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Analysis of the physical layer in the vehicle wiring harness:

Neatly separated

The visualization of automotive Ethernet data streams on a BroadR-Reach link is not a simple task, as uplink and downlink share one wire pair in full duplex operation. Conventional examinations, e.g. by means of eye diagrams, are nevertheless possible when using a special measurement coupler.

By Stephan Schreiner, Thomas Müller and Dr. Gunnar Armbrecht

For the communication between control units, the Ethernet protocol is increasingly implemented in vehicles in order to supplement existing bus systems with low data rates, such as CAN, LIN and FlexRay as well as fast point-to-point pixel links via LVDS. Ethernet variants particularly optimized for the requirements in the automotive sector – 100BASE-T1 and 1000BASE-T1 – are standardized within IEEE, allowing for data rates of 100 Mbit/s and 1 Gbit/s via a differential pair of wires. OPEN Alliance has already adopted a number of specifications which, among other things, define channel and components limits as well as various tests on the interoperability. System integration is a critical step in implementing new bus systems in vehicles. As unshielded Ethernet transmission channels are involved here, so-called coexistence analyses play a major role. They serve to examine the interaction of Ethernet connections with any other on-board

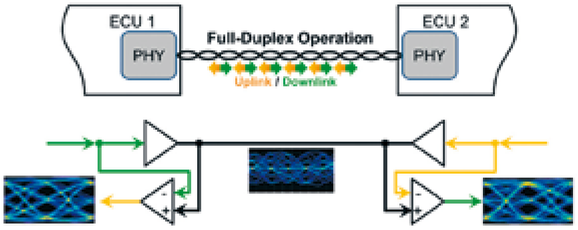

Figure 1. Operating principle of the echo cancellation in full duplex data links via differential wire pair. (Images: Rosenberger)

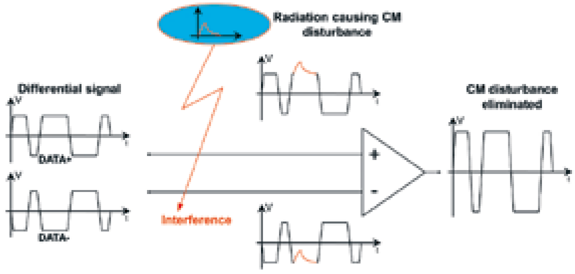

Figure 2. Advantage of differential data transmission: calculating the difference at the receiver eliminates the interference.

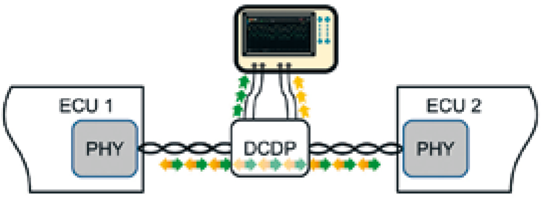

Figure 3. The measurement coupler (DCDP) decouples the overlaid signals of uplink and downlink separately.

network nodes and the high-voltage drive train. Thus the evaluation and verification of the Ethernet systems in the installed wiring harness come increasingly to the fore – even if not yet mandatory in any of the above-mentioned standards.

The challenge: full duplex transmission

The new 100BASE-T1 and 1000BASE-T1 Ethernet protocols generate a full duplex connection via a differential pair of wires for data transmission. It means that the same physical wire pair serves to transmit messages from ECU 1 to ECU 2 (downlink) and simultaneously from ECU 2 back to ECU 1 (uplink). Due to this method, uplink signals and downlink signals overlay on the cable, propagating in opposite direction. Despite the signal overlay in the line, readability of the data is ensured for the transceivers involved in the transmission as both transceivers know their own transmit data und thus also the contribution of their own signal in the overlaid signals on the line. Therefore they are able to reconstruct the incoming signal to be received out of the sum signal, as depicted in simplified terms in **figure 1**. Here it becomes clear that this method, known as echo cancellation, requires knowledge of the own transmit data in order to reconstruct the receive data. Whereas this is not a problem for the transceivers involved in the transmission, simple evaluation of signals, symbols and frames on any point on the line by conventional debugging using an oscilloscope and probes is not possible as none of the two signals is known. Unlike longer established systems like CAN or FlexRay, which work in semi-duplex operation and thus ensure that only one transmitter is active at a time, full duplex systems make it necessary to separate the uplink and downlink data stream for measurement and decoding. A symmetrical line structure with two signal conductors and ground can be operated in the common mode or in differential mode. As shown in **figure 2**, the transmission of information takes place in differential mode, in which both conductors are excited with opposite polarity. Due to the small distance between the conductors, any incoming interference affects both conductors in phase and therefore occurs in common mode. Calculating the difference at the receiver eliminates the interference – so much for the theory. In practice, however, already the slightest differences between the wire pairs lead to mode conversion, resulting in the conversion of a part of the energy from differential mode to common mode and vice versa. Therefore this parameter plays a decisive role, particularly in unshielded systems. At the time of vehicle integration, the components to be used have already been selected and it has been made sure that they comply with the specifications of the OEM or public standard (OPEN Alliance, IEEE). In this vehicle development stage, degrees of freedom exist primarily in cable routing and in packaging (arrangement of control units) in the vehicle. Finding ideal solutions in this respect specifically requires measurements of the signal integrity of transmission links in regular operation and under influence of any potential electromagnetic noise sources and loads in the vehicle.

