Investigation of CAN-XL EMC performance at car level

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For well-known reasons (e.g. ADAS), ever faster data connections have been integrated into vehicles in recent years. Consequently, the CAN bus has also been further developed, from CAN via CAN-FD and CAN-SIC to the current CAN-XL. This article shows the current status of EMC investigations in the vehicle. It compares different IC implementations and their EMC behavior in terms of interference emissions and interference immunity in the vehicle.

EMC in the vehicle

The electromagnetic compatibility (EMC) of electronic systems is the ability to work satisfactorily in their electromagnetic environment without interfering with each other or being disturbed [1]. This means that an electronic system must have high immunity against interference and at the same time low electromagnetic emissions.
In this case, the system is the physical layer of CAN-XL, i.e. transceiver (TRX), common mode choke (CMC), possibly external ESD suppression devices, the cables and the corresponding topologies. The electromagnetic environment is largely defined by the vehicle.

In addition to the legal requirement the compliance with the EMC requirements for emissions and immunity in the vehicle is an essential characteristic for the quality of various customer functions.

With increasing levels of networking in the vehicle [2], with every new bus technology and with every new electronic control unit (ECU), the EMC requirements for the electromagnetic emissions and electromagnetic immunity of the electrical system also increase.

When introducing a new bus system such as CAN-XL, the typical 3 stages of EMC development are run through in loops in order to derive the requirements for the bus system from the findings [3].

The basic investigations and optimizations of the CAN-XL interface are carried out at the semiconductor level (IC level). The influence of network parameters, cable material, connectors, pin assignment and assembly is examined at the control unit level (ECU level). At vehicle level (car level), different topologies are tested in different vehicles and compared with the measurement results of the IC and ECU level.

The aim is to assess the effects of new networking technologies on EMC in advance.

Based on the EMC behavior in the vehicle the limit values and requirements as well as the test conditions for the semiconductors and the on-board electrical system are derived and specified in order to ensure smooth integration into the vehicle.

In the following chapters, examples of vehicle measurement results are presented and an initial outlook on the IC measurements is given.

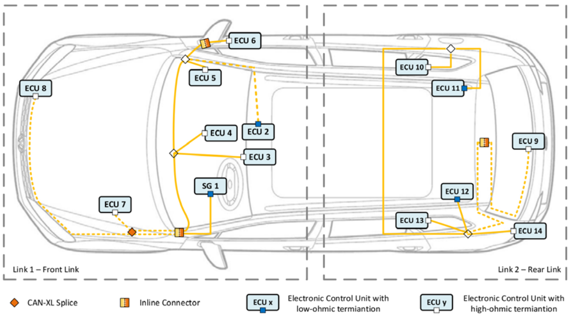
The naming of the transceivers with Type A, D, E etc. is chosen completely arbitrarily for each measurement and therefore does not allow any conclusions about the overall performance of a transceiver.

CAN-XL Topologies

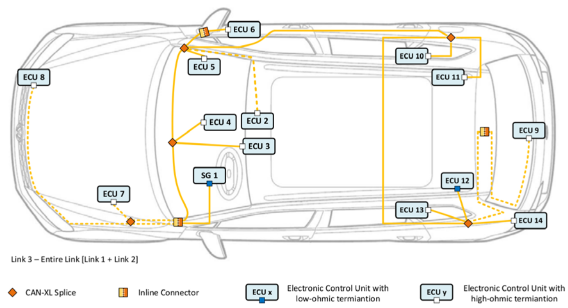
The topologies shown in Figure 1 are used to characterize the EMC behavior of CAN-XL networks in vehicles. They are based on the topology that was already used for studies on CAN-FD with 5 Mbit/s and adapted for CAN-XL [CS].

The network is divided into a front (link 1) and a rear link (link 2) so that vehicle-specific influencing factors, such as field exposure or the position of ECUs in relation to the antennas, can be examined. Links 1 and 2 are mutually connected to form a “worst-case” link (link 3). The position of the ECUs and the routing of the bus cables do not change. There is only added an additional cable to connect the two-star points.

