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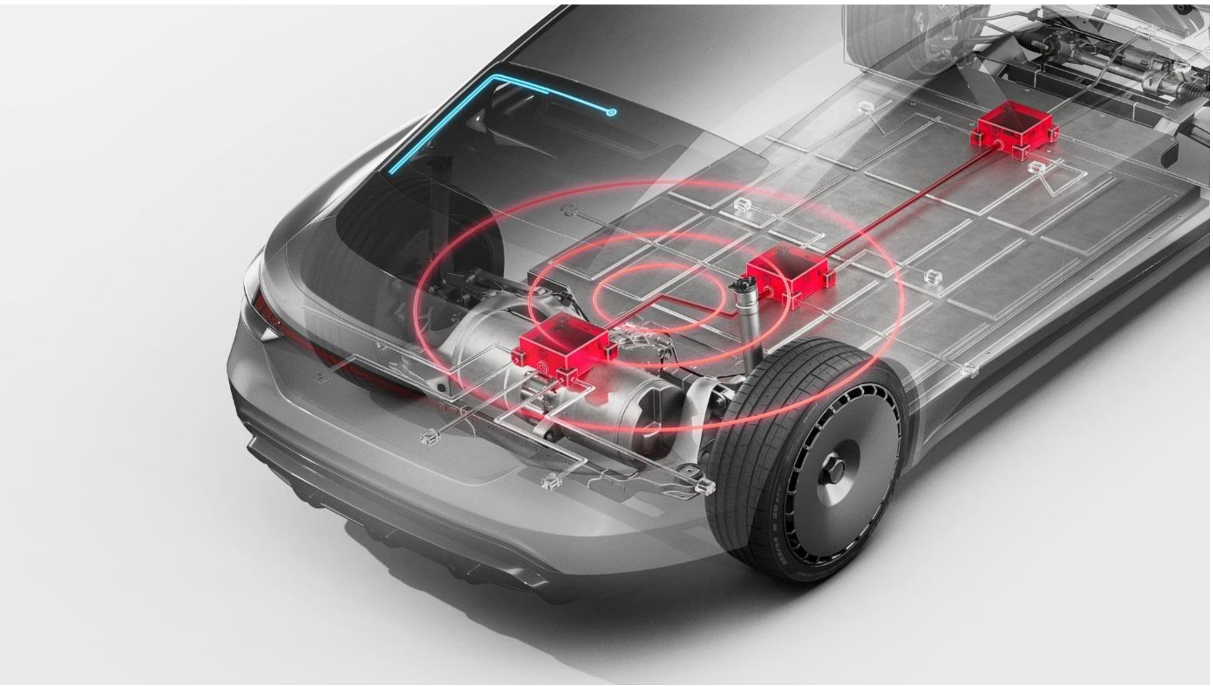

Realize the Shielding Dividend

1000BASE-T1 in Vehicle Implementation

Unlike 100BASE-T1, 1000BASE-T1 over unshielded transmission channels doesn’t meet all EMC requirements at vehicle level at present. Therefore, shielded cabling systems are predominantly used for Gigabit Ethernet. While shielded systems have been added to the cabling specification in OPEN Alliance (OA) TC9, the circuitry on the printed circuit board (Media Dependent Interface, MDI) has not yet been adapted in TC12. Is the use of shielded systems only transitory? If not, there is untapped potential for cost and space savings.

Status Summary

One of the standardization-objectives of 1000BASE-T1 in IEEE 802.3bp [1] was to use unshielded twisted pair (UTP) cables with jacket. The vision was to combine cost, weight and electrical properties in a cost-effective solution. To ensure sufficient EMC performance, system-level measurements based on assemblies were successfully performed. However, it has subsequently turned out, that passing system tests such as CISPR25 antenna measurement according to ALSE method or stripline, is no guarantee to pass EMC measurements at vehicle level, as Figure 1 shows.

