SURFACE VEHICLE RECOMMENDED PRACTICE

J1939™-14 | APR2022

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Physical Layer, 500 kbit/s

RATIONALE

Document is updated for compatibility with other SAE J1939 physical layer documents.

FOREWORD

The set of SAE J1939 Recommended Practice documents define a high speed ISO 11898 CAN protocol based communications network that can support real-time closed loop control functions, simple information exchanges, and diagnostic data exchanges between electronic control units (ECUs) physically distributed throughout the vehicle.

The SAE J1939 communications network is developed for use in heavy-duty environments and suitable for use in horizontally integrated vehicle industries. The physical layer aspects of SAE J1939 reflect its design goal for use in heavy-duty environments. Horizontally integrated vehicles involve the integration of different combinations of loose package components, such as engines and transmissions, which are sourced from many different component suppliers. The SAE J1939 common communication architecture strives to offer an open interconnect system that allows the ECUs associated with different component manufacturers to communicate with each other.

The SAE J1939 communications network is intended for light-duty, medium-duty, and heavy-duty vehicles used on-road or off-road, and for appropriate stationary applications which use vehicle derived components (e.g., generator sets). Vehicles of interest include, but are not limited to, on-highway and off-highway trucks and their trailers, construction equipment, and agricultural equipment and implements.

This set of SAE Recommended Practices has been developed by the SAE Truck and Bus Control and Communications Network Committee of the SAE Truck and Bus Electrical and Electronics Steering Committee. The SAE J1939 communications network is defined using a collection of individual SAE J1939 documents based upon the layers of the Open System Interconnect (OSI) model for computer communications architecture. These SAE J1939 documents are intended as a guide toward standard practice and are subject to change to keep pace with experience and technical advances.

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1. SCOPE

This document defines a physical layer having a higher bandwidth capacity than other physical layers defined for SAE J1939. Newer transceiver technologies are utilized to minimize EMI.

CAN controllers are now available which support the flexible data rate frame format. These controllers, when used on SAE J1939-14 networks, must be restricted to use only the classical frame format compliant to ISO 11898-1:2015.

This SAE Recommended Practice is intended for light- and heavy-duty vehicles on- or off-road, as well as appropriate stationary applications which use vehicle derived components (e.g., generator sets). Vehicles of interest include, but are not limited to, on- and off-highway trucks and their trailers, construction equipment, and agricultural equipment and implements.

1.1 Purpose

Implementing a robust CAN network involves many tradeoffs affecting both the network layout and ECU design. This document presents a standard by which ECUs, tools, and vehicle networks from different sources may be compatible. The document is intended to stand alone, yet borrows from the many existing standards and papers for its methodology.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1128 Low Voltage Primary Cable

SAE J1939-11 Physical Layer, 250 Kbps, Twisted Shielded Pair

SAE J1939-13 Off-Board Diagnostic Connector

SAE J1939-15 Physical Layer, 250 Kbps, Un-Shielded Twisted Pair (UTP)

SAE J1939-16 Automatic Baud Rate Detection Process

SAE J2030 Heavy-Duty Electrical Connector Performance Standard

2.1.2 ISO Publications

Copies of these documents are available online at http://webstore.ansi.org/.

ISO 11898-1:2015 Road Vehicles - Controller Area Network (CAN) - Part 1: Data Link Layer and Physical Signalling

ISO 11898-2:2016 Road Vehicles - Controller Area Network (CAN) - Part 2: High-Speed Medium Access Unit

3. DEFINITIONS

Many of the definitions in this document can also be found in SAE J1939-11, and in some cases paraphrase definitions given in ISO 11898-1:2015 or ISO 11898-2:2016.

3.1 TIME QUANTA (TQ)

The interval of the CAN system clock. An integer multiple of the system clock period, the smallest division of a bit time used by the CAN controller.

3.2 BIT TIME

The duration of 1 bit in either the arbitration or data phase. See Section 6 for timing requirements. Bus management functions executed within this bit time, such as ECU synchronization behavior, network transmission delay compensation, and sample point positioning, are defined by the programmable bit timing logic of the CAN controller.

