

Electromagnetic Compatibility (EMC) of CAN+*

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Abstract

With increasing complexity in automobiles, the demand for more bandwidth on communication networks is raising. To tackle this problem, an extension to the well established Controller Area Network (CAN) [1] has been developed: CAN+. Now it is possible to enhance the data rate by 16 times, while being backward-compatible to the standard CAN. This speedup is possible by using partially higher bit rates. In this paper, we analyze if these higher bit rates cause additional electromagnetic problems compared to standard CAN. This is done by building a prototype setup which is measured in a Gigahertz Transverse Electromagnetic Cell (GTEM [2]) cell. The results show that the emission of CAN+ is very close to standard CAN. The frequencies in which CAN+ has transmission problems during electromagnetic radiation are equal to standard CAN. The only difference is that at a 30 MHz higher frequency CAN+ had data errors. These results show that CAN+ can be treated equally to standard CAN in terms of EMC.

1 Introduction

The CAN has established itself to be the de facto standard communication structure in automotive and automation. Even though new protocols in automotive networking are trying to replace CAN, the advantages still justify immense use of CAN. One of the main advantages lies in the arbitration mechanism itself, where time-triggered priority based communication is used and therefore a short transmission delay is possible. This arbitration also enables that Electronic Control Units (ECUs) can easily be added and removed from the system. Another major advantage is that CAN components are very low-cost. This is possible because its popularity enables mass production. The only disadvantage of CAN is that the maximum usable data rate is below 65 Kbyte/s. With the steadily increasing functionality in modern cars, the need for more bandwidth is raising. To solve this dilemma we proposed in a former work the extension CAN+ [3], which allows a backward-compatible increase in data rate by inserting additional information on the bit level.

Furthermore, the raising density of electronic components in cars opens new problems. All these components not only effect themselves, but also emit energy to their surroundings. This energy can lead to unwanted effects in other components. Therefore it is not possible only to consider the functionality of the component, rather the component should also not interfere other electrical components in the surrounding. This goal is summarized in the term electromagnetic compatibility (EMC). It can be subdivided into two categories. The first one is concerning the amount of energy the unit under test is allowed to emit and is called electromagnetic interference (EMI). In contrast,

the amount of energy the unit under test can tolerate without malfunction is called electromagnetic susceptibility (EMS).

In this paper we want to investigate the EMC properties of CAN+.

The rest of this paper is organized as follows. Section 2 gives a description of the protocol CAN+. Section 3 presents EMC tests. This section is divided into four parts: Introduction, setup of the EMC tests, electromagnetic interference and electromagnetic susceptibility. Conclusion and future work are presented in Section 4.

2 CAN+

In this section the CAN+ protocol is explained. First a short introduction to CAN is given, as this is the basis for CAN+. Then the extensions are presented. Finally some prototype results are given.

2.1 CAN Protocol

The CAN specification [4] defines the data link layer and roughly describes the physical layer of the ISO/OSI-Model. The physical setup consists of a terminated 2-wire bus. Bits are represented by the Non-Return-To-Zero method, where a logical "0" is represented by a voltage difference and a logical "1" equal voltage level. This bit representation results in a dominance of the logical "0". The length of a bit is depending on the bit rate used, e.g. 1 μ s at 1Mbit/s. Each bit is sampled once at about 2/3 of the bit time length.

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To find the sample point an edge detection at the beginning of a bit is done.

On data link layer a message oriented approach is chosen. The most important message is the data frame which is used for data exchange. Its content and origin is described by a unique identifier. This identifier defines the priority by which the bus access is granted. Bus arbitration is done by Carrier Sense Multiple Access with Bitwise Arbitration (CSMA/BA). The method of bitwise arbitration can be described as follows: Each node that would like to have access to the bus, starts sending its message, as soon as the bus is idle for 3 bit times. Every sent bit is also watched. When the sent bit differs from the watched, then a message with higher priority is also sending and transmission is stopped. After sending the identifier, only the message with the highest priority is left and has exclusive bus access.

This arbitration scheme and the acknowledgment method implies a speed limitation depending on the length of the bus. The reason is, that while multiple nodes have bus access at the same time it needs to be assured that every node can read and react to every other node. Therefore the length of the bit must be at least two times the maximum delay of the signal. The propagation delay consists of two components: Signal delay on the cable and delay within the controller and transceiver. The delay of the controller could be minimized by using faster hardware, but the signal propagation delay on the bus is unavoidable. Therefore, the length of the bus cable significantly dictates the speed limit.

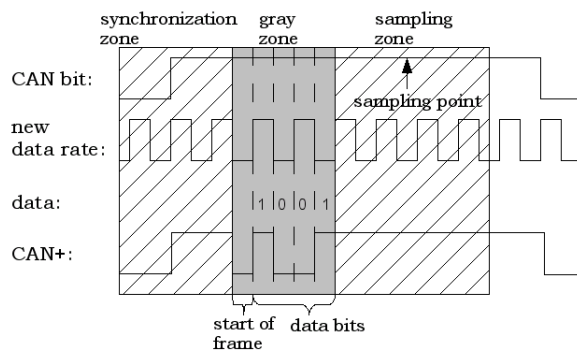


Figure 1 Transmission of a data bit for standard CAN and CAN+

2.2 Methodology and Extensions

As seen in the last section a general increase of the bit rate in CAN is physically not possible. The reason for this limitation lies in the arbitration and acknowledgment phases. However, during the data transmission itself there is no physical limitation on the bit rate. A simple increase in data rate would lead to read errors at standard CAN nodes and they would interrupt the communication by sending dominant error messages. To avoid this problem we suggest to use a so called gray zone to send additional data. The gray zone is shown in Fig. 1. It is limited by the synchronization

and the sampling zone. Within the gray zone additional data can be transmitted without disturbing the standard CAN communication. We use an asynchronous protocol such as UART to encode the data. From now on we will call the bits which are additionally added fast bits.

