Troubleshooting in automotive Ethernet networks

For driver assistance systems to operate reliably, the sensor data must reach the control units unimpaired. The details of communications between sensors and control units are regulated by the new automotive Ethernet standard. However Ethernet protocol analysis by itself is usually not sufficient if there are signal transmission problems. In such cases, the new trigger and decode solution for the R&S®RTO and R&S®RTE oscilloscopes can help.

Reliable Ethernet communications is essential for driver assistance systems

Automotive Ethernet is being increasingly used as a fast bus system for onboard driver assistance systems, infotainment systems and more. The automotive industry has therefore developed the 100BASE-T1 Ethernet interface, which is based on BroadR-Reach technology and standardized by IEEE working group 802.3bw. 100BASE-T1 implements a full-duplex Ethernet connection over an unshielded twisted pair (twisted-pair Ethernet). The 100BASE-T1 signals are PAM-3 modulated with differential signal levels between –1 V and +1 V. The data rate of 100 Mbit/s is significantly higher than with

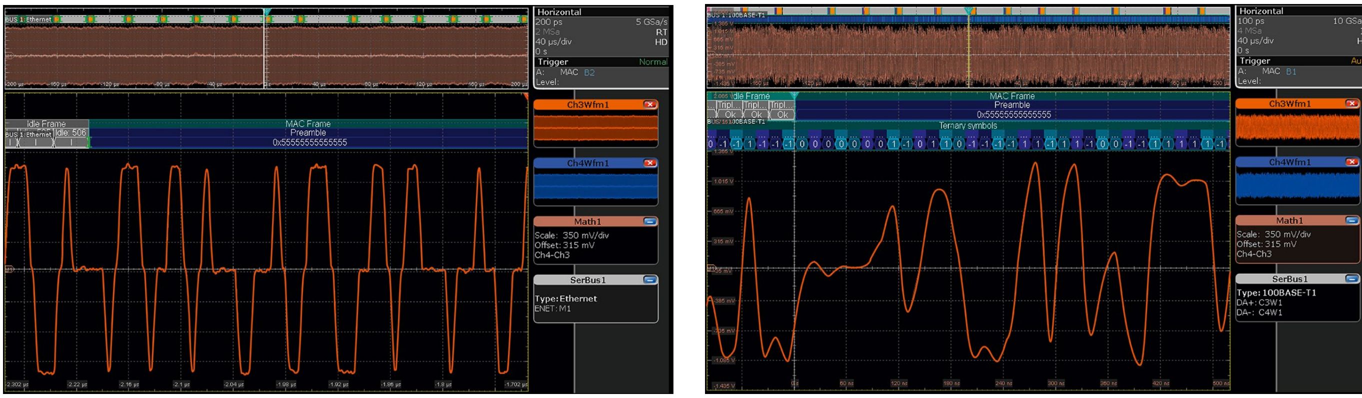


Fig. 2 On the left is a differential 100BASE-TX signal. The three levels and steep transition edges are clearly visible. An automotive 100BASE-T1 signal is shown on the right for comparison. Due to predistortion in the equalizer, the levels of the PAM-3 signal are not always clearly recognizable.

conventional automotive buses such as the CAN bus. This enables the development of driver assistance systems where large data volumes, such as occur in camera signals and radar signals, can also be transmitted reliably and with sufficiently short latency.

To ensure reliable transmission over the unshielded cable with minimum RF leakage, the transmitter uses an equalizer to shape the frequency response of the signals. The 100BASE-T1 PHY chips measure the frequency response of the cable when a connection is established and determine the appropriate signal predistortion. Compared to standard 100BASE-TX Ethernet, which works without equalizers, the signals in the 100BASE-T1 system are highly distorted and therefore the signal quality cannot be read directly from an analysis of the signal levels, for example in an eye diagram (Fig. 2).

Fig. 1: A complete measurement solution for 100BASE-T1 and 1000BASE-T1 automotive Ethernet compliance tests and link segment tests is available for the R&S®RTO oscilloscope.

Testing automotive Ethernet interfaces

The automotive industry association Open Alliance has defined detailed specifications for Ethernet interface tests. In the compliance tests for the physical layer (PMA tests in the Open Alliance Automotive Ethernet ECU Test Specification), the electrical properties of the interfaces are measured in the lab using an oscilloscope and a network analyzer. The compliance tests only check the electrical properties of the transmitter (using test signals). No tests are performed on the receiver. The quality of communications between two control units is simply measured indirectly by reading out the signal quality parameters of the PHY chips.