3.3 BAUD RATE PRESCALER (BRP)

A parameter of the CAN controller that determines a divisor by which the system clock frequency is reduced to produce the CAN system clock.

3.4 SYNCHRONIZATION JUMP WIDTH (SJW)

The maximum interval by which PHASE_SEG1 and PHASE_SEG2 may be adjusted.

3.5 SYNC_SEG

The first 1 Tq portion of a bit time. An edge is expected within this bit segment.

3.6 PROP_SEG

A part of the bit time used to compensate for the physical delay times within the network.

3.7 PHASE_SEG1

The first segment of the bit time used to compensate for phase errors. May be lengthened by an amount less than or equal to SJW.

3.8 PHASE_SEG2

The second segment of the bit time used to compensate for phase errors. May be shortened by an amount less than or equal to SJW.

3.9 TSEG1

Combination of the PROP_SEG and PHASE_SEG1.

3.10 TSEG2

Same as PHASE_SEG2.

3.11 SAMPLE POINT

The point of time at which the bus level is read and interpreted as the value of that respective bit. Its location is at the end of PHASE_SEG1.

3.12 DIFFERENTIAL VOLTAGE

The voltages of CAN_H and CAN_L relative to ground of each individual ECU are denoted by V_{CAN_H} and V_{CAN_L}. The differential voltage between V_{CAN_H} and V_{CAN_L} is defined by Equation 1:

$$V_{diff} = V_{CAN\_H} - V_{CAN\_L} \quad \text{(Eq. 1)}$$

3.13 COMMON-MODE BUS VOLTAGE RANGE

The common-mode bus voltage is defined as the boundary voltage levels of CAN_H and CAN_L, measured with respect to the individual ground of each ECU, for which proper operation is guaranteed when all ECUs are connected to the bus line.

3.14 INTERNAL RESISTANCE

The internal resistance, R_{IN}, of an ECU is defined as the resistance between CAN_H (or CAN_L) and ground during the recessive state, with the ECU disconnected from the bus line.

3.15 DIFFERENTIAL INTERNAL RESISTANCE

The differential internal resistance, R_{DIFF}, is defined as the resistance between CAN_H and CAN_L during the recessive state, with the ECU disconnected from the bus line.

3.16 INTERNAL CAPACITANCE

The internal capacitance, C_{IN}, of an ECU is defined as the capacitance between CAN_H (or CAN_L) and ground during the recessive state, with the ECU disconnected from the bus line

3.17 DIFFERENTIAL INTERNAL CAPACITANCE

The differential internal capacitance, C_{DIFF}, of an ECU is defined as the capacitance between CAN_H and CAN_L during the recessive state, with the ECU disconnected from the bus line.

3.18 TYPE I ECU

An ECU that does not contain bus line termination.

3.19 TYPE II ECU

An ECU that includes a bus line termination resistor or split termination. Such an ECU, if used, shall be located at one or both ends of a network and shall be marked as specified in 4.3.2.

4. NETWORK

Physical wiring specifications for harness designers and wiring system manufacturers.

4.1 Wire

Cables meeting SAE J1939-11 or SAE J1939-15 are acceptable.

4.1.1 Type

Shielded or unshielded twisted pair wire may be used. Maintaining the twist to the greatest extent possible is critical to meeting radiated emissions and susceptibility requirements. The twist requirements are specified in Table 1 and are controlled by the lay length specification. Jacketed cable is recommended to maintain consistent twisting and impedance. When using shielded cable, it is especially important to observe the minimum bend radius requirement to avoid internal damage to the shield.

When shielded cable is used, shield should be terminated as described in SAE J1939-11. For mixed shielded/unshielded configurations, follow recommendations in SAE J1939-15.

4.1.2 Environmental Requirements

Cable should meet the environmental requirements of the application. Typically, cables for heavy-truck applications will need to meet SAE J1128 requirements for SXL or GXL type wire.

