Chapter 2
Physical Layer

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The transfers of data which have been processed in the data link layer are done in the physical layer. The physical layer consists of:

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- Transceiver
- Controller area network (CAN) choke (optional)
- Electro magnetic compatibility (EMC) and electrostatic discharge (ESD) protection devices (optional)
- Connector
- Network or data bus, e.g. a two-wire cable

There are two different concepts for the physical layer, which is, on the one hand, the so-called *Fault-Tolerant Low-Speed CAN Physical Layer* and the *High-Speed CAN Physical Layer* on the other. They are different in the maximum data rate (1 Mbit/s for high-speed CAN and 125 kbit/s for low-speed CAN) and the concepts for bus termination which enable the fault-tolerant low-speed CAN transceiver to continue the communication in all error conditions. This is not feasible for high-speed CAN communication if there is, for instance, a short circuit condition between the bus lines. Nevertheless, high-speed CAN physical layer meanwhile is applied for the communication between all modules in cars. The area of application of low-speed CAN is typically limited to the vehicle interior applications—the so called "body". The fault-tolerant low-speed CAN physical layer is preferably applied by European car manufacturers. However, American and Japanese automotive manufacturers solely apply the more simple high-speed CAN physical layer. Nevertheless, European car manufacturers have dropped low-speed CAN in the meantime. In newer vehicle generations, they almost only apply the newer version of the high-speed CAN transceivers. The basic characteristics of the transceivers and the related physical layers are specified in the ISO 11898 standard.

2.1 Basic Elements

2.1.1 Transceiver

The transceiver transmits and receives the physical data to and from the bus. The basic concept of the transceiver is identical for high-speed CAN and low-speed CAN transceiver. For this basic concept, a transmitter and a receiver are needed. The transmitter is a buffer, which transforms the logical signal on pin TxD (transmit data) into a slew rate-controlled analog signal on the pins CAN_H and CAN_L. Both are open drain outputs. CAN_H is a high-side driver and CAN_L is a low-side driver. Both have reverse polarity diodes to protect these outputs against reverse operation. The minimum voltage range for both outputs is required to be between −27 and +40 V. The maximum output current is controlled to protect this output stage and the CAN coils (if implemented) against shorts to ground and supply…. The current will normally be limited between 40 and 200 mA, but in newer products the maximum value is reduced to 100 mA to protect the 100-µH CAN coils too. The receiver is a differential comparator and converts the differential signal into a logical signal on pin RxD (receive data). A logical high on RxD corresponds with a recessive differential level on the bus, and a logical low on pin RxD corresponds with a dominant signal