Tools such as Vector CANoe or Wireshark are usually used to verify that the control unit application communicates correctly. These software tools perform extensive analyses of the protocol content by acquiring all Ethernet data traffic with special interface modules. However, they only indicate transmission errors as data packet errors. If the data packet errors are caused by coupled-in interference for example, a more detailed analysis is not possible with these software tools. In such cases, an oscilloscope with suitable trigger and decode functions is commonly used.

The new solution for triggering and decoding on 100BASE-T1 buses for the R&S®RTO (Fig. 1) and R&S®RTE oscilloscopes makes it possible for the first time to analyze data packet content correlated with the electrical bus signals. Troubleshooting becomes nearly as simple as on conventional CAN buses.

Decoupled signal acquisition

If the signals on the twisted pair are tapped directly using an oscilloscope probe, the superimposed signals traveling in both directions are acquired. However, protocol analysis is not possible without separating these signals. The R&S®RT-ZF5 Ethernet probing fixture (Fig. 3) uses directional couplers to separate the signals, allowing decoupled acquisition of 100BASE-T1 communications with an oscilloscope (Fig. 4). The maximum additional attenuation of the signals is 1 dB, which does not affect data transmission.

Since the 100BASE-T1 transmitter's equalizer highly distorts the acquired signals, the signals are equalized by complex algorithms before decoding in the oscilloscope. The R&S®RTO displays the decoded data packets and idle frames as color-coded bus signals and in a table (Fig. 6). Time correlation of the 100BASE-T1 electrical signal levels with the transmitted protocol content enables detailed analysis of bus communications and data packet errors. Users can also trigger on data packet errors or on data packets with specific transmit or target addresses.

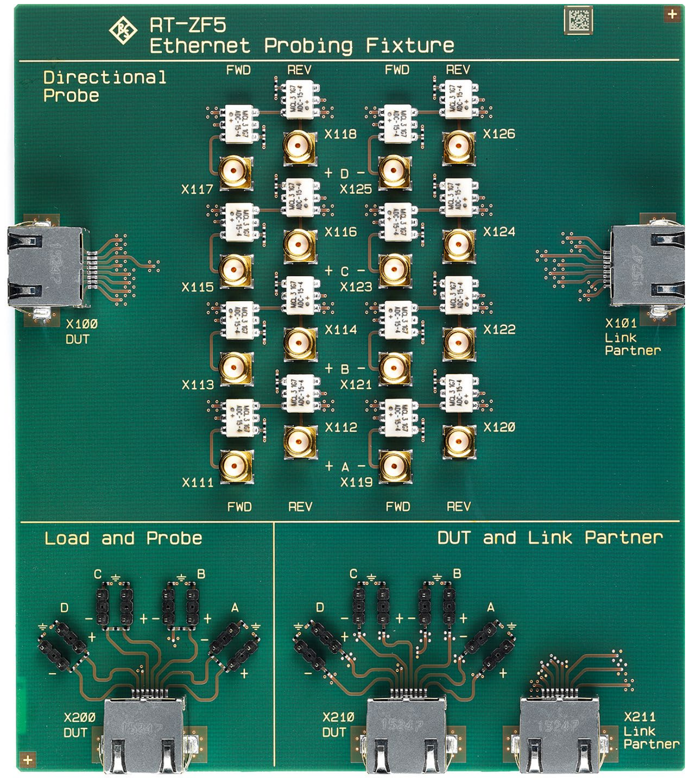
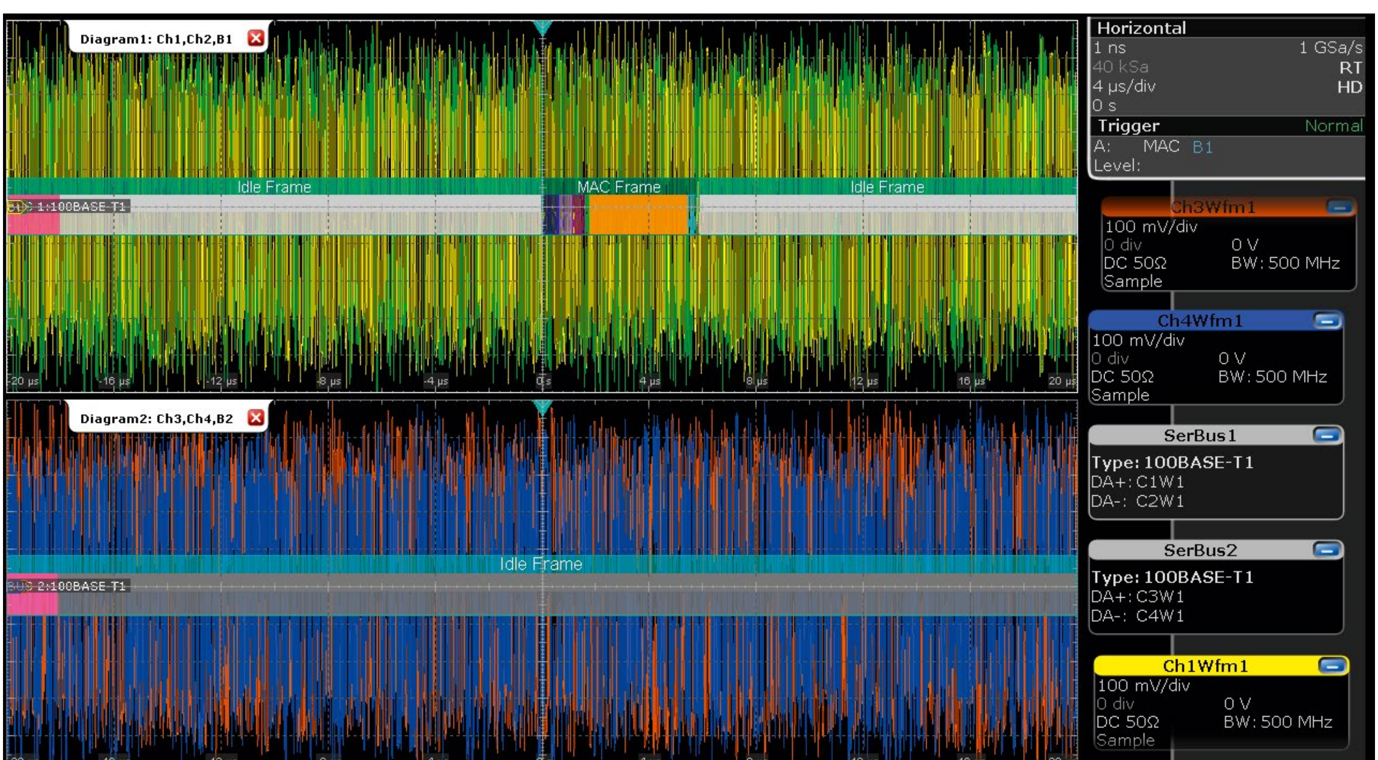