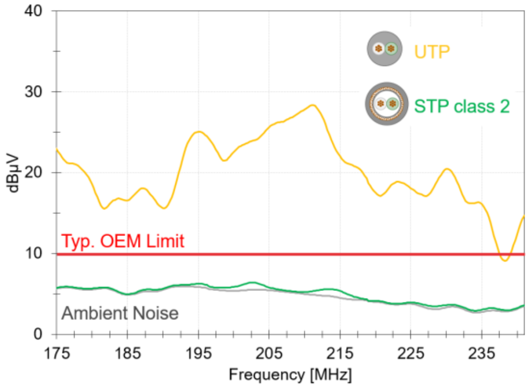

Figure 1: Emissions of a 1000BASE-T1 link into in-vehicle DAB antennas

The example shows the measured RF emissions of a 1000BASE-T1 data connection into an in-vehicle DAB antenna. In order to be able to unambiguously assign the emissions to this specific Ethernet connection, all other active electronic systems in the vehicle are deactivated during this test. The fully shielded STP system complies with the vehicle manufacturer's limit in the entire frequency range and exceeds the measurable background noise only slightly. In contrast to that, the UTP transmission channel qualified as "compliant" according to IEEE/OA, while providing best possible unbalance attenuation (balance/common mode rejection), exceeds the limit by up to 15 dB and cannot be implemented. Recent publications [2] and [3] prove that this example is not an exception. Since common-mode rejection is considered de facto exhausted in state-of-the-art UTP systems and other optimization approaches do not exist, the only practical option is to use shielded systems. OA TC9 [4] defines two shielding classes: STP class 1 for basic shielded connector systems, often based on UTP connectors which were retrofitted with two contact points. STP class 1 systems require additional effort in form of special mode conversion optimized STP cables, while STP class 2 are 360° fully shielded in conjunction with conventional STP cables. Using STP class 2 solves the EMC issues reliably, but there may be more opportunities to improve the cost-benefit ratio, which will now be discussed in detail.

Root Cause Analysis

Let's start with some basic information about differential data transmission, since a basic understanding of how common-mode interference arises and how to avoid it is essential to understanding the differences between UTP and STP and the causes of EMC effects at vehicle level. Differential data transmissions uses the differential mode (DM), in which the two conductors of a differential pair carry the same the signal in amplitude, but with opposite phase. Interference is predominantly emerging on both conductors with identical phase, i.e. in common mode (CM). By substracting the signals on both conductors at the receiver, interference in common mode is largely suppressed, which improves immunity to interference. The mechanism is different for emissions. Common mode interference on the differential transmission path may cause EMC problems depending on frequency, cable length and the installation situation. A typical measure to reduce common mode interference is the use of common mode chokes (CMC). This is a component on the printed circuit board that attenuates common mode signals (Figure 2). The CMC is usually complemented by the common mode termination (CMT), a filter network placed between the CMC and the connector to provide a matched termination for common mode noise. Since a CMT must be able to handle peak pulses and power as well, it requires a large amount of space and, like the CMC, represents a cost factor that should not be neglected.

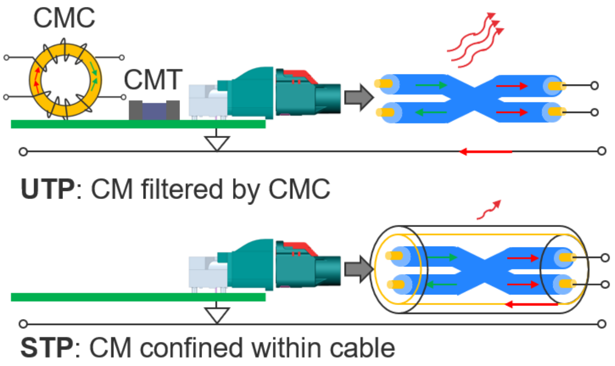

Figure 2: Sources of common mode interference and measures for reduction

CMCs are essential when using UTP and part of the 1000BASE-T1 reference circuit according to OA TC12 [5]. Costs and space requirements for CMC/CMT scale according to the number of ports within a switch. CMCs may also introduce electrical disadvantages such as attenuation of the data signal or additional unbalance. They have a typical frequency response with decreasing common mode rejection towards high frequencies. As will be shown later in the article, common mode interference emitted by the transceiver IC can be observed in the spectrum up to the GHz range. The common mode rejection required for CMCs according to [6] is 32.5 dB at 600 MHz. However, no values are specified for frequencies above this and the behavior is therefore unpredictable.

