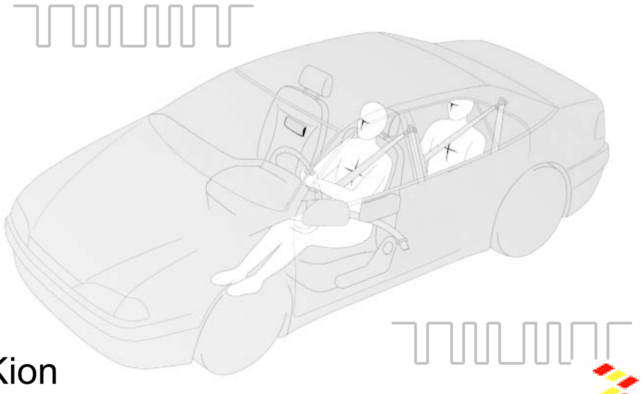
Peripheral Sensor Interface for Automotive Applications



Contents

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 this technical specification are responsibly managed by the "PSI5 Steering Committee", formed by the companies Autoliv, Bosch, and Continental.

This PSI5 technical specification V2.0 is a joint development of the companies Autoliv, Bosch, Continental, Analog Devices, CS Group, ELMOS, Freescale, Hella, IHR, Infineon, Seskion, ST, TRW and OnSemi.

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

This updated Version 2.0 contains several new features in terms of Physical and Data Link Layer parameters in order to enlarge the application range of the PSI5 Interface. Due to backward compatibility established parameters according to Specification V1.3 are still valid; the alternative implementations are mainly optional and specifically indicated.

Though, general interface parameters are given within this Basic Specification document, application specific frameworks and conditions are given in the effective substandards "airbag", "vehicle dynamics control" and "powertrain". Recommended operation modes and system configurations are given therein, as well as forbidden configurations are excluded.

Please be aware, that not every feature can be combined among one other. Hence 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.

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 System Setup & Operation Modes

2.1 System Setup

Figure 1 shows a possible system setup for peripheral sensors connected to an ECU with PSI5.

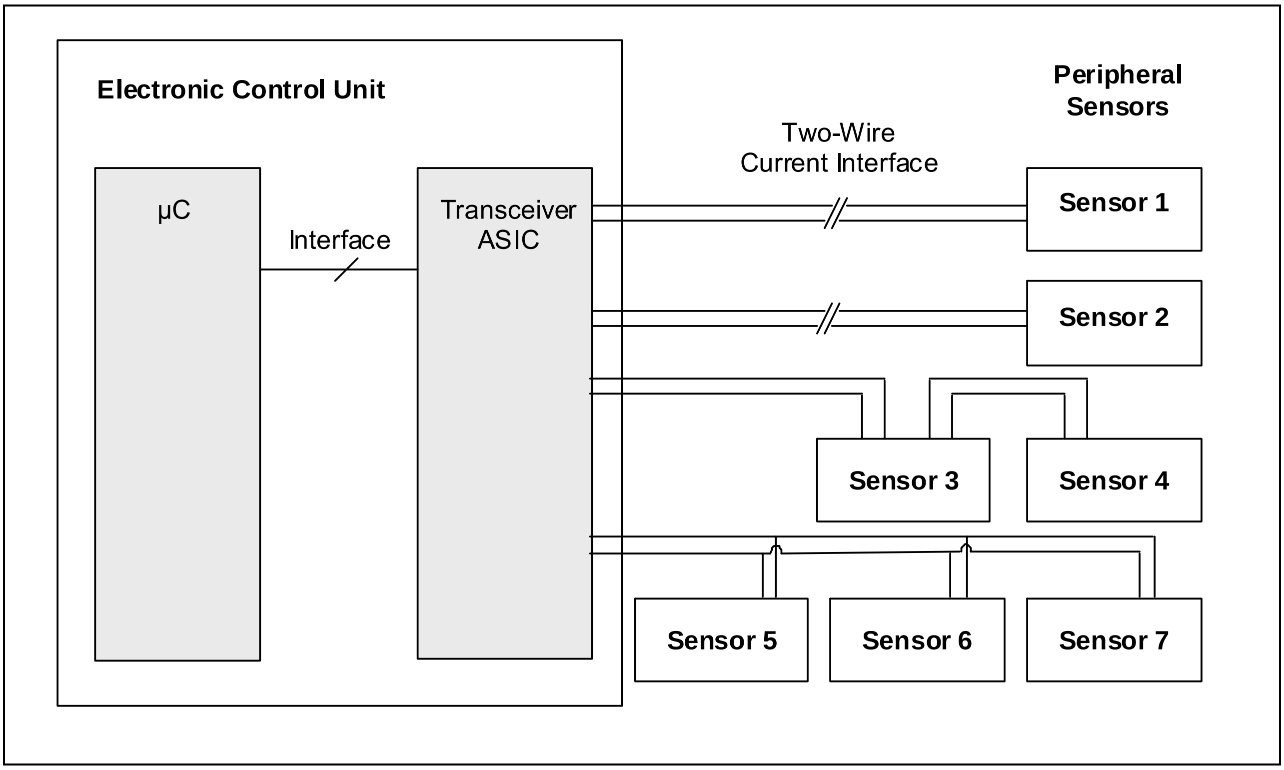

Figure 1 Connection of peripheral sensors to an ECU (Example)

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.

2.2 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.

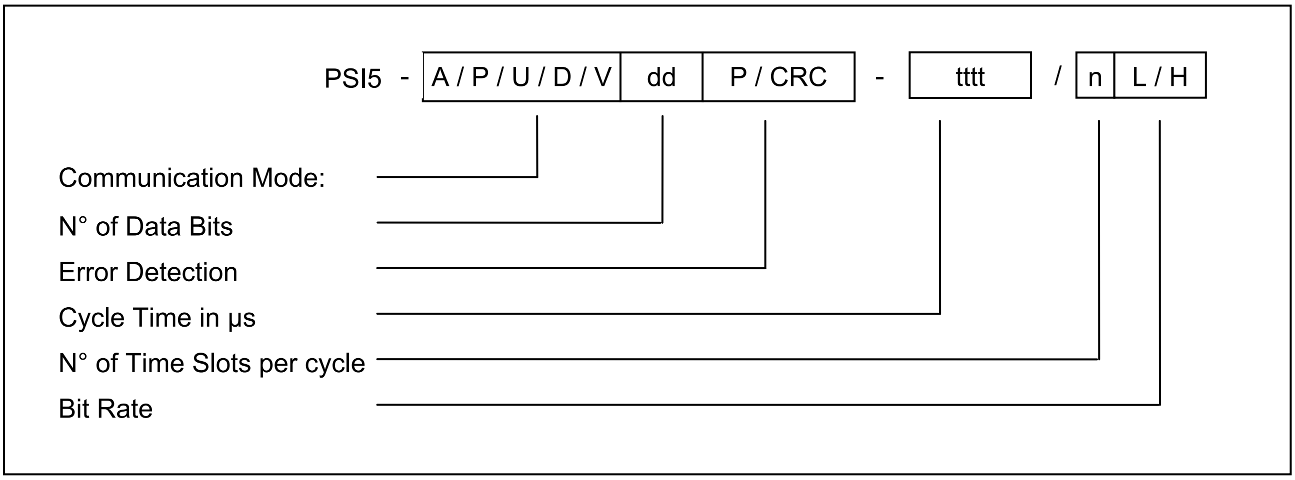

Figure 2 Denomination of PSI5 operation modes

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.

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)

2.3 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.

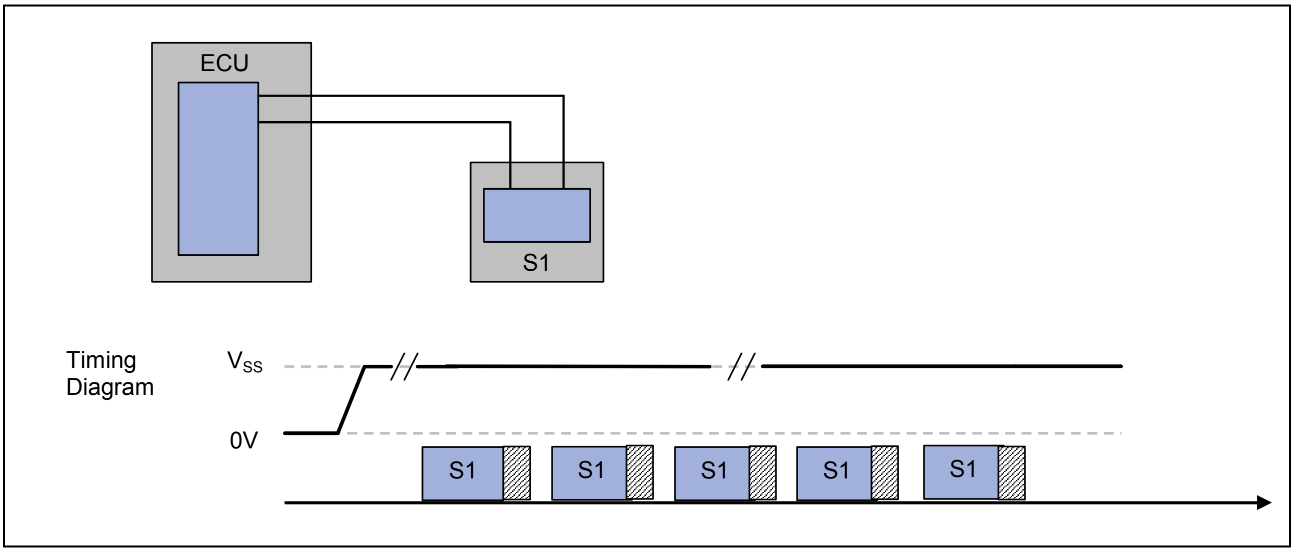

Figure 3 PSI5-A asynchronous point-to-point connection

2.3.1 Asynchronous Single Sensor Configuration

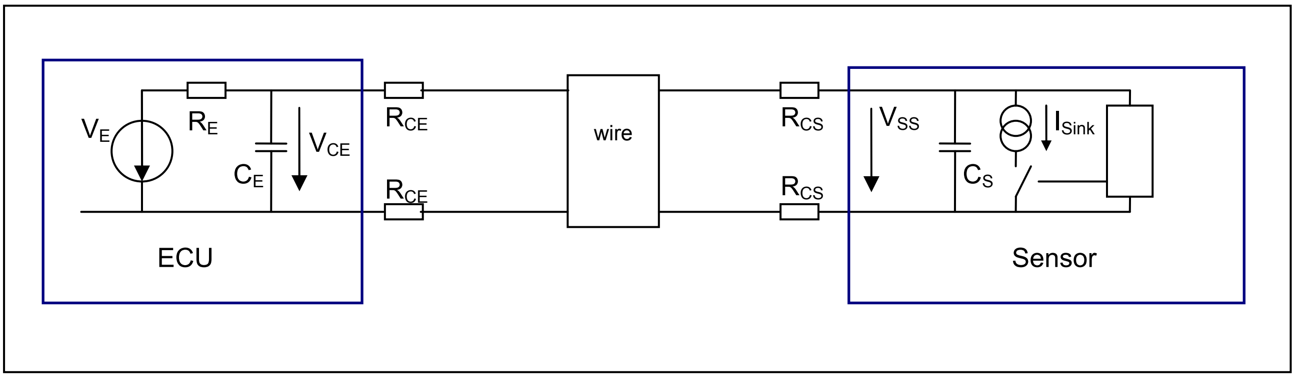

Figure 4 Single sensor configuration (simplified diagram)

2.4 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.

