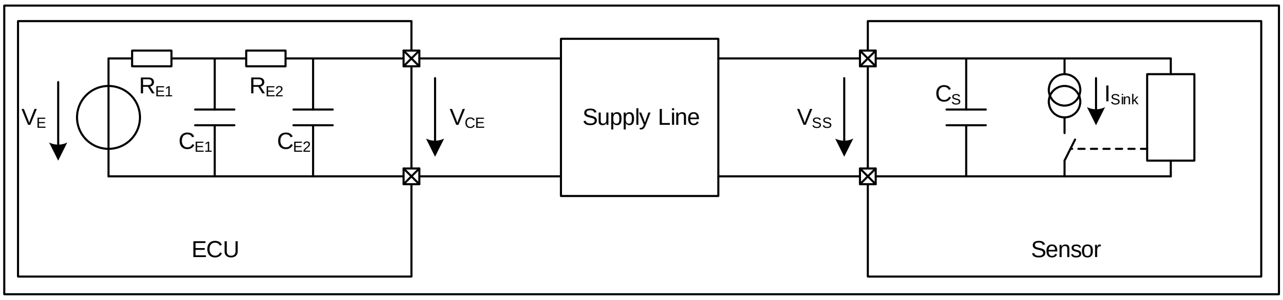

Figure 14: Single sensor configuration (simplified diagram)

4.3.2 Parameter Specification for Single Sensor Configuration

Table 11: Parameter specification for single sensor configuration

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1	ECU total internal capacitance $C_E = C_{E1} + C_{E2}$	C_E		6.0		47	nF
2	Sensor equivalent internal capacitance	C_S	@ 10…200kHz	6.0		47	nF
3			@ 200kHz…2MHz	1.32		47	nF
4	ECU total internal resistance $R_E = R_{E1} + R_{E2}$	R_E	Standard	5		12.5	Ω
5			Advanced	5		9.5	Ω
6	Sensor equivalent internal resistance	R_S		2.5			Ω

4.4 Multi Sensor, Bus Topologies

4.4.1 Synchronous Parallel Bus Mode (PSI5-P)

PSI5-P describes a bus configuration for synchronous data transmission of one or more sensors connected to a single interface of the transceiver within the ECU.
Each sensor is connected to the ECU by a separate pair of wires (star topology).

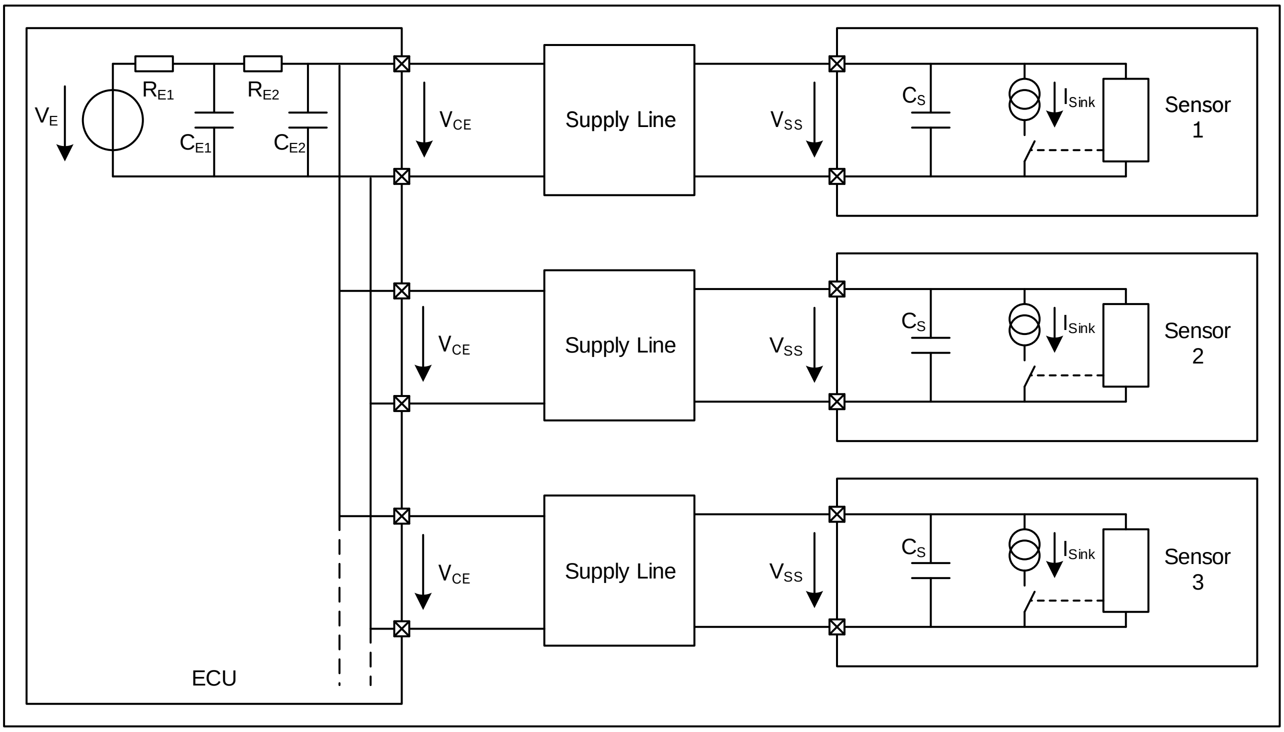

Figure 15: Synchronous parallel bus mode (simplified schematic)

In order to provide an interchangeability of different sensor and transceiver components, additional interface parameters for ECU, sensors, and wiring are specified for this bus mode in Chapter 4.4.4.

4.4.2 Synchronous Universal Bus Mode (PSI5-U)

PSI5-U describes a bus configuration for synchronous data transmission of one or more sensors connected to a single interface of the transceiver within the ECU.

The sensors can be connected to the ECU in different wiring topologies including splices or pass-through configurations. In all cases the total supply line, i.e. sum of all supply lines, shall not exceed the maximum values given in Table 12.

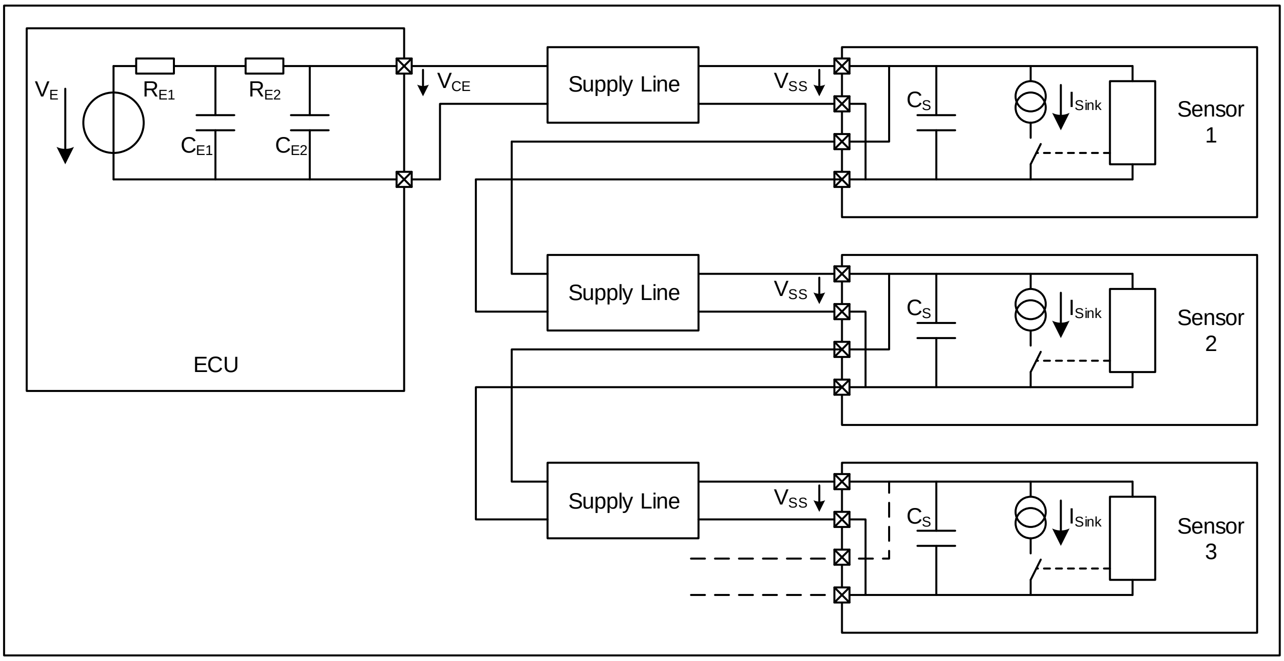

Figure 16: Example for a pass-through configuration (simplified schematic)

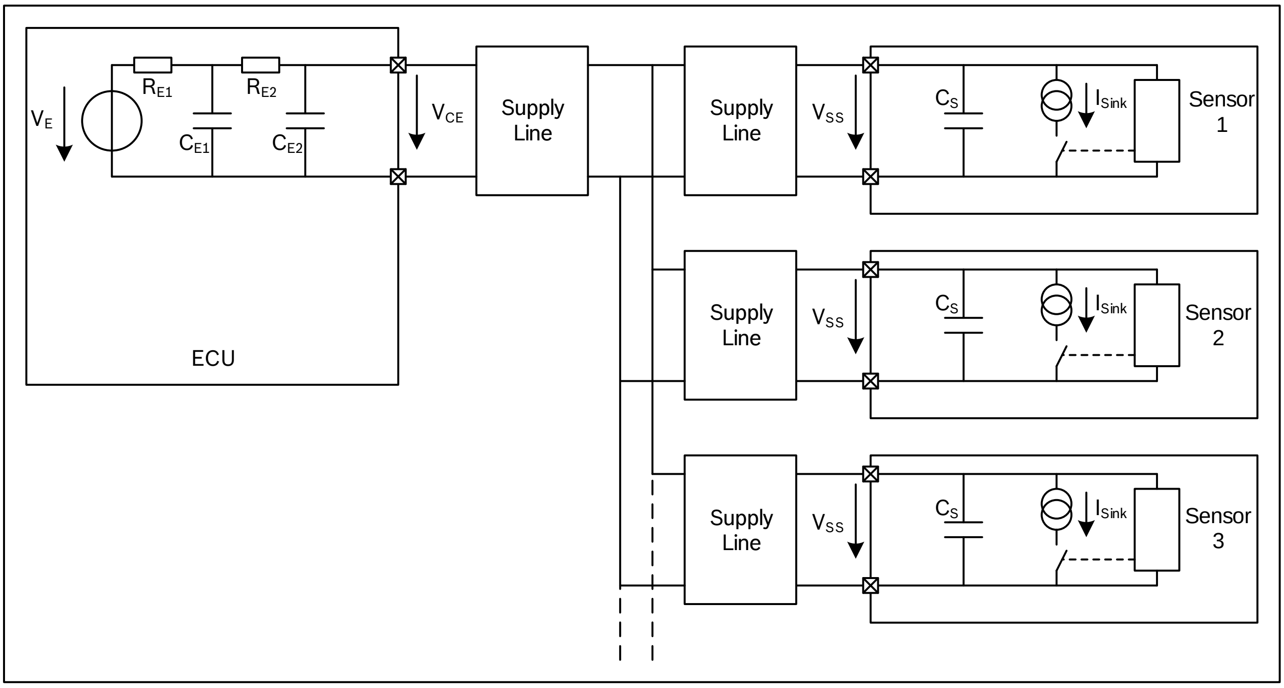

Figure 17: Example for a splice configuration (simplified schematic)

The wiring and sensors are considered as a “black box” resulting in a limited interchangeability of sensor and transceiver components. Interface parameters in Chapter 4.4.4 are given for the ECU and the “black box” only.

4.4.3 Synchronous Daisy Chain Bus Mode (PSI5-D)

PSI5-D describes a bus configuration for synchronous data transmission of one or more sensors connected in a daisy chain configuration to a single interface of the transceiver within the ECU.

The required addressing of the sensors during start up is specified in Chapter 5.3.2. Interface parameters for ECU, sensors, and wiring are specified in Chapter 4.4.4.

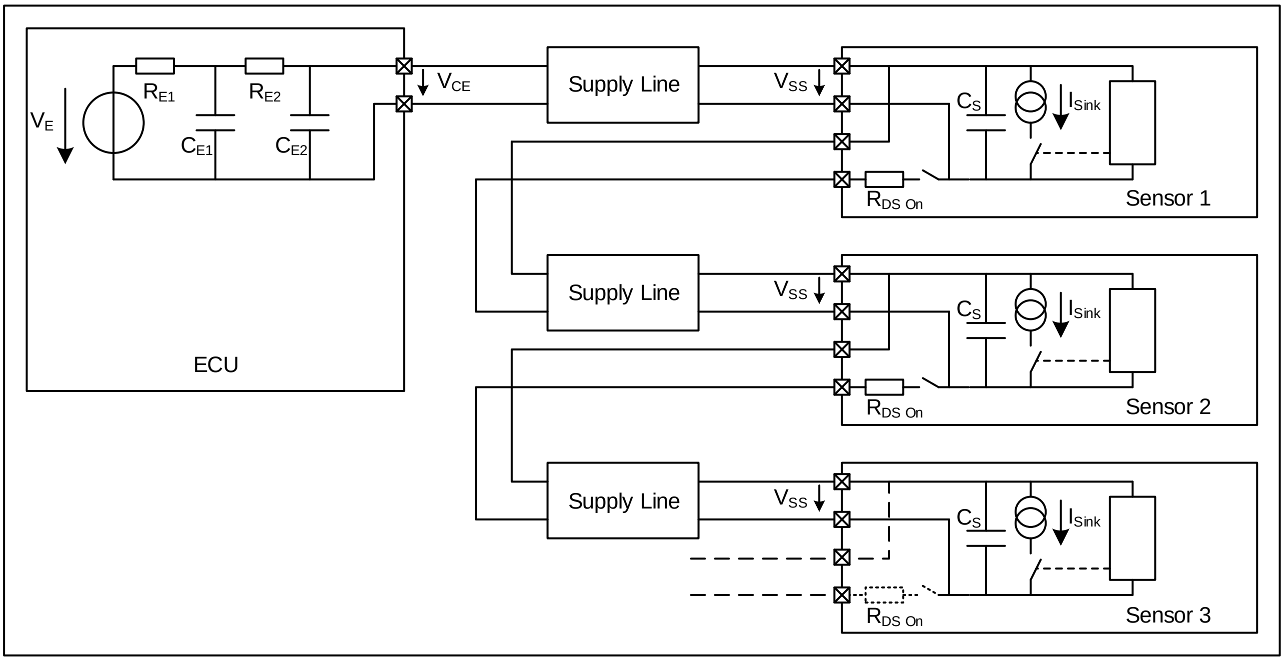

Figure 18: Synchronous daisy chain bus (simplified schematic)

4.4.4 Parameter Specification for Bus Topologies

Table 12: Parameter specification for bus topologies

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1*	ECU total internal capacitance $C_E = C_{E1} + C_{E2}$	C_E		15		35	nF
2*	Sensor (equivalent) internal capacitance	C_S	@ 10…200kHz	9		24	nF
3*			@ 200kHz…2MHz	1.32		24	nF
4	Bus capacitance	C_B	$CB=\sum C_S$	9		72	nF
5*	Overall capacitive bus load	C_{Bus}	$C_{Bus}=C_E+C_B$	24		107	nF
6	ECU total internal resistance	R_E	Standard	5		12.5	Ω
7	$R_E = R_{E1} + R_{E2}$		Advanced	5		9.5	Ω
8	Sensor (equivalent) internal resistance	R_S		2.5			Ω
9	Bus inductance	$\sum(LW)$	Sum of all wire inductance: $\sum(2 * (L_W / 2))$			8.7	µH

1*) Damping is required in ECU to limit oscillations on the bus lines.

2-3*) Maximum value for C_S is given for an out of context design; If system integration requires it C_S for single sensors can be exceeded but max Bus capacitance C_B shall not be violated and system design shall ensure proper signal behavior

5*) Wire capacitance C_W not included due to negligible value

4.5 Sensor to ECU Communication

Data transmission from the sensor to the ECU is realized by current modulation of the power supply by a sensor internal controlled source. Resulting supply line current oscillations are damped by the ECU and sensor input impedances. An exemplary sensor to ECU communication is shown in the figure below on the basis of the sensor current I_S.

- A "low" level ($I_{S,LOW}$) is represented by the normal (quiescent) current consumption of the sensor.
- A "high" level ($I_{S,HIGH}$) is generated by an increased current sink of the sensor ($I_{S,LOW} + \Delta I_S$).

The current modulation is then detected within the transceiver ASIC as a manchester coded stream, where a logic "0" is represented by a rising slope and a logic "1" by a falling slope of the current in the middle of T_{Bit} (see PSI5 data link layer definition).