In principle, once common mode signals are on the UTP line, they couple largely unhindered into in-vehicle antennas. Due to the short distance to antennas or unfavorable directional characteristics of the antenna in reference to the installed link, in-vehicle measurements may end up in more stringent emission requirements than what is needed to pass standardized system level tests. A proven solution to reduce coupling with surrounding systems is shielding. Common mode signals propagate within the cable, but are effectively prevented from coupling with the surrounding environment by appropriately high shielding attenuation up to very high frequencies (Figure 2). Common mode suppression by CMCs and shielding are thus complementary effects. If very good 360° shielding is available anyway, it should therefore be possible to reduce the effort required for common mode rejection, which would allow savings to be made on CMC/CMT on the printed circuit board.

Modular Test Platform and Hedging Strategy

To be able to efficiently investigate different line and MDI configurations, Rosenberger has developed a modular evalboard platform for automotive data protocols. The base module communicates with a PHY board that comprises a 1000BASE-T1 chipset from an established manufacturer. The detachable MDI board is connected to the PHY board via a board-to-board connector and contains the passive components up to the PCB connector. This enables us to measure the EMC behavior of different wiring and MDI variants in a quick and reproducible way.

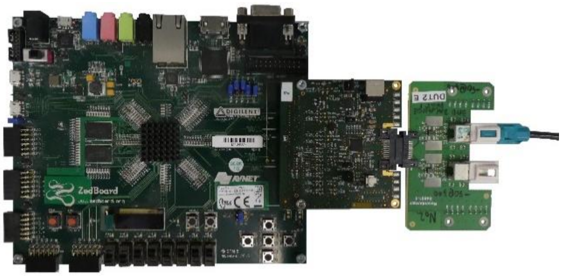

Figure 3: Multi-part structure of the modular test platform

Figure 3 shows the fundamental design of the modular test platform. The evalboard platform was successfully tested for compliance according to the common device specifications as per OA TC8 [7] and TC12 [8] (Figure 4). The cabling meets the requirements for the transmission channel as well as the individual components according to OA TC9 as per [4] and [9] respectively.

	Standard	Spezifikation	Parameter	Ergebnis
ECU	TC8	ECU test specification	Mandatory and additional	✓
	TC12	PMA test suite	Layer 1 mandatory	✓
Link segment	TC9	Channel and components		✓
EMV	CISPR25	Antenna Emissions (ALSE)	30 - 3000 MHz	✓
	ISO 11452-4	Bulk current injection (BCI)	1 - 400 MHz, 200 mA	✓

Figure 4: Modular test platform successfully qualified

In order to confirm that CMC and CMT are not needed when using Rosenberger H-MTD®, measurements were carried out using various methods. While performing EMC measurements, the electronics were placed in a shielded enclosure. Immunity to interference was measured by Bulk Current Injection (BCI) method according to ISO 11452-4 in the substitution method variant. The coupling clamp applies an interference current of 200 mA to the DUT in the frequency range 1 to 400 MHz. All three configurations, i.e. also including STP system without CMC, passed this test.

Based on the measurement of shielding and coupling attenuation, the circuit variants of the PCB in the triaxial cell were measured according to IEC 62153-4-7. In EMC measurements with active electronics the result is always a mixture of negative and common mode components, since both are already present in the generated spectrum of the source. The measurement in the triaxial cell by means of a network analyzer makes it possible to cleanly separate negative and common mode components. The CMC reduces the coupling in the common mode, analogous to an improved shielding effectiveness, while the coupling for the differential mode hardly changes. The triaxial measurement of assemblies is therefore suitable for investigating the effect of changes to the circuitry of the printed circuit board on EMC behavior.

Antenna Near-Field Measurement increases Measurement Dynamic Range

How can the correlation between system and vehicle level be improved, so that situations can be avoided in future, in which all EMC assessments were "green" for integration in the vehicle and only the vehicle measurement jumps to "red", as shown in Fig. 1? Our approach was to use an antenna near-field measurement method based on [10], adapted to the application. The measurement setup consists of a 1000BASE-T1 evalboard connected to a cable assembly (Fig. 5). The far-end of the cable assembly is terminated via 2 x 50 Ω to ground. Therefore the termination impedance are 100 Ω in differential and 25 Ω in common mode.