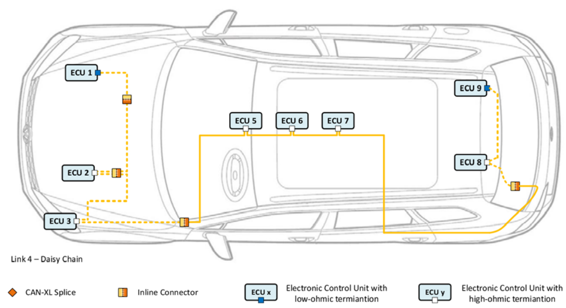
Link 3 does not meet any of the expected design rules for signal integrity but is used to explore the limits of CAN-XL. To determine the topology dependency, a “daisy chain” bus structure with link 4 is examined as well.



Link 1 – Front Link: nodes 8 / length 15 m
Link 2 – Front Link: nodes 6 / length 12 m



Link 3 – Entire Link: nodes 14 / length 32 m



Link 4 – Daisy Chain: nodes 8 / length 16 m

Figure 1: Topologies for EMC validation

The topologies shown in Figure 1 are installed in different Group vehicles to validate the EMC behavior in different electromagnetic environmental conditions. The electronic control units are equipped with an FPGA on which the Bosch CAN-XL IP is running and operates with a 160 MHz clock. The various transceivers are connected to the FPGA. Data transmission takes place via an unjacketed 100 Ω twisted pair cable, as is also used for FlexRay.

Immunity against RF interference

The frequency range of interest for interference immunity is 100 kHz to 3 GHz. Based on previous findings, only results up to 220 MHz are shown below. A summary of RF immunity test results is given in Table 1 for data rate of 5 Mbit/s and in Table 2 for a data rates of 10 or 12.3 Mbit/s. Figure 2 illustrates an example of a failure curve on which the evaluation is based. Even small deviations from the limit line are rated as “fail”.

Table 1: RF immunity test results with data rate of 5 Mbit/s

No.	Link	Frequency [MHz]	Type A	Type B	Type C	Type D
1	1	0,1 - 30	fail	pass	pass	pass
2		20 – 220	pass	pass	fail	pass
3	2	0,1 - 30	pass	pass	pass	pass
4		20 – 220	pass	pass	pass	pass
5	3	0,1 - 30	fail	pass	fail	pass
6		20 – 220	pass	pass	fail	pass
7	4	0,1 - 30	-	pass	-	pass
8		20 – 220	-	pass	-	pass

Table 2 RF-immunity test results with data rate of 10 Mbit/s or 12.3 Mbit/s

No.	Link	Frequency [MHz]	Type A	Type B	Type C	Type D
1	1	0,1 - 30	fail	pass	pass	pass
2		20 – 220	pass	pass	fail	pass
3	2	0,1 - 30	pass	pass	pass	pass
4		20 – 220	pass	pass	pass	pass
5	3	0,1 - 30	fail	pass	fail	pass
6		20 – 220	pass	fail	fail	pass
7	4	0,1 - 30	-	pass	-	pass
8		20 – 220	-	pass	-	pass

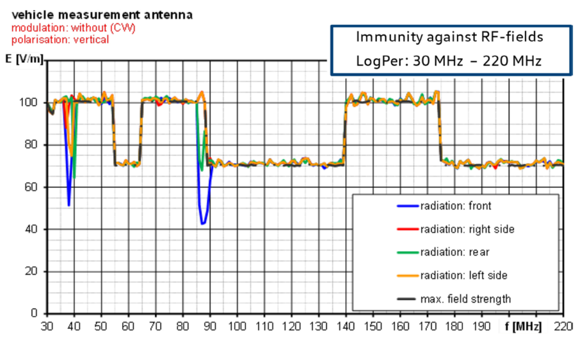


Figure 2: Example of failure curve of RF immunity measurements

For data rates up to 12.3 Mbit/s it can be observed that the fails are related to narrow-band failures. The number and threshold of these failures depend on the selection of topology and transceiver. To further analyze the EMC influencing factors and to create more dynamics, some transceivers were operated in selected topologies with a data rate of 20 Mbit/s. It should be mentioned that none of these transceivers were final developed and ready for this high data rate. The results are summarized in Table 3.

The used CAN-XL transceivers behave significantly different with respect to interference immunity. While one transceiver type experience small narrowband failures (Figure 3), others show significant wideband failures (see Figure 4).