Fig. 3: The directional couplers in the R&S®RT-ZF5 Ethernet probing fixture allow decoupled acquisition of both data streams in full-duplex 100BASE-T1 communications.

Fig. 4: 100BASE-T1 decoding of both data streams in full-duplex communications. The MAC frame is highlighted in orange, the continuously transmitted idle frames are shaded gray.



Analyzing data packet errors

100BASE-T1 decoding can be used to show the timing of bus communications relative to other signals. For example, the start-up time of a control unit can be determined by triggering the oscilloscope on the 12 V supply voltage. The start-up time is the time between power-up and when the first valid data packet appears.

Intermittent bus errors caused by coupled-in interfering signals are difficult to find without simultaneously analyzing bus communications and 100BASE-T1 electrical signal levels. Decoding allows bus communications to be analyzed time-correlated over all seven OSI communications layers, which allows the source of the coupled-in interfering signal to be identified (Fig. 5).

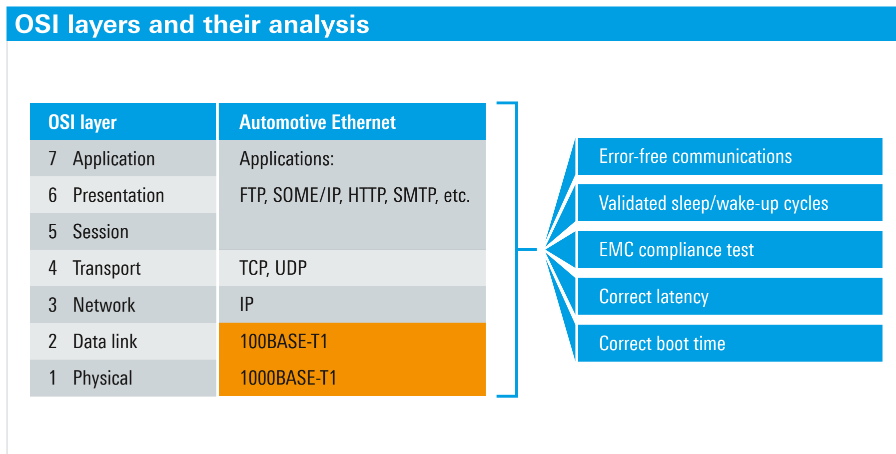
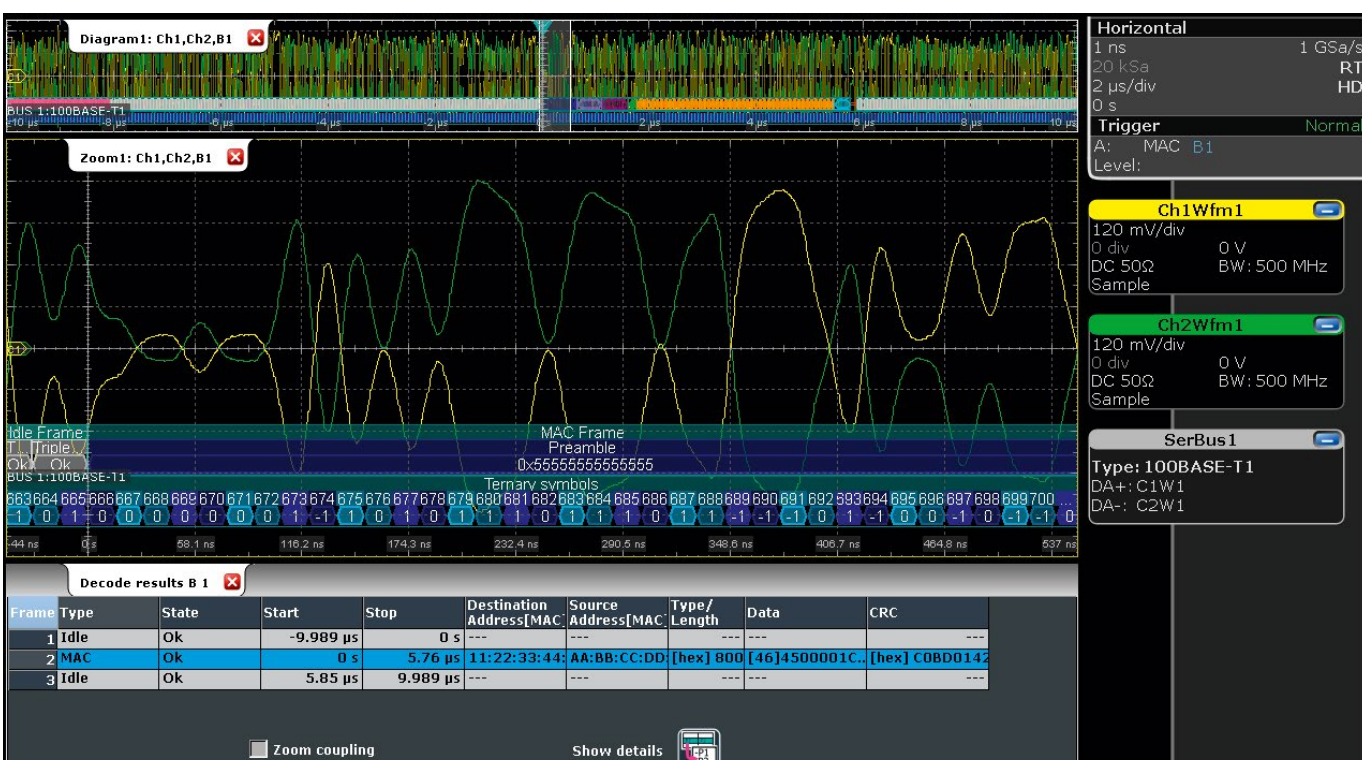


Fig. 5: The oscilloscope with the trigger and decode option analyzes all seven OSI layers of Ethernet communications.

Fig. 6: Decoding 100BASE-T1 electrical signal levels. The two levels of the 100BASE-T1 differential signal and the decoded data packet content are clearly visible.