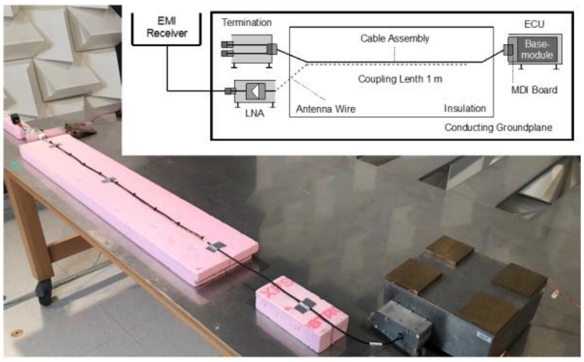

Figure 5: Antenna near-field measurement

During the measurement, the Ethernet transceiver continuously sends data packets in a standardized test mode. A wire is attached to the cable assembly which serves as receiving antenna to pick up emissions along the cable, which then are routed to the measuring receiver via a low-noise preamplifier. In this measurement setup, different cable types and MDI configurations can be reproducibly compared with good dynamic range and sensitivity. The presence of the antenna wire had only a negligible effect of less than 1 dB on the line unbalance attenuation, even in the unfavorable case of UTP. STP with and without CMC was compared to UTP with CMC as reference.

In the antenna near-field measurement, the measured emissions of STP are up to 40 dB lower than those of UTP, depending on the frequency range (Fig. 6). If a CMC is not used, there is only a slight increase in emissions of a few dB over wide ranges. At 750 MHz, the symbol rate results in a null in the data spectrum, so that even the UTP emission drops close to noise level at some points. The power spectral density generate dby the chipset in differential mode is only specified up to 600 MHz. In practice, however, the spectrum doesn't end abruptly there. Together with narrowband emissions from the transceiver IC, e. g. as multiples of the clock frequencies, there are clearly measurable interference emissions over a large part of the TV/mobile bands above 600 MHz, especially in the UTP case.

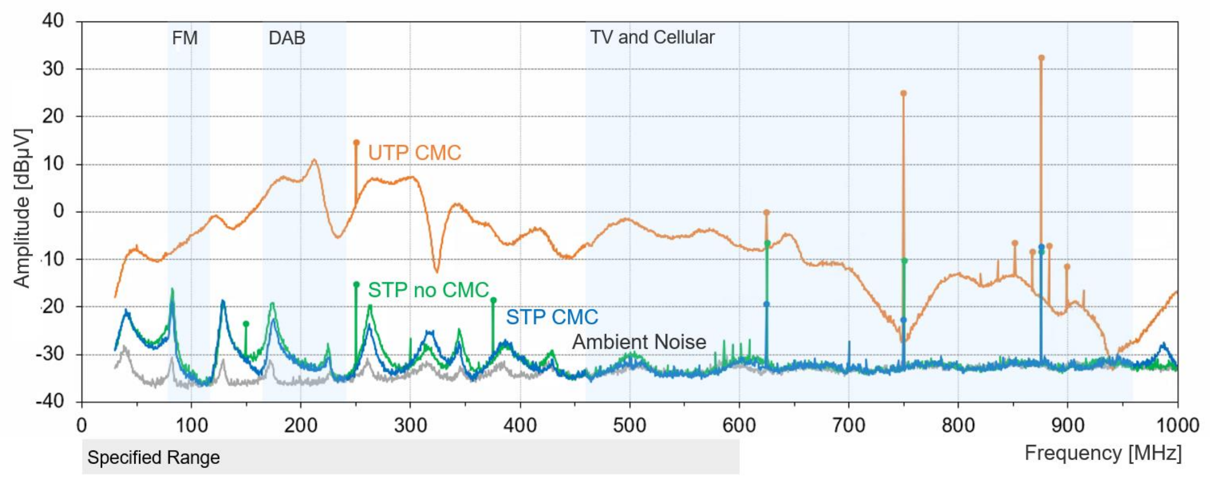

Figure 6: Comparison of UTP and STP with and without CMT/CMT using antenna near-field measurement method within and also above the spectral range specified in IEEE/OA.