2.4.1 Timing of Synchronous Operation Modes

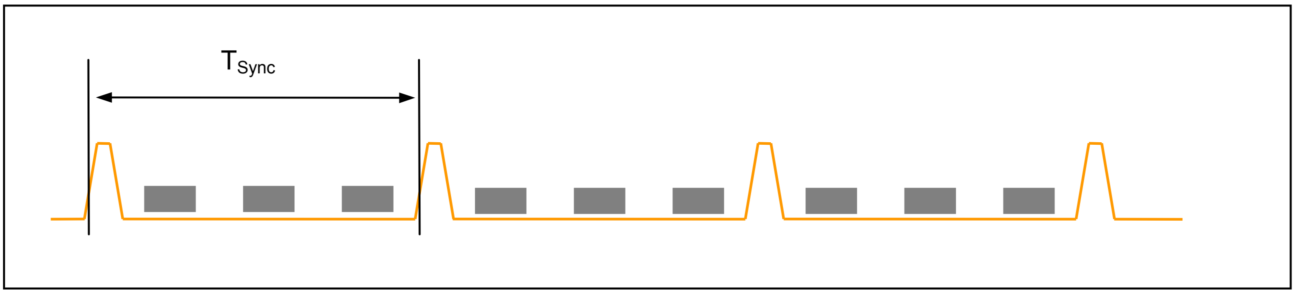

Figure 5 Fixed time triggered synchronous operation

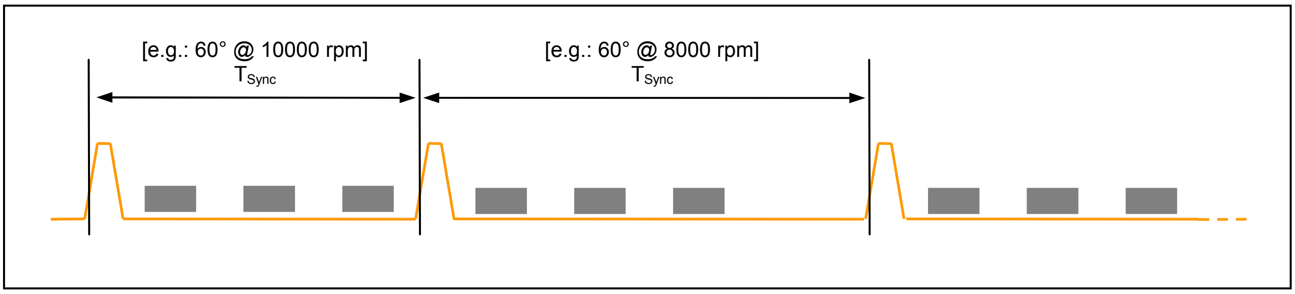

Figure 6 Variable time triggered synchronous operation

2.4.2 Bus Operation Principle

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

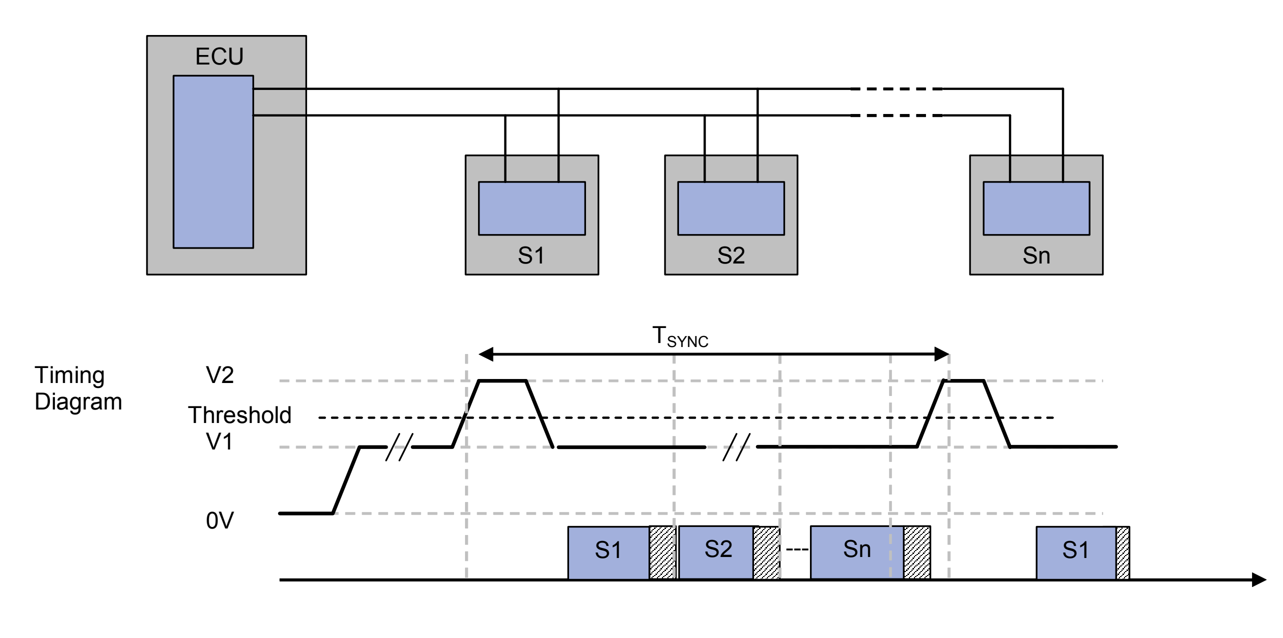

Figure 7 Basic PSI5 bus topology

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.

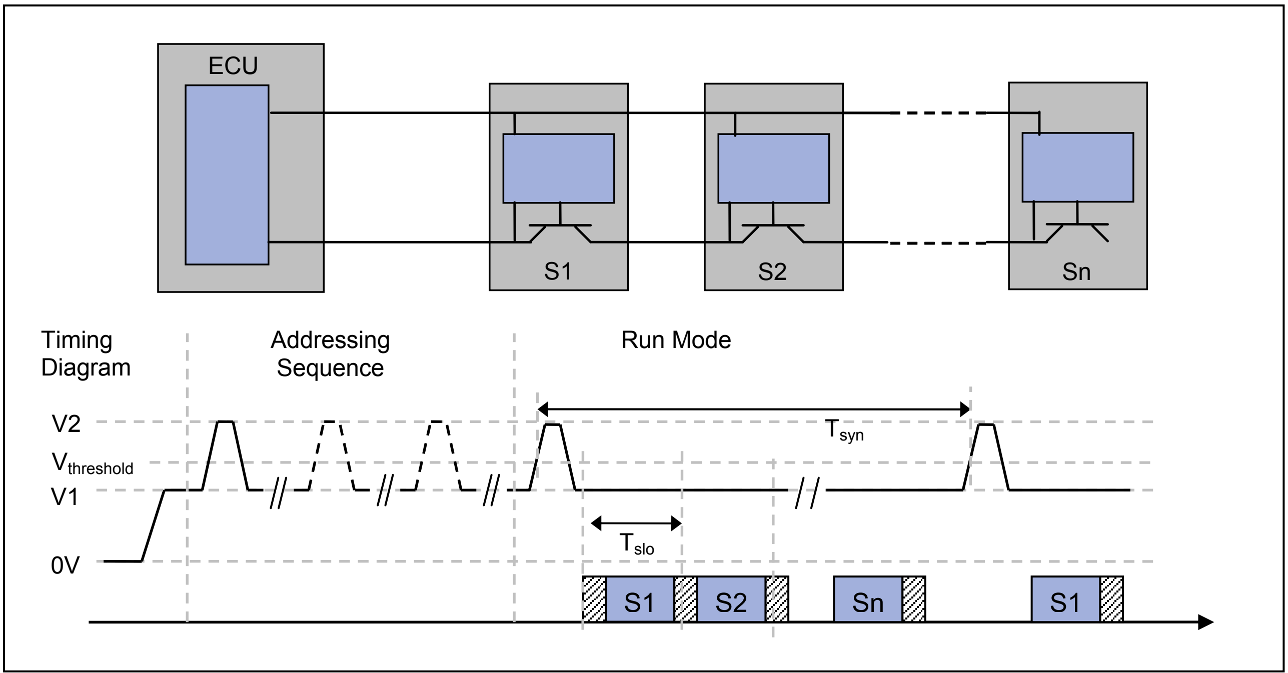

Figure 8 Daisy Chain Bus Topology

2.4.3 Synchronous Parallel Bus Mode (PSI5-P)

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

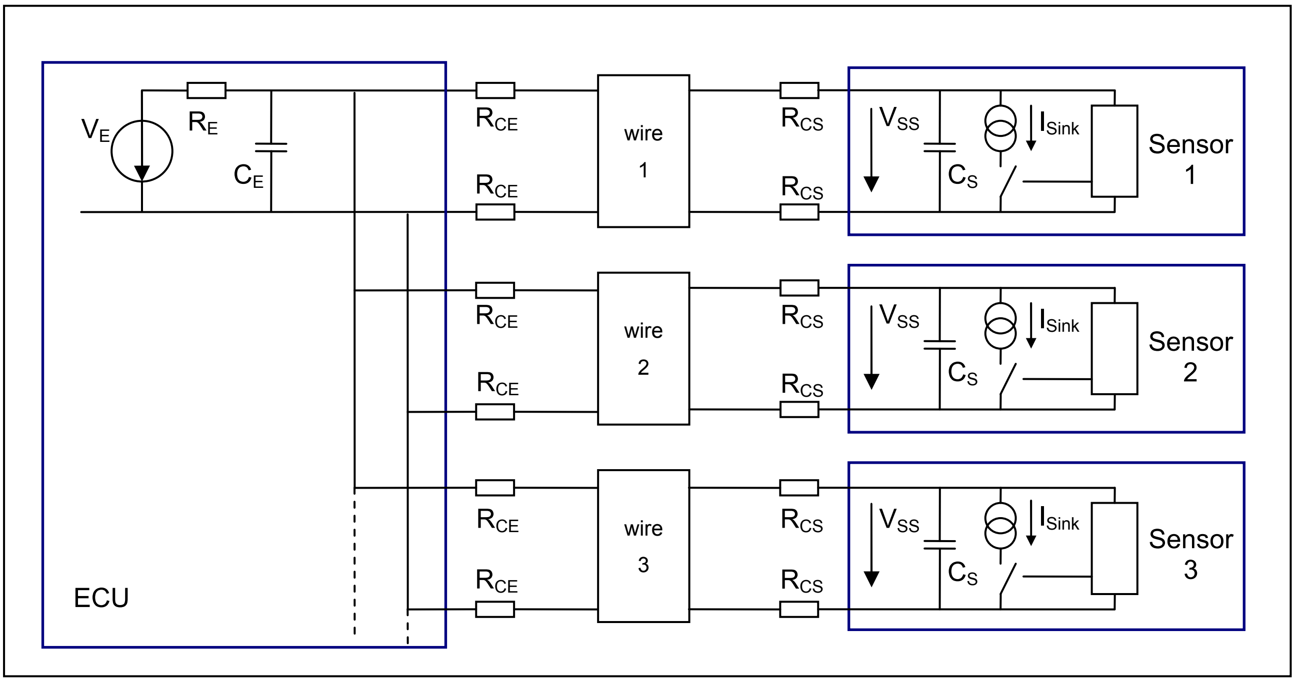

Figure 9 Synchronous Parallel Bus Mode (simplified schematic)

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 (see chapter 7.3).

2.4.4 Synchronous Universal Bus Mode (PSI5-U)

PSI5-U describes a bus configuration for synchronous data transmission of one or more sensors. The sensors are connected to the ECU in different wiring topologies including splices or pass-through configurations.

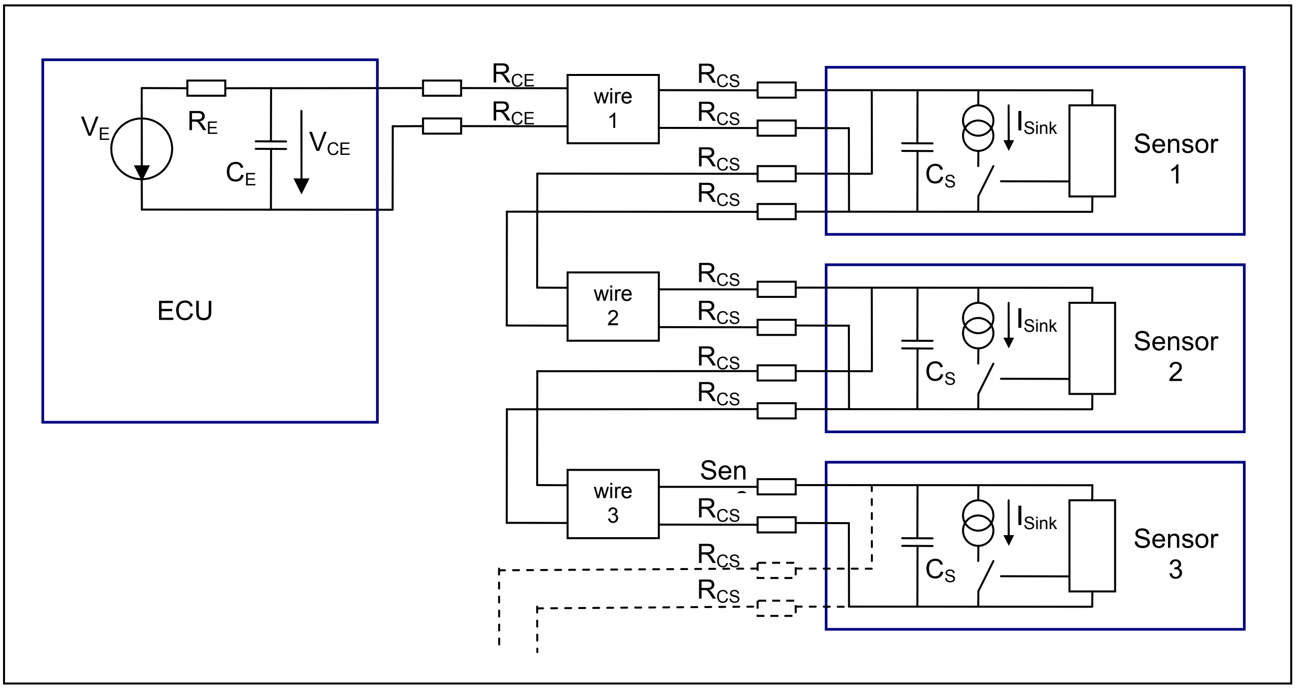

Figure 10 Example for a pass-through configuration (simplified schematic)

The wiring and sensors are considered as a "black box" resulting in a limited interchangeability of sensor and transceiver components. Interface parameters are given for the ECU and the "black box" only (see chapter 7.4).

2.4.5 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. The required addressing of the sensors during start up is specified in chapter 5.2.2.

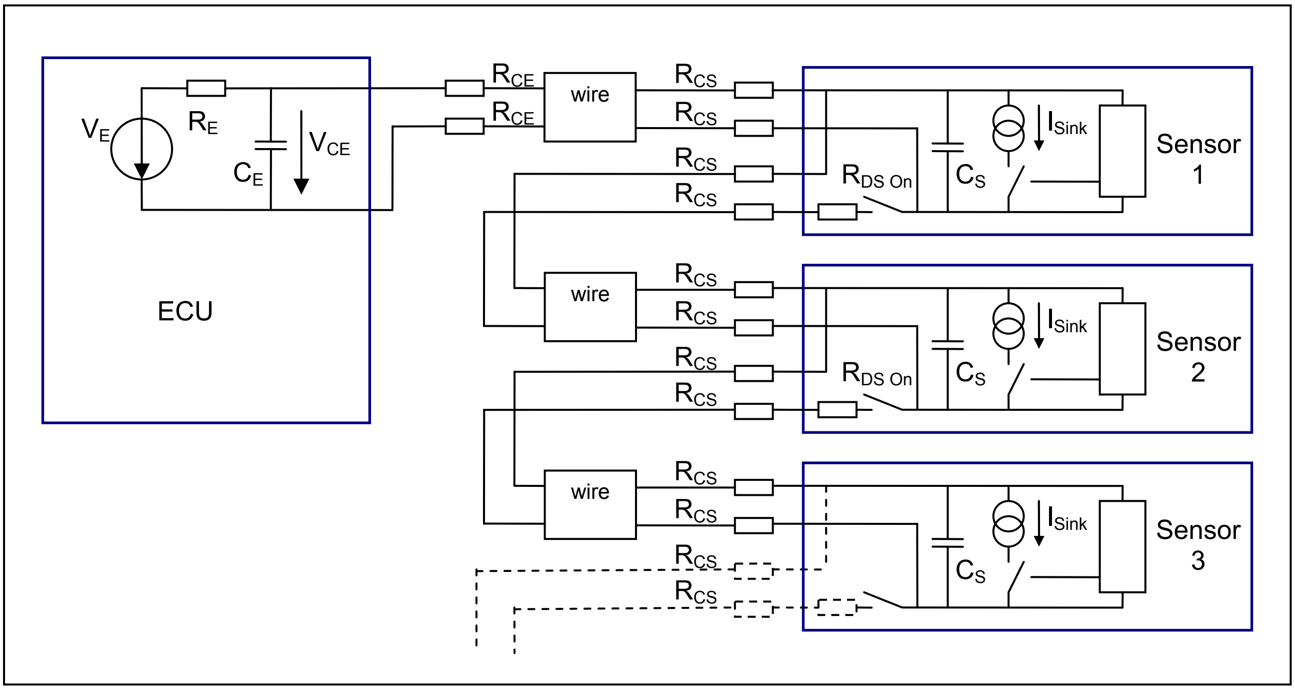

Figure 11 Synchronous Daisy Chain Bus (simplified schematic)

2.4.6 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.