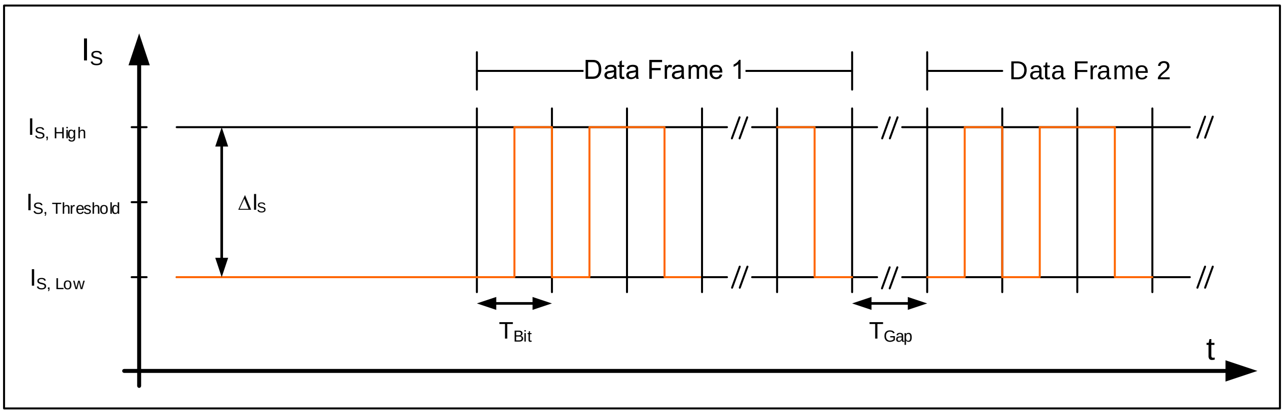

Figure 19: Bit encoding and data frame timing for sensor to ECU communication

Table 13: Parameter specification of sensor to ECU communication (related to the sensor)

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1*	Bit time (based on Standard clock tolerance)	T_{Bit}	125kbps mode	7.6	8.0	8.4	µs
2*			189kbps mode	5.0	5.3	5.6	µs
3*	Clock tolerance of the transmitter (sensor)	C_T	Standard			5	%
4*	Sensor clock deviation during data frame (see Substandard)	CD_S	Standard			1	%
5*			Legacy			0.1	%
6	Gap time	T_{Gap}	125kbps mode; $T_{Gap} > T_{Bit}$	8.4			µs
7			189kbps mode; $T_{Gap} > T_{Bit}$	5.6			
8*	Rise Time Current Slope	T_{RISE}	20%..80% (of ΔI_S)	(0.33)		(1.0)	µs
9*	Fall Time Current Slope	T_{FALL}	80%..20% (of ΔI_S)	(0.33)		(1.0)	µs

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
10*	Mark/Space Ratio	MSR	@ Sensor $(t_{fall, 80} - t_{rise, 20}) / T_{Bit}$ $(t_{fall, 20} - t_{rise, 80}) / T_{Bit}$	47	50	53	%
11	Maximum clock drift rate	ΔC_T				1	%/sec

1,2*) corresponding to a standard clock tolerance of the transmitter C_T

3*) Advanced clock tolerance refers to tighter clock tolerances needed for longer messages (see Chassis and Safety Substandard).

4,5 *) @ maximum temperature gradient and maximum frame length; the overall clock tolerance of the transmitter must not be exceeded.

8,9*) Small rise and fall times lead to increased radiated emission. Different definitions may apply for Universal Bus and Daisy Chain Bus. Parameters in brackets are given as a hint for the sensor development. Tighter tolerances might apply to the current sink in the transmitter.)

4.6 ECU to Sensor Communication

While the sensor to ECU communication is realized by current signals, voltage modulation on the supply lines is used to communicate with the sensors. The PSI5 “sync signal” is used for the sensor synchronization in all synchronous operation modes and also as physical layer for bidirectional communication.

ECU to Sensor communication is performed according to either the so called Tooth Gap or Pulse Width method as defined hereafter.

4.6.1 Tooth Gap method

A logical “1” is represented by the presence of a regular (“short”) sync signal, a logical “0” by the absence of the sync signal at the expected time window of the sync signal period. The voltage for a logical “0” must remain below the sync slope reference voltage V_{t0} specified as the sync signal t_0 start condition.

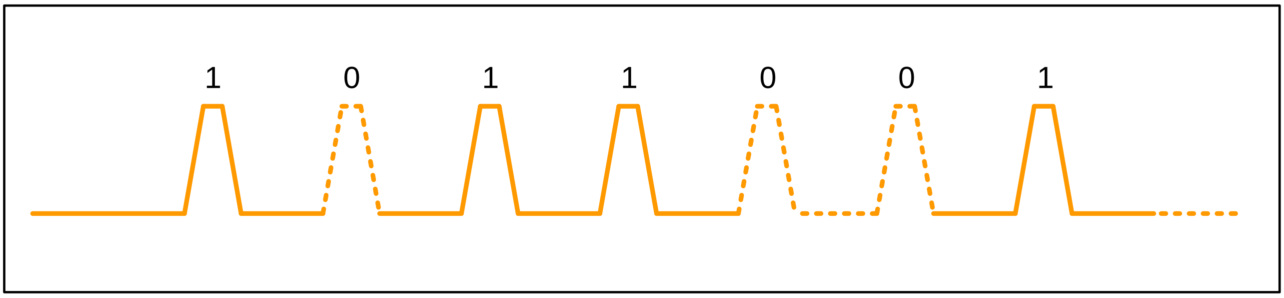

Figure 20: Bit encoding according to the Tooth Gap method

This bit encoding method is only applicable with a fixed sync signal period.

4.6.2 Pulse Width method

A logical “0” is represented by the presence of the regular (“short”) PSI5 sync signal, a logical “1” by a longer sync signal (see Chapter 4.9)

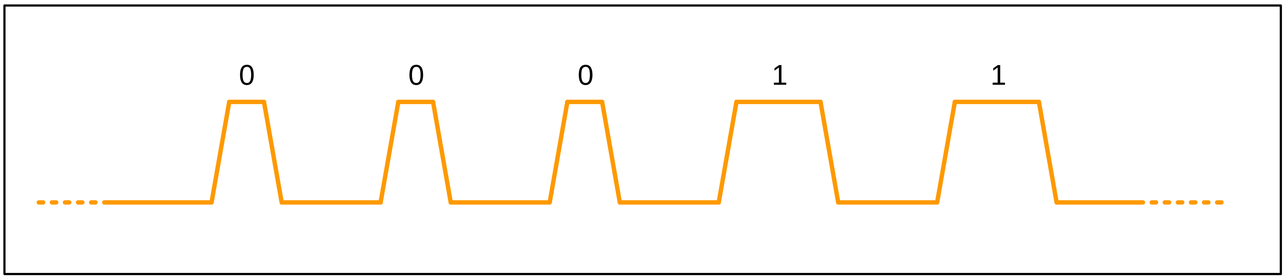

Figure 21: Bit encoding via Pulse Width method

4.7 General Parameters

In this section an overview is given of all parameters valid under all operating conditions including temperature range and life time. Detailed information is given within the corresponding paragraphs of the following pages.

4.7.1 Supply and Communication Parameters Definitions

In Figure 22 an overview of the current and voltage behavior for both sensor and ECU is shown during ECU to sensor and sensor to ECU communication.

Current behavior is given in terms of ECU current I_E, measured at the ECU connector pins. Voltage behavior, on the other hand, is given in terms of supply voltages V_{CE} and V_{SS}, which are the (resulting) voltages at the ECU / Sensor connector pins. They include static and dynamic effects of the current modulation, where the dynamic effects are originated in the dynamic sink current ΔI_S through the parasitic supply line (R_W, L_W, C_W) as well as ECU (C_E) and sensor (C_S) internal elements leading for example to ripple voltages and noise. It therefore follows that the minimum and maximum supply voltage @ sensor $V_{SS, min}$ and $V_{SS, max}$ shall not be violated during any condition. Additionally, base supply voltages $V_{CE, BASE}$ and $V_{SS, BASE}$ are defined as the static voltages at the ECU and sensor connector pin when no communication is taking place (i.e. no sync pulse or current modulation). Here, $V_{SS, BASE}$ is equivalent to $V_{CE, BASE}$ minus the static supply voltage drops resulting from interface quiescent current I_{LOW} over the supply line resistances, where additional static voltage drops over the ECU (R_E) or sensor internal resistors are not included in the base supply voltages $V_{CE, BASE}$ and $V_{SS, BASE}$.

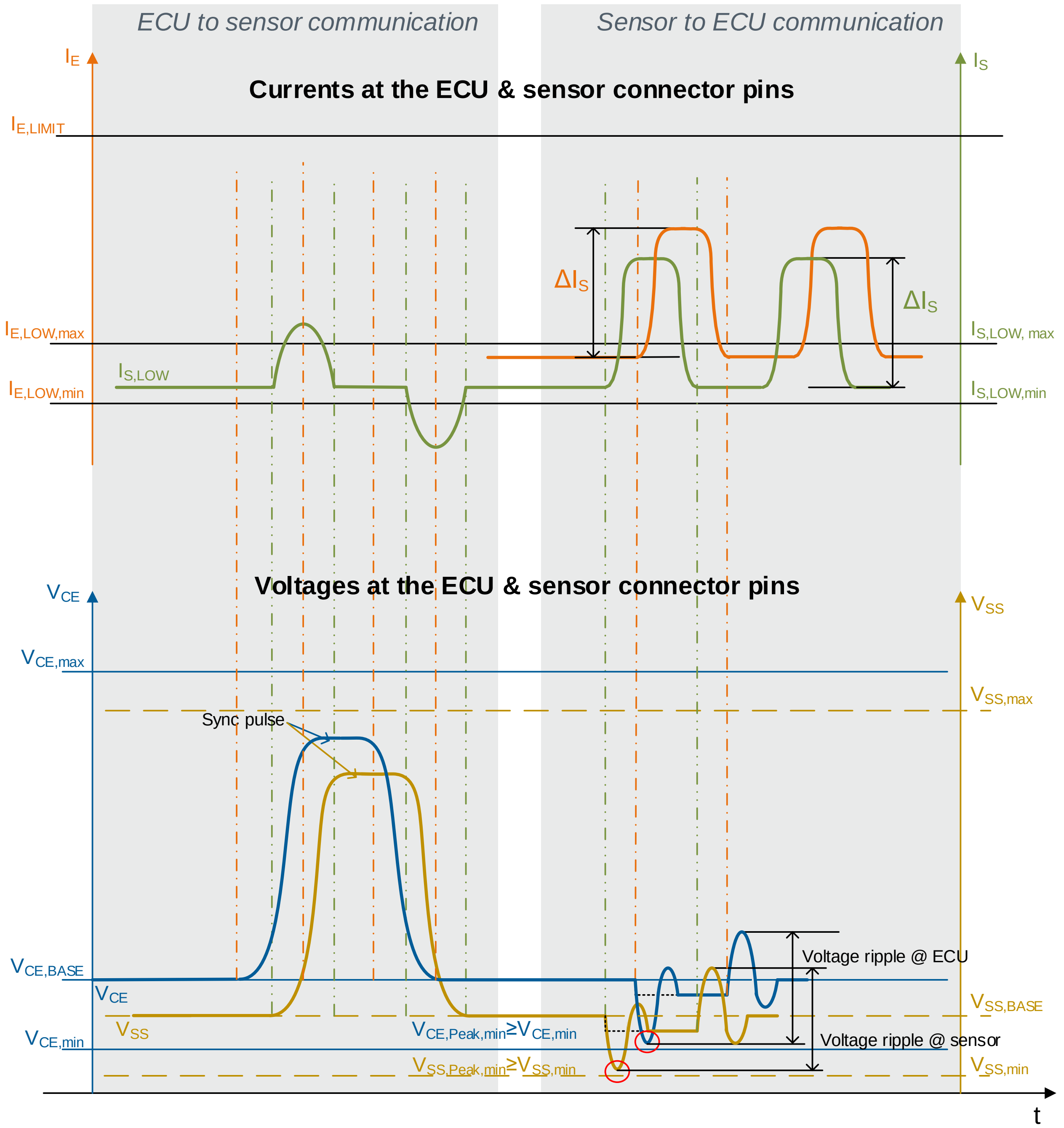

Figure 22: System current and voltage definitions

244 In the table below all voltage and current values are measured at the sensor's connector pins unless otherwise
245 noted.

Table 14: System parameter specification

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1*	Supply Voltage	V_{SS}	Standard Voltage	5.0		16.5	V
2*	@ Sensor		Low Voltage	4.0		16.5	
3*	Base supply voltage	$V_{SS,\ BASE}$	Standard Voltage;	5.0		11.0	V

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
4*	@ Sensor		Low Voltage	4.0		11.0	
5*	Supply Voltage @ ECU	V_{CE}	Standard Voltage	5.5		16.5	V
6*			Low Voltage	4.2		16.5	
7*			Increased voltage	6.5		16.5	
8*	Base supply voltage @ ECU	$V_{CE, BASE}$	Standard voltage	5.7		11.0	V
9*			Low voltage	4.4		11.0	
10*			Increased voltage	6.7		11.0	V
11	Sink current @ Sensor	ΔI_S	Common mode; $\Delta I_S = I_{S, HIGH} - I_{S, LOW}$	22.0	26.0	30.0	mA
12			Low power mode; $\Delta I_S = I_{S, HIGH} - I_{S, LOW}$	11.0	13.0	15.0	mA
13*	Interface quiescent current @ Sensor	$I_{S, LOW}$	Standard current	4.0		19.0	mA
14			Extended current	4.0		35.0	mA
15*			Daisy chain mode	4.0		12.0	mA
16*	Interface quiescent current tracking @ ECU	$I_{E, LOW} = \Sigma I_{S,LOW}$	Standard current	4.0		19.0	mA
17*			Extended current	4.0		35.0	mA
18*	Quiescent current drift rate @Sensor	$\|dI_S/dt\|$	measured after 1st order high-pass filter with corner frequency $f_{C,1}$=1Hz			10	mA/sec
19*	Current limitation @ ECU	$I_{E,LIMIT}$	Standard current	50.0		105	mA
20*			Extended current	65.0		130	mA
21*	Dynamic current limitation @ ECU	$I_{E,LIMIT,dyn.}$	Standard current with dynamic load condition	65.0			mA
22*			Extended current with dynamic load condition	80.0			mA
23*	signal noise limit @ Sensor (peak to peak, $f_{C,1} = 1Hz < f < 5MHz = f_{C,2}$)	$\Delta(I_{S, LOW})$	Standard noise limit	-2		+2	mA
24*			Extended noise limit	-3		+3	mA
25*			Reduced noise limit	-1		+1	mA
26	signal noise limit @ ECU (Σ(Sensors))	$\sum\Delta(I_{S, LOW})$	sqrt(4x$\Delta(I_{S, LOW})^2$)			+4	mA

1, 2*) In any case during normal operation V_{SS} shall not be violated. This includes dynamic effects like ripple voltage and noise.

7, 10*) Optional increased base supply voltage to overcome additional voltage drops in Universal Bus and Daisy Chain Bus applications.

5-7*) To be guaranteed by the ECU at the output pins of the ECU under all specified conditions including over- and undershoot due to changes in line load when in Universal Bus Mode and Daisy Chain Bus Mode. Tested as defined in the ECU reference test in Chapter 4.8.1.3.

13-15*) When implemented in a bus configuration $I_{S,\,LOW}$ will determine the number of sensors allowed as limited by the maximum Quiescent current @ECU

15*) In Daisy Chain Bus Mode the quiescent current limitations apply for a single sensor.

16-17*) Range of tracked current supply for sensor.

17*) Extended current range for higher current consumption e.g. in bus or sensor cluster configurations.

21, 22*) Dynamic load condition: The ECU must have the capability to provide the current $I_{E,LIMIT,dyn}$ for t_{SET1}. For Daisy Chain Bus Mode this current has to be provided for at least 10ms when a sensor is powered on (see Table 22).

23-25*) Parameters denote the sum over all bus participants. I_{LOW} is the (initial and average) quiescent current of the bus. Over lifetime and temperature, the quiescent current may vary but must not exceed the limits for I_{LOW}. Means for an adaptive current threshold may be required in the transceiver in order to cope with varying quiescent currents, especially when connected in bus systems. Data loss of the whole system as a consequence of an abrupt quiescent current drift after loss of one sensor connection also needs to be considered.

24*) For complex sensor clusters an extended noise limit is allowed and must be specified in the corresponding Substandard. Corner frequencies $f_{C,1}$ and $f_{C,2}$ are 3dB frequencies of 1st order filter characteristics. There is no noise limit for frequencies lower than $f_{C,1}$ or higher than $f_{C,2}$.

4.7.2 Absolute Maximum Ratings

Table 15: Parameter specification of absolute maximum ratings

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1*	Reverse polarity protection	I_{rev}	Standard; t < 80ms	-105			mA
2*			Extended; t < 50ms	-130			mA

1,2*) ECU to switch off the supply voltage after max. 80ms and 50ms respectively.