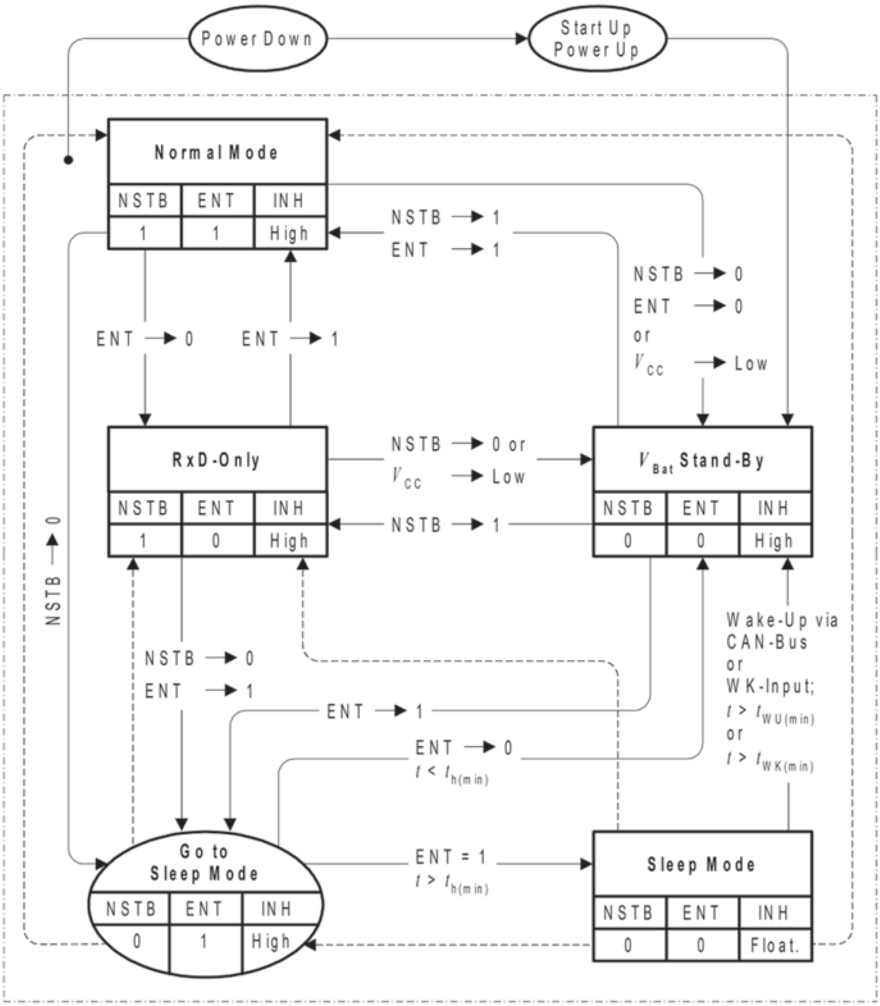

Fig. 2.1 Typical mode diagram of a transceiver

on the bus. The receiver in normal mode is always active and receives the signal on the bus, independent of whether these signals are transmitted from him or other participants on the bus. The differences between fault-tolerant low-speed and high-speed CAN transceivers will be discussed in the following chapters.

2.1.1.1 Transceiver Mode

In ISO 11898-3- (fault-tolerant low-speed CAN) and ISO 11898-5 transceiver (high-speed CAN with remote wake-up), special modes are implemented. A typical mode diagram is shown in Fig. 2.1 and will be described in more detail.

The most important transceiver modes are:

- Sleep mode
- Stand-by mode
- Normal mode
- Go-to-sleep mode

Sleep Mode

The fault-tolerant low-speed CAN transceiver (according to ISO 11898-3) and the high-speed CAN transceiver (according to ISO 11898-5) with remote wake function can be permanently supplied and have a sleep mode to reduce the current consumption below 30 μA. In this mode, the pin Inhibit (INH) is switched off. In the transceiver itself, the receiver is active with a very low current consumption to monitor CAN communication on the bus. A valid differential signal on the bus wakes the transceiver up, sets the transceiver in standby mode and switches on the INH pin. If a local wake pin is implemented, the transceiver can be woken up with level changes on this pin too.

Standby Mode

The standby mode is an intermediate mode after a transceiver wake up. The reasons for a wake-up can be:

- Power-up
- Level change on local wake pin
- Remote bus wake-up

In standby mode, the transmitter is blocked and set to recessive to guarantee no disturbance on the bus during microcontroller ramp-up. Depending on the implementation, the wake-up source is flagged. Normally, a remote wake-up is flagged on the pin RxD with a permanent dominant signal. A mode change in normal mode resets this flag. In standby mode, the INH pin (if available) is set to high. An INH-controlled voltage regulator will be switched on.

Normal Mode

In normal mode, the transceiver transmits and receives data. The transceiver can be set in normal mode via the mode pin EN. This mode pin is controlled from the microcontroller. In some transceiver products, a TxD-dominant time-out protection is implemented too. In case of a permanent dominant signal on the pin TxD, the bus is blocked and the communication on the bus is corrupted. After a defined time, the TxD-dominant time-out protection will set the transmitter to recessive and the communication on the bus can be continued. The release of this TxD-dominant time-out latch depends on the implementation of the product. Most of the time, a logical high on pin TxD releases the latch. An over-temperature to protect the output stages CAN_H and CAN_L is normally implemented in a standard transceiver and switches off the output stages CAN_H and CAN_L. A recessive level on pin TxD will reset the over-temperature protection.

Go-to-Sleep Mode

If an INH pin is available, a voltage regulator, connected to this INH pin, can be controlled from the transceiver. In sleep mode, the INH pin is switched off and the voltage regulator is switched off as well. The go-to-sleep mode is implemented to delay the host command sleep mode until the INH is switched off. During this time, the microcontroller can finalize the activities. After remote wake-up, the transceiver changes into standby mode and switches on the INH pin and the controlled voltage regulator.