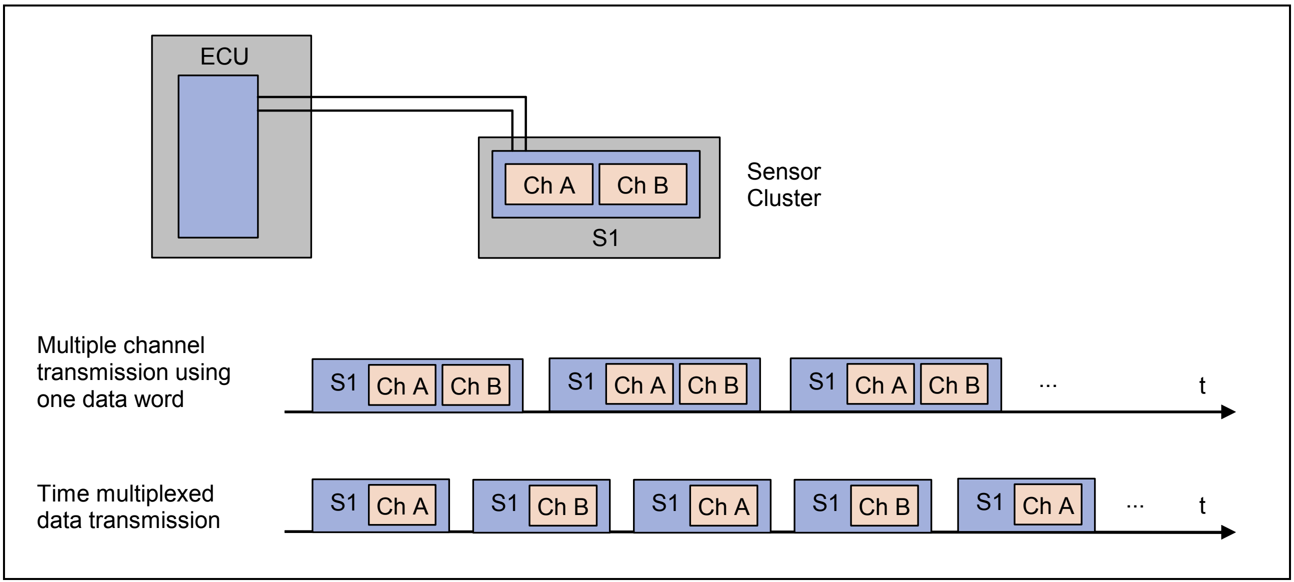

Figure 12 Implementation example sensor cluster

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

3 Sensor to ECU communication

3.1 Physical Layer

PSI5 uses two wires for both power supply to the sensors and data transmission. The ECU provides a pre-regulated voltage to the sensor. Data transmission from the sensor to the ECU is done by current modulation on the power supply lines. Current oscillations are damped by the ECU.

3.1.1 Bit Encoding - Sensor to ECU Communication

A "low" level ($I_{S,Low}$) is represented by the normal (quiescent) current consumption of the sensor(s). 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 detected within the transceiver ASIC.

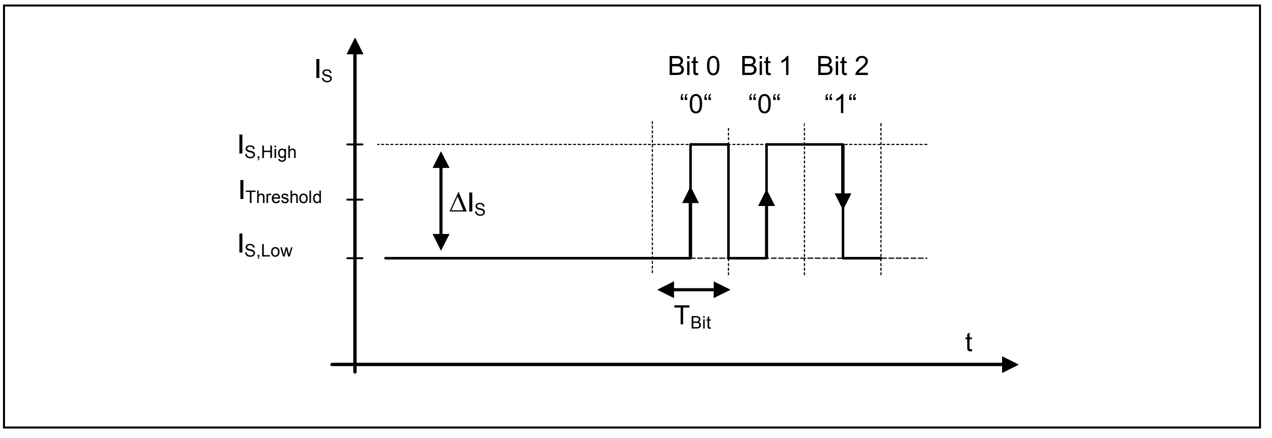

Figure 13 Bit encoding using supply current modulation

Manchester coding is used for data transmission. 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}.

3.2 Data Link Layer

3.2.1 Data Frames - Sensor to ECU Communication

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 PSI5 data frame consists of *p* bits containing

- two start bits (S1 and S2),
- one parity bit (P) with even parity or alternatively 3 CRC bits (C0, C1, C2), and
- a data region (D0 … D[k-1]) with k = 10.. 28 bit.

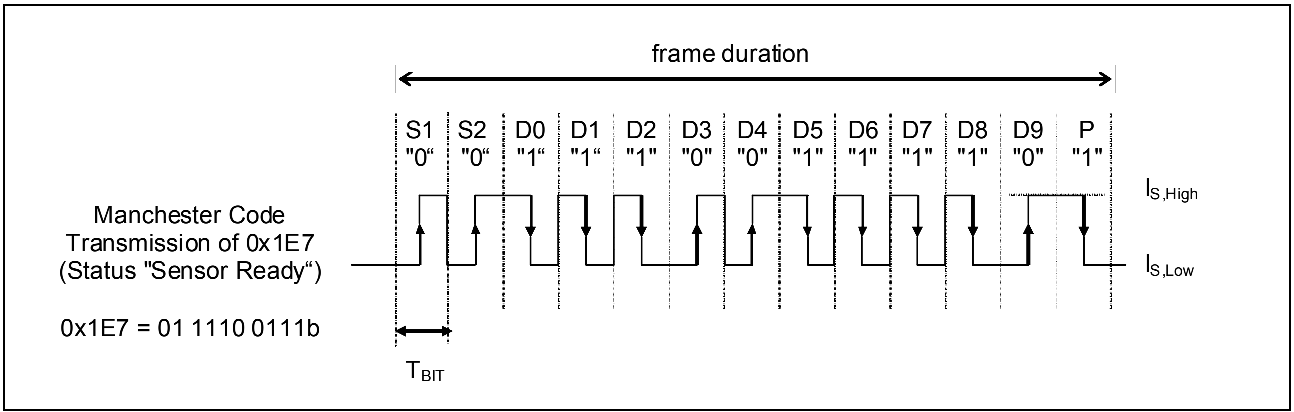

Figure 14 Example of a data frame with 10 data bits (D0-D9), 2 start bits (S1,S2) and one parity bit (P).

The total length of a PSI5 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 data region. The length of the data region can vary between *k* = 10… 28 bits (with 1-bit granularity).

3.2.2 Error Detection

Error detection is realized by a single bit even parity (for 10 bit data words) or a three bit CRC (recommended for longer data words). The generator polynomial of the CRC is $g(x)=1+x+x^3$ with a binary CRC initialization value "111". The transmitter extends the data bits 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"						

CRC Calculation Scheme

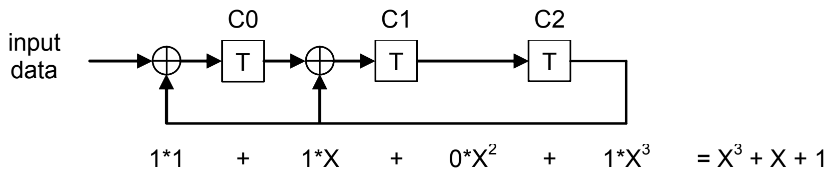

Figure 15 16 Bit Data word example with 3-Bit CRC

3.2.3 Frame Format

The data frame may contain one or more data regions.

- One mandatory Data Field A with data bits A0 … A[*n*-1] (scalable *n* = 10…24 with 1-bit granularity)

And additional optional fields:

- Data Field 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, type of frame F0, …F[*q*-1] (optional 0, 1, 2, 3 or 4 bit)
- Serial messaging channel M0, M1 (optional 0 or 2 bit)

Each optional data region can be omitted in total or varied in bit length, but, if applied, the specific hierarchy of the data regions must be kept as shown in fig. Figure 16.

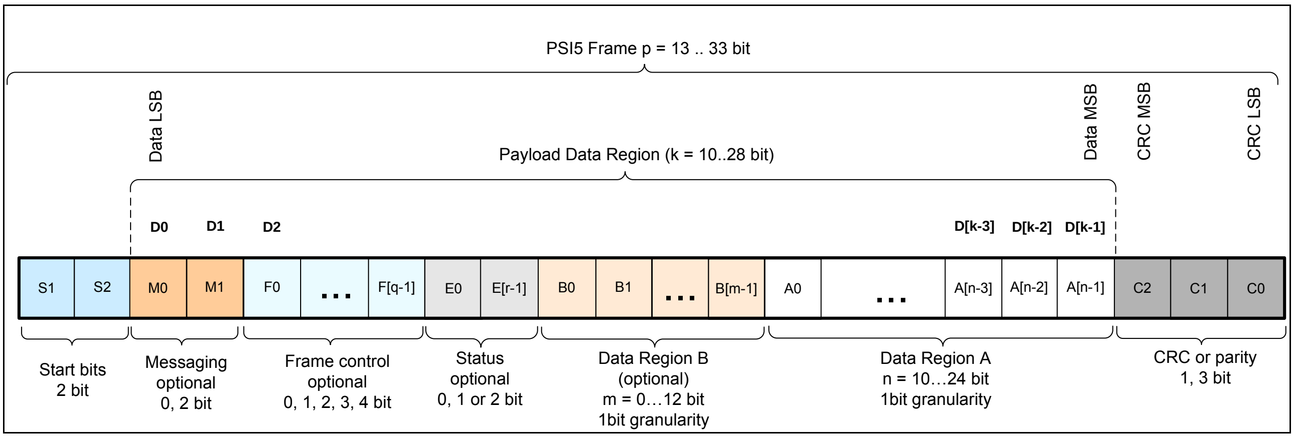

Figure 16 different parts of the PSI5 data frame

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[n-1]	Payload Data	0, 1, 2, … , 12	Additional data region B (optional)
A0 … A[m-1]	**Payload Data**	**10, … , 24**	**data region A (mandatory)**

3.3 Data Range

PSI5 data messages 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.

3.3.1 Data Range (10 Bit)

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 5.1). The range from +481 to +511 is used for status and error messages.

Dec	Hex	Signification	Range	
+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 Diagnostic 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."		
+480	0x1E0	Highest Positive Sensor Signal	Sensor Output Signal	1
:	:	:		
0	0x000	Signal Amplitude "0"		
:	:	:		
-480	0x220	Highest Negative Sensor Signal		
-481	0x21F	Status Data 1111	Block ID's and Data for Initialization	3
:	:	:		
-496	0x210	Status Data 0000		
-497	0x20F	Block ID 16		
:	:	:		
-512	0x200	Block ID 1		

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

(*2) Reserved for future extensions of this specification, usage not recommended.

3.3.2 Scaling of Data Range (for data words longer than 10 bit)

The sensor output signal range scales with the data word length, 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 region 2 and 3. Hence, during Initialization with the Data range method, the 10 bit codes MSB of the payload region are always used for signaling as defined in Chapter 5.1. The remaining bits of the payload region (either A[10]…A[23] or an optional Data region B) are free to use.