4.7.3 Configuration Modes & Options

In general, system parameters are grouped into two main configuration modes: “Common Mode” and “Low Power Mode”. These constitute a basic preselection of physical layer parameters. The choice of physical layer parameters compiled for common mode is supporting, due to legacy reasons, parameters from PSI5 Standards V1.3 as well as new parameters introduced since V2.0. The limitation of the physical layer parameters compiled for low power mode is done with motivation to lower the power supply needs of the interface for future applications.

In addition, from PSI5 Technical Specification V2.0 onwards, several physical layer options have been defined in order to satisfy extended application requirements. The affected parameters are:

- Supply voltage V_{CE}, V_{SS}
- Sync Signal Sustain Voltage V_{t2}, sensor trigger threshold V_{TRIG}
- Sink Current ΔI_S
- Signal noise limit ΔI_{LOW}
- Interface quiescent current I_{LOW} @ ECU
- Internal ECU Resistance R_E

Please be aware, that not all options can be combined and their selection must be made for specific applications as described in the respective Substandard. Because of this it is in responsibility of the system vendor to evaluate what features are necessary to fulfill the system requirements and assure that the combination of features is compatible.

Table 16: Parameter compilation for Common Mode and Low Power Mode operation

N°	Parameter	Symbol	Option	Remark	Common Mode	Low Power Mode
1	Supply Voltage @ ECU / Sensor	V_{CE}, V_{SS}	Standard Voltage		X	X
2			Low Voltage		X 1)	X
3			Increased Voltage 2)	Only relevant for V_{CE}	X	X
4	Sync signal sustain voltage	V_{t2}	Reduced sync pulse	Affects related parameters V_{TRIG}, V_{EMC} see Table 22	X	X
5			Standard sync pulse		X	-
6	Sink current	ΔI_S	Common Mode		X	-
7			Low Power Mode		-	X
8	Signal noise limit	$\Delta(I_{S,LOW})$	Standard noise limit		X	-
9			Extended noise limit	For complex sensor cluster only	X	-
10			Reduced noise limit		-	X
11	Interface quiescent current tracking @ ECU	$I_{E,LOW}$	Standard	Affects related parameters $I_{E,LIMIT}$, $I_{E,LIMIT, dyn}$	X	X
12			Extended		X	X
13	Internal ECU resistance	R_E	Standard		X	-
14			Advanced		X	X

1) Low supply voltage can conflict with the maximum sink current with respect to full functionality within the scope of all given PSI5 parameters. For low voltage operation additional reduction of interface quiescent current is recommended.

2) Increased Supply Voltage @ ECU can optionally be applied to overcome additional voltage drops in Universal Bus and Daisy Chain Bus applications.

<u>Voltage options:</u>

- Standard voltage operation values of V_{CE}, $V_{CE, BASE}$, V_{SS}, $V_{SS, BASE}$ in this specification have been determined by simulation under Worst Case values of current and wire parasitic elements.

- Operation with increased supply voltage @ ECU can optionally be applied to overcome additional voltage drops in Universal Bus and Daisy Chain Bus applications in combination with standard supply voltage @ Sensor.
- In particular in low voltage operation, functionality has to be ensured by system designer. Constraints on full bus mode operability are possible in single cases and depend upon parameter dimensioning of the system in total. For Common Mode low supply voltage can conflict with the maximum sink current with respect to full functionality within the scope of all given PSI5 parameters.
- In addition to supply voltage options a reduced sync pulse option can be used to ease the requirement on the sync pulse generation. The reduced sync pulse scheme is valid for new applications compliant with PSI5 Technical Specification V2.0 onwards and defined for both common and low power mode. The standard sync pulse voltage is in compliance with former PSI5 versions, still valid and defined for the common mode only.

Current options:

- For low power mode an option for a lower sink current ΔI_S is available, which will affect the functionality and robustness of system implementations within the full range of all given PSI5 parameters. It follows that for low power operation simple configurations and shorter cable lengths (e.g. in point to point configuration) are beneficial, yet a specific system validation is required. For low voltage operation additional reduction of quiescent current is recommended
- Extended noise limit $\Delta(I_{S,LOW})$ applies to complex sensor clusters in single sensor configuration
- Reduced noise limit $\Delta(I_{S,LOW})$ is valid for standard and extended current.
- Extended current range is intended for applications with higher current consumption e.g in bus or sensor cluster configurations.

Other options:

- The advanced option for R_E is to be used with advanced systems capable of using low power mode. Other systems can use the standard option.

4.8 Dynamic Bus Behavior

4.8.1 Test Network Parameters

For compliance testing purposes of either sensor or ECU as DUT a dedicated a set of network parameters for the remaining system is given in the section below.

4.8.1.1 Sensor Damping Behavior

The sensor damping behavior is described by a complex impedance Z_S containing an equivalent resistance R_S and an equivalent capacitance C_S connected in serial, as shown in Figure 23. It should be noted that both C_S and R_S have to stay within the limits given at the Sections 4.3 and 4.4 for the specified frequency range.

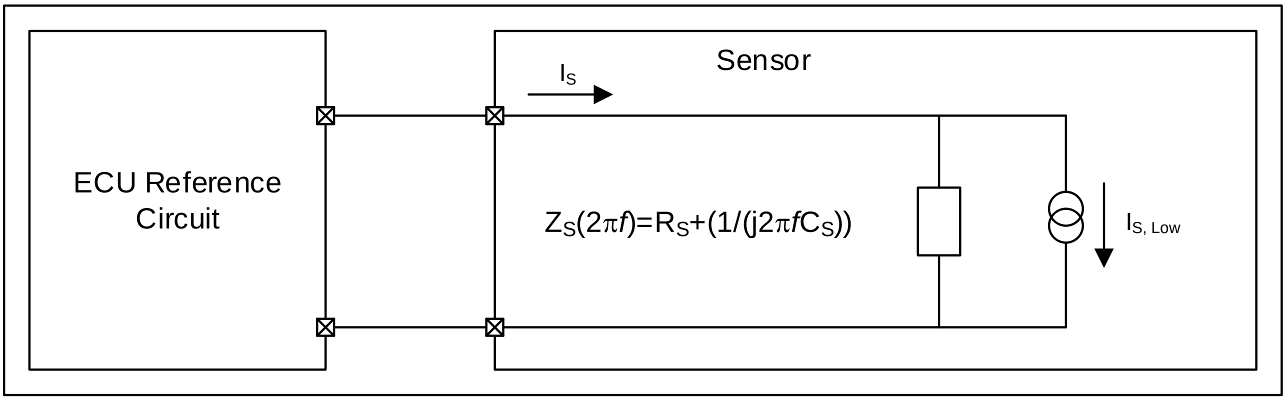

Figure 23: Reference circuit for sensor damping behavior

4.8.1.2 Sensor Testing

All indications in this section are valid for all configurations with N_S up to three sensors and for a data transmission rate of 125kbps.

Table 17: Reference network for sensor testing

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
1*	Supply voltage	V_E			11	V
2*	ECU internal resistance	R_{E1}	2.5		10	Ω
3*	ECU resistance at output pin (damping resistor)	R_{E2}		2.5		Ω
4*	ECU internal capacitance	C_{E1}	13		33	nF
5*	ECU capacitance at output pin	C_{E2}		2.2		nF
6*	Bus load capacitance @ DUT (ECU & other sensors)	$C_L = C_{E2} + (N_S-1)C_S$	2.2		50	nF

1*) Minimum supply voltage has to be adjusted to meet $V_{SS,\,min}$.
2*) Maximum internal ECU resistance R_{E1} has to be adjusted to meet the allowed R_E maximum values.
2-3*) $R_{E1} + R_{E2} = R_E$, shown in Section 4.3 and 4.4.
4-5*) $C_{E1} + C_{E2} = C_E$, shown in Section 4.3 and 4.4.
6*) Wire capacitance C_W can be omitted.

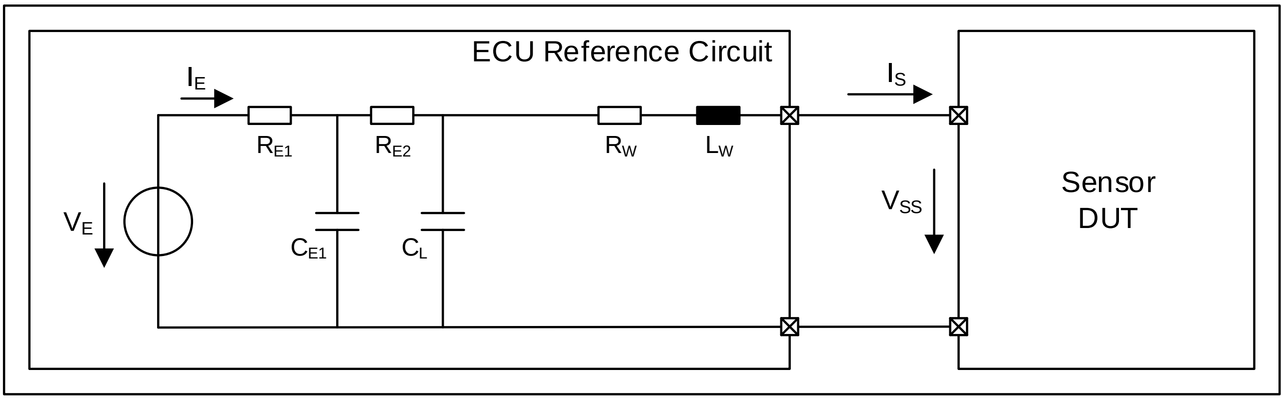

Figure 24: Reference circuit for sensor testing

4.8.1.3 ECU Testing

All indications in this section are valid for all configurations with N_S up to three sensors and for a data transmission rate of 125kbps. All other sensor parameters follow the values given at Sections 4.3 and 4.4.

Table 18: Reference network for ECU testing

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
6*	Bus load capacitance @ DUT (all sensors)	$C_L = (N_S)C_S$	2.2		50	nF

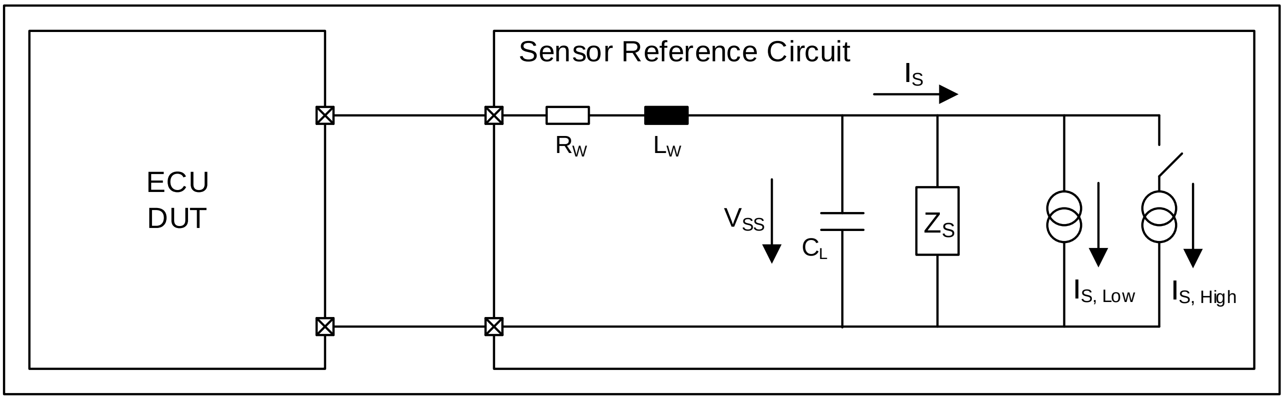

Figure 25: Reference circuit for ECU testing

4.8.2 Requirements for Dynamic Sensor Testing

In order to verify the proper sensor behavior the dynamic performance needs to be tested. To do so two test scenarios are given below: A and B. These represent the inductive (A) and capacitive (B) worst case coupling on a bus respectively. The fulfillment of the parameters below are a necessary requirement for compliance of the sensor device to PSI5 Specification. Nevertheless it is mandatory to verify the proper communication within a bus configuration in the final application. In Figure 26 and Table 19 all relevant test conditions are given.

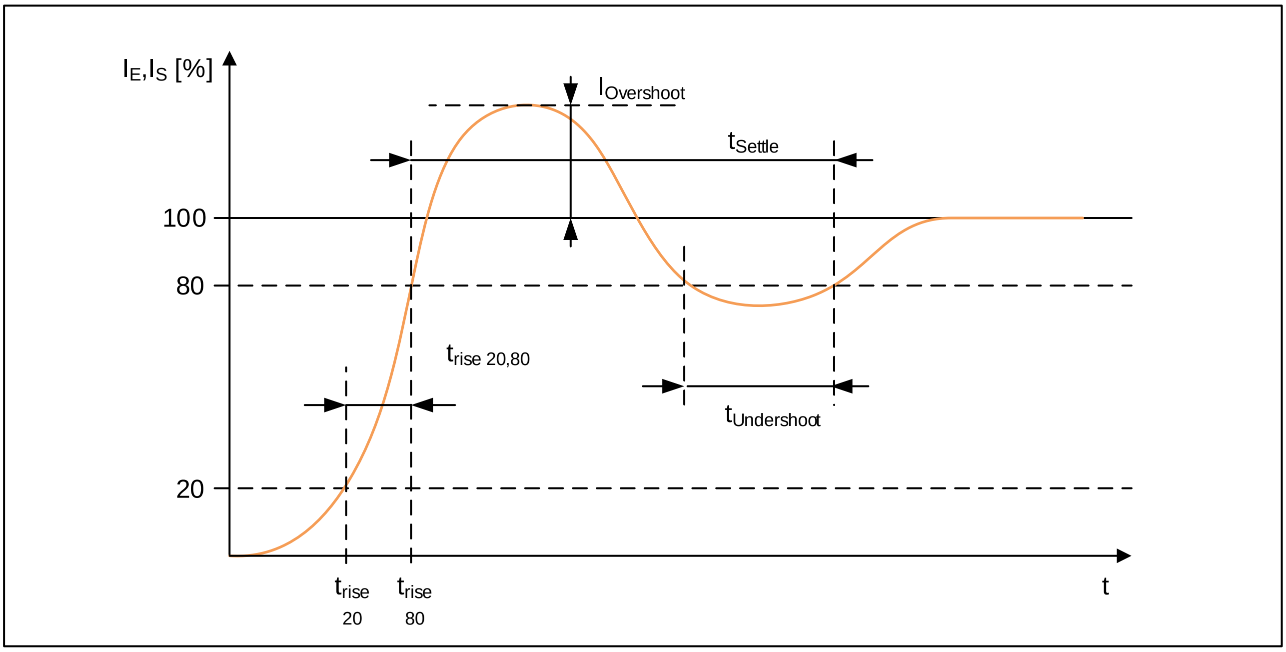

Figure 26: Dynamic behavior of supply / communication current

Table 19: Parameter specification for sensor reference test

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
A*	Worst case overshoot @ ECU					
	Test condition: R_{E1} = 2.5Ω; C_E variable between 13nF and 33nF; C_L = 2.2nF; R_W = 0.1Ω; L_W = 8.7µH					
A1	Sending current over- / undershoot @ ECU	$I_{Overshoot,\ rise}$ & $I_{Undershoot,\ fall}$ (I_S)			50	%
A2	Time for under- / overshoot @ ECU	$t_{Undershoot,\ rise}$ & $t_{Overshoot,\ fall}$ (I_E)			0.52	µs
A3	Settling time @ ECU	t_{Settle} (I_E)			1.72	µs
A4*	Voltage ripple @ Sensor	referenced to $V_{SS,\ base}$	-0.8		+0.8	V
B*	Worst case timing @ ECU					
	Test condition: R_{E1} = 10Ω (7Ω); C_E = 33nF; C_L = 50nF; R_{wire} = 2.5Ω; L_{wire} = 0µH					
B1	Sending current rise/fall time @ ECU	$t_{rise\ 20,\ 80}$ & $t_{fall\ 80,\ 20}$ (I_E)			1.8	µs

A*) The sensor has to fulfill reference Test A for every value of the capacitance C_E.

A4*) Parameter is only valid for systems in common mode operation with a minimum V_{CE} of 5.5V (V_{SS}=5.0V). For low voltage operation the maximum allowed voltage ripple can differ, but has to be validated on system level.

B*) Maximum internal ECU resistance R_{E1} has to be adjusted to meet the allowed R_E maximum values.

4.8.3 Requirements for Dynamic ECU Testing

In order to verify the proper ECU behavior the dynamic performance needs to be tested. To do so two test scenarios are given below: A and B. These represent the inductive (A) and capacitive (B) worst case coupling on a bus respectively. The fulfillment of the parameters below are a necessary requirement for compliance of the ECU to the PSI5 Specification. Nevertheless it is mandatory to verify the proper communication within a bus configuration in the final application.

Table 20: Parameter specification for ECU reference test

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
A*	Worst case overshoot @ ECU					
	Test condition: R_{E1} = 2.5Ω; C_L = 2.2nF; R_W = 0.1Ω; L_W = 8.7µH; C_S variable between 9nF and 24nF @10 …200KHz and between 1.32nF and 24 nF @ 200KHz…2MHz;					
A1*	Supply Voltage @ ECU		$V_{CE,min}$		$V_{CE,BASE,max}$	V
B*	Worst case timing @ ECU					
	Test condition: R_S = 10Ω; C_S = 24nF; C_L = 50nF; R_{wire} = 2.5Ω; L_{wire} = 0µH;					
B1*	Supply Voltage @ ECU		$V_{CE,min}$		$V_{CE,BASE,max}$	V

A*) The sensor has to fulfill reference Test A for every value of the capacitance C_S.