4.1.3 Cable Properties

Table 1 - Cable properties

Parameter	Symbol	Min	Nom	Max	Unit
Impedance	Z	108	120	132	Ω
Specific Resistance	r_b	0	25	50	mΩ/m
Specific Line Delay	t_p	n/a	5.0	5.5	ns/m
Lay Length	n/a	20	25	38	mm
Cable Bend Radius	r	4x diameter of cable	n/a	n/a	n/a

4.1.4 Color

The CAN_H conductor should be yellow and the CAN_L conductor should be green. Variations on this are acceptable for identifying other SAE J1939 networks or SAE J1939 network segments, as long as CAN_H contains yellow and CAN_L contains green. (For example, white with yellow stripe and solid green.)

4.2 Topology

The network shall have a linear topology consisting of a backbone and multiple stubs by which ECUs are connected. Stubs may have zero length, provided that the backbone is properly terminated at the ends.

4.2.1 Stubs

The maximum length of a stub shall be 1.67 m. A stub may be left unconnected to an ECU, but this stub will count towards the maximum number of nodes on the network. It is recommended that the length of stubs be varied to reduce the likelihood of coincident reflections.

4.2.2 Distance Between Nodes and Number of Nodes

The minimum distance between stubs should be 30 cm to minimize impedance mismatch on the backbone due to accumulated capacitive load.

The maximum distance between the farthest nodes (including stubs) on the network is allowed to vary according to the number of nodes on the network. Each node connected to the network adds capacitive load and effectively slows the rate of signal propagation on the network. The maximum number of nodes is 30.

Table 2 - Node count versus distance

Number of Nodes	Maximum Distance Between Nodes
2	56 m
3	56 m
4	55 m
5	54 m
6	53 m
7	53 m
8	52 m
9	51 m
10	51 m
11	50 m
12	49 m
13	49 m
14	48 m
15	47 m
16	47 m
17	46 m
18	46 m
19	45 m
20	45 m
21	44 m
22	44 m
23	43 m
24	43 m
25	42 m
26	42 m
27	41 m
28	41 m
29	40 m
30	40 m

4.3 Connectors

Either splices or connectors may be used to connect stubs to the backbone. Splice methodologies and connectors should be chosen to minimize the untwisted length of wire. Connectors should meet performance specifications of SAE J2030 for “signal level circuits.” Circuits of this type are defined in SAE J2030 as a circuit in which open circuit voltage is typically less than 5 V and current is typically less than 0.05 A.

4.3.1 Terminators

Each of the two endpoints of the backbone must be terminated across the CAN_H and CAN_L conductors with a resistance equal to the characteristic impedance of the cable. These terminators suppress signal reflections. Also, without these resistors, the proper differential voltage is not produced between the conductors.

4.3.1.1 Termination Resistance

Termination resistance may be included within an ECU connected at the end of the network. If so, it shall be clearly identified in the device documentation or on the device itself.

Table 3 - Terminating resistor parameters

Parameter	Symbol	Min	Nom	Max	Unit
Resistance	R_L	110	120	130	Ω

4.3.1.2 Split Termination of Backbone

One or both ends of the backbone may be terminated with split termination in which R_L is divided into two well matching resistors. In order to achieve good electro-magnetic emission performance, it is recommended not to exceed ±1% tolerance between the two identical resistors of the split termination locally. Refer to ISO 11898-2:2016.

The center tap between the resistors should be connected to ground through a 4.7 nF capacitor, C_L.

4.3.1.3 Node Termination

Impedance characteristics of the CAN connections at the ECU specified within this document preclude the use of termination at the node. Providing termination at nodes (excepting those that terminate the backbone) would reduce the number of nodes capable of being supported on the network.

4.3.2 ECU Type 1 and Type II Markings

An ECU that does not contain an internal load resistor (R_L) shall be designated as a Type I ECU and does not require a marking. An ECU that contains an internal R_L shall be designated as a Type II ECU. The Type II ECU shall have a unique marking on the outside housing to easily determine the internal R_L feature.

4.3.3 Diagnostic Connection

A stub may be provided for temporary connection of diagnostic tools. The length of this stub to the diagnostic connector should not exceed the maximum stub length requirement of the network. Some regulations require that a 5 m cable from the diagnostic connector to a scan tool must be supported. Where compliance with this regulation is required, the diagnostic stub must be located on the network such that the additional cable does not cause the maximum distance between nodes to be exceeded.