The following fractions of the Payload Data Region are not affected by signaling range definition:
- Remaining bits above 10 of Data Region A (A[10]...A[23])
- Data Region B (optional)
- Serial Messaging Channels (optional)
- Frame Control (optional)
- Status (optional)

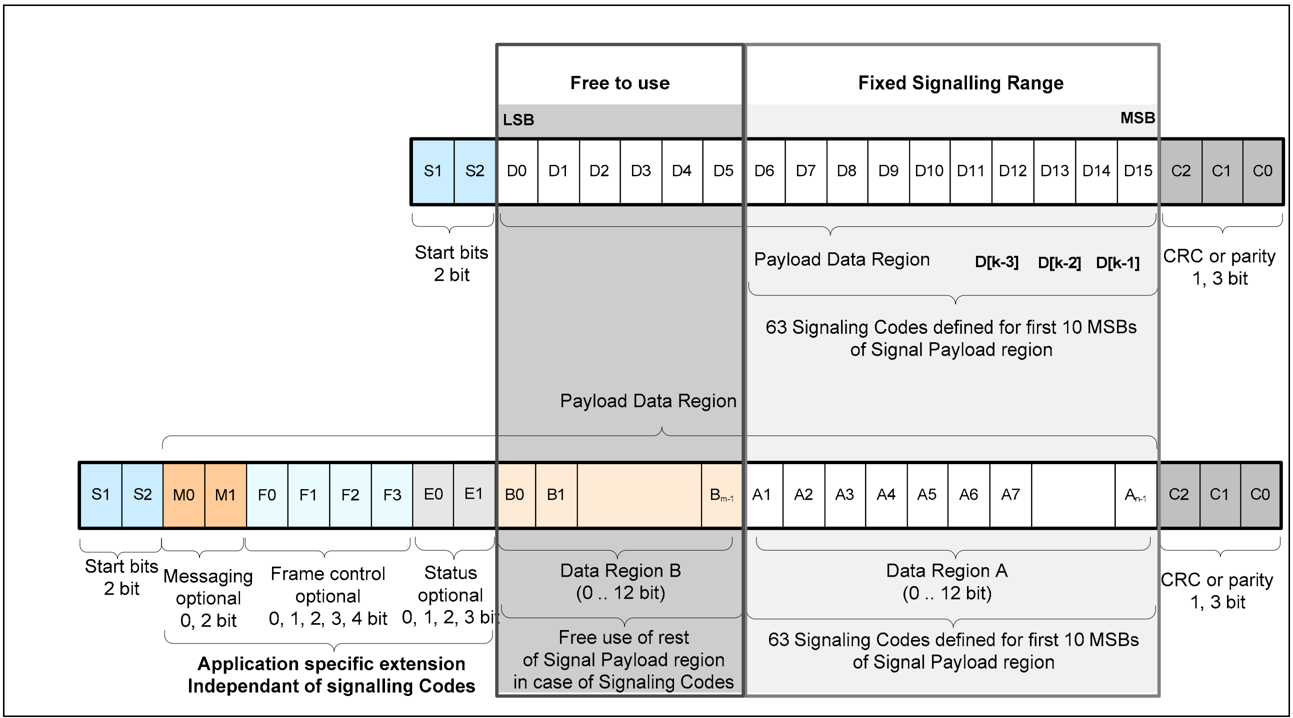

Figure 17 Scaling of Data range

3.4 Serial Channel

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 frame, or its constituent messaging bits, respectively, is assigned to the related time slot of the corresponding PSI5 frame.

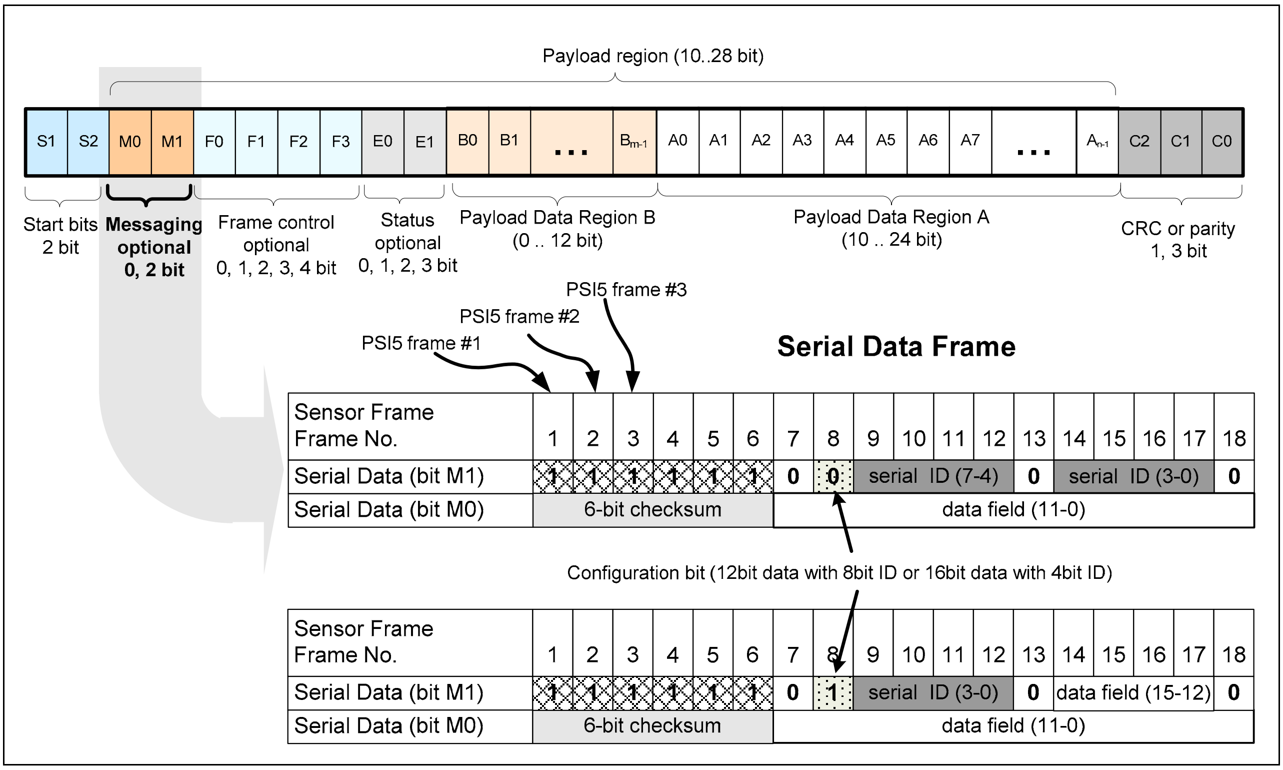

Figure 18 Serial Data Frame generated by the two messaging bits of the sensor data frame (messaging channel)

The generator polynomial of the 6bit checksum is $g(x)=1+x^3+x^4+x^6$ with a binary initialization value "010101". The CRC value is derived from the serial messaging contents of sensor frame 7 to 18, the bits are read in to 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 fig. 19.

For CRC generation the transmitter extends the message data by six zeros. This augmented data word is fed 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. These six check bits shall be transmitted MSB first [C5, C4, ... C0]

Messaging bits for checksum Calculation

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 19 Read in order for checksum generation

4 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.

4.1 Physical Layer

ECU to Sensor communication is performed according to either one of the following two procedures.

4.1.1 „Tooth Gap" method

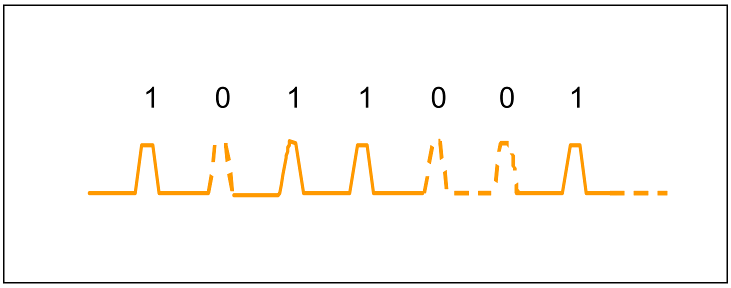

Figure 20 Bit Encoding according to the Tooth Gap Method

A logical "1" is represented by the presence of a sync signal, a logical "0" by the absence of a sync signal at the expected time window of the sync signal period. The voltage for a logical "0" must remain below the 0.5V limit specified as the sync signal t_0 start condition.

This Bit Encoding method is only applicable with a fixed sync signal period.

4.1.2 „Pulse Width" method

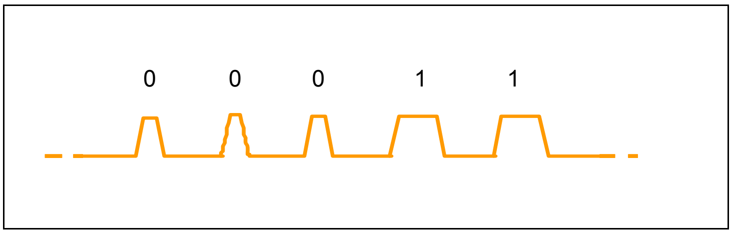

Figure 21 Bit Encoding via Pulse width

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 6.5)

4.2 Data Link Layer

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
- The sensor address
- 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.

Data Frames and Formats

ECU to Sensor data frames are structured as described below. They are applied in different ways for the bit coding method in use. The Tooth Gap method is limited to usage of data frame formats 1-3, whereas the Pulse Width method is applicable with all 4 frames. A combined usage of the frame types 1-3 and frame 4 within one implementation is forbidden in order to ensure safe data recognition. Specific regulations must be given in the corresponding substandards or specific product specifications.

The frames 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”.

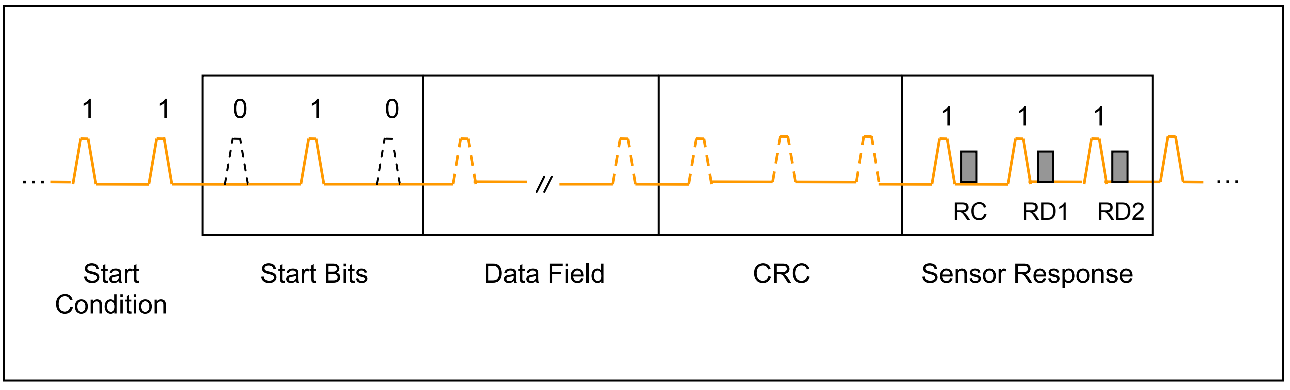

Figure 22 Data frame ECU to sensor communication – e.g. Tooth Gap method applicable to frame formats 1-3

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 Adress (SAdr) and the function Codes (FC) as shown in fig. 23. The calculation of the three bit checksum is given in Ch. 3.2.2

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 2 „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 2 „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 23 Data frames 1-3 ECU to Sensor Communication

Data frame 4 is composed by nine start bits, a four bit sensor address field, a 20-bit data field containing application specific data and a six bit CRC. “Stuffing Bits” (logical “0”) are introduced at each sixth bit position 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.

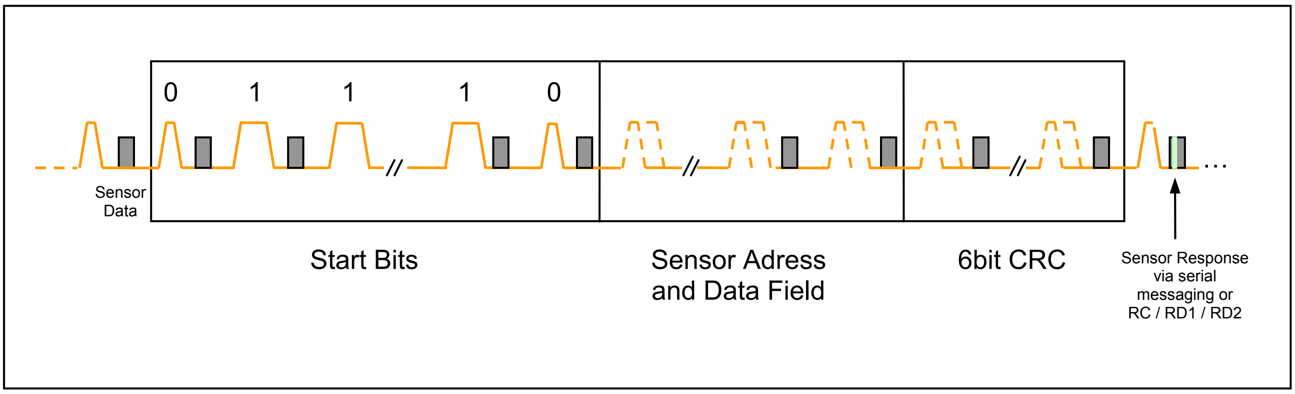

Figure 24 Data frame ECU to Sensor Communication –e.g. Pulse width method with frame format 4 (frame formats 1-3 are also applicable)

S: Synchronisation Bit [0]

C: Configuration Bit
[1] Mapping of frames 1-3
[0] all other applications

Frame 4 „XXLong“

Start									SAdr				Data									CRC					
S	1	1	1	1	1	1	1	S	A0	A1	A2	C	D0	D1	S	D2	…	D7	S	D8-D19 + Sync Bits	S	C0	C1	C2	C3	C4	C5

N° Bits: 43 (21.5ms @ 500µs)

Figure 25 Data frame4 ECU to Sensor Communication

The generator polynomial of the six bit CRC of frame 4 is $g(x)=x^6 + x^4 + x^3 + 1$ with a binary CRC initialization value “010101”. The transmitter extends the data bits by six zeros (as MSBs). This augmented data word shall be fed (LSB first) into the shift registers of the CRC check. Start bits and sync 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 six check bits shall be transmitted LSB first [C0, C1 .. C5].

Mapping of Data frames

In case the function codes as defined in Ch. 5.2 shall be used in combination with frame 4, they are mapped as shown below.