2.1.2 CAN Coil

The advantages of a CAN coil include:

- Reduction of electromagnetic emission
- Improvement of immunity
- Sometimes improving the ESD performance

The typical used values for CAN coils in CAN networks are 22, 51 or 100 µH.

The CAN coil reduces the emission from the transceiver and increases the immunity robustness against disturbances.

2.1.3 Network Concepts

Two different concepts of physical layer implementations are available now:

- The high-speed CAN physical layer concept with baud rates up to 1 Mbaud
- The fault-tolerant low-speed CAN concept with baud rates up to 125 kbaud

These concepts are different from each other and will be described in the next chapter.

2.1.4 Fault-Tolerant Low-Speed CAN Physical Layer

The application areas for the fault-tolerant low-speed CAN physical layer are body application in cars and applications where the fault tolerance is needed and the lower baud rate can be accepted.

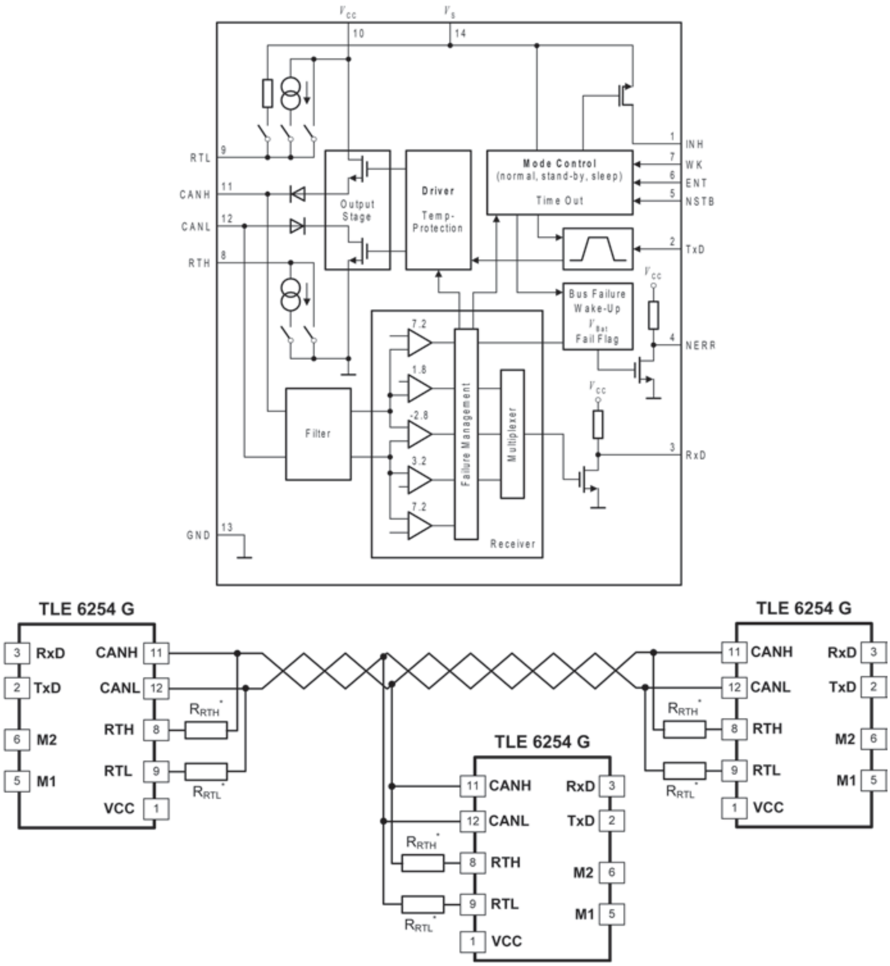

Fig. 2.2 Block diagram of TLE6254-3G and a typical fault-tolerant low-speed CAN network

This concept is tolerant against:

- CAN_H short to ground
- CAN_L short to ground
- CAN_H short to supply or battery voltage
- CAN_L short to supply or battery voltage
- CAN_H short to VCC (5 V supply for microcontroller and transceiver supply)
- CAN_L short to VCC (5V supply for microcontroller and transceiver supply)
- CAN_L short to CAN_H
- CAN_H open wire
- CAN_L open wire

In addition, the combination of all of these failures can be detected as double failure. In total, 120 combinations are possible and can be handled. How does this