5. ECU TRANSCEIVER REQUIREMENTS

This section details requirements to aid the designer in choosing an appropriate transceiver. It may also be used by chip makers when developing or marketing their devices.

5.1 Impedance

Impedance requirements are given in the table below and encompass the ECU as a whole, including the transceiver and additional filtering or protection circuitry.

Table 4 - ECU impedance

Parameter	Symbol	Unit	Min	Nom	Max
Input Resistance	R_{IN}	kΩ	5	n/a	50
Resistance Deviation CANH to CANL	$R_{IN(d)}$	%	-3	n/a	3
Differential Input Resistance	R_{DIFF}	kΩ	10	n/a	100
Input Capacitance	C_{IN}	pF	n/a	20	120
Differential Capacitance	C_{DIFF}	pF	n/a	n/a	60

Unusually challenging EMC environments such as some stationary generator applications may require additional capacitance which will affect node count or choice of transceiver.

5.2 Transmitter

5.2.1 Voltage Levels

The following table gives required voltage levels for transmitting signals on the bus.

Table 5 - Transmitter requirements

Parameter	Symbol	Unit	Min	Nom	Max
Recessive Bus Voltage	$V_{O(r)}$	V	2.0	2.5	3.0
Dominant Bus Voltage	$V_{O(CANH)}$	V	2.75	3.5	4.5
	$V_{O(CANL)}$	V	0.5	1.5	2.25
Recessive Differential Bus Voltage	$V_{DIFF(r)(o)}$	mV	-500	0	+50
Dominant Differential Bus Voltage	$V_{DIFF(d)(o)}$	V	1.5	2.0	3.0

5.2.2 Symmetry

To minimize radiated emissions, it is necessary that the CANH and CANL signals match each other in both amplitude and timing. Any mismatch will create a common mode signal that is not able to be cancelled out by the twisted wire pair.

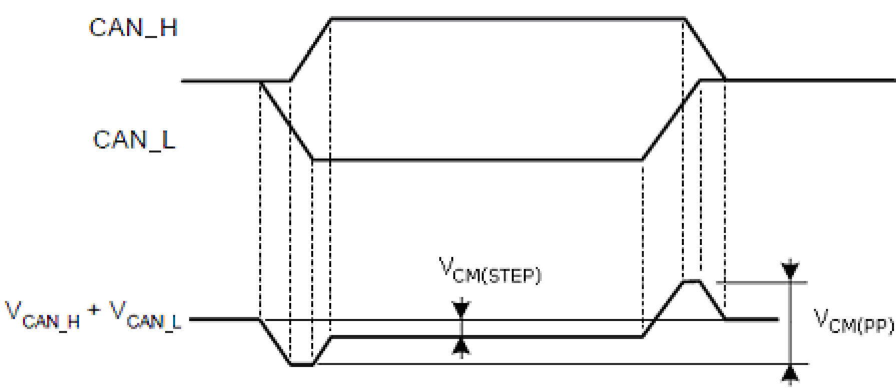

Figure 1 - Common mode result of CAN_H/CAN_L mismatch

Table 6 - Symmetry recommendations

Parameter	Symbol	Unit	Min	Nom	Max
Common Mode Peak to Peak	$V_{CM(PP)}$	mV	n/a	n/a	300
Common Mode Step	$V_{CM(STEP)}$	mV	-150	n/a	150

5.3 Receiver

The following table lists voltages above which the bus is defined to be in a dominant state and below which the bus is in a recessive state.

Table 7 - Receiver threshold voltages

Parameter	Symbol	Unit	Min	Nom	Max
Recessive Differential Voltage	$V_{DIFF(r)(i)}$	V	-1	n/a	0.5
Dominant Differential Voltage	$V_{DIFF(d)(i)}$	V	0.9	n/a	5.0

5.4 Time Delay

The total delay allowed for the ECU is 390 ns. This is the sum of all of the following delays:

Bus input signal to transceiver RXD logic output
CAN controller logic processing
Transceiver TXD logic input to bus output signal
Common mode choke or other filtering components

5.5 Protection

Bus terminals shall be protected against the following transients and fault conditions.