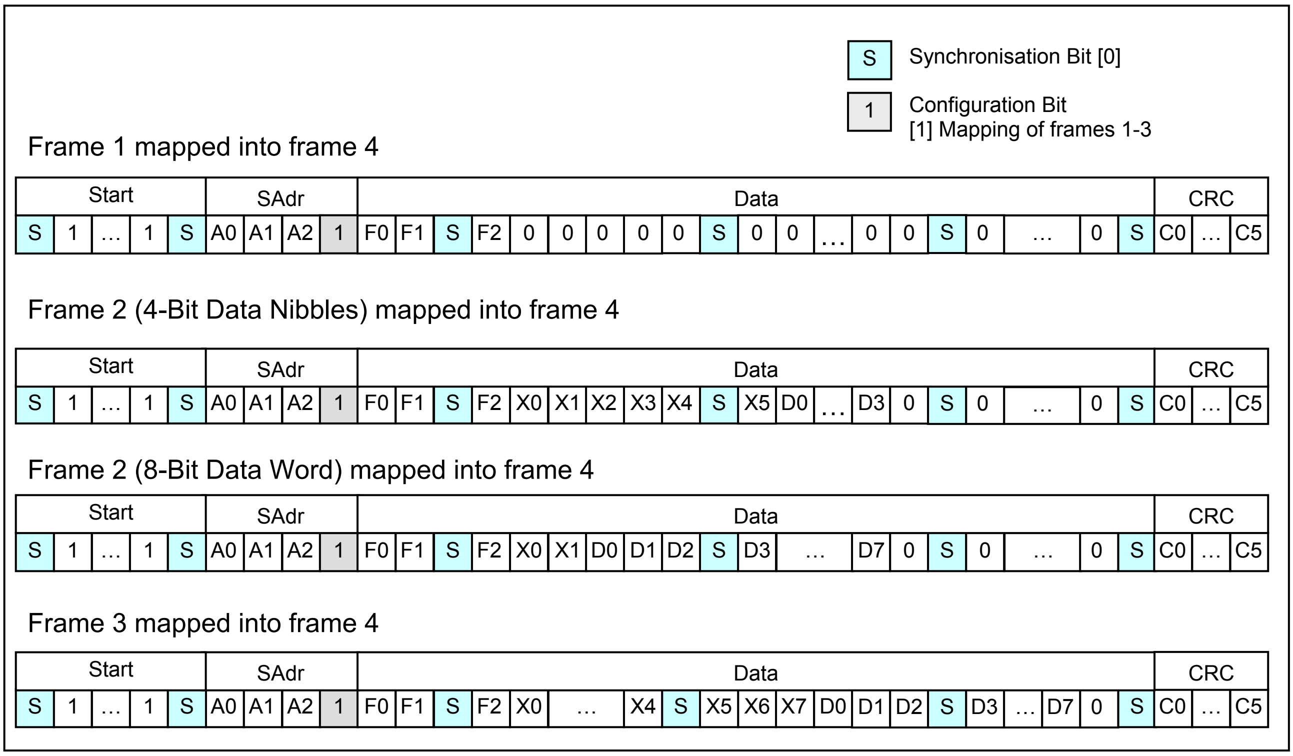

Figure 26 Mapping of frames 1-3 into frame 4

5 Application Layer Implementations

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 sensor initialization and bidirectional communication are made in this chapter.

5.1 Sensor Initialization / Identification

Sensor identification 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.

Chapter 5.1.1 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 5.1.2 and 5.1.3 define basic regulations of the Application Layer that need to be followed by both identification procedures.

5.1.1 Frame Format - Data range initialization

The initialization data is transmitted within the range of “Payload Data Region 1” using ID and data blocks out of the reserved data range 3 containing each 16 block identifiers and 4-bit data nibbles.

Block Identifier and Data Nibbles

Block ID 1-16 (0x200 – 0x20F)

A9	A8	A7	A6	A5	A4	A3	A2	A1	A0
1	0	0	0	0	0	0000 - 1111			

Data Nibbles ”0000” – “1111” (0x210 – 0x21F)

A9	A8	A7	A6	A5	A4	A3	A2	A1	A0
1	0	0	0	0	1	0000 - 1111			

Figure 27 Block ID and Data Nibbles

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

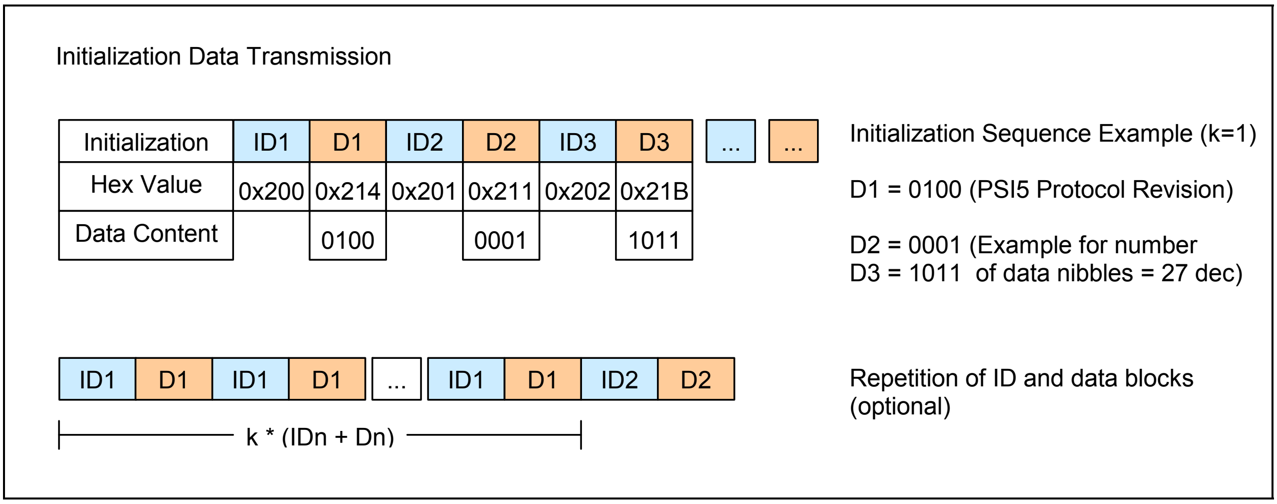

Figure 28 Startup Sequence

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.

5.1.2 Meta Information

At the very beginning of the identification phase a "meta information" header is transmitted minimum once 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).

Name	Parameter definition	Value
Header	Protocol Description (D1)	
	PSI5 1.x	0100
	PSI5 2.0, Data Range Initialization	0110
	PSI5 2.0, Serial Channel Initialization	0111

5.1.3 Vendor ID

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

Name	Parameter definition	ASCII Code
Vendor ID (8bit Sensor Manufacturer Code)	Analog Devices	0110 0001
	Autoliv*)	0100 0001
	Bosch*)	0100 0010
	Continental*)	0100 0011
	ELMOS	0100 0101
	Freescale	0100 0110
	Hella	0100 1000
	IHR	0110 1001
	Infineon	0100 1001
	OnSemi	0100 1111
	Seskion	0111 0011
	ST Microelectronics	0101 0011
	TRW	0101 0100
	Other sensor manufacturers	tbd

Further Details of Initialization Data Structure and Contents are given in the respective Substandards.

*) the here given Vendor IDs are effective for PSI 5 V2.0 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).

5.2 Bidirectional Communication

Up- and Downstream Combinations

Upstream (Sensor response to ECU)	Downstream (ECU to Sensor)	Remark
Data Range 2	Tooth Gap method note: frame format is restrained to frame 1-3 (see Ch. 5.2.1)	PSI5 1.3 compliant
Data Range 2	Pulse Width method	
Serial Channel	Pulse Width Method	

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

5.2.1 Sensor Adresses

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

5.2.2 Function Codes and responses for bidirectional communication – Frame 1 to 3

Mnemonic	**SAdr**			**FC**			**Signification**	**Response**	
	A2	**A1**	**A0**	**F2**	**F1**	**F0**		**o.K.**	**Error**
Set Sensor Address & Run Command (Short Data Frame) Condition: SAdr = “000” or SAdr = “111”									
SetAdr	0	0	0	Address to be pro-grammed			Set Sensor Address & Close Bus Switch (The “FC” field contains the sensor address)	RC: “o.K.” RD1: “Address”	RC: “Error” RD1: “ErrN°”
				A2	A1	A0			
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				1	0	1	Execute Specific Function #2		
Exec 3				1	1	0	Execute Specific Function #3		
Exec 4				1	1	1	Execute Specific Function #4		
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				0	1	1	Write nibble or byte to sensor (*)		
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°”
WR_X				0	0	1	Write data byte to sensor		

(*) 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.

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

ErrN°	Mnemonic	Signification
0000	General	General Error (*)
0001	Framing	Framing Error
0010	CRC	CRC Checksum Error
0011	Address	Sensor Address not supported
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

(*) Unspecific, may replace all other error codes

6 Parameter Specification

All voltage and current values are measured at the sensor's connector pins unless otherwise noted. Values in brackets denote redundant parameters that can be calculated by other specified values and are for illustration purposes only. All parameters are valid under all operating conditions including temperature range and life time.

6.1 General Parameters

6.1.1 Absolute Maximum Ratings

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1	Supply voltage	$V_{SS\ max}$, $V_{CE\ max}$ (see fig. 4)			16.5	V
2	Reverse polarity protection (standard) **	t < 80ms	-105			mA
3	Reverse polarity protection (extended) **	t < 50ms	-130			mA

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

6.1.2 System Parameters

With PSI5 Specification V2.0 additional physical layer definitions are implemented in order to satisfy extended application requirements. The affected parameters are:

- Supply voltage V_{CE}, V_{SS}
- Sink Current ΔI_S
- Sync Signal Sustain Voltage V_{t2}, sensor trigger threshold V_{TRIG}
- Internal ECU Resistance R_E

Detailed information is given within the corresponding paragraphs of the following pages. Not every feature can be combined among one other. Hence it is in responsibility of the system vendor to evaluate which feature is necessary to fulfill the system requirements and assure that the combination of features is compatible. A first basic preselection is done with the two recommended parameter assemblies given below for “Common Mode” and “Low Power Mode” operation. They still contain several options for particular parameters. Therefore additional selections must be made for specific applications as they are given in the effective substandards, for example.

Common Mode

N°	Parameter	Symbol	Min	Typ	Max	Unit
1*	Supply Voltage (standard)	V_{SS}	5.0		11.0	V
2*	Supply Voltage (low voltage)		4.0		11.0	
3*	Supply Voltage (standard)	V_{CE}	5.5		11.0	V
4*	Supply Voltage (low voltage)		4.2		11.0	
5*	Supply Voltage (Increased voltage)		6.5		11.0	
6	Sink current ΔI_S	$\Delta I_S = I_{S,High} - I_{S,Low}$	22.0	26.0	30.0	mA
7*	Sync signal sustain voltage, referenced to $V_{CE,\ BASE}$	V_{t2}	2.5			V
8*			3.5			
9*	Internal ECU resistance	R_E	5		9.5	Ω
10*					12.5	
11*	Sensor trigger threshold (for V_{t2} = 3.5V)	V_{TRIG}	1.4	2.0	2.6	V
12*	Sensor trigger threshold (for V_{t2} = 2.5V)		1.2	1.5	1.8	
13*	Interface Quiescent Current (Standard Current)	I_{LOW}	4.0		19.0	mA
14*	Interface Quiescent Current (Extended Current)		4.0		35.0	mA
15*	Drift of quiescent current		-4.0		4.0	mA
16*	Quiescent current, drift rate				1.0	mA/sec
17*	ECU current limitation (Standard Current)	I_{LIMIT}	50.0		105	mA
18*		$I_{LIMIT,\ dyn.}$	65.0			mA
19*	ECU current limitation (Extended Current)	I_{LIMIT}	65.0		130	mA
20*		$I_{LIMIT,\ dyn.}$	80.0			mA
21*	Daisy Chain Sensor Quiescent Current	$I_{LOW,\ sensor}$	4.0		12.0	mA

Low Power Mode

N°	Parameter	Symbol	Min	Typ	Max	Unit
1*	Supply Voltage (standard)	V_{SS}	5.0		11	V
2*	Supply Voltage (low voltage)		4.0		11	
3*	Supply Voltage (standard)	V_{CE}	5.5		11	V
4*	Supply Voltage (low voltage)		4.2		11	
5*	Supply Voltage (Increased Voltage)		6.5		11	
6*	Sink current ΔI_S	$\Delta I_S = I_{S,High} - I_{S,Low}$	11.0	13.0	15.0	mA
7*	Sync signal sustain voltage, referenced to $V_{CE,\ BASE}$	V_{t2}	2.5			V
9*	Internal ECU resistance	R_E	5		9.5	Ω
11*	Sensor trigger threshold (for V_{t2} = 2.5V)	V_{TRIG}	1.2	1.5	1.8	V
13*	Interface Quiescent Current (Standard Current)	I_{LOW}	4.0		19.0	mA
14*	Interface Quiescent Current (Extended Current)		4.0		35.0	mA
15*	Drift of quiescent current		-4.0		4.0	mA
16*	Quiescent current, drift rate				1.0	mA/sec
17*	ECU current limitation (Standard Current)	I_{LIMIT}	50.0		105	mA
18*		$I_{LIMIT,\ dyn.}$	65.0			mA
19*	ECU current limitation (Extended Current)	I_{LIMIT}	65.0		130	mA
20*		$I_{LIMIT,\ dyn.}$	80.0			mA
21*	Daisy Chain Sensor Quiescent Current	$I_{LOW,\ sensor}$	4.0		12.0	mA

1,2*) To be guaranteed by the ECU at the pins of the sensors under all conditions including dynamic load conditions in Asynchronous Mode and Parallel Bus Mode.

2,4*) 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. For low voltage operation, reduced sink current of ≤ 26mA maximum and, if possible, additional reduction of quiescent current is recommended

3,4*) To be guaranteed by the ECU at the output pins of the ECU under all conditions including dynamic load conditions in Universal Bus Mode and Daisy Chain Bus Mode.