Table 3: RF-immunity with data rate of 20 Mbit/s

No.	Link	Frequency [MHz]	Type A	Type B	Type C	Type D
1	1	0,1 - 30	-	-	fail	pass
2		20 – 220	-	-	fail	pass
3	2	0,1 - 30	-	pass	fail	-
4		20 – 220	-	fail	fail	-
5	3	0,1 - 30	-	pass	-	-
6		20 – 220	-	fail	-	-
7	4	0,1 - 30	-	pass	-	pass
8		20 – 220	-	pass	-	pass

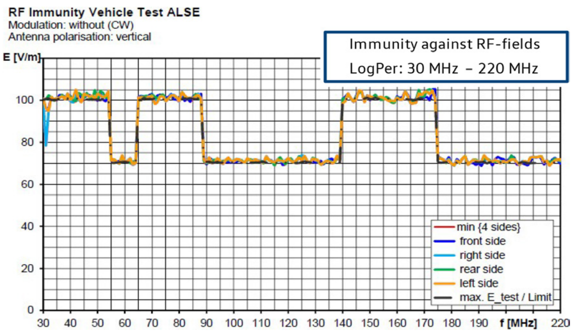


Figure 3: Narrowband failures in immunity measurements with 20 Mbit/s

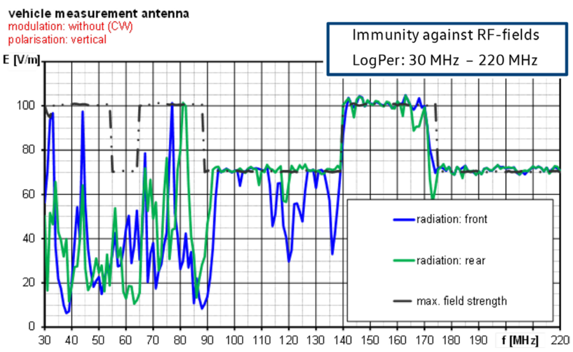


Figure 4: Broadband failures in immunity measurements with 20 Mbit/s

The evaluation of results for data rates of up to 12.3 Mbit/s show that the present CAN-XL test ICs already have a high level of immunity against radiated electro-magnetic fields. Even in the worst-case topology (Link 3) there are transceivers which doesn't show failures at maximum field exposure.

In the topology (Link 4), which provides a good signal integrity, there are no failures even at data rates of 20 Mbit/s. Therefore, it can be concluded that a "suitable" bus design can facilitate sufficient immunity against electromagnetic interference even for data rates up to 20 Mbit/s.

After the design rules for the CAN-XL bus have been determined, the measurement data obtained from the vehicle tests can be compared with the DPI immunity results from the IC level test according to IEC 62228-3 [4].

Based on the findings, the limiting values for interference immunity will be defined. This includes, for example, determining the bus asymmetry or the bus filters to be used for testing.

Emission of RF interference

To measure the electromagnetic emissions, the CAN-XL network is also operated in the topologies as shown in Figure 1. It is operated exclusively, i.e. the rest of the vehicle has been disconnected from the battery.

Of particular interest is the interference coupling into the various antenna systems in the vehicle, especially in the FM and DAB frequency bands.

In the first step, the RF emission is determined in homogeneous networks (i.e. all ECUs use the same type of transceiver), which enables a comparison of the different CAN-XL transceivers within the respective frequency bands.

Figure 5 illustrates this comparison for link 1 in the FM band and in Figure 6 for link 2.

By comparing the measurement results of the RF emissions from the front link with the results of the rear links (link 1 vs. link 2), the influence of the position of the ECUs and the wiring harness can be figured out.

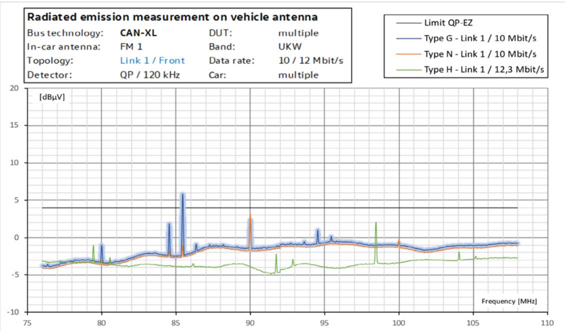


Figure 5: Link 1 - Comparison of RF emissions in the FM band for 12 Mbit/s for different CAN-XL transceivers