A1,B1*) For min max values see Table 14.

4.9 Synchronization Signal

Purpose of the synchronization signal is to provide a time base for all devices connected to the interface. The synchronization signal is realized by a positive voltage modulation on the power supply lines. For ECU to sensor communication, bits are encoded in present or missing sync pulses, respectively. Or optional by generating long and short sync pulses. The sync pulses are defined as shown in Figure 27 and in the Table 21.

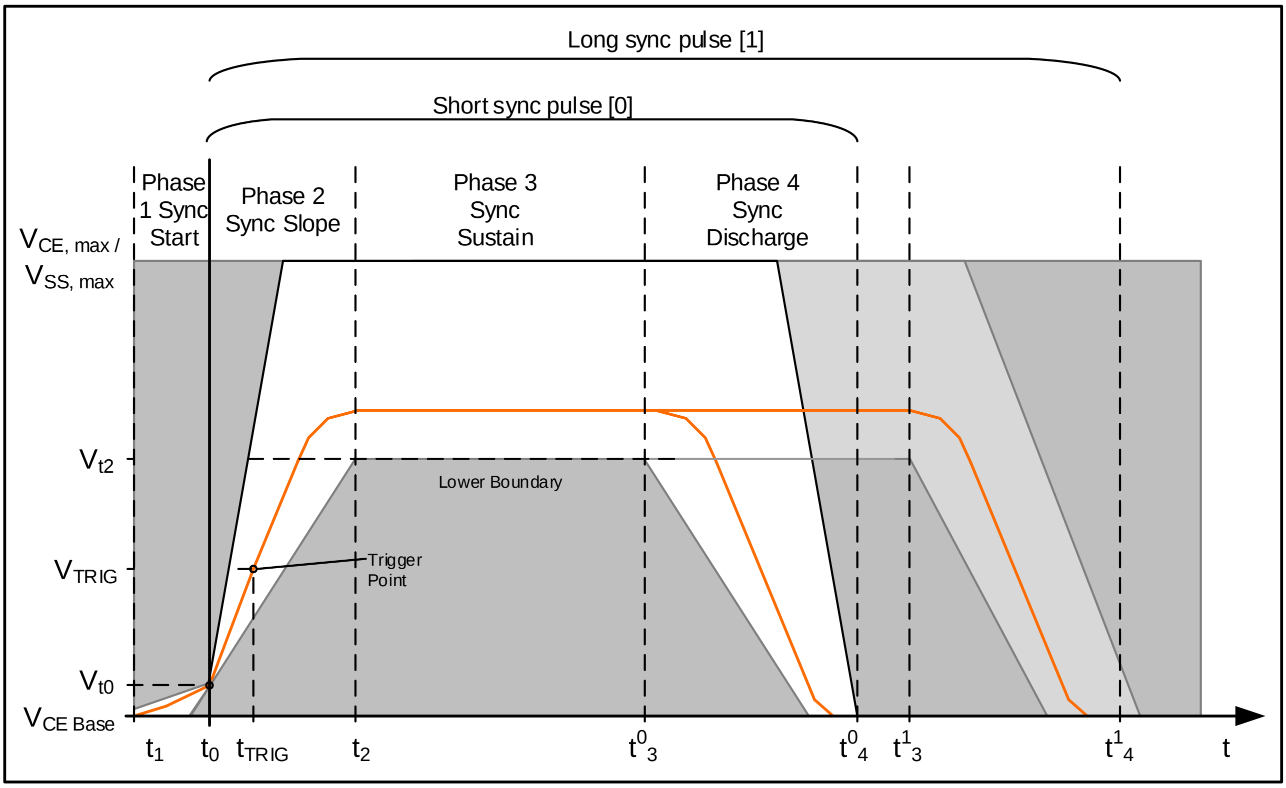

Figure 27: Shape and timing of synchronization signal at ECU

The synchronization signal start time t_0 is defined as a crossing of the V_{t0} value. In the "Sync Start" phase before this point, a "rounding in" of the voltage starting from $V_{CE,\ Base}$ to V_{t0} is allowed for a maximum of t1. During the "Sync Slope" phase, the voltage rises within given slew rates to a value between the minimum sync signal voltage V_{t2} and the maximum interface voltage $V_{CE,\ max}$ / $V_{SS,\ max}$. After maintaining between these limits until a minimum of t^0_3 (t^1_3), the voltage decreases in the "Sync Discharge" phase until having reached the initial $V_{CE,\ base}$ value until latest t^0_4. (t^1_4)

Table 21: Parameter specification of synchronization signal

N°	Parameter	Symbol	Conditions/Remark	Min	Nom	Max	Unit
1*	Sync slope reference voltage	V_{t0}	Referenced to $V_{CE,\ BASE}$		(0.5)		V
2*	Sync signal sustain voltage	V_{t2}	Reduced sync pulse; Referenced to $V_{CE,\ BASE}$	2.5			V
3*			Standard sync pulse; Referenced to $V_{CE,\ BASE}$	3.5			
4*	Reference time	t_0	Reference time base		(0)		µs
5	Sync signal earliest start	t_1	Delta current less than 2mA	-3			µs
6	Sync signal sustain start	t_2	@ V_{t2}			7	µs
7*	Sync slope rising slew rate	$V_{Sync,\ SR,\ rise}$		0.43		1.5	V/µs

N°	Parameter	Symbol	Conditions/Remark	Min	Nom	Max	Unit
8	Sync slope falling slew rate	$V_{Sync, SR, fall}$		-1.5			V/µs
9	Sync signal sustain time	t^0_3		16			µs
		t^1_3		43			
10*	Discharge time limit	t^0_4				35	µs
		t^1_4				62	
11	Start of first sensor data word	$t_{Slot\ 1\ Start}$	Tooth gap method	44			µs
12			Pulse width method	71			µs

1,4*) Theoretical value

2*) The reduced sync pulse scheme is valid for new applications compliant with PSI5 Technical Specification V2.0 onwards. However, in compliance with former PSI5 versions the standard sync pulse scheme is still valid.

2,3*) $V_{t2, max}$ is subject to application specific definitions and limited by absolute maximum ratings to ($V_{CE, max}$ - $V_{CE, BASE}$).

7*) Lower limit is valid for rising slew rate Vt_0 to Vt_2

10*) <u>Common Mode</u>: Remaining discharge current <2 mA, to be guaranteed by the ECU; <u>Low Power Mode</u>: With Low Power Mode sink current ΔI_S a remaining discharge current <0.4 mA has to be guaranteed by the ECU

In the sensors, the trigger is detected within the “trigger window” during the rising slope of the synchronization signal at the trigger point with the trigger voltage V_{TRIG} and the trigger time t_{TRIG}.

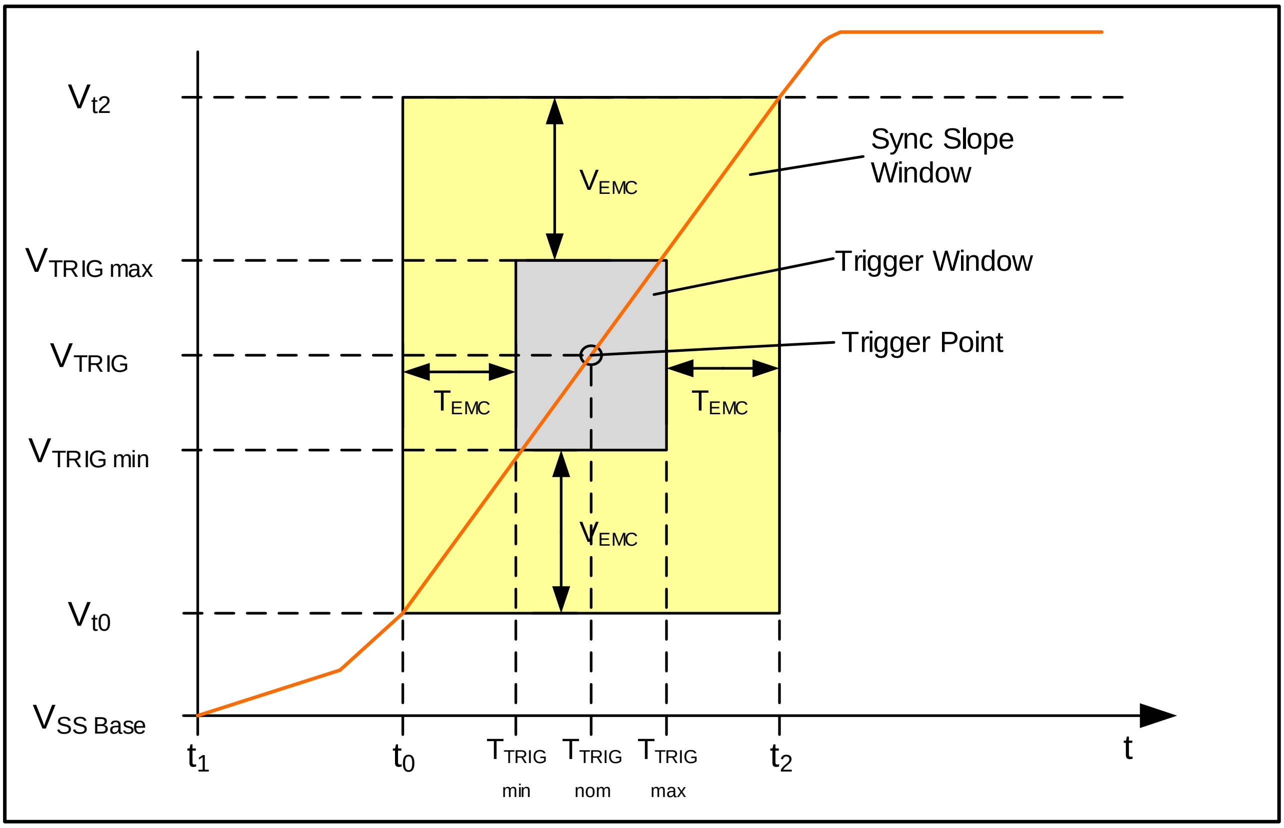

Figure 28: Synchronization signal detection in the sensor

In order to take into account voltage differences at different points of the interface lines, an additional safety margin for the trigger detection is defined by V_{EMC} and t_{EMC}.

Table 22: Parameter specification of synchronization signal detection at the sensor

N°	Parameter	Symbol	Conditions/Remark	Min	Nom	Max	Unit
1	Margin for voltage variations of the signal on the interface line due to EMC effects	V_{EMC}	Reduced sync pulse	-0.7		+0.7	V
2			Standard sync pulse	-0.9		+0.9	
3*	Sensor trigger threshold	V_{TRIG}	Reduced sync pulse; Sensor to detect trigger	1.2	1.5	1.8	V
4*			Standard sync pulse; Sensor to detect trigger	1.4	2.0	2.6	V
5*	Nominal trigger detection time	t_{TRIG}	@ V_{TRIG} , @ Sensor Pins	(2.1)	(3.5)	(4.9)	µs
6	Variation time of the signal on the interface line due to EMC	T_{EMC}	Relative to nominal trigger window time	-2.1		+2.1	µs
7	Tolerance time of internal trigger detection delay at sensor	$T_{tol\ detect}$				3	µs

N°	Parameter	Symbol	Conditions/Remark	Min	Nom	Max	Unit
8*	Trigger detection window	T_{TRIG}	$T_{TRIG} = t_{TRIG,max} + T_{tol\ detect} + T_{EMC}$ Reference for sensor timebase	0		10	µs

3-4*) Referenced to $V_{SS,\ BASE}$.

5*) Referenced to a straight sync signal slope with nominal slew rate. Values in brackets are for illustration purposes only

8*) Additional fixed internal delays are possible but have to be considered for the data slot time calculation

4.10 Timing Definitions for Synchronous Operation Modes

This section describes how the timing of a sensor configuration has to be calculated considering all tolerances. Each single implementation has to assure that sensor frames and sync pulse do not overlap or conflict. For different applications different timing considerations are of importance and hence, a transceiver should not rely on concrete time slots but rather be individually configurable for different time slots. In general, timing calculation is done for independent sensors at each slot. If more than one slot is used by the same sensor, or two sensors rely on the same timing base, respectively, slot tolerances can be considered as dependent and the timing can be tightened[1].

State of the art operation modes and timings are specified within the effective application specific Substandard.

[1] E.g. Substandard Chassis and Safety, Operation Mode PSI5-P20CRC-500/2L

4.10.1 Generic Time Slot Calculation

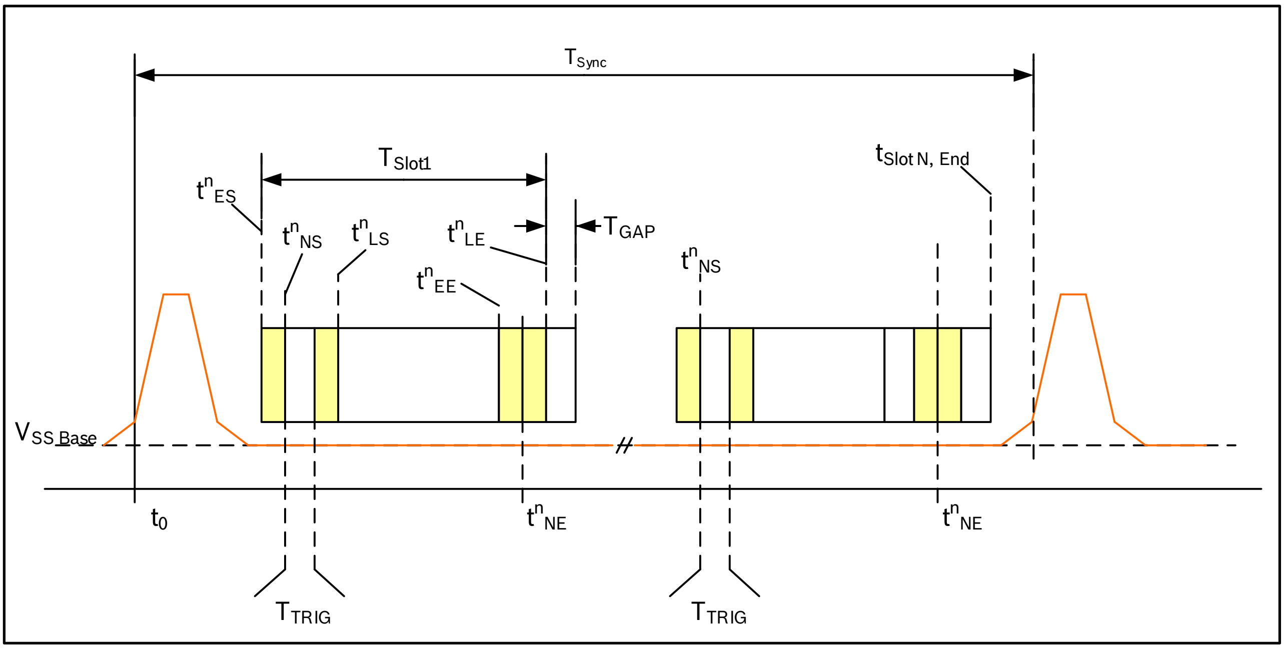

Figure 29: Timing of synchronous operation

t^n_{ES} : Earliest start of frame, slot n; this is the earliest time when the transceiver or any other sensor on the bus can expect that the frame no. n begins.

t^n_{NS} : Nominal start of frame, slot n; this is the nominal time when the sender (sensor) transmits data according to its own internal clock. It is the nominal time when the transceiver or any other sensor on the bus can expect that the frame no. n begins.

$t^n_{NS, prog}$: nominal start value of frame, slot n, that is programmed to the sensor. It is derived from t^n_{NS} by rounding up to the next discretization value.

t^n_{LS} : Latest start of frame, slot n; this is the latest time when the transceiver or any other sensor on the bus can expect that the frame no. n begins.

t^n_{EE} : Earliest end of frame, slot n; this is the earliest time when the transceiver or any other sensor on the bus can expect that the frame no. n is over.

t^n_{NE} : Nominal end of frame, slot n.

t^n_{LE} : Latest end of frame, slot n; this is the latest time when the transceiver or any other sensor on the bus can expect that the frame no. n is over.

T_{GAP}: Minimum gap time which must be guaranteed between two frames (see Table 13)

T_{TRIG}: Trigger detection window to detect the sync pulse = $t_{TRIG,max}$ + $T_{tol\ detect}$ + T_{EMC} (see Table 22)

T_{Sync}: Duration of sync period e.g. for 1% transceiver clock tolerance: $T_{Sync, min} = T_{Sync}*0.99$; $T_{Sync, max} = T_{Sync}*1.01$

$t_{Slot\ 1\ Start}$: Earliest Start of first sensor data word (see Table 22)

T_{BIT}: Nominal time for a single bit (see Table 13)

t_1 : Sync signal earliest start (see Table 21)

M^n: No. of bits including start, data and parity or crc bits for frame, slot n.