5*) Optional increased supply voltage to overcome additional voltage drops in Universal Bus and Daisy Chain Bus applications.

6*) The reduced sink current in Low Power Mode affects the functionality and robustness of system implementations within the full range of all given PSI5 parameters. For low power operation simple configurations and shorter cable lengths (e.g. in point to point configuration) are recommended and a specific system validation is required.

7,8*) V_{t2} = 2.5V is recommended for new applications compliant with PSI5 V2.0; however, in compliance with former PSI5 versions V_{t2} = 3.5V still is valid.

9,10*) R_E = 9.5V is recommended for low voltage applications, when no additional voltage source is implemented in the ECU; however, in compliance with former PSI5 versions R_E = 12.5V still is valid.

11,12*) Referenced to $V_{SS,\ BASE}$

13,14*) Parameters denote the sum over all sensors.

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

15, 16*) I_{LOW} is the (initial) quiescent current of the bus. Over lifetime and temperature, the quiescent current may vary by +/- 4.0 mA 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 consequence of an abrupt quiescent current drift after loss of one sensor connection also needs to be considered.

17-20*) A maximum slope rate of 55mA/µs has to be provided by the ECU.

18,20*) Dynamic load condition: The ECU must have the capability to provide the current $I_{LIMIT,\ dynamic}$ for at least 10µs. For Daisy Chain Bus Mode this current has to be provided for at least 10ms when a sensor is powered on.

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

6.2 Sensor Power-on Characteristics

To ensure a proper startup of the system, a maximum startup time is specified. During this time, the ECU must provide a minimum current to load capacitances in sensors and wires. After this time, 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 $I_{LIMIT, dynamic}$.

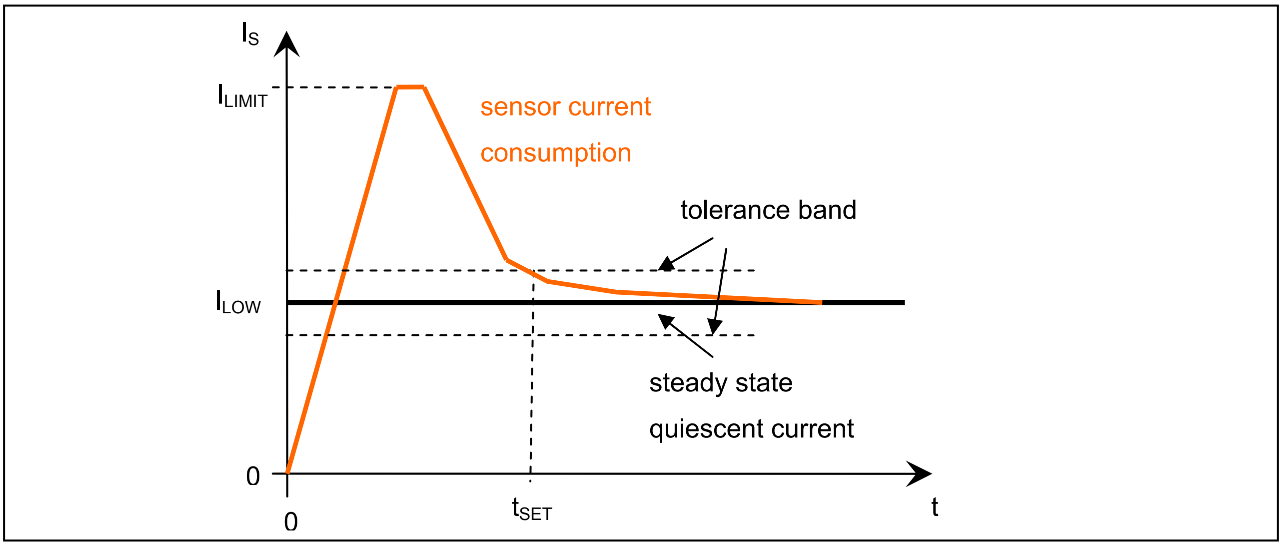

Figure 29 Current consumption during startup

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1*	Settling time for quiescent current I_{LOW}	t_{SET}			5.0	ms
2*	Settling time for quiescent current I_{LOW} (Daisy Chain Bus)	$t_{SET, Daisy Chain Bus}$			10.0	ms

1*) Final value settles to +/-2mA with respect to I_{LOW}

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

6.3 Undervoltage Reset and Microcut Rejection

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.

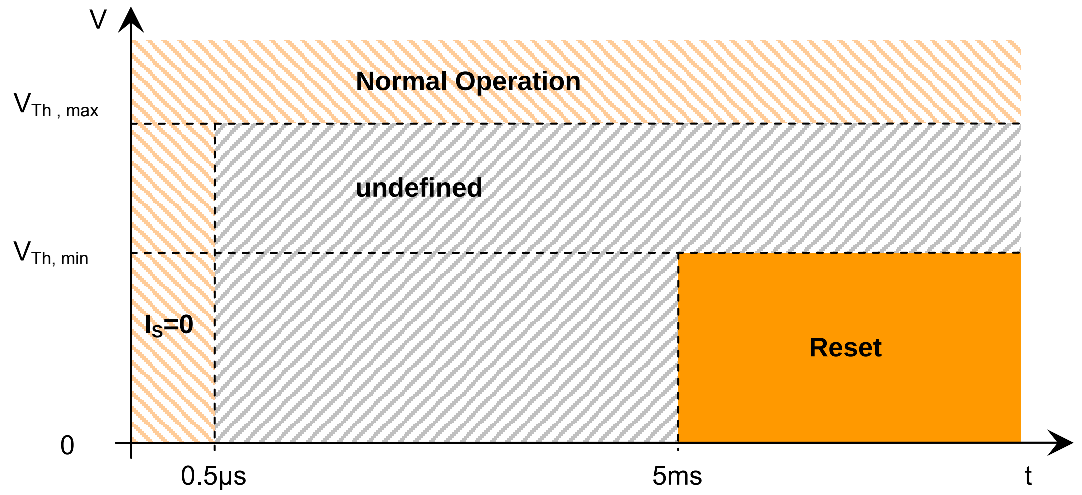

Figure 30 Undervoltage reset behaviour

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1	Undervoltage reset threshold	V_{Th} - PSI5 1.3 legacy	3		5	V
	($V_{Th,\,min}$ = must reset; $V_{Th,\,max}$ = $V_{SS,\,min}$)	V_{Th} - low voltage mode	3		4	V
2	Time below threshold for the sensor to initiate a reset	t_{Th}			5	ms
3	Microcut rejection time (no reset)	I_S=0	0.5			µs

The voltage V_{Th} is at the pins of the sensors. In case of microcuts (IS=0) to a maximum duration of 0.5µs the sensor must not perform a reset. If the voltage at the pins of the sensor remains above V_{TH} the sensor must not perform a reset. If the voltage at the pins of the sensor falls below 3V for more than 5ms the sensor has to perform a reset.

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

6.4 Data Transmission Parameters

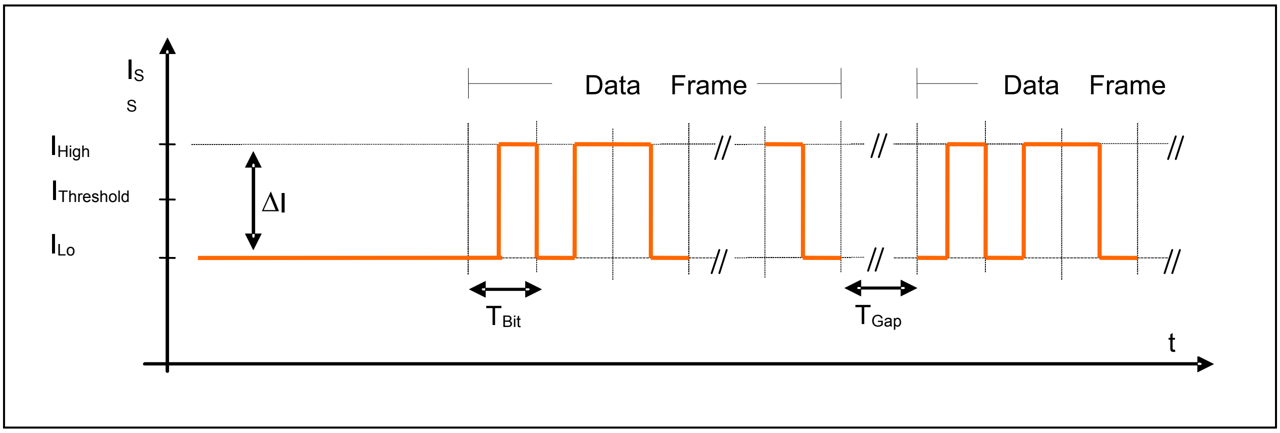

Figure 31 Data Frame Timing

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1	Bit time (125kbps mode)	T_{Bit}	7.6	8.0	8.4	µs
2	Bit time (189kbps mode)	T_{Bit}	5.0	5.3	5.6	µs
3*	Sensor clock deviation during data frame				0.1	%
4	Gap time (125 kbps mode)	$T_{Gap} > T_{Bit}$	8.4			µs
5	Gap time (189 kbps mode)	$T_{Gap} > T_{Bit}$	5.6			µs
6	Sink current ΔI_S	$\Delta I_S = I_{S,High} - I_{S,Low}$	22.0	26.0	30.0	mA
7			11.0	13.0	15.0	mA
8*	Fall/Rise Time Current Slope	20%..80% (of ΔIs)	(0.33)		(1.0)	µs
9*	Mark/Space Ratio (at Sensor)	$(t_{fall,\,80} - t_{rise,\,20}) / T_{Bit}$ $(t_{fall,\,20} - t_{rise,\,80}) / T_{Bit}$	47	50	53	%
10	Maximum clock drift rate				1	%/sec

All parameters related to the sensor.

3*) @ maximum temperature gradient and maximum frame length

8*) 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. (Sensors/Bus must meet the test conditions in chapter 7.6. Tighter tolerances might apply to the current sink in the transmitter.)

9*) Single sensor configuration, reference network “A” (see chapter 7.6)

6.5 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 32 and in the table below.

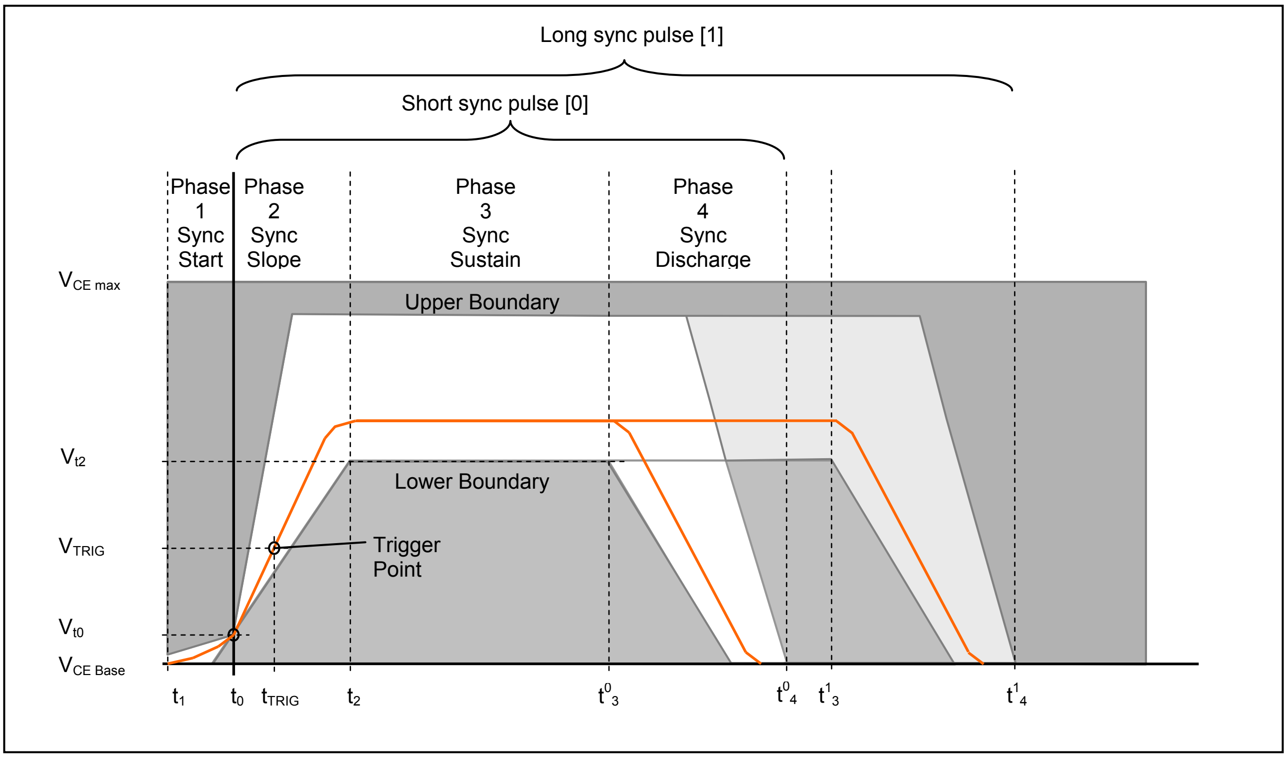

Figure 32 Shape and timing of Synchronization Signal at Receiver

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 t_1. 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 $V_{CE,\ max}$. 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)

N	Parameter	S	Remark	Min	Nom	Max	Unit
1*	Base supply voltage (low voltage)	$V_{CE, BASE}$	Mean voltage value at ECU I/F	4.4		11.0	V
2	Base supply voltage (standard)	$V_{CE, BASE}$	Mean voltage value at ECU I/F	5.7		11.0	V
3*	Base supply voltage (increased)	$V_{CE, BASE}$	Mean voltage value at ECU I/F	6.7		11.0	V
4*	Sync Slope Reference Voltage	V_{t0}	Referenced to $V_{CE, BASE}$		(0.5)		V
5*	Sync signal sustain voltage	V_{t2}	Referenced to $V_{CE, BASE}$	2.5			V
				3.5			
6*	Reference time	t_0	Reference time base		(0)		µs
7	Sync signal earliest start	t_1	Delta current less than 2mA	-3			µs
8	Sync signal sustain start	t_2	@ V_{t2}			7	µs
9*	Sync slope rising slew rate		@ Vt2 = 2.5V	0.43		1.5	V/µs
			@ Vt2 = 3.5V				
10	Sync slope falling slew rate			-1.5			V/µs
11	Sync signal sustain time	t^0_3		16			µs
		t^1_3		43			
12*	Discharge time limit	t^0_4				35	µs
		t^1_4				62	
13	Start of first sensor data word	$t_{Slot\ 1\ Start}$	Tooth gap method	44			µs
			Pulse width method	71			µs

1*) Optional low voltage mode

Note: 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.