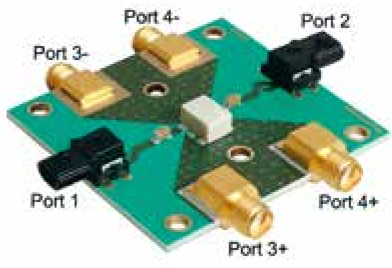

Figure 4. The differential measurement coupler for automotive Ethernet is equipped with Rosenberger's MTD connector at port 1 and port 2.

New approach for measurements

In order to gain insight into the data transmission it is possible to insert

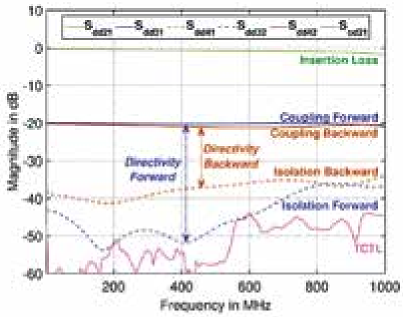

Figure 5. Set of differential S-parameters of the DCDP as example.

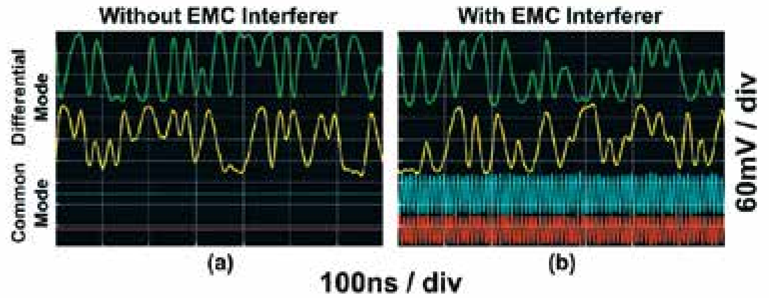

Figure 6. Typical result of a DCDP measurement within a BroadR-Reach link without (left) and with EMC interference (right).

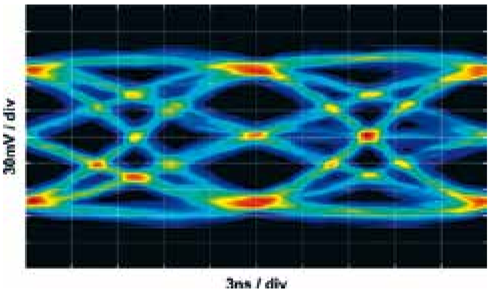

Figure 7. Eye diagram of a BroadR-Reach downlink signal measured by means of DCDP