N: No. of time slots within one sync cycle

CT^n: Clock tolerance of the transmitter (sensor) sending the frame no. n.

For n=1

$t^1_{ES} = t_{Slot\ 1\ Start} + T_{TRIG,\ min}$

t^1_{NS} 2*) $\geq t_{Slot\ 1\ Start} / (1-CT^1)$

$t^1_{LS} \geq t^1_{NS,\ prog} * (1+CT1) + T_{TRIG,\ max}$

$t^1_{EE} \geq t^1_{ES} + M^1 * T_{BIT} * (1-CT^1)$

t^1_{LE} : $\geq t^1_{LS} + M^1 * T_{BIT} * (1+CT^1)$

For n=2…N

$t^n_{ES} \geq (t^{n-1}_{LE} + T_{GAP}) + T_{TRIG,\ min}$

t^n_{NS} *) $\geq (t^{n-1}_{LE} + T_{GAP}) / (1-CT^n)$

$t^n_{LS} \geq t^n_{NS,\ prog} * (1+CT^1) + T_{TRIG,\ max}$

$t^n_{EE} \geq t^n_{ES} + M^n * T_{BIT} * (1-CT^n)$

$t^n_{LE} \geq t^n_{LS} + M^n * T_{BIT} * (1+CT^n)$

The last frame must end before the next sync pulse starts. For secure data reception a final T_{GAP} should be considered[3)]:

$t_{Slot\ N,\ End} = t^N_{LE}\ (+\ T_{GAP}) < T_{Sync,\ min} + t_1$

Note:

- "≥" is used since the final frame timing should be equalized in order to cover the whole sync period with maximum margins.
- Transceiver clock tolerance determines effective sync pulse duration. A clock tolerance of 1% is assumed. (see also T_{SYNC})
- A discretization of the calculated timings of nominal 0.5us is proposed

Please refer to each Substandard for details on timing specification and typical operation modes.

[2)] The nominal trigger detection tolerance is neglected for calculation of t^n_{NS} since the nominal start time typically is used for sensor programming where detection tolerances do not apply. For the same reason it is recommended to round up t^n_{NS} to 0.5µs and use the rounded value ($t^n_{NS,\ prog}$) for the calculation of the latest start time t^n_{LS}

[3)] Exceptional definitions omitting final T_{GAP} are possible.

4.11 Sensor Power-on Characteristics

To ensure a proper startup of the system, a maximum startup time t_{SET1} is specified. During this time, the ECU must provide a minimum current to load capacitances in sensors and wires. After this, the sensor must sink to quiescent current within the specified tolerance band.
During power on the ECU may reduce the output voltage to limit the current. However, this situation must be avoided in case of the daisy chain bus. Therefore, in a Daisy Chain Bus the sensor architecture must ensure that the overall bus current stays below $I_{LIMIT,\ dyn.}$.

4.11.1 Sensor Bus Configuration

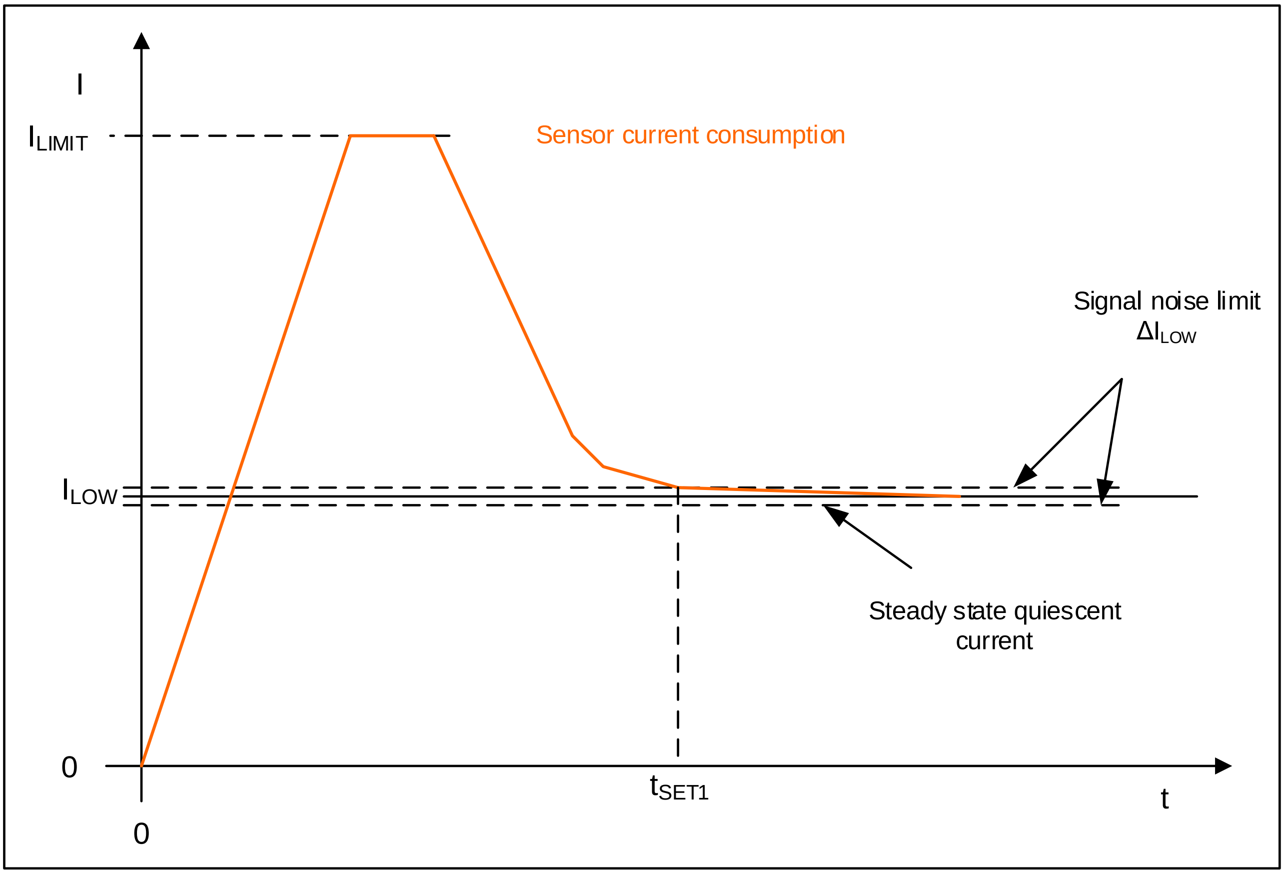

Figure 30: Current consumption during startup for sensor bus configuration

Table 23: Settling time specification for sensor bus configuration

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1*	Settling time for quiescent current I_{LOW}	t_{SET1}	inrush current limitation			5.0	ms
2*			Daisy Chain Bus			10.0	ms

1*) Final value settles to I_{LOW} with the defined signal noise limits ΔI_{Low} (see Table 14).

2*) Mandatory settling time for quiescent current in Daisy Chain Bus. The Bus does not sink a current over $I_{LIMIT,dyn.}$ at any time.

4.11.2 Extended Settling Time for Single Sensor Configuration

For certain sensors an extended stabilization time t_{SET2} is defined, where the current may fluctuate within the specified tolerance band for I_{LOW} before it reaches its steady state value (i.e. fluctuations between I_{LOW_min} and I_{LOW_max} are allowed). The application of such sensors is limited to single sensor configuration, since this behavior after an internal restart of one sensor in a bus configuration might disturb communication on the bus.

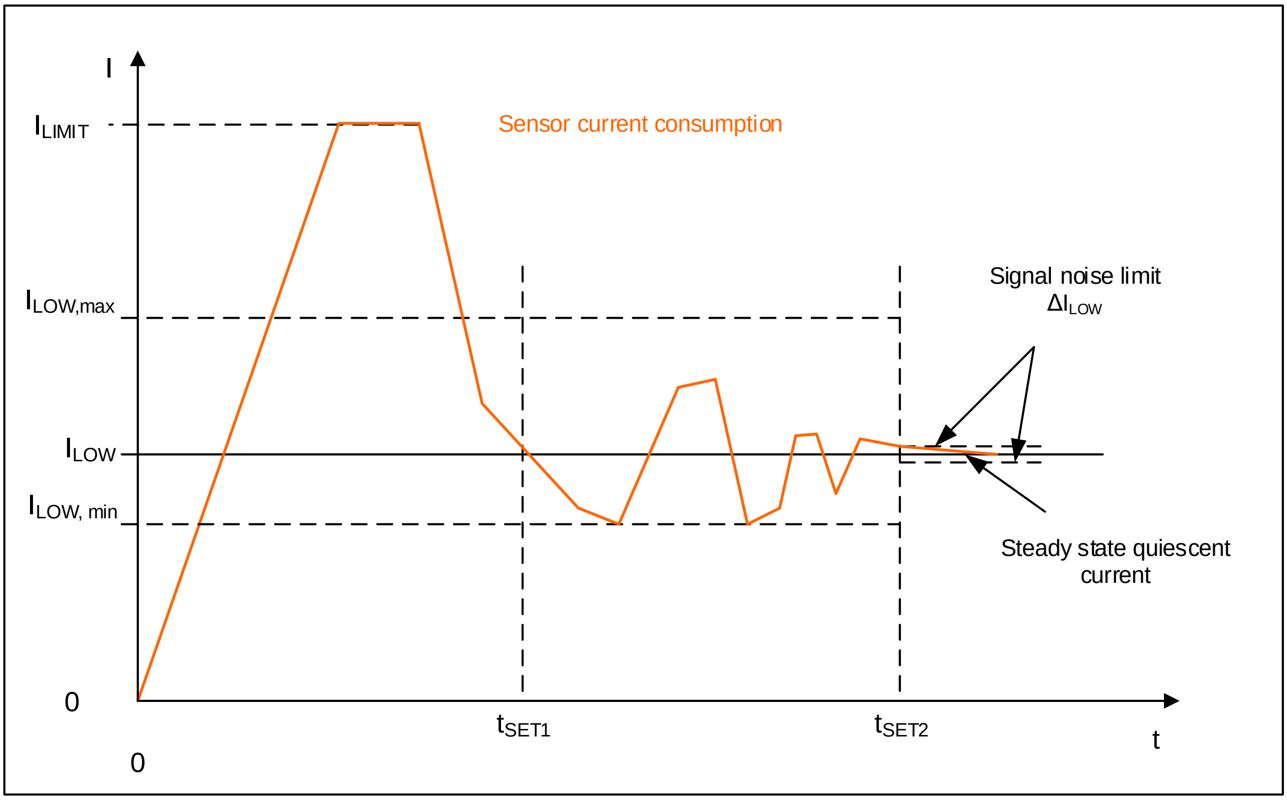

Figure 31: Current consumption during start up for certain single sensor configurations

Table 24: Extended settling time specification for single sensor configuration

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1*	Settling time for quiescent current I_{LOW}	t_{SET1}	inrush current limitation between $I_{LOW,min}$ and $I_{LOW,max}$			5.0	ms
2*		t_{SET2}	Extended stabilization time			*	ms

1,2*) The time elapsed between t=0 and $t=t_{SET2}$, max cannot exceed the minimum duration of Initialization Phase I (<50ms for airbag and chassis and safety; <10ms for power train; preferably limited to ½ of the minimum time limit of Initialization Phase I); the final value is given in the application specific Substandard;

2*) Fluctuations between I_{LOW_min} and I_{LOW_max} are allowed; the receiver might indicate communication error for $t < t_{SET2}$. Final value settles to I_{LOW} with the defined signal noise limits ΔI_{LOW} (see Table 14).

4.12 Undervoltage Reset and Microcut Rejection

The application-specific Substandards specify, whether an internal reset of the sensor is mandatory or optional. In those cases where mandatory, undervoltage reset thresholds are also specified in detail within the respective Substandard.

If specified, the sensor must perform an internal reset if the supply voltage drops below a certain threshold for a specified time. By applying such a voltage drop, the ECU is able to initiate a safe reset of all attached sensors. Microcuts might be caused by lose wires or connectors. Microcuts within the specified limits shall not lead to a malfunction or degraded performance of the sensor.

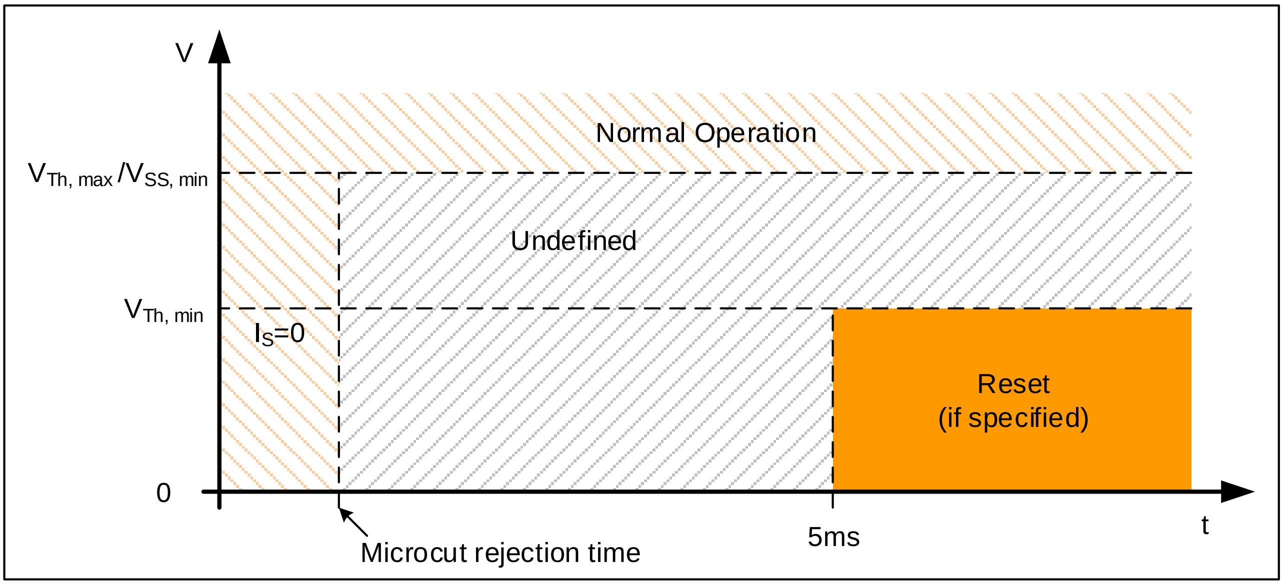

Figure 32: Undervoltage reset behavior

Table 25: Parameter specification for undervoltage reset and microcut rejection

N°	Parameter	Symbol	Conditions/Remark	Min	Typ	Max	Unit
1	Undervoltage reset threshold	V_{Th}	Standard Voltage; $V_{Th,\,min}$ = must reset; $V_{Th,\,max} = V_{SS,\,min}$	(*)		5	V
2			Low Voltage; $V_{Th,\,min}$ = must reset; $V_{Th,\,max} = V_{SS,\,min}$	(*)		4	V
3	Time below threshold for the sensor to initiate a reset	t_{Th}		(*)		5	ms
4	Microcut rejection time (no reset)	I_S=0		0.5			µs

(*) Defined within the application specific Substandard

The voltage V_{Th} is at the pins of the sensors. In case of microcuts (I_S=0) to the maximum duration of the microcut rejection time the sensor shall not perform a reset. If the voltage at the pins of the sensor remains above $V_{Th,max}$ the sensor must not perform a reset. If the voltage at the pins of the sensor falls below $V_{Th, min}$ for more than 5ms the sensor has to perform a reset, if a reset is specified in the application specific Substandard.

Different definitions may apply for Universal Bus and Daisy Chain Bus.

5 Application Layer

Specific application layer implementations are defined in the application Substandards or in individual product specifications. In order to enable global interoperability between PSI5 compatible components and to avoid potential system malfunction due to erroneous recognition of components, some global definitions about data range, sensor initialization and bidirectional communication are made in this section.

5.1 Data Range

PSI5 data messages, transmitted in data region A, are divided into three separate ranges: a data range for the sensor output signal, a range for status and error messages and a range for initialization data.
For 10 bit sensors, the decimal values –480 to +480 are used for the sensor output signal. The range –512 to –481 is reserved for the block and data ID's and can be used for transmitting initialization data during startup of the sensor (see Chapter 5.2). The range from +481 to +511 is used for status and error messages.