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

4*), 6*) Theoretical value

5*) V_{t2}=2.5V is effective for PSI 5 V2.0 and strongly recommended for all applications; in compliance with former PSI5 versions 3.5V is still valid.

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

12*) Common Mode: Remaining discharge current <2 mA, to be guaranteed by the ECU;

Low Power Mode: With reduced Sink current ∆IS a remaining discharge current <0,4mA 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}.

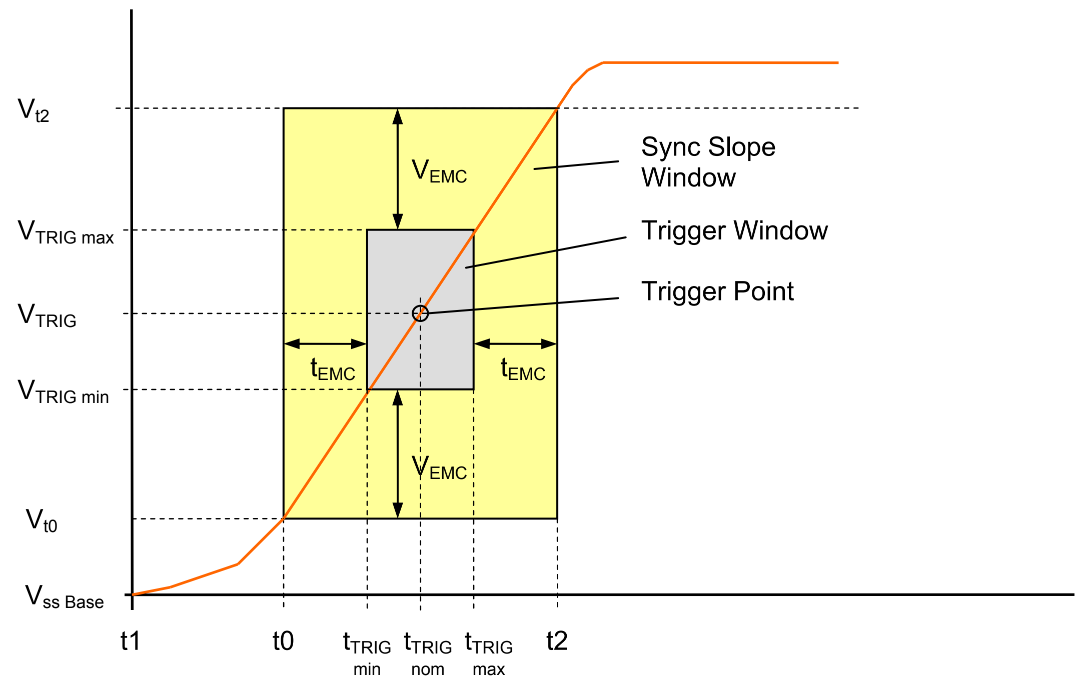

Figure 33 Synchronization signal detection in the sensor

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}.

N°	Parameter	Symbol	Remark	Min	Nom	Max	Unit
12	Margin for voltage variations of the signal on the interface line	V_{EMC}	for V_{t2} = 2.5V	-0.7		+0.7	V
			for V_{t2} = 3.5V	-0.9		+0.9	
13*	Sensor trigger threshold (Sensor to detect trigger)	V_{TRIG}	for V_{t2} = 2.5V	1.2	1.5	1.8	V
			for V_{t2} = 3.5V	1.4	2.0	2.6	V
14*	Nominal trigger detection time	t_{TRIG}	@ V_{TRIG} , @ Sensor Pins	(2.1)	(3.5)	(4.9)	µs
15	Margin for timing variations of the signal on the interface line	t_{EMC}	Relative to nominal trigger window time	-2.1		+2.1	µs
16	Tolerance of internal trigger detection delay at sensor	$t_{tol\ detect}$				3	µs
17*	Trigger detection time	T_{TRIG}	$T_{TRIG} = t_{TRIG} + t_{tol\ detect} + t_{EMC}$ Reference for sensor timebase	0		10	µs

13*) Referenced to $V_{SS,\ BASE}$;

14*) Referenced to a straight sync signal slope with nominal slew rate

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

6.6 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 do not overlap or conflict with a sync pulse. 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[*)].

Recommended operation modes and timings are specified within the effective application specific substandards.

6.6.1 Generic Time slot calculation

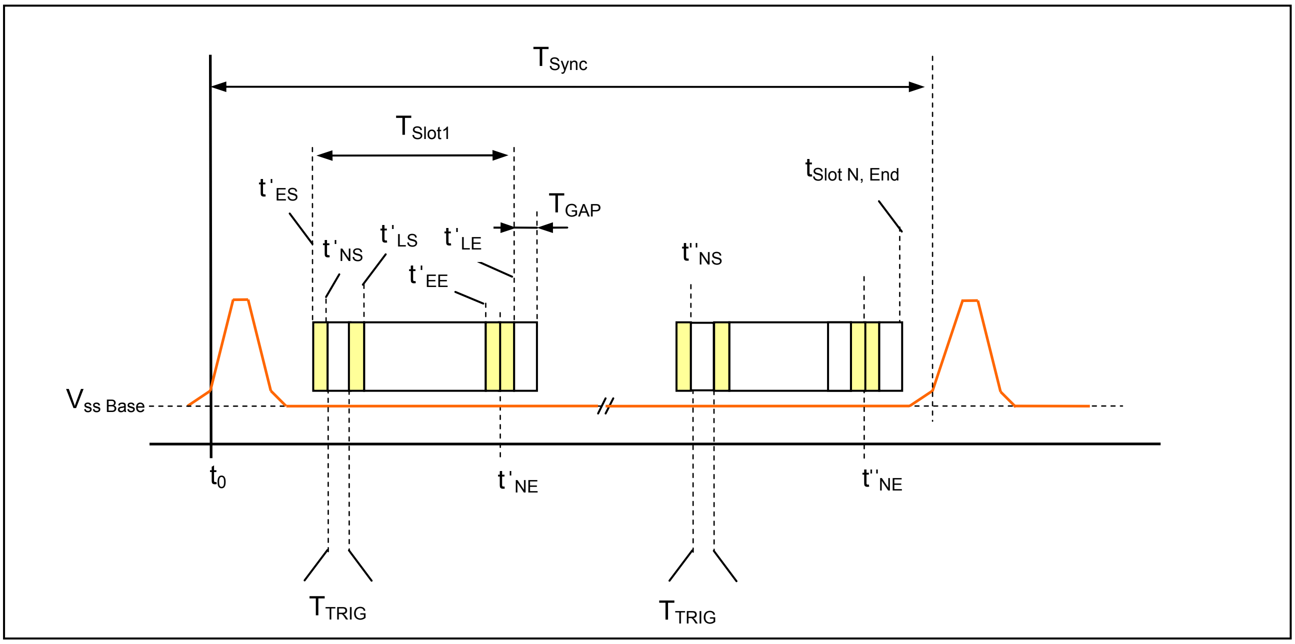

Figure 34 Timing of synchronous operation

t^n_{ES} : Earliest start of frame 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 n; this is the nominal time when the sender (sensor) transmits data according to it’s 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_{LS} : Latest start of frame n, this is the latest time when the transceiver or any other sensor on the bus can expect that the frame no. n begins.

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*) E.g. Substandard Vehicle Dynamics Control, Operation Mode PSI5-P20CRC-500/2L

t^{n}_{EE} : Earliest end of frame 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 n

t^{n}_{LE} : Latest end of frame 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 [5.6us / 8.4us]

T_{TRIG}: T_{TRIG} = tolerance to detect the sync pulse = $t_{TRIG} + t_{tol\_detect} + t_{EMC}$
[min = 0µs; nom = 3,5µs; max = 10µs].

T_{Sync}: Duration of sync period
e.g. for 1% transceiver clock tolerance: $T_{Sync, min} = T_{Sync}*0{,}99$; $T_{Sync, max} = T_{Sync}*1{,}01$

tSlot 1 Start : Earliest Start of first sensor data word [44 or 71us]

T_{BIT}: Nominal time for a single bit [5.3us / 8.0 us]

t_1 : Sync signal earliest start [nom: -3us]

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

N: No. of time slots within one sync cycle

CT^N: Clock tolerance of the transmitter (sensor) sending the frame no. n.
[standard: 5% advanced: 1%]

For n=1

t^1_{ES} = tSlot 1 Start $+T_{TRIG, min}$

t^1_{NS} * ≥ tSlot 1 Start $/(1-CT^1)$

t^1_{LS} ≥ tSlot 1 Start $*(1+CT^1)/(1-CT^1)+T_{TRIG, max}$

t^1_{EE} ≥ $t^1_{ES}+M^1*T_{BIT}*(1-CT^1)$
= tSlot 1 Start $+M^1*T_{BIT}*(1-CT^1)$

t^1_{LE} : ≥ $t^1_{LS}+M^1*T_{BIT}*(1+CT^1)$
= tSlot 1 Start $*(1+CT^1)/(1-CT^1)+T_{TRIG, max}+M^1*T_{BIT}*(1+CT^1)$

for n=2..N

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

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

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

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

t^n_{LE} : $\geq t^n_{LS}+M^n*T_{BIT}*(1+CT^n)$
$= (t^{n-1}_{LE}+T_{GAP})*(1+CT^X)/(1-CT^X)+T_{TRIG, max}+M^n*T_{BIT}*(1+CT^n)$

*) The nominal trigger detection tolerance is neglected for calculation of t^1_{NS} since this value typically is used for sensor programming where detection tolerances do not apply.

Last frame must end before next sync pulse starts – according to specific application requirements a final T_{GAP} has to be considered:

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

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 discretisation of the calculated timings of nominal 0.5us is proposed

Please refer to the corresponding substandard for details on timing specification and recommended operation modes.

7 System Configuration & Test Conditions

7.1 System Modelling

7.1.1 Supply Line Model

PSI5 usually uses twisted pair lines which are modeled as shown in Figure 35. Parameter specification is done for the different system configurations. All indications are based on standard CAN cable with a maximum inductance of 0.72µH/m.

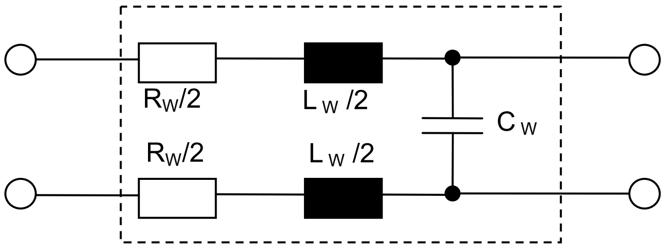

Figure 35 Supply line model for PSI5

7.2 Asynchronous Mode

Parameter Specification

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1*	Capacitive ECU bus load	C_E	6.0		47	nF
2*	Capacitive sensor bus load	C_S	6.0		47	nF
3*	Internal ECU resistance	R_E	5		9.5 (12.5)	Ω
4	ECU Connector resistance	R_{CE}		(0.2)		Ω
5	Sensor Connector resistance	R_{CS}		(0.2)		Ω
6	Single wire resistance	$R_W/2$		(0.5)		Ω
7	Overall line resistance incl. wire	$2 * (R_{CE} + R_W/2 + R_{CS})$			2.5	Ω
8*	Wire inductance	$2 * (L_W / 2)$			8.7	µH
9	Wire capacitance	C_W			600.0	pF

1,2,8*) Large cable lengths / inductances may require appropriate selection of sensor and ECU capacitance values and / or additional damping measures.

3*) R_E = 9.5V is recommended for low voltage applications, when no additional voltage source is implemented in the ECU; however, in compliance with former PSI5 versions R_E = 12.5V still is valid.

7.3 Parallel Bus Mode

Parameter Specification

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1*	Capacitive ECU bus load	C_E	15		35	nF
2*	Capacitive sensor bus load	C_S	9		24	nF
3*	Overall capacitive bus load	CBus=CE+ΣCS	(24)		(107)	nF
4*	Internal ECU resistance	R_E	5		9.5 (12.5)	Ω
5	ECU Connector resistance	R_{CE}		(0.2)		Ω
6	Sensor Connector resistance	R_{CS}		(0.2)		Ω
7	Single wire resistance	$R_W/2$		(0.5)		Ω
8	Overall line resistance incl. wire (each wire)	$2 * (R_{CE} + R_W/2 + R_{CS})$			2.5	Ω
9	Wire inductance	$2 * (L_{Wn} / 2)$			8.7	μH
10	Wire capacitance	C_W			600.0	pF

All values specified for a 125kbps data rate and a maximum of three sensors.

1,2*) Damping is required in ECU and sensors to limit oscillations on the bus lines. Please refer to chapter 7.6 for the corresponding equivalent circuits

3*) Wire capacitance not included

4*) R_E = 9.5V is recommended for low voltage applications, when no additional voltage source is implemented in the ECU; however, in compliance with former PSI5 versions R_E = 12.5V still is valid.