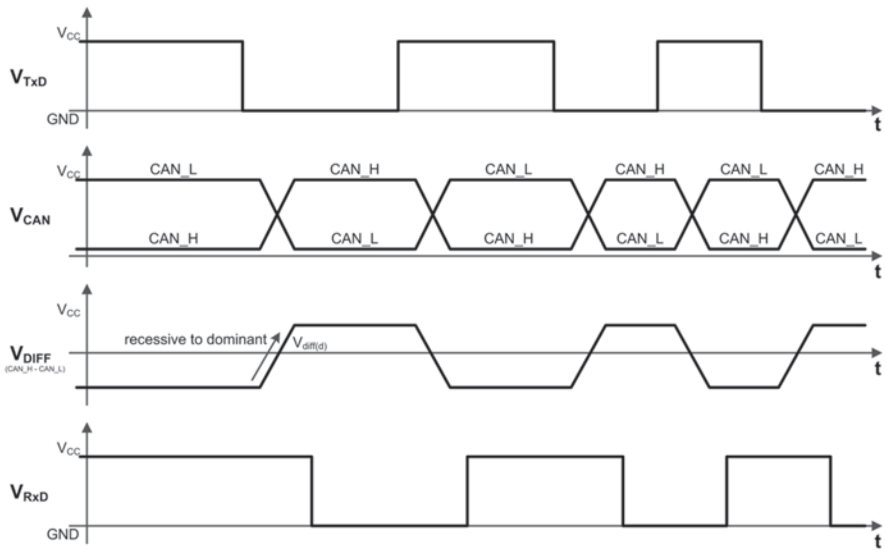

Fig. 2.3 Typical signals for a fault-tolerant low-speed CAN network

work? In principle, CAN_H and CAN_L work separately and in ant phase. CAN_H has a termination resistor to ground (via switch RTH) and CAN_L has a termination resistor via switch RTL to VCC (see Fig. 2.2). The signal will be transmitted via the CAN_H path and CAN_L low in ant phase. All receivers obtain the differential signal if there is no short or open wire on the bus. In this mode, the common-mode range and robustness is very high. If one short is detected, the transmitter deactivates this path (for example, if CAN_H is shorted to ground, CAN_H will be disabled and the communication will be transmitted over CAN_L only). For the termination, all nodes are complete. The value for the termination resistor can be between 500 Ω and 5 kΩ. In total, the value for all resistors (in a parallel connection) should be in a range of 100 Ω. Values less than 100 Ω are not allowed.

A high level on pin TxD corresponds with a recessive level on the bus. A recessive level on the bus means 0 V on CAN_H and 5 V on CAN_L. A low level on pin TxD corresponds with a dominant level on the bus. A dominant level on the bus means CAN_H and CAN_L are switched on and the levels are 4 V for CAN_H and 1 V for CAN_L. The absolute level depends on the busload. This ends in a differential level for recessive state of typical −5 V ($V_{CAN\_H} - V_{CAN\_L}$) and −3 V for the dominant state. In Fig. 2.3, the typical behaviour is demonstrated.

A fault-tolerant receiver consists of five different receivers which work in parallel. These receivers are:

- A differential receiver (for standard communication), with threshold voltage at −3 V
- A single-ended receiver for CAN_H (used in case of CAN_H short), with threshold voltage at 1.8 V
- Asingle-ended receiver for CAN_L (used in case of CAN_H short), with threshold voltage at 3.2 V

- Asingle-ended comparator for CAN_H (to detect CAN_H short to Vbatt), with threshold voltage at 7.2 V
- Asingle-ended comparator for CAN_L (to detect CAN_L short to Vbatt) with threshold voltage at 7.2 V

All receivers and comparators are also used to analyse failure cases on the bus. The failure management logic decides when there is a failure on the bus and changes from differential mode to single-ended mode. In the single-ended mode, the shorted transmitter is switched off (for example, in the case of CAN_H short to ground the CAN_H transmitter) and the single-ended CAN_L receiver is used. In the case of a CAN_L short to VCC or Vbatt, the CAN_L transmitter is switched off and the CAN_H single-ended receiver is used. The disadvantage of this single-ended mode is the lower noise robustness and the lower possible ground shift between the sender node and the receiver nodes.