The difference with and without CMC in common mode coupling is about 20 dB in the relevant frequency range up to 300 MHz, which roughly corresponds common mode attenuation of the CMC. The difference with and without CMC in differential mode coupling is small, since the CMC attenuates the differential signal only slightly. Unlike an unshielded solution, STP reduces common mode coupling to ambient systems by up to 40 dB even without CMC. In the reference circuits, the impedance of the CMT is matched to the high common mode impedance of nominally 200 Ω of the CMC in conjunction with a UTP line. Depending on the installation situation of the UTP cable in a vehicle, the common mode impedance can vary widely with distance to the reference ground. In contrast, the common mode impedance of a STP cable is 25 – 45 Ω with very little fluctuation. A CMT matched to this low impedance would attenuate the wanted signal too much. Therefore, it makes sense to dispense with both CMC and CMT. Depending on the layout, the space required on the PCB can be reduced by up to 30 % (Figure 7) which supports the trend towards multi-header connectors that are optimized in installation space.

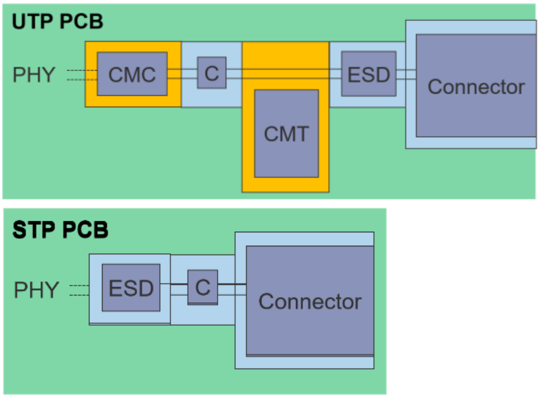

Figure 7: Space savings on the printed circuit board by dispensing with CMC/CMT

If CMC and CMT are dispensed with, compatibility with UTP is no longer given. Consequently, it is no longer possible to change from STP to UTP on the cable side without adapting the circuitry of the PCB. It should be noted that if CMC and CMT are not used, the ESD protection concept should be checked which consists of the internal fuse protection of the transceiver IC and optional external ESD protection diodes. Due to the omission of the high inductance of the CMC, the arrangement of an optional external ESD diode and its trigger characteristics may need to be adapted. Initial investigations are promising - however, more detailed investigations should be carried out.

Conclusion: Reliable EMC Qualification with Reduced Overall Costs

Will the UTP vision for 1000BASE-T1 possibly become a UTP illusion? From vehicle level EMC perspective, there is currently no plausible reason to assume the need to use of STP for Gigabit Ethernet will fundamentally change in future. All UTP components consisting of MDI, connectors and cables can be considered to be optimized to a level what is physically possible with reasonable effort.

Within this article we demonstrated by means of various measurements, that additional savings on Ethernet-enabled devices are possible by using 360° fully shielded OA TC9 STP class 2 channels, such as Rosenberger H-MTD®. This potential arises primarily by dispensing with CMC and CMT on both sides of a data link. The result is a functional and reliably EMC-qualifiable solution that directly reduces the space requirement of an STP class 2 solution on the PCB by about 30 % and the relative costs by about 20 % (Figure 8). The CMC/CMT component costs in combination with an one meter cable assembly serve as a reference.

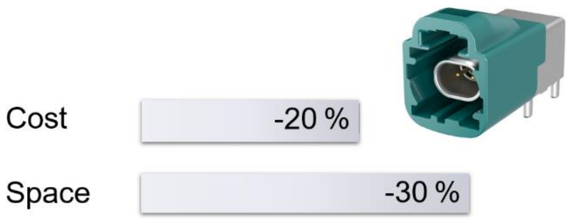

Figure 8: STP class 2 enables savings on the PCB as a kind of shielding dividend.

Therefore, we advise to verify the potential of these cost and space savings by detailed investigations (e. g. ESD protection) and, if possible, to realize the shielding dividend in new projects in the form of reduced component costs by abandoning CMC and CMT.

SOURCES

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