Table 26: Data range (10 Bit)

value		Signification	Range	
Dec	Hex			
+511	0x1FF	Reserved (ECU internal use) 1)	Status & Error Messages	2
:	:	Reserved (ECU internal use) 1)		
+504	0x1F8	Reserved (ECU internal use) 1)		
+503	0x1F7	Reserved (Sensor use) 2)		
+502	0x1F6	Reserved (Sensor use) 2)		
+501	0x1F5	Reserved (Sensor use) 2)		
+500	0x1F4	"Sensor Defect"		
+499	0x1F3	Reserved (ECU internal use) 1)		
:	:	Reserved (ECU internal use) 1)		
+496	0x1F0	Reserved (ECU internal use) 1)		
+495	0x1EF	Reserved (Sensor use) 2)		
:	:	Reserved (Sensor use) 2)		
+489	0x1E9	"Sensor in Service Mode"		
+488	0x1E8	"Sensor Busy"		
+487	0x1E7	"Sensor Ready"		
+486	0x1E6	"Sensor Ready but Unlocked"		
+485	0x1E5	Reserved (Sensor use) 2)		
+484	0x1E4	Reserved (Sensor use) 2)		
+483	0x1E3	Reserved (Sensor use) 2)		
+482	0x1E2	Bidirectional Communication: RC "Error"		
+481	0x1E1	Bidirectional Communication: RC "O.K."		

value		Signification	Range	
Dec	Hex			
+480	0x1E0	Maximum Sensor Data value	Sensor Output Signal	1
:	:	:		
0	0x000			
:	:	:		
-480	0x220	Minimum Sensor Data value		
-481	0x21F	Status Data 1111	Data for Initialization	3
:	:	:		
-496	0x210	Status Data 0000		
-497	0x20F	Block ID 16	Block ID's	
:	:	:		
-512	0x200	Block ID 1		

1) Usage for ECU internal purpose possible (e.g. “No Data”, “Manchester Error” etc.)

2) Reserved for application specific definitions. Detailed description is given within the application specific Substandard.

5.1.1 Scaling of Sensor Output

For sensors with a data word length of more than 10 bit, the data range scales as described in Chapter 3.1.3. In this case status and initialization data words of range 2 and 3 are filled up with a value to be defined in the application specific substandard.

Mapping of Status & Initialization Data

16 Bit Data Word

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
1	0	0	0	0	0	1	1	1	1	X	X	X	X	X	X

10 Bit Data Word

D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
1	0	0	0	0	0	1	1	1	1

Example „Block ID 16" 0x20F

„2“	„0“	„F“

Figure 33: Mapping of status and initialization data into a data word

5.2 Sensor Initialization / Identification

Sensor Initialization data is sent after each power on or reset. Therefore two different transmission procedures can be applied:

1) Data Range Initialization: Identification data is sent during an initialization procedure before any effective sensor data is sent.
2) Serial Channel Messaging: For immediate access to measurement data, identification data is transmitted parallel to sensor data via serial channel bits M0 and M1. The sensor immediately starts with parallel transmission of measurement and sensor identification data.

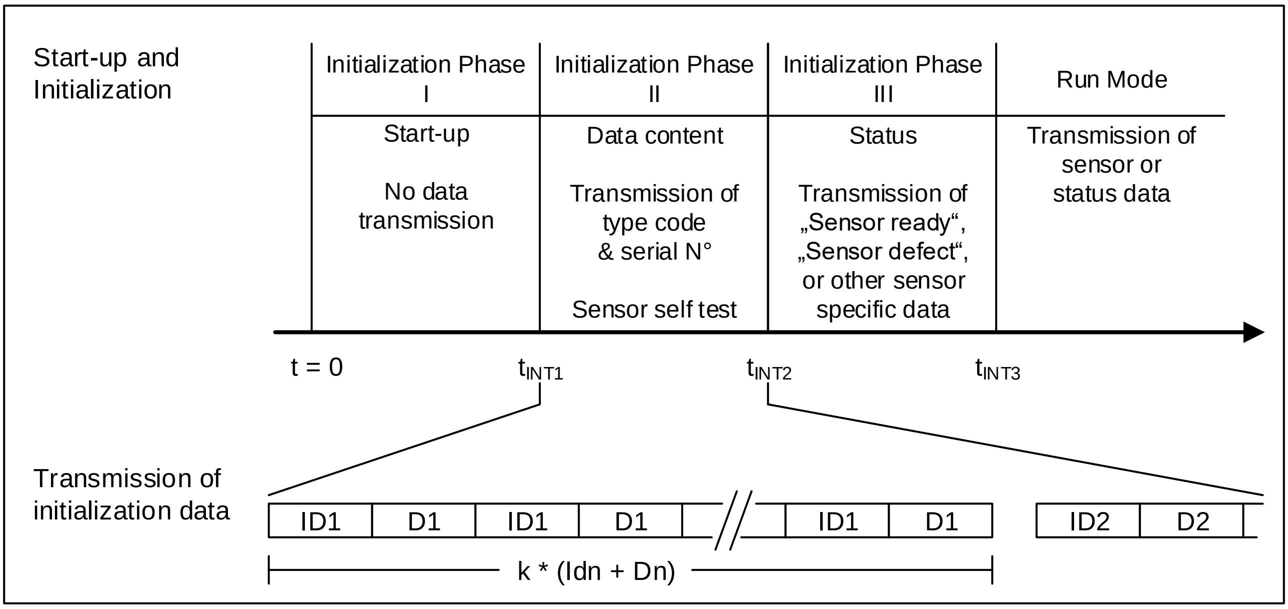

Figure 34: Sensor initialization sequence for Data Range Initialization

Chapter 5.2.1 defines the Data format of the Data Range Initialization procedure, further details are given in the corresponding Substandards. The Serial Channel Messaging is fully defined on application level, i.e. within the specific Substandard. Chapter 5.2.2 and 5.2.3 define basic regulations of the Application Layer that need to be followed by both identification procedures.

5.2.1 Frame Format - Data Range Initialization

The initialization data is transmitted within the range of "Payload Data Region A" out of the reserved data range 2 and 3 in Table 26. Sensor identification data is sent via data range 3 using ID and data blocks containing each 16 block identifiers and 4-bit data nibbles. Exceptions or failure modes are sent via data range 2.

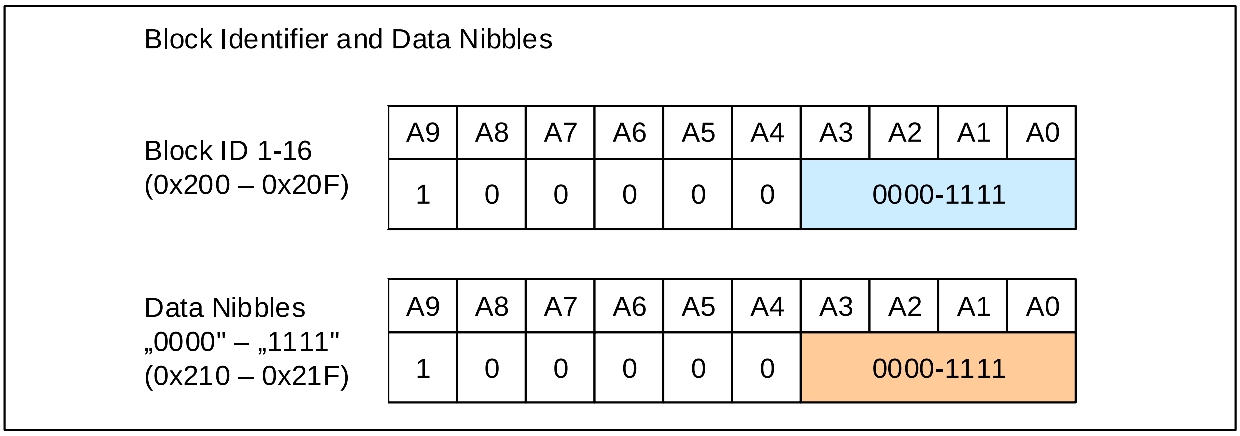

Figure 35: Block ID and data nibbles

ID blocks and data blocks are sent in an alternating sequence.

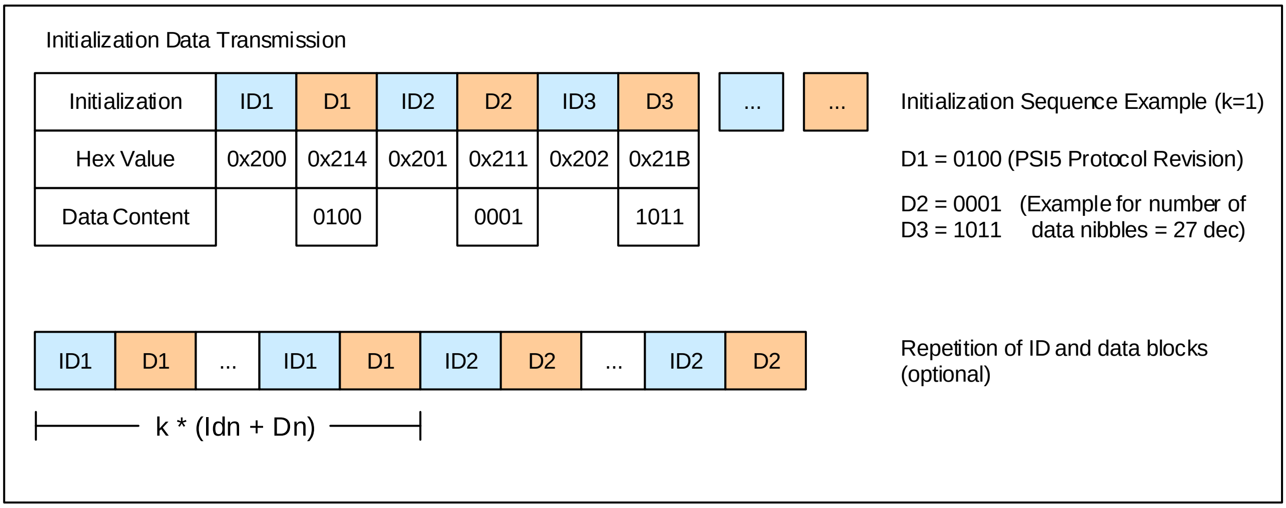

Figure 36: Startup sequence

If the initialization data exceeds 4x16=64 bit, data can be "paged". The ID codes are reused for every 64 bit page of data to be transmitted. Data pages are not numbered. Mapping of the information contained in different data pages has to be derived from the chronology of the startup sequence. It is not mandatory to transmit complete data pages.

5.2.2 Data Content - Data Range Initialization

Table 27: Mandatory definitions

	Header	Initialization		Vendor ID		Product ID			
Data field	F1	F2		F3		F4		F5	
Data nibble	D1	D2	D3	D4	D5	D6	D7	D8	D9
	PSI5 version	No. of data nibbles		Vendor ID		Sensor type		Sensor parameters	

Table 28: Initialization data content

Field	Name	Parameter definition	Value
F1 (D1)	Meta Information (See section below)	Protocol Description (D1) PSI5 1.3 PSI5 2.x, Data Range Initialization	 0100 0110
F2 (D2, D3)	Initialization data length Number of data nibbles transmitted	Example: F1-F9	Example: 0010 0000
F3 (D4, D5)	Vendor ID	s. chapter 5.2.4	
F4 (D6, D7)	Sensor Type Definition of the sensor type (acceleration, pressure, temperature, torque, force, angle, etc.)	Acceleration Sensor (High g) Acceleration Sensor (Low g) Pressure Sensor (high sensitivity)* Pressure Sensor (low sensitivity)* Position Sensor (Angular) Position Sensor (Linear) other sensors	XXXX 0001 XXXX 0010 XXXX 1000 XXXX 1100 XXXX 0110 XXXX 0111 tbd
F5 (D8,D9)	Sensor Parameter Definition of sensor specific parameters e.g . measurement range.	Information depending on the corresponding sensor type	Sensor specific definition

*) Differentiation between low and high sensitivity/acceleration is meant to distinguish between different sensitivity ranges for sensors on the same bus.

Further details of initialization data structure and contents are given in the respective Substandards. In addition to the mandatory definitions of this document and the Substandards extended sensor parameters can be appended if needed (F2 to be changed accordingly).

5.2.3 Meta Information

In cases where sensors from different application fields are connected to one bus system (e.g. powertrain and chassis and safety sensors) the interoperability of the different protocols must be guaranteed. For that reason an optional "meta information" header is transmitted minimum once at the very beginning of the identification phase indicating the PSI5 version and the method used for identification data transmission. Irrespective of the applied identification procedure the header data field is sent in status data format (10-Bit value out of data range 3).

For systems that use the Data Range Initialization the meta header is mandatory and consists of at least one identifier (ID1) and one data nibble (D1).

Table 29: Meta Header

Name	Parameter definition	Value
Header	Protocol Description (D1)	
	PSI5 1.x	0100
	PSI5 2.x, Data Range Initialization	0110
	PSI5 2.x, Serial Channel Initialization	0111

5.2.4 Vendor ID

The Vendor ID is sent with both methods and coded as defined below.

Table 30: Vendor IDs

Name	Parameter definition	ASCII Code
Vendor ID (8 bit Sensor Manufacturer Code)	AB Elektronik	1100 0000
	AMS	1110 0000
	Analog Devices	0110 0001
	Autoliv*	0100 0001
	Bosch*	0100 0010
	Continental*	0100 0011
	Denso	0100 0100
	ELMOS	0100 0101
	Hella	0100 1000
	IHR	0110 1001
	Infineon	0100 1001
	Hyundai Mobis	0100 1101
	TDK	0110 1101
	NXP	0100 0110
	OnSemi	0100 1111
	Seskion	0111 0011
	ST Microelectronics	0101 0011
	TRW	0101 0100
	Other sensor manufacturers	tbd

*) These vendor IDs are effective from PSI5 Technical Specification V2.0 onwards and mandatory for all future applications; in compliance with PSI5 V1.3 former codes are still valid. That is specifically regarding Autoliv (0100 0000), Bosch (0001 0000), Continental (1000 0000), Siemens VDO (0010 0000).

5.3 Bidirectional Communication

515 In the table below the allowed up- and downstream combinations are shown.

Table 31: Combination of bidirectional communication options

Upstream (Sensor response to ECU)	Downstream (ECU to Sensor)	Remark
Data range 2 & 3	Tooth Gap method note: frame format is restricted to frame 1-3 (see Chapter 5.3.1)	PSI5 1.3 compliant
Data range 2 & 3	Pulse Width method	
Serial channel	Pulse Width Method	

516 In the following basic regulations of data contents are given that need to be followed by all PSI5 applications.

5.3.1 Sensor Addresses

Table 32: Sensor addresses

Mnemonic	SAdr			Signification
	A2	A1	A0	
S0	0	0	0	Address of an unprogrammed sensor (Daisy Chain)
S1	0	0	1	Sensor 1 (Slot #1)
S2	0	1	0	Sensor 2 (Slot #2)
S3	0	1	1	Sensor 3 (Slot #3)
S4	1	0	0	Sensor 4 (Slot #4)
S5	1	0	1	Sensor 5 (Slot #5)
S6	1	1	0	Sensor 6 (Slot #6)
BCast	1	1	1	Broadcast address for all sensors

5.3.2 Function Codes and Responses for Bidirectional Communication – Frame 1 to 3

Table 33: Function codes and responses for bidirectional communication – Frame 1 to 3

Mnemonic	SAdr A2	SAdr A1	SAdr A0	FC F2	FC F1	FC F0	Signification	Response o.K.	Response Error
Set Sensor Address & Run Command (Short Data Frame) **Condition: SAdr = “000” or SAdr = “111”**									
SetAdr	0	0	0	Address to be programmed: A2	A1	A0	Set Sensor Address & Close Bus Switch (The “FC” field contains the sensor address)	RC: “o.K.” RD1: “Address”	RC: “Error” RD1: “ErrN°”
Run	1	1	1	0	0	0	Sensors to enter “Run Mode” (Broadcast Message to all sensors)	RC: “o.K.” RD1: “0000”	RC: “Error” RD1: “ErrN°”
Execute device specific function (Short Data Frame) **Condition: SAdr = “001” to “110” and F2=”1”**									
Exec 1	Sensor Address 001 .. 110			1	0	0	Execute Specific Function #1	RC: “o.K.” RD1: Specific	RC: “Error” RD1: “ErrN°”
Exec 2	Sensor Address 001 .. 110			1	0	1	Execute Specific Function #2	RC: “o.K.” RD1: Specific	RC: “Error” RD1: “ErrN°”
Exec 3	Sensor Address 001 .. 110			1	1	0	Execute Specific Function #3	RC: “o.K.” RD1: Specific	RC: “Error” RD1: “ErrN°”
Exec 4	Sensor Address 001 .. 110			1	1	1	Execute Specific Function #4	RC: “o.K.” RD1: Specific	RC: “Error” RD1: “ErrN°”
Read / Write Command (Long Data Frame) **Condition: F2=”0” and F1=”1”**									
RD_L	Sensor Address 001 .. 110			0	1	0	Read nibble or byte from sensor*	RC: “o.K.” RD1: Data_Lo RD2: Data_Hi**	RC: “Error” RD1: “ErrN°” RD2: “0000”
WR_L	Sensor Address 001 .. 110			0	1	1	Write nibble or byte to sensor*	RC: “o.K.” RD1: Data_Lo RD2: Data_Hi**	RC: “Error” RD1: “ErrN°” RD2: “0000”
Read / Write Command (XLong Data Frame) **Condition: F2=”0” and F1=”0”**									
RD_X	Sensor Address			0	0	0	Read data byte from sensor	RC: “o.K.” RD1,RD2: Data	RC: “Error” RD1: “ErrN°” RD2: “0000”
WR_X	Sensor Address			0	0	1	Write data byte to sensor	RC: “o.K.” RD1,RD2: Data	RC: “Error” RD1: “ErrN°” RD2: “0000”

*) Nibble (4 Bit) or Byte (8 Bit) instruction depending on device internal memory organization.