Table 8 - Protection

Parameter	Symbol	Unit	Min	Nom	Max
ESD Voltage	V_{ESD}	kV	±15	n/a	n/a
Short Circuit Voltage (12/24 V systems)	V_{SHORT}	V	±32	n/a	n/a
Short Circuit Voltage (48 V systems)	V_{SHORT}	V	±58	n/a	n/a

6. BIT TIMING

The limiting factors in the overall length of a CAN bus network is the ability of arbitration to correctly succeed between two nodes at opposite ends, and the ability of the CAN controllers to properly differentiate between local and global errors in order to increment appropriate error counters. Success depends on the propagation delay which is a function of the physical and electrical specifications in Section 4, and the bit timing parameters given in this section.

6.1 Oscillator Tolerance

An oscillator must be chosen such that the tolerance on the resulting bit time is less than ±0.05% (500 ppm) over the applicable temperature range and life of the device.

6.2 Number of Time Quanta (Tq)

The CAN controller has some capability to synchronize with the incoming bit stream. (For more information, refer to SAE J1939-11 or the ISO 11898-1:2015 specification.) A higher number of Tq (and smaller division of the bit time interval) allows for better synchronization and more margin for propagation delay.

6.3 Synchronization Jump Width (SJW)

For the oscillator tolerance specified in this document, SJW should always be 1 Tq.

6.4 Number of Samples

Many controllers offer the option of sampling either 3 times or once. This parameter should be set to once.

6.5 Sample Point

The sample point shall be set as close to, but no later than, 87.5% of a bit time and shall not be less than 80.0% of a bit time. See Table 9 for acceptable values with commonly used oscillator frequencies.

6.6 Examples

The nomenclature describing portions of the bit time varies between different controller manufacturers. See the definitions given in Section 3 for nomenclature in the following table. The following table gives bit timing parameters based on the recommendations in this section.

Table 9 - Bit timing parameters

Oscillator (minimum)	NQ (Tq)	SJW (Tq)	TSEG1 (Tq)	TSEG2 (Tq)	Sample Point (%)
80.0 MHz	80	4	69	10	87.5
40.0 MHz	80	4	69	10	87.5
11.0 MHz	22	1	18	3	86.4
10.5 MHz	21	1	17	3	85.7
10.0 MHz	20	1	16	3	85.0
9.5 MHz	19	1	15	3	84.2
9.0 MHz	18	1	14	3	83.3
8.5 MHz	17	1	13	3	82.4
8.0 MHz	16	1	13	2	87.5
7.5 MHz	15	1	12	2	86.7
7.0 MHz	14	1	11	2	85.7
6.5 MHz	13	1	10	2	84.6
6.0 MHz	12	1	9	2	83.3
5.5 MHz	11	1	8	2	81.8
5.0 MHz	10	1	7	2	80.0

NQ = Number of time quanta (Tq) per nominal bit time.

7. NOTES

7.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE SAE TRUCK AND BUS CONTROL AND COMMUNICATIONS NETWORK COMMITTEE OF THE SAE TRUCK AND BUS ELECTRICAL AND ELECTRONIC STEERING COMMITTEE