In case of CAN_H short to Vbatt or VCC or a CAN_L short to ground, a high current flows through the termination resistors in sleep mode. This is the reason why termination resistor switches are implemented. In case of a short on the bus, the termination resistors are switched off. Pin RTL is the switch for the CAN_L termination resistor and RTH is the switch for the CAN_H termination resistor. In sleep mode, normally the 5 V supply VCC is switched off, floating or 0 V. To have a positive termination voltage, CAN_L will be high ohmic terminated to Vbatt. When CANS communication is started, the transmitter of the transmitting node pulls the CAN_L to ground and all other detects this as a remote wake-up event and the transceivers change into standby mode. In standby mode, INH is activated and switches on the voltage regulator and ramps up the microcontroller. After the successful ramp-up of the microcontroller, the transceiver should be set to normal mode for normal communication on the bus. In transceiver standby mode, the termination switches RTL and RTH on and terminates the CAN_H and CAN_L wires.

2.1.4.1 High-Speed Physical Layer

An ideal high-speed CAN physical layer has a termination resistor of 120 Ω on both ends of the wire. This reduces the echo on the wire to a minimum. All other nodes are connected in between. This concept allows a data rate of up to 1 Mbaud. The ringing, especially after the dominant to recessive edge, is minimized and the high data rate is possible. After switching on the CAN_H and CAN_L output stages, a current flows from CAN_H to CAN_L over the termination resistors. The result is a voltage drop over both termination resistors between 1.5 and 3 V. This is called dominant level. If both output stages are switched off, the voltage drop over the termination resistors is zero. This is called recessive level. The receiver thresholds are between 500 and 900 mV. A voltage drop higher than 900 mV will be detected as dominant level on the bus and a voltage drop smaller than 500 mV will be detected as recessive level. The common-mode range for the receiver is from −12 to +12V. If the bus common-mode voltage is higher or lower, the receiver can detect wrong signals. This concept is not proven against CAN_H shorts to ground and a CAN_L short to battery voltage. In this case, the communication can be corrupted.

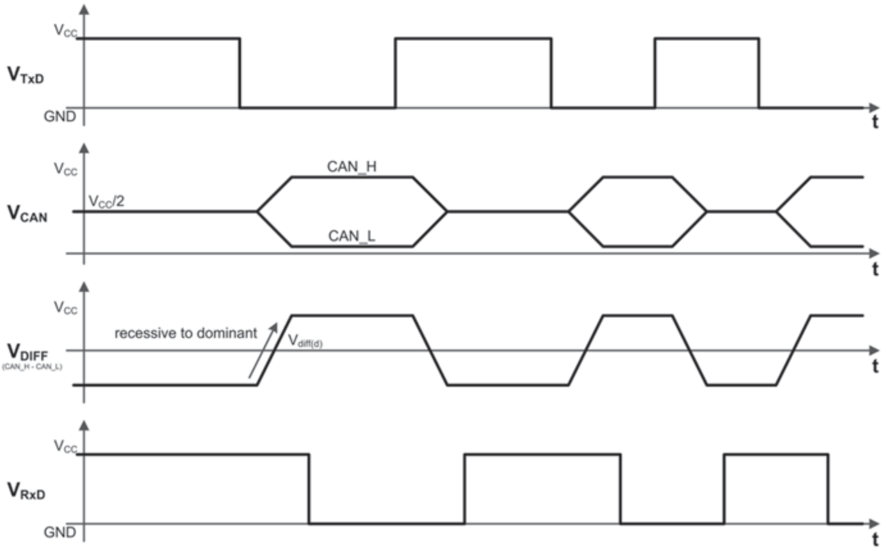

Fig. 2.4 Typical signal for a high-speed CAN physical layer

Figure 2.4 shows a typical high-speed CAN bus signal.

High-Speed Transceiver

Two different kinds of transceivers are in the market now:

- ISO 11898-2 transceiver
- ISO 11898-5 transceiver, with remote wake-up feature

The typical high-speed CAN transceiver consists of a transmitter and a receiver. Two 20-kΩ resistors, connected to an internal voltage source of 2.5 V , stabilize the bus voltage to 2.5 V in recessive state. The receiver is a differential comparator with electromagnetic compatibility (EMC) filter. This comparator monitors the bus levels and transforms the differential signal of the bus levels to a logic signal on pin RxD. High level on RxD is recessive level on the bus and low level on RxD is dominant level on the bus.