**) In case of Nibble (4 Bit) transmission Data_Hi has to be zero.

5.3.3 Returned Error Codes – Sensor Response for Frame 1-3

Table 34: Returned error codes – Sensor response for Frame 1-3

Err N°	Mnemonic	Description
0000	General	General Error*
0001	Framing	Framing Error
0010	CRC	CRC Checksum Error
0011	Address	Sensor Address not supported

Err N°	Mnemonic	Description
0100	FC	Function code not supported
0101	Data range	Data range (register address) not supported
0110	Write Protect	Destination address write protected
0111		Reserved
1xxx		Application specific

519 *) Unspecific, may replace all other error codes.

6 System Setup & Operation Modes

6.1 System Setup

Figure 37 shows a possible system setup for peripheral sensors connected to an ECU with PSI5.

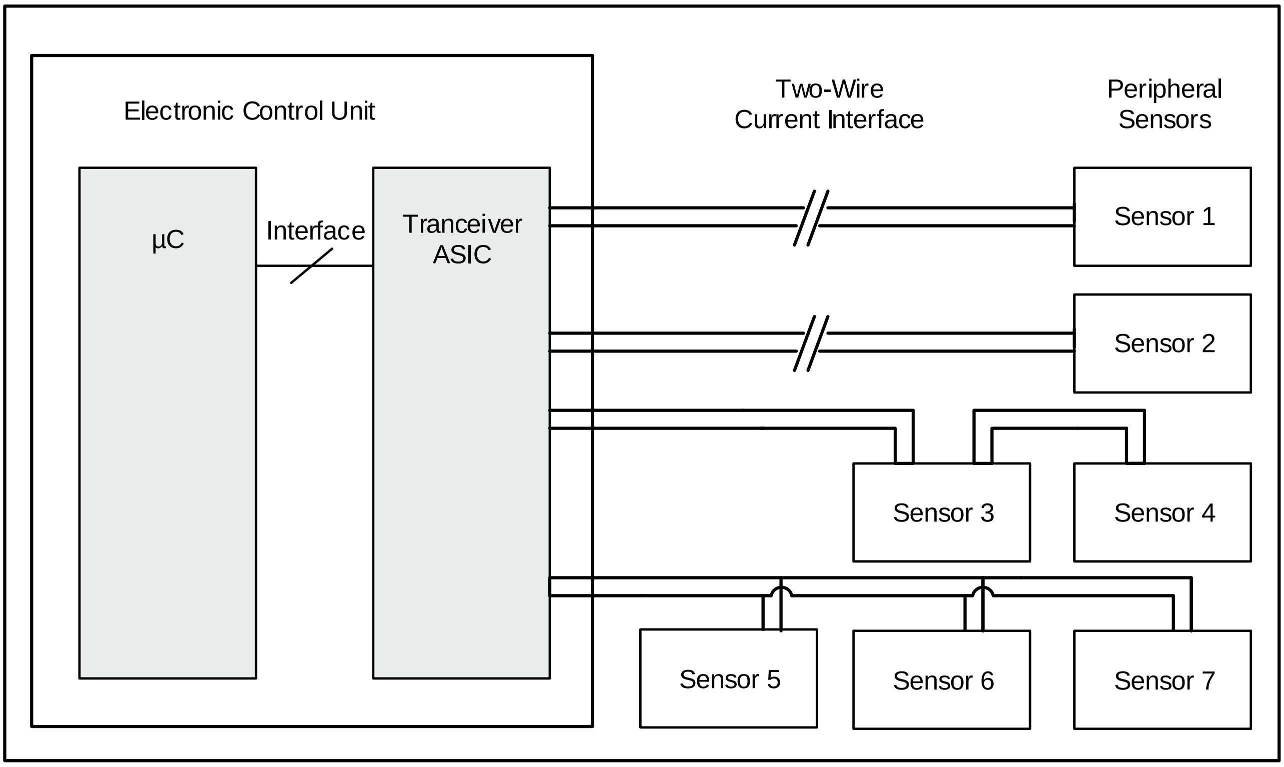

Figure 37: Connection of peripheral sensors to an ECU (Example)

The sensors are connected to the ECU by just two wires, using the same lines for power supply and data transmission. The transceiver ASIC provides a pre-regulated voltage to the sensors and reads in the transmitted sensor data. The example above shows a point-to-point connection for sensor 1 and 2 and two different bus configurations for sensor 3 and 4, and 5 to 7, respectively.

6.2 PSI5 Operation Modes

The different PSI5 operation modes define topology and parameters of the communication between ECU and sensors such as communication mode, number of data bits, error detection, cycle time, number of time slots per cycle and bit rate.

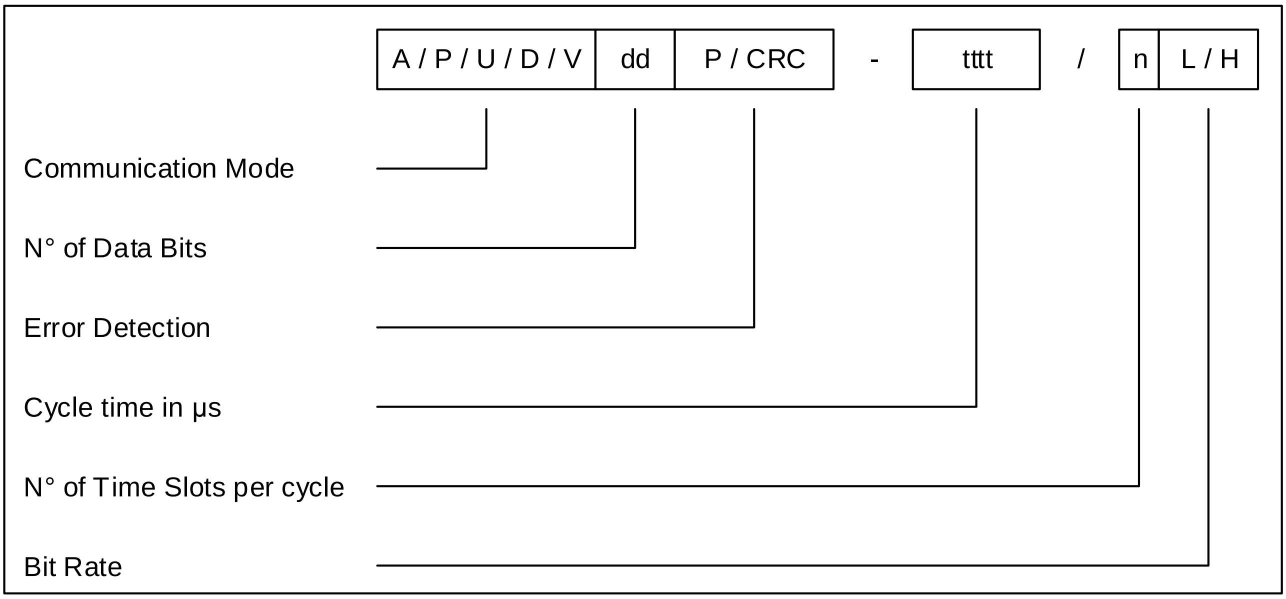

Figure 38: Denomination of PSI5 operation modes

Example “PSI5-P10P-500/3L”:

PSI5 synchronous parallel bus operation, 10 data bits with parity bit, 500µs sync cycle time with three time slots and a standard 125 kbps data rate.

Table 35: PSI5 operation modes

Communication Modes	
A	Asynchronous Mode
P	Synchronous Parallel Bus Mode
U	Synchronous Universal Bus Mode
D	Synchronous Daisy Chain Bus Mode
V	Variable Time Triggered Synchronous Operation Mode
Error Detection	
P	One Parity Bit
CRC	Three Bits Cyclic Redundancy Check
Bit Rate	
L	125 kbps
H	189 kbps
Cycle time	
tttt	cycle time in µs (e.g. 500)
	or minimum allowed cycle time in µs for variable time triggered operation (e.g. 228)

6.3 Asynchronous Operation (PSI5-A)

PSI5-A describes a point-to-point connection for unidirectional, asynchronous data transmission. Each sensor is connected to the ECU by two wires. After switching on the power supply, the sensor starts transmitting data to the ECU periodically. Timing and repetition rate of the data transmission are controlled by the sensor.

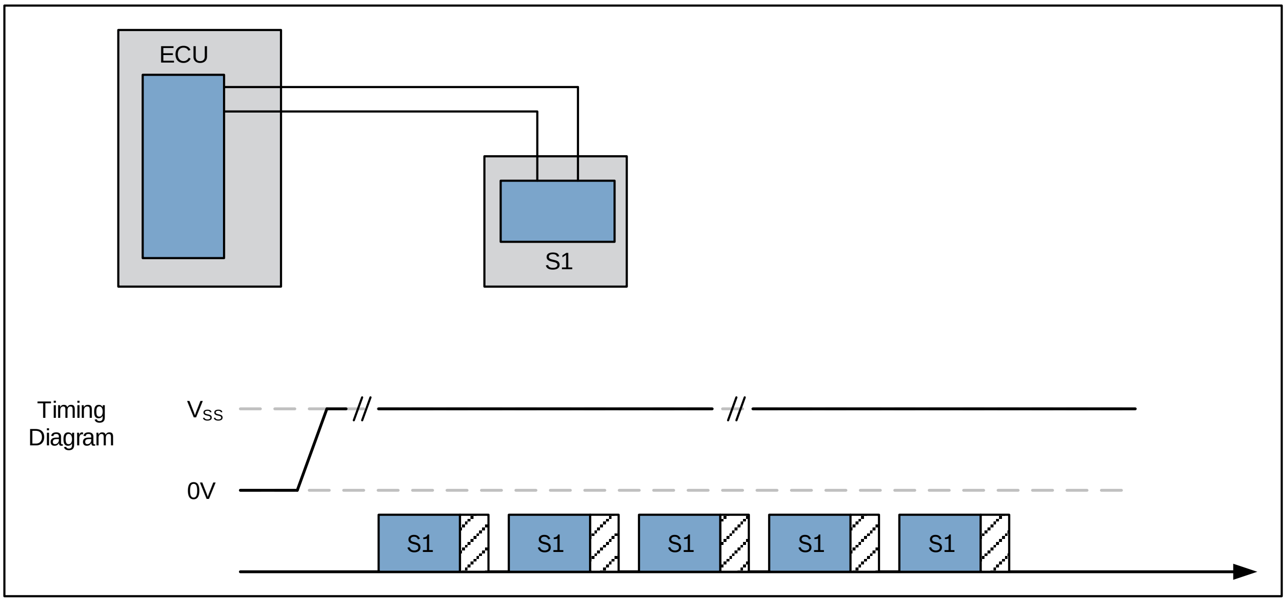

Figure 39: PSI5-A asynchronous point-to-point connection

6.4 Synchronous Operation

The synchronous operation modes work according to the TDMA method (Time Division Multiple Access). The sensor data transmission is synchronized by the ECU using voltage modulation. Synchronization can optionally be used for point-to-point configurations and is mandatory for bus modes.

6.4.1 Timing of Synchronous Operation Modes

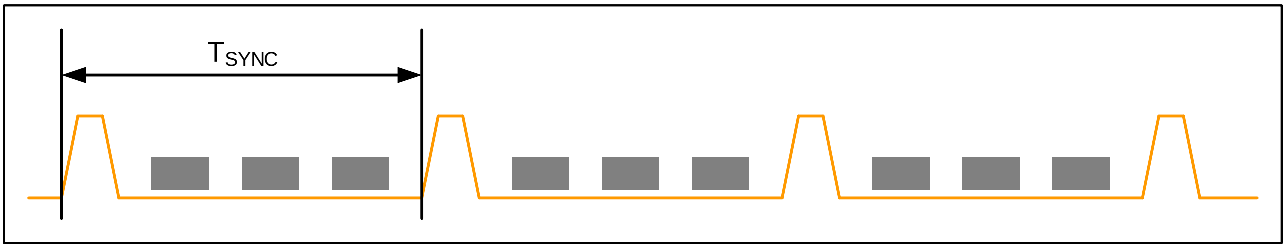

Figure 40: Fixed time triggered synchronous operation

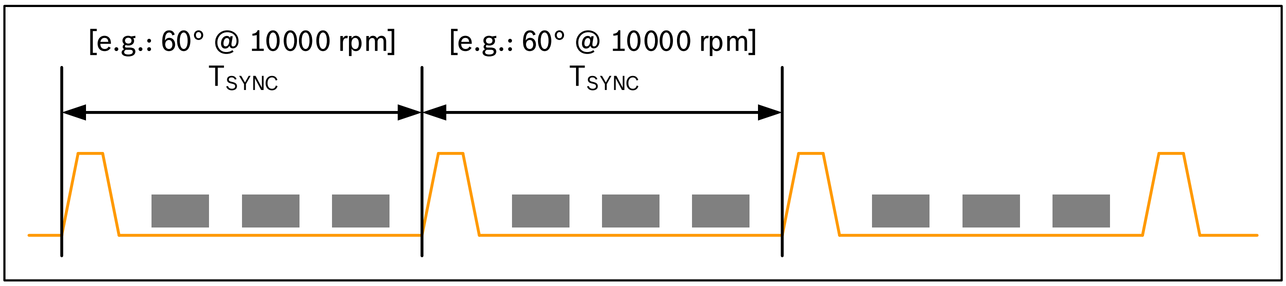

Figure 41: Variable time triggered synchronous operation

6.4.2 Bus Operation Principle

In the PSI5 bus topologies, one or more sensors are connected to the ECU in parallel.

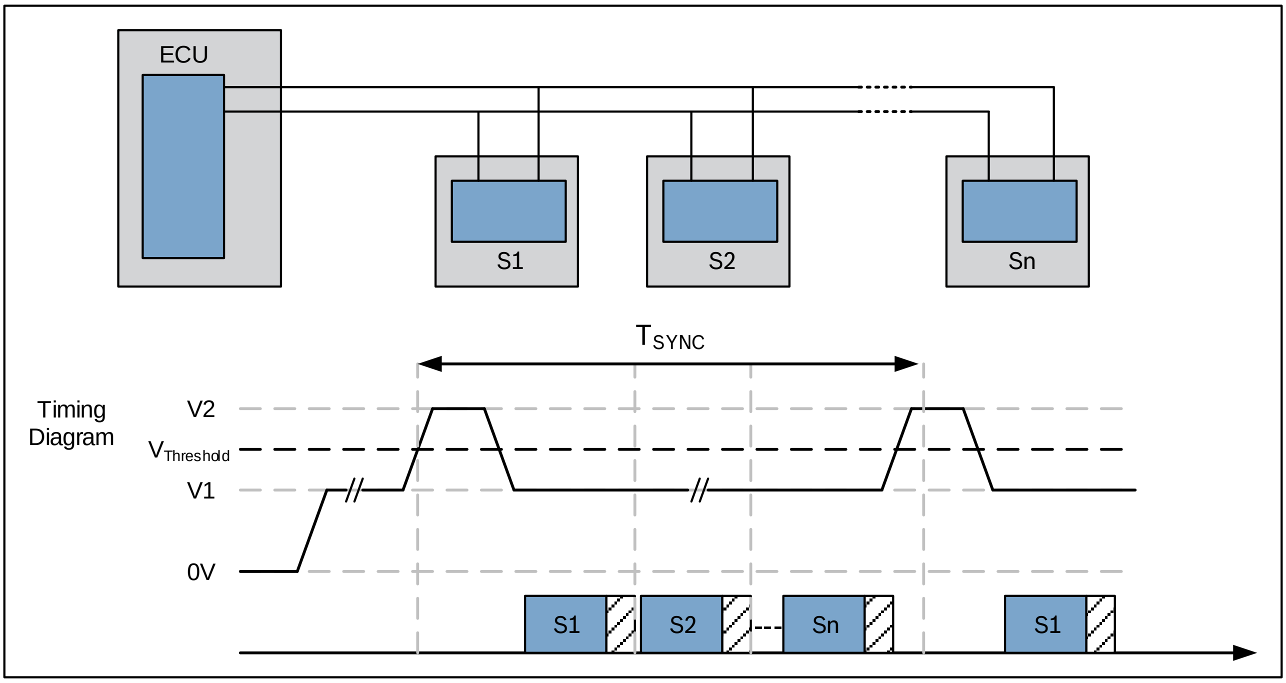

Figure 42: Basic PSI5 bus topology

Each data transmission period is initiated by a voltage synchronization signal from the ECU to the sensors. Having received the synchronization signal, each sensor starts transmitting its data with the corresponding time shift in the assigned time slot.