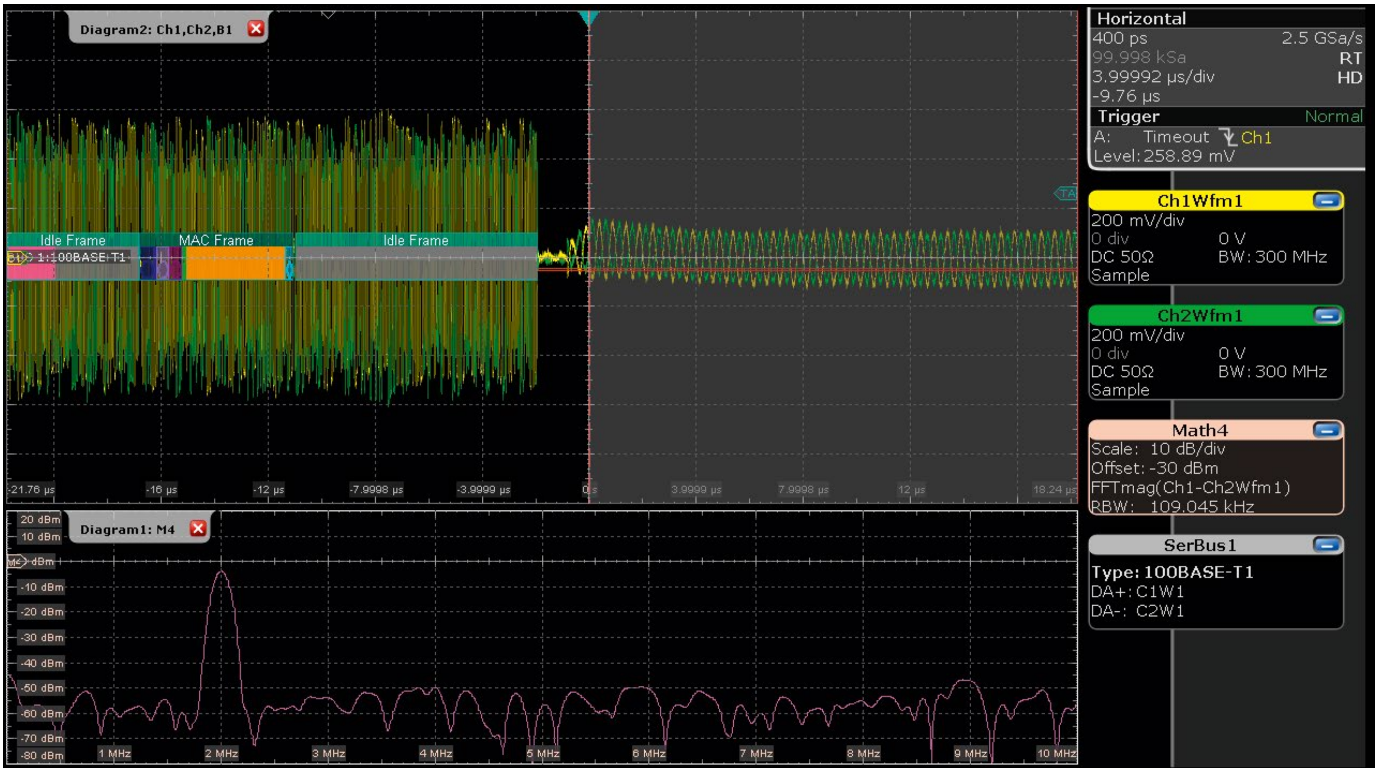


Fig. 7: Combining protocol analysis and frequency analysis to investigate an intermittent interruption of bus communications.

In the measurement in Fig. 7, for example, the MAC frame and the idle frames are transmitted correctly at the start of the acquisition. However, the data stream abruptly stops in the middle of the acquisition. The bottom window shows the frequency spectrum of the faulty time slice (the area shaded gray at the upper right). A spike at 2 MHz is clearly visible. This interfering signal is apparently responsible for the bus problem. Troubleshooting such problems is simplified by combining decoding with the oscilloscope's other analysis tools, such as frequency analysis. Problems that would otherwise be difficult to track down can be recognized at a glance with the oscilloscope.

Required oscilloscope configuration

- Oscilloscope: **R&S®RTO2004**
  (4 channels, ≥ 600 MHz bandwidth)
  or R&S®RTE1054
  (4 channels, ≥ 500 MHz bandwidth)
- **R&S®RTO-K57 or R&S®RTE-K57 option** to support 100BASE-T1
- **R&S®RT-ZF5 Ethernet probing fixture** for channel separation

Additionally recommended:

- R&S®RTE-TDBNDL option for serial trigger and decode functionality
- R&S®RTO-K24 100BASE-T1 compliance test option
- R&S®RTO-K87 1000BASE-T1 compliance test option
- R&S®ZND vector network analyzer

Summary

For the development of control units with an automotive Ethernet interface, Rohde & Schwarz offers a complete 100BASE-T1 trigger and decode solution, including an Ethernet probing fixture, for decoupled signal acquisition. It enables analysis of bus communications across all seven OSI communications layers. Extensive functions for triggering and displaying transmitted data packets facilitate the analysis of protocol content and identification of the causes of bus errors.

A dedicated option is available for 100BASE-T1 and 1000BASE-T1 automotive Ethernet compliance tests and link segment tests.

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