Figure 2.5 shows a block diagram of an ISO 11898-2 transceiver (left) and the ISO 11898-5 transceiver with remote wake-up (right).

Transceiver according to ISO 11898-2

A transceiver according to ISO 11898-2 is a transceiver with a transmitter and a receiver to transmit and receive data only. In the first generation of this kind of transceiver, no additional function was implemented. In newer generations, the ESD robustness is dramatically increased up to 15 kV and the emission is reduced to very

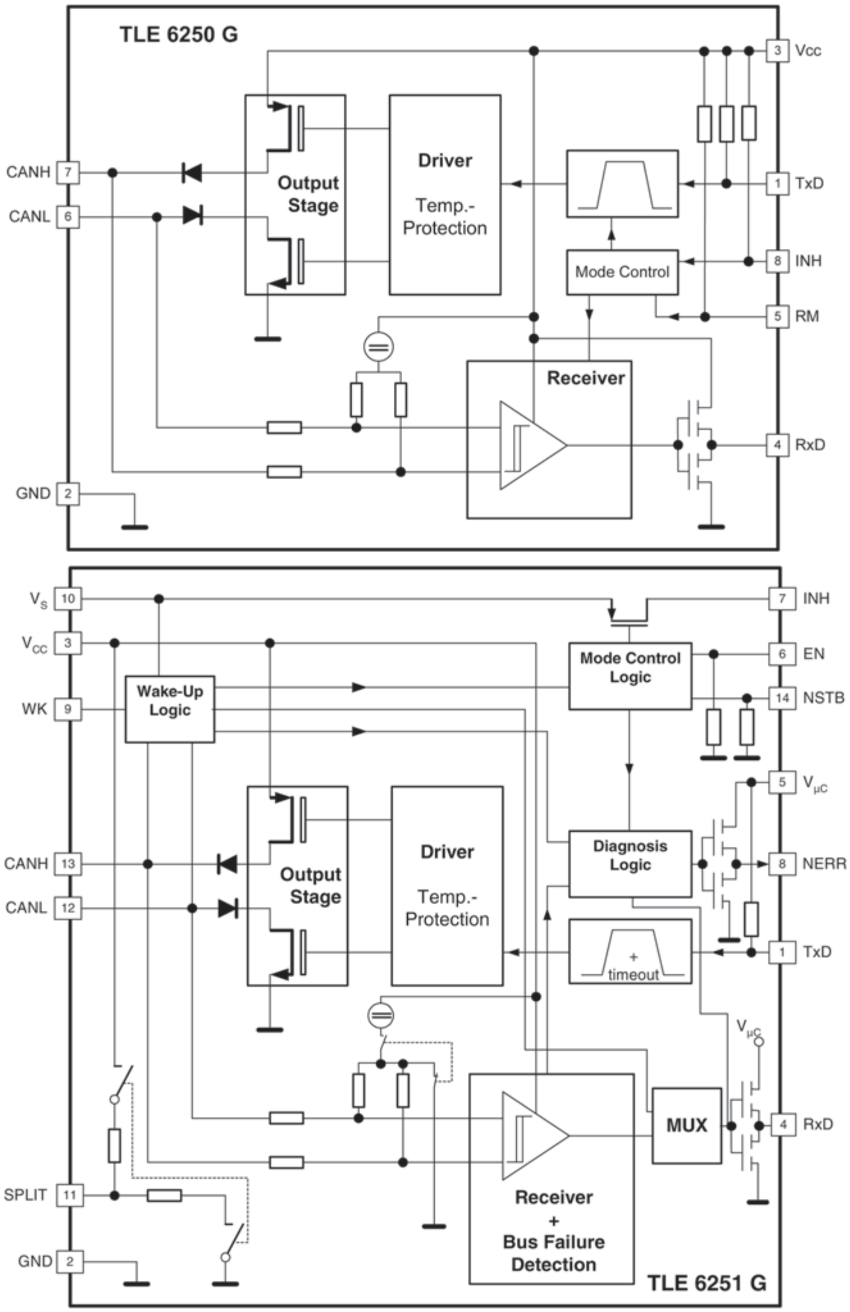

Fig. 2.5 Block diagram: comparison of ISO 11898-2-/ISO 11898-5 transceiver

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