APPENDIX A - EXAMPLE CIRCUITS

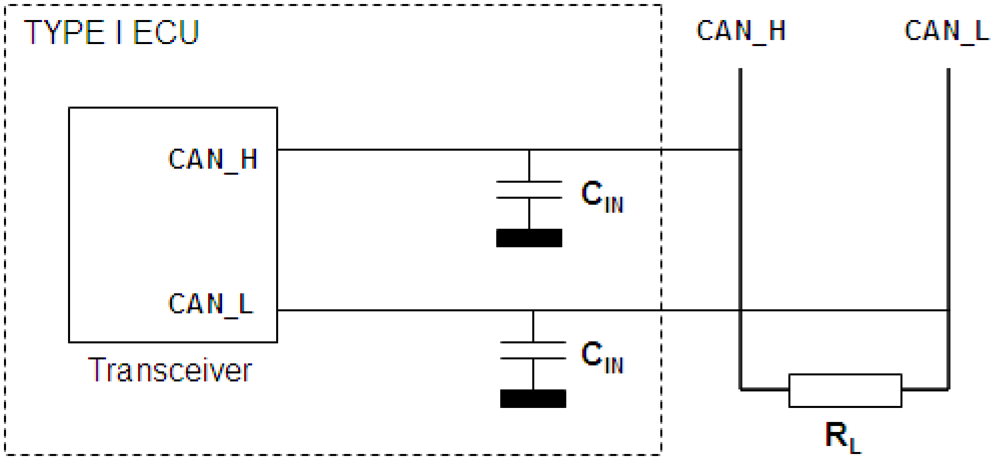

Figure A1 - Circuit with external backbone termination

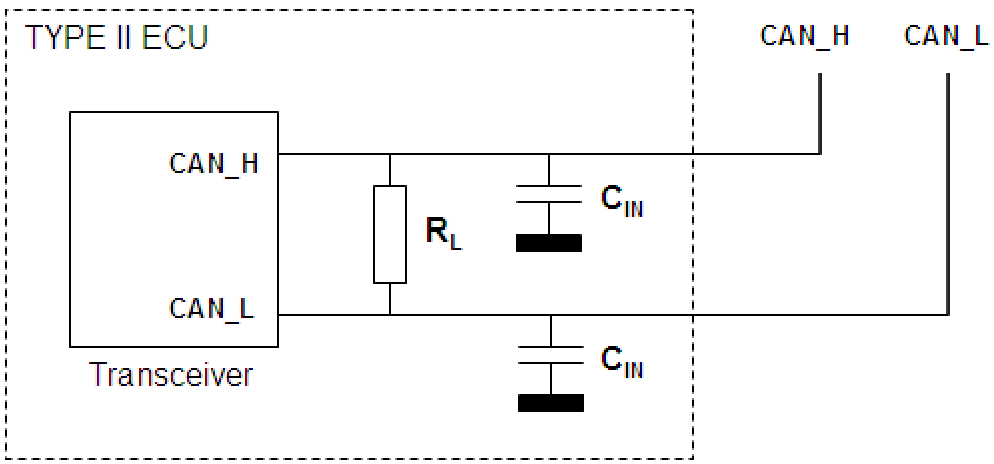

Figure A2 - Circuit with internal backbone termination

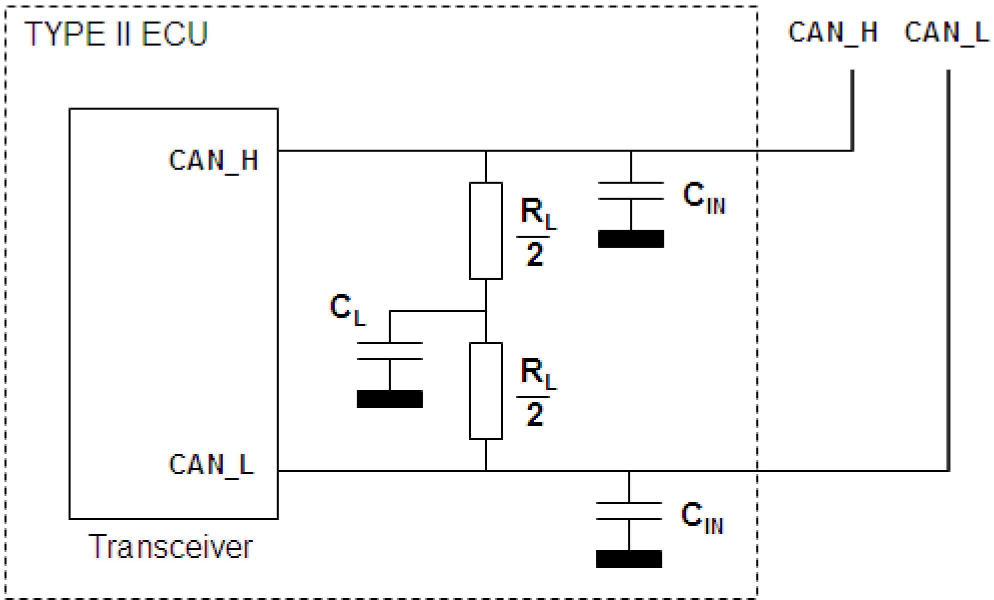

Figure A3 - Circuit with internal backbone split termination