network switches into a link. These switches serve as data distributors and are able to make the data packets available at additional digital ports. By applying this method data are received, actively processed and forwarded within the switch, which makes it impossible to assess the signal quality directly, e.g. by means of eye diagrams, and to evaluate jitter components. Compared to operation in a series production vehicle, the link properties are significantly influenced by inserting the additional switch. Therefore measuring the signals and evaluating the signal integrity is not possible. In order to allow an evaluation of the signal integrity Rosenberger has developed a passive probe in the form of a differential measurement coupler bearing the name „Differential and Common Mode Directional Probe (DCDP)". As shown in **figure 3**, the DCDP can be inserted anywhere in the link, decoupling the overlaid signals of uplink and downlink and making a small portion of both signals available on separate coaxial measurement ports. The influence on the data link to be measured is influenced only to a minor extent in this way. The DCDP can be used for both data rates (100 Mbit/s and 1 Gbit/s), covering a frequency range of 1 MHz to 600 MHz. As already described, uplink and downlink signals of automotive Ethernet propagate in opposite directions. In order to separate the data signals from each other, the operating principle of the measurement coupler is therefore based on so-called directional coupling – known from antenna- and other high-frequency technology. Directional couplers can be realized with different concepts. The DCDP integrates two directional couplers based on coupled transformers. This topology offers the advantage that – as already shown in figure 2 – both the data payload in differential mode and interfering signals in common mode can be monitored. The common-mode impedance in unshielded differential systems depends on the environment of the link and its relation to ground and other cables. Depending on the routing within a wiring harness, it is within a range of 100 Ω to 200 Ω. In order to influence the EMC-relevant system parameters in the least possible way, a common-mode impedance of approximately 150 Ω has been selected for the DCDP. Thus it intentionally deviates from the 25 Ω as seen when two coaxial cables are operated in differential mode as used within metrological systems. When selecting a design as depicted in **figure 4**, in which the integrated couplers are symmetrically arranged on the top and bottom side, it is possible to optimize the parameters mode conversion, insertion loss, common-mode impedance and differential mode impedance. **Figure 5** shows an example of a set of the S-parameters S_{dd21} (insertion loss), S_{dd31} (coupling loss in forward direction), S_{dd42} (coupling loss in backward direction), S_{dd32} (isolation in forward direction), S_{dd41} (isolation in backward direction), and S_{cd21} (mode conversion in transfer direction). The margin between coupling and isolation of one direction is referred to as directivity and it is the central parameter to separate uplink and downlink. With regard to directivity, the coupler has a preferred direction in which a directivity of more than 22 dB is achieved over the entire frequency range of 1 MHz to 600 MHz. The insertion loss of the DCDP is below 1 dB over the whole frequency range, whereas the mode conversion, i.e. the conversion of a differential mode signal into a common-mode signal and vice versa, can be regarded as very low due to its value of less than -40 dB.

The measurement coupler in application

Figure 6 shows the signals on a BroadR-Reach transmission line with a length of 10 m. It shows the separation of both data streams in differential mode and also the effect of EMC interference in common mode. BroadR-Reach data signals are PAM3 modulated and therefore can have values of -1, 0 and +1. Figure 6a does not contain any common-mode signal as there is no

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EMC interference in the link. A transmission is evaluated in Figure 6b in which an additional EMC interference signal with a frequency of 100 MHz has been applied using a BCI coupling probe. This illustrates the advantages of differential data transmission, as already shown in figure 2. Whereas the interference signal in common mode is clearly visible as a fast sine wave, the data signal remains almost uninfluenced due to the very good mode conversion behavior of the components used within the link. By means of decoding software in the measurement instrument or by evaluating the recorded data on a PC it is possible to recover the PAM3 symbols sent. This makes it possible to evaluate various link parameters like jitter components, eye diagrams,latency as well as wake-up behavior. **Figure 7** shows an example of the differential downlink signal in the form of an eye diagram.

The DCDP represents a measurement probe for automotive Ethernet systems according to 100BASE-T1 and 1000BASE-T1. It supplements already known and specified measurements procedures for transmission channels and individual components by providing the possibility to measure a wiring harness that is already installed in the vehicle. In the verification phase of a vehicle platform, the DCDP enables engineers to verify network topologies as well as the selected packaging for their suitability for automotive Ethernet. Thanks to the possibility to analyze data signals in differential mode and any possible EMC interference in common-mode on an unshielded transmission channel separately, the integration of automotive Ethernet systems into vehicles is supported. The DCDP for automotive Ethernet now completes Rosenberger's portfolio for coexistence analysis in the wiring harness, which has so far comprised measurement couplers for high-voltage systems [1] and shielded LVDS data links [2]. Therefore comprehensive cross-domain coupling examinations in the vehicle are now possible. The DCDP will soon be available directly at Rosenberger as a commercial product. A software option for direct decoding of the DCDP measurement values will be available from well-known oscilloscope manufacturers soon. *ku*

Literatur

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