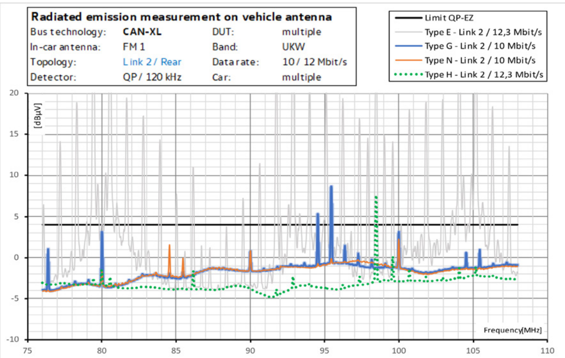


Figure 6: Link 2 - Comparison of RF-emissions in the FM band for 12 Mbit/s for different CAN-XL transceivers

The comparison of emission profile of link 1 and link 2 illustrate the well-known dependence of the interference spectrum on the position of the ECUs, the wiring harness routing and the distance to the antenna structure. In all cases an increase in the interference amplitude of 3 dB – 6 dB can be observed.

In addition to the observed data-dependent broadband emissions of the CAN-XL network, mainly significant narrowband interference (SBS) can be measured. The frequency of the SBS depends on the selected data rate. The different development stages in terms of optimized RF emission of tested CAN-XL transceivers can also be clearly seen.

Figure 7 shows the electromagnetic emissions of various ICs for a data rate of 10 Mbit/s, based on the 150 Ω method as required by IEC 62228-3.

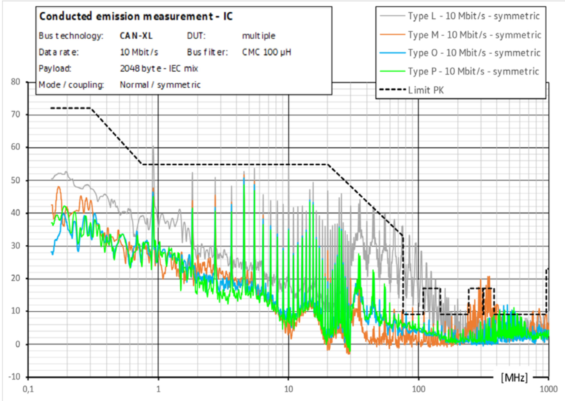


Figure 7 Examples of interference emissions – 150 Ω method

The measured emission spectrums on IC level matches well with the measured emission spectrums on the vehicle antennas for the investigated bands. The narrowband interferences can also be noticed. The comparison between IC and vehicle measurements in the FM and DAB bands also shows that the limit of 9 dBµV represents a good compromise.

Summary

From the EMC studies carried out so far it can be seen that the immunity against RF interference has already reached a high level. Some narrowband failures are observed in the topologies that are not designed for optimized signal integrity. In the next step, the corresponding design rules for CAN-XL topologies must be defined. As soon as this was happened further EMC investigations can be carried out in order to define the RF immunity requirements for IC level tests.

The measurements of interference emissions have shown that there are significant differences between the CAN-XL transceivers from different vendors. The narrow-band interference, which violates limit values, is caused by harmonics of the fundamental frequency.

The EMC vehicle measurements shown above were compared with the measurements at IC level in order to derive the EMC requirements for the CAN-XL transceivers. There is a strong indication that the current limits as specified for other communication.

References

[1] Richtlinie 2014/30/EU des Europäischen Parlaments und des Rates vom 26. Februar 2014 zur Harmonisierung der Rechtsvorschriften der Mitgliedstaaten über die elektromagnetische Verträglichkeit
[2] Schanze ,Carsten; Future of CAN from the prospective of an OEM; Key Note iCC 2020
[3] Dr.-Ing. Körber, B., Dipl.-Ing Welzel, S., Dipl.-Ing. Winderlich, T., Dr.-Ing. Diaz-Ortega, L.; „Auswirkungen der Unsymmetrie von Kabeln und passiven Bauteilen auf die EMV der Busschnittstelle am Beispiel von Ethernet für Kfz Anwendungen“; emv Düsseldorf 2014
[4] IEC 62228-3 Integrated circuits – EMC evaluation of transceiver – Part 3: CAN transceiver

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