In a parallel bus configuration, an individual identification of the sensors is required. Alternatively the sensors can be connected in a “Daisy Chain” configuration to the ECU. In this configuration the sensors have no fixed address and can be connected to each position on the bus. During startup, each sensor receives an individual address and then passes the supply voltage to the following sensor subsequently. The addressing is realized by bidirectional communication from the ECU to the sensor using a specific sync signal pattern. After having assigned the individual addresses, the sensors start to transmit data in their corresponding time slots in the same way as specified in the parallel bus topology.

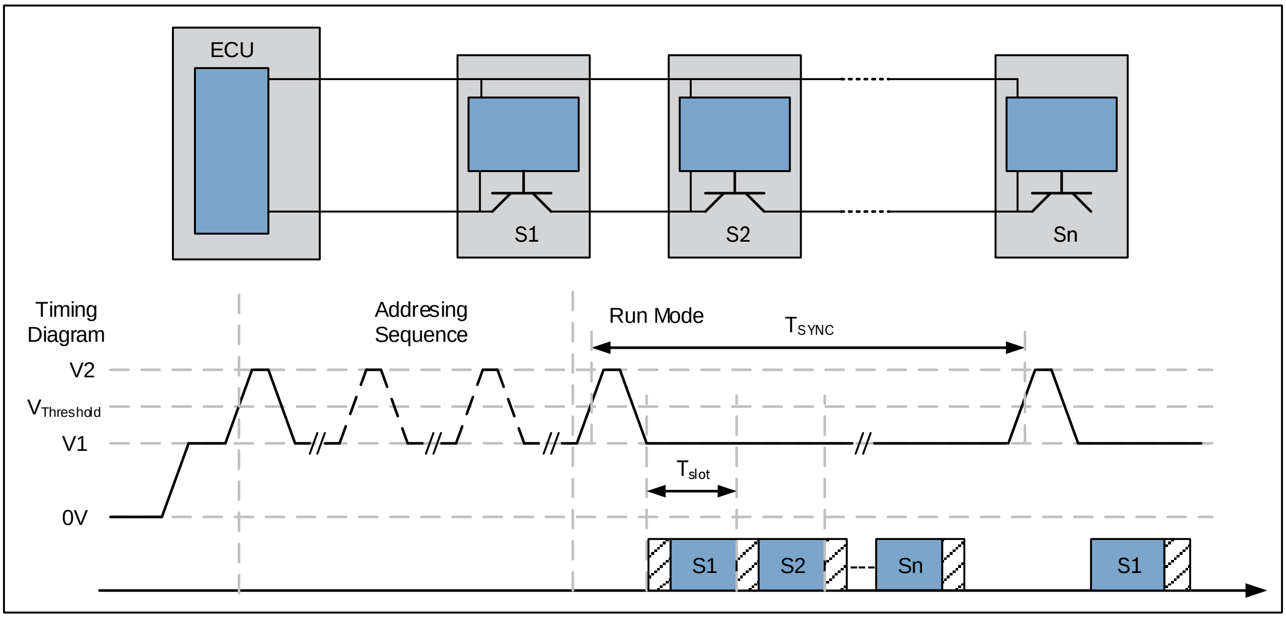

Figure 43: Daisy chain bus topology

6.4.2.1 Preferred Daisy-Chain Mode: Parallel Initialization Phase[4)]

The aim of this section is to provide some guidelines applicable for a PSI5 interface when it is operated in Daisy-Chain mode, and especially to enhance the application layer specification for this mode.

In this operation mode, each sensor sends out the initialization sequence over the previously assigned sensor time slot. The timeslot is assigned by an address setting instruction. The ECU shall assign the addresses in reverse order, i.e. that timeslot TS1 is the last one receiving its address. Furthermore, timeslot TS1 is defined as being the default timeslot for sensor error reporting in case of an unsuccessful address assignment.

Principle of operation

1. ECU applies supply voltage to PSI5 Interface (power on)

[4)] Valid from PSI5 Technical Specification V2.1 onwards and for all Substandards except Powertrain Substandard. For backward compatibility with PSI5 V1.3 for airbag application a thorough description is given within the Airbag Substandard.

2. Wait for supply settling time
3. ECU assigns sensor address for time slot “TSi” to the next sensor that has not yet received its configuration
4. Addressed sensor responds by sending its internal status (acknowledge or error) message and address confirmation. Sensor closes daisy-chain switch to supply next sensor.
5. Repeat steps 2, 3 and 4 until all sensor addresses have been successfully assigned (From TSn down to TS1)
6. ECU to send RUN broadcast instruction to start runtime mode
7. All sensors to send out their initialization data within their assigned timeslot
8. All sensors to send out “sensor_OK“ messages
9. All sensors to send out their sensor data

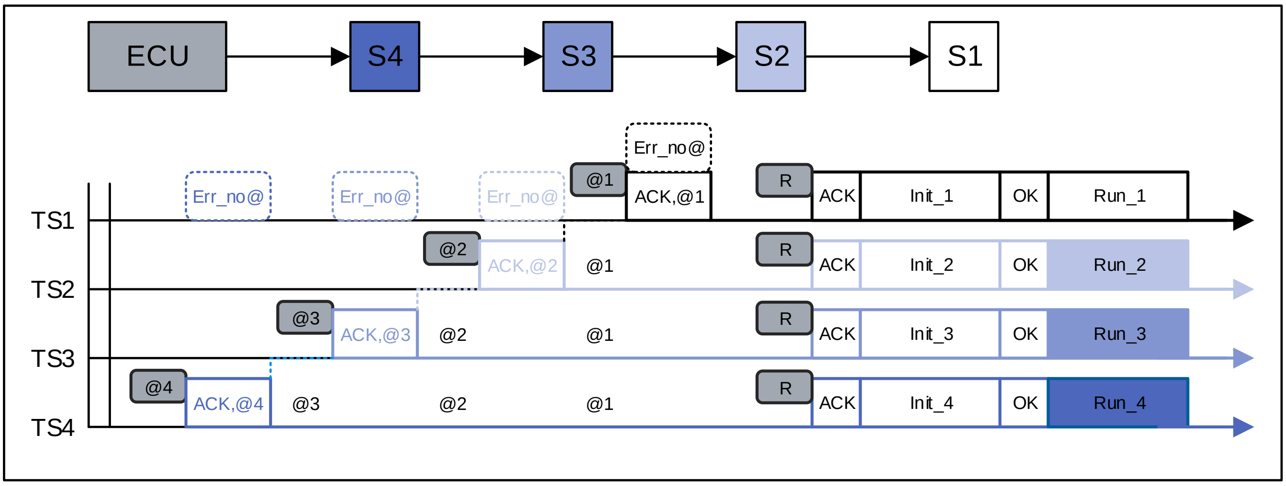

Figure 44: Daisy chain bus implementation (example with 4 time slots)

6.4.3 Sensor Cluster / Multichannel

In a sensor cluster configuration, one physical sensor contains two or more logical channels. Examples could be a two channel acceleration sensor or a combined temperature and pressure sensor.
The data transmission of the different channels can be realized by splitting up the data word of each data frame into two or more blocks or by transmitting the data for the different channels in separate data frames using time multiplex.

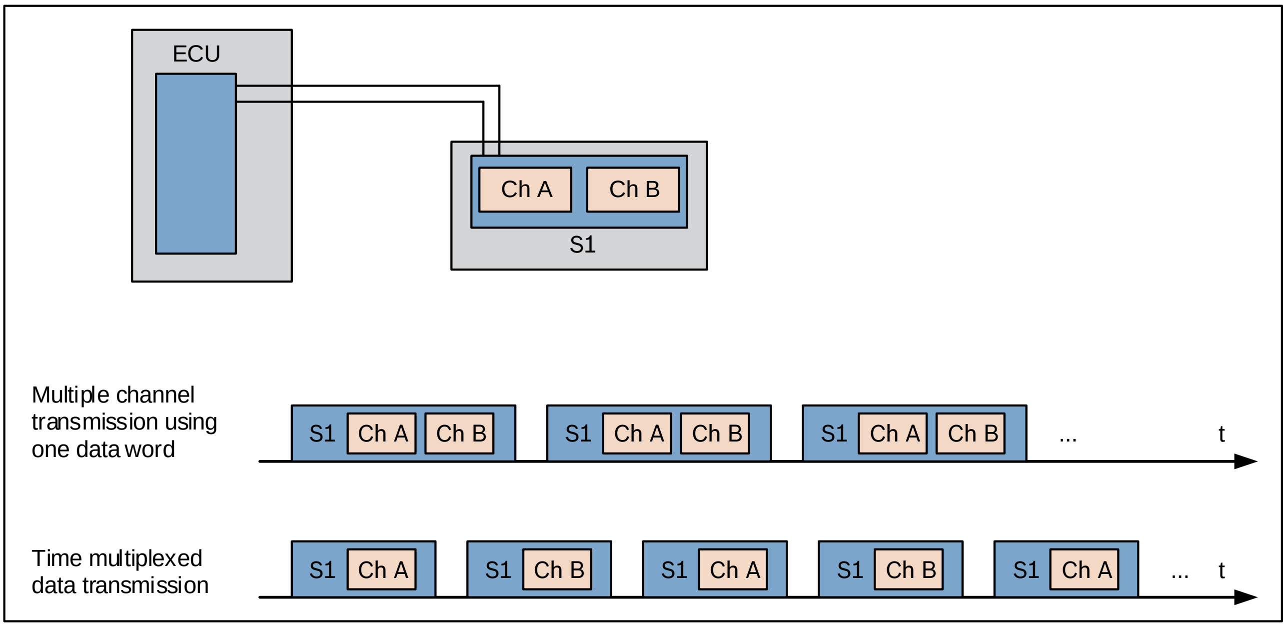

Figure 45: Implementation example sensor cluster

572 Sensor cluster / multichannel operation modes can be combined with both asynchronous and synchronous
573 data transmission and with the different bus configurations.

7 Interoperability Requirements

PSI5 defines all basic characteristics of an electrical sensor interface including the physical layer, data link layer and - to a certain extend - the application layer. Interoperability between ECU and sensors (asynchronous / synchronous mode) or bus (parallel / universal bus mode and daisy chain mode) requires the definition of the following additional, system specific parameters:

- Sensor configurations, operation modes and timings (single sensor, bus configuration or sensor cluster)
- System supply voltage (low, standard or increased)
- Current driving capabilities vs. current load of the sensors (standard or extended)
- Initialization data content i.e. also including determination of the repetition count (k)

Other sensor parameters such as mechanical and dimensional characteristics, signal evaluation path and functional characteristics or reliability and environmental test conditions are beyond the scope of the PSI5 specification and have to be specified in separate documents to assure cross compatibility.

8 Document History & Modifications

Rev.N°	Chapter	Description / Changes	Date
1.0	all	First Edition	15.07.2005
1.1	div.	see Version 1.1	30.06.2006
1.2	1.2	Optional 189kbps data transmission speed added	12.06.2007
	2.3	Synchronous operation: new denomination for operation modes	
	2.3.2	Serial topology: changed form voltage shift method to low-side “daisy chain” switching with bidirectional addressing sequence	
	3.3.1	Data Range: Updated Status & Error Messages	
	3.3.2	Scaling of data range: definition for initialization data added	
	3.4.1	Description of Initialization phase extended	
	3.4.2	Initialization data content summarized in Chapter 3.4.3; Mandatory header information includes F5 - sensor parameter.	
	4	Structure of parameter specification reorganized; General parameters (4.1) : - Quiescent current 4 .. 19mA, extended current max. 35mA - Current limitation added Data transmission parameters (4.4) : - correction of start bit values in the data frame timing figure - bit time for 189kbps mode added - communication current tolerance narrowed - fall / rise time communication current changed (see Chapter 5) - clock drift rate specified Synchronization signal (4.5): - detailed specification of only one, unified sync signal Timing of synchronous operation modes (4.6): - specification of time slots	
	5	System configurations (new Chapter): - denomination of PSI5 operating modes specified (5.1) - recommended operating modes (5.2) - detailed system configuration: asynchronous operation (5.4) - detailed system configuration: parallel bus modes (5.5.1, 5.5.2) - detailed system configuration: serial bus mode (5.6) - reference networks & test conditions (5.7) - operation modes PSI5-P10P (5.8)	
1.3	div.	Siemens VDO replaced by Continental	06.06.2008
	2.2	Shifted from Chapter 5.	

		Denomination of operation modes changed: - Asynchron - Parallel Bus (Parallel Configuration) - Universal Bus (Pass-Through Configuration) - Daisy Chain Bus (Serial Configuration)	
	2.3;2.4	Simplified diagrams of sensor configurations shifted from Chapter 5	
	3	Chapter renamed: Sensor to ECU Communication	
	3.4.4	Diagnostic Mode added.	
	4	Chapter added: ECU to Sensor Communication	
	5.1.1	Reverse polarity protection: - 100ms replaced by 80ms and 50ms respectively - min value of 105mA for standard mode	
	5.1.2	- Supply voltage for Universal Bus and Daisy Chain Bus added - Daisy Chain Sensor Quiescent Current added	
	5.2	Optional settling time for Daisy Chain Bus added	
	5.3	Figure replaced for clarity	
	6.3	Min value for capacitive sensor bus load changed to 6nF	
	6.4	Parameter Specification for Universal Bus added	
	6.5	Parameter Specification for Daisy Chain Bus added	
	6.6.1	- Definition of max value for supply voltage instead of nominal value - Definition of min and max value for ECU internal capacitance instead of nominal value - Sensor damping behavior redefined	
	6.6.2	Reference network for Universal Bus Mode and Daisy Chain Bus Mode added	
	7.2	Recommended Configurations shifted from Chapter 5.2	
2.0		Full revision; plus technical changes, amendments and formal changes of the document structure. Application specific Substandards “airbag”, “vehicle dynamics control” and “powertrain” are added to the PSI5 “Base Standard” document. Main features are: Changes to Physical Layer: optional Vss voltage level 4,0V; bidirectional communication downstream with short & long sync signal; optional reduced sync voltage; reduced sending current Changes to Data Link Layer: enhanced data word length up to 28bit; initialization option based on "Serial Channel"	06/2011
2.1		Full revision plus technical changes (see below)	10/2012

	2.4.2	Daisy Chain implementation added	
	3.2	Explicit definition added that both start bits always are coded as two "zeros"	
	3.3.1	- Signification for reserved Data in Data Range 1 and 2 changed - Status & Error Messages; signification +489 "Sensor in Diagnostic Mode" renamed	
	4.1	Tooth Gap Method connected to the usage of the "short" sync pulse only	
	5.2.2	Xlong Data Frame: Definition of Sensor Response RD2 added	
	6.2	settling time quiescent current changed to 10ms	
	6.3	Undervoltage Reset and Microcut Rejection; split definition in base document (general) and Substandard (application specific min/max values for the affected parameters)	
	6.4	Sensor clock deviation during data frame widened for Chassis and power train applications, two alternative options defined in base specification (0.1%; 1%)	
	6.6.1	Additional explanations given for time slot calculation	
	7.6.4 7.7	Change of Test Parameter Specification, ECU reference test added, additional explanations.	
	div.	Editorial changes, consecutive line numbers for traceability	
2.2	1.1	Updated members	05/2016
	3.4	Example of CRC Calculation	
	5.1.2	Added section “Data Content – Data Range Initialization”	
	6.1	New parameter definition “signal noise limit” and “quiescent current drift rate”; detailed explanation of absolute maximum ratings	
	6.1.2	Quiescent current drift rate changed from 1 mA/s to 10 mA/s	
	6.1.2	Sync signal upper boundary (16.5V)	
	6.1.2	Signal noise limit defined (+/- 2mA for common mode)	
	6.2.1	New Chapter “Sensor Bus Configuration”, settling time quiescent current changed to 5ms (larger settling times to be addressed in new Chapter “extended settling time”)	
	6.2.2	New Chapter “6.2.2 Extended Settling Time for single sensor configuration”	
	6.4	Maximum sensor clock deviation during data frame changed from 0.1% to 1%.	
	div.	Editorial changes, Term “recommended” mainly removed from standard. Standardization of document naming.	

2.3	2	Chapter "Definition of Terms" introduced with Symbol/Parameter Definitions, Glossary and Acronyms, Abbreviations	31.07.2017
	3	Chapter "Data Link Layer" introduced which consolidates all relevant definitions concerning PSI5 data link layer; consolidated information deleted out of former chapters	
	4	Chapter "Physical Layer" introduced which consolidates all relevant definitions concerning PSI5 physical layer; consolidated information deleted out of former chapters	
	4.7.1	Chapter "Supply and Communication Parameters Definitions" introduced. Figure 22: System current and voltage definitions added. Table 15: Parameter specification of absolute maximum ratings added which defines common and low power mode with related physical layer compilations	
	4.7.3	Definitions and explanations for Supply Voltages, Supply Voltage operation options and Interface Current operation options added. Former separate table for Common Mode and Low Power Mode consolidated in Table 16: Parameter compilation for Common Mode and Low Power Mode operation	
	4.9	Explanation added for different sync pulse levels with linked parameters	
	4	Introduced "Conditions/Remark" column to all tables	
	div.	Table captions and list of tables added. List of figures added. All figures have been redrawn. Line numbering has been completely reworked. Document has been completely reformatted.	

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