7.4 Universal Bus Mode

Parameter Specification

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1*	Capacitive ECU bus load	C_E	15		35	nF
2*	Overall capacitive bus load	CBus=CE+ΣCS	24		107	nF
3*	Internal ECU resistance	R_E	5		9.5 (12.5)	Ω
4	Bus inductance	2 * (L_{Wn} / 2)			8.7	μH
5	Bus capacitance	C_B	9		72	nF

All values specified for a 125kbps data rate.

1*) Damping is required in ECU to limit oscillations on the bus lines. Please refer to chapter 7.6 for the corresponding equivalent circuit.

2*) Wire capacitance not included

3*) R_E = 9.5V is recommended for low voltage applications, when no additional voltage source is implemented in the ECU; however, in compliance with former PSI5 versions R_E = 12.5V still is valid.

7.5 Daisy Chain Bus Mode

Parameter Specification

N°	Parameter	Symbol/Remark	Min	Typ	Max	Unit
1*	Capacitive ECU bus load	C_E	15		35	nF
2*	Overall capacitive bus load	CBus=CE+ΣCS	24		107	nF
3*	Internal ECU resistance	R_E	5		9.5 (12.5)	Ω
4	Bus inductance	2 * (L_{Wn} / 2)			8.7	μH
5	Bus capacitance	C_B	9		72	nF

All values specified for a 125kbps data.

1*) Damping is required in ECU to limit oscillations on the bus lines. Please refer to chapter 7.6 for the corresponding equivalent circuit.

2*) Wire capacitance not included

3*) R_E = 9.5V is recommended for low voltage applications, when no additional voltage source is implemented in the ECU; however, in compliance with former PSI5 versions R_E = 12.5V still is valid.

7.6 Test Conditions & Reference Networks – Sensor Testing

7.6.1 Reference Networks for Asynchronous Mode and Parallel Bus Mode

All indications in this section are valid for asynchronous mode and parallel bus mode with up to three sensors and for a data transmission rate of 125kbps.

ECU and Wiring Reference Network for asynchronous mode and parallel bus mode

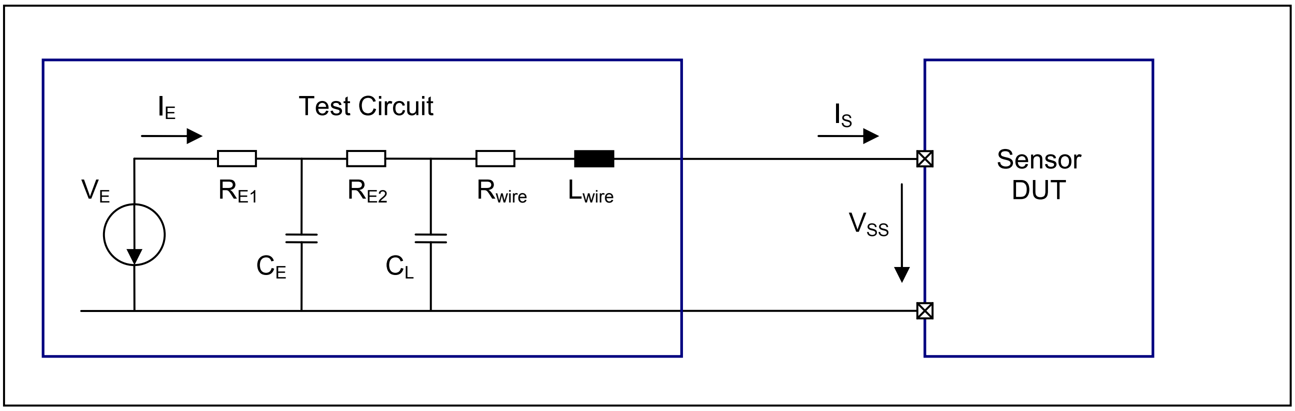

Figure 36 Reference test bench for sensor testing

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
		R_{E2}		2.5		Ω
3*	ECU internal capacitance	C_E	13		33	nF
4*	Bus load capacitance (ECU & other sensors)	C_L	2.2		50	nF
5*	Wire & connector resistance	R_{wire}	0.1		2.5	Ω
6*	Wire inductance	L_{wire}	0		8.7	µH

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 implemented $R_{E,max}$ (9.5Ω/12.5Ω)

*) see corresponding test conditions in section 7.6.4.

Sensor damping behaviour for asynchronous mode and parallel bus mode

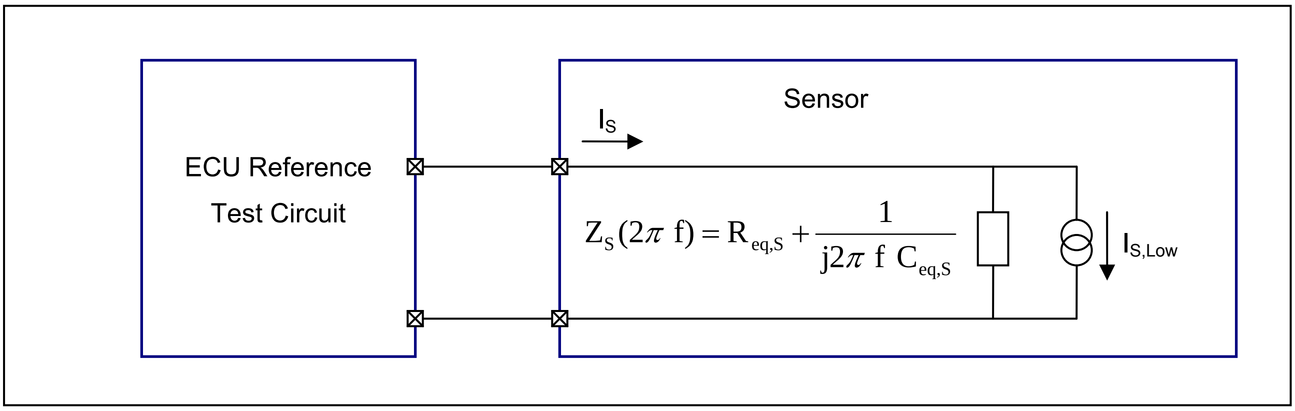

Figure 37 Reference circuit for sensor damping behaviour

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
1	Sensor internal capacitance	$C_{eq,S}$ @ 10…200kHz	9		24	nF
		$C_{eq,S}$ @ 200kHz…2MHz	1.32		24	
2	Sensor internal resistance	$R_{eq,S}$	2.5			Ω
3	Frequency	f	10		2000	kHz

The sensor damping behaviour is described by a complex impedance Z_S containing of an equivalent resistance $R_{eq,S}$ and an equivalent capacitance $C_{eq,S}$ connected in serial. For the given frequency range Z_S has to stay in the limits defined in the table above.

7.6.2 Reference Networks for Universal Bus Mode and Daisy Chain Bus Mode

All indications in this section are valid for universal bus mode and daisy chain bus mode with up to three sensors and for a data transmission rate of 125kbps.

ECU reference network for universal bus mode and daisy chain bus mode

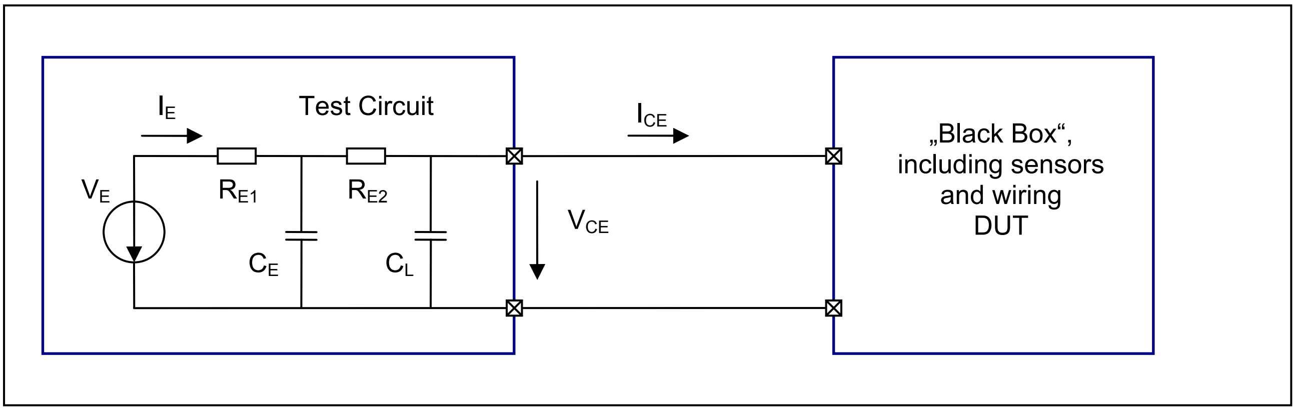

Figure 38 Reference test bench for bus testing

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
		R_{E2}		2.5		Ω
3*	ECU internal capacitance	C_E	13		33	nF
4	Bus load capacitance (ECU & other sensors)	C_L		2.2		nF

1*) Minimum supply voltage has to be adjusted to meet $V_{CE, min}$.

2*) Maximum internal ECU resistance R_{E1} has to be adjusted to meet the implemented $R_{E,max}$ (9.5Ω/12.5Ω)

*) see corresponding test conditions in section 7.6.5.

7.6.3 Test Parameter Specification

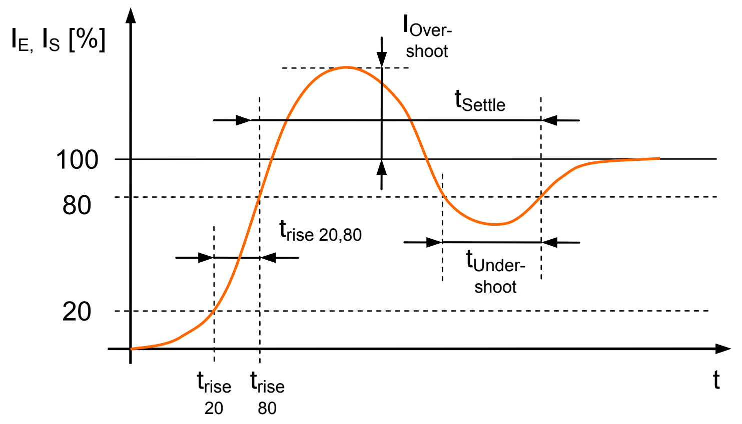

Figure 39 Test parameter sending current

7.6.4 Sensor Reference Tests for Asynchronous Mode and Parallel Bus Mode

The sensor has to fulfill the reference tests for every voltage V_E between a minimum voltage to meet $V_{SS,min}$ at the sensor pins and 11V.

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
A*	Worst case timing @ sensor					
	Test condition: RE1 = 10Ω; CE = 33nF; CL = 2.2nF; Rwire = 2.5Ω; Lwire = 0µH					
A1	Sending current rise/fall time (sensor)	$t_{rise\ 20,\ 80}$ & $t_{fall\ 80,\ 20}$ (I_S)			1	µs
B*	Worst case overshoot @ sensor					
	Test condition: RE1 = 2.5Ω; CE variable between 13nF and 33nF; CL = 2.2nF; Rwire = 0.1Ω; Lwire = 8.7µH					
B1	Sending current rise/fall time (sensor)		0.33			µs
B2	Sending current over- / undershoot @sensor	$I_{Overshoot,\ rise}$ & $I_{Undershoot,\ fall}$ (I_S)			50	%
B3	Time for under- / overshoot @ECU	$t_{Undershoot,\ rise}$ & $t_{Overshoot,\ fall}$ (I_E)			0.52	µs
B4	Settling time @ECU	t_{Settle} (I_E)			1.72	µs
B5	Voltage ripple @sensor	referenced to $V_{SS,\ base}$	-0.8		+0.8	V
C*	Worst case timing @ ECU					
	Test condition: RE1 = 10Ω; CE = 33nF; CL = 50nF; Rwire = 2.5Ω; Lwire = 0µH					
C1	Sending current rise/fall time @ECU	$t_{rise\ 20,\ 80}$ & $t_{fall\ 80,\ 20}$ (I_E)			1.8	µs
D	Sensor internal damping					
	A sensor internal damping behaviour is required corresponding to the equivalent sensor reference network (see chapter 6.6.1). A test condition for the sensor damping will be specified in a future version of the PSI5 test specification					

See section 7.6.1 for ECU and wiring reference network.

A,C*) Maximum internal ECU resistance RE1 has to be adjusted to meet the implemented RE,max (9.5Ω/12.5Ω)

B*) The sensor has to fulfill reference Test B for every value of the capacitance CE between 13nF and 33nF.

7.6.5 Sensor Reference Tests for Universal Bus Mode and Daisy Chain Bus Mode

The sensor has to fulfill the reference tests for every voltage V_E between a minimum voltage to meet $V_{CE,min}$ at the output pins of the ECU and 11V.

N°	Parameter	Symbol/Remark	Min	Nom	Max	Unit
B	Worst case overshoot @ ECU output					
	Test condition: RE1 = 2.5Ω; CE variable					
B2	Sending current over- / undershoot @ ECU output pins	$I_{Overshoot, rise}$ & $I_{Undershoot, fall}$ (I_{CE})			50	%
B3	Time for under- / overshoot @ ECU	$t_{Undershoot, rise}$ & $t_{Overshoot, fall}$ (I_E)			0.52	µs
B4	Settling time @ ECU	t_{Settle} (I_E)			1.72	µs
C*	Worst case timing @ ECU					
	Test condition: RE1 = 10Ω; CE = 33nF					
C1	Sending current rise/fall time @ECU	$t_{rise\ 20,\ 80}$ & $t_{fall\ 80,\ 20}$ (I_E)			1.8	µs

See section 7.6.2 for ECU and wiring reference network.

B*) The sensor has to fulfill reference Test B for every value of the capacitance CE between 13nF and 33nF.

C*) Maximum internal ECU resistance RE1 has to be adjusted to meet the implemented RE,max (9.5Ω/12.5Ω)

7.7 Test Conditions & Reference Networks - Transceiver / ECU Testing

Test conditions & reference networks for transciever / ECU will be specified in a future version of the PSI5 test specification.

8 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.

9 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 behaviour 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