2.3 Results

A prototype to show the feasibility of the shown concept has been developed. It consists of two FPGA evaluation boards with custom CAN-transceivers and a standard CAN analysis node, as shown in Fig. 2. The custom CAN-transceivers were developed to enable the high data rates. Connecting these three components with a standard terminated 2-wire CAN-bus, we could show that a speedup of the usable data rate of 16 times compared to 1Mbit High-Speed CAN [5] is possible. This fast communication is possible even if standard CAN Nodes, here represented by the analysis node, are connected and communicating.

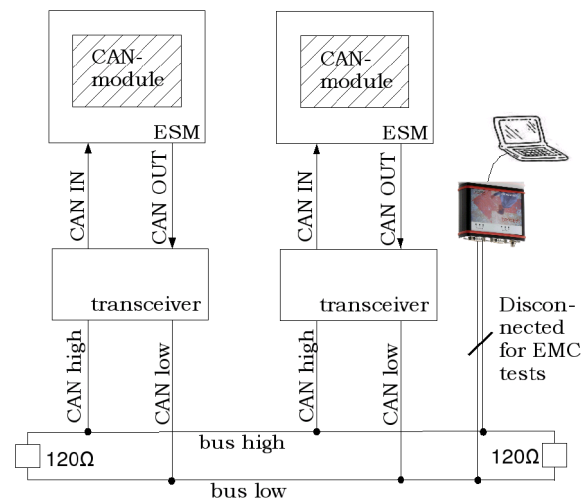


Figure 2 Schematic setup of the CAN+ prototype

3 EMC

In this section we will first give a glimpse into the theoretic aspects of EMC. Then we will present the experiments and the results first for EMS and then for EMI.

3.1 Introduction

In the field of EMC one can distinguish between four major reasons for disturbance: Conductive coupling, capacitive coupling, inductive coupling and radiative coupling. The first three reasons belong to the family of near distance disturbances. This means the interfering source is in the designer's hand and can be eliminated. This of course is not an easy task, still we don't see this as an unsolvable problem. In contrast to the near distance disturbances, radiative coupling is almost impossible to eliminate and to predict. For that reason we focus our study on radiative coupling. In

addition the new protocol operates at higher frequencies so that radiative coupling might get a problem. Basic EMC literature [6] says that radiative coupling needs to be considered when the length l of the interfering cable is comparable or exceeds the wavelength λ of the signal:

$$l \geq \lambda = \frac{c}{f}$$

For High-Speed CAN this can be calculated as follows:

$$\lambda = \frac{3 \cdot 10^8 \frac{m}{s}}{0,5 \text{ MHz}} = 600 \text{ m}$$

For CAN+ this can be calculated as follows:

$$\lambda = \frac{3 \cdot 10^8 \frac{m}{s}}{20 \text{ MHz}} = 15 \text{ m}$$

The calculation shows us, that on High-Speed CAN radiative coupling is not of practical relevance as the length is restricted to 40m. This also applies for slower variants. But for our new protocol we need to investigate if it induces different problems than standard CAN.

3.2 Setup of the Prototype

To measure the electromagnetic emission and reception of CAN+ we build up a prototype setup shown in Fig. 2. It consists of two FPGA evaluation platforms each connected with a transceiver to the bus cable. The cable is wired as specified in the CAN standard. This means, we are using differential wiring with two 120 Ohm termination resistors at both ends.

We focused our measurement only on the cable of the setup for three reasons: First, the cable acts like an antenna and will therefore transmit and receive most of the disturbances. Second, the CAN+ nodes itself are much easier to protect because of their smaller size. Third, the prototype platform is far from being EMC-optimal designed and the complex functionality of the evaluation boards induces additional EMI effects. Therefore, they would give unrealistic high results.

We used two types of cables for our experiments to represent shielded and unshielded twisted pair wiring. As a shielded cable we used LEONI Dacar 533 FL09YBY 2x0,35+(0,35). It has the impedance of 100 Ohm, which is not exactly suited for CAN, but shouldn't have any influence on the EMC-properties. To represent a simple unshielded cable, a standard CAN 0,22mm twisted pair copper cable was used.

3.3 Electromagnetic Interference

In this section, first the measurement procedure is described. Then the results of the experiments are shown and discussed.

3.3.1 Setup of the Measurement

The first experiment for measuring the EMI of the cables that are communicating using CAN or CAN+ was by placing the cable on top of a measurement table within an anechoic chamber. The transmitting and receiving CAN or CAN+ nodes had to be placed within the chamber. An antenna in 3m distance to the cable was measuring the emitted radiation. Different measurements with connected and unconnected communication showed, that the emission of the evaluation boards was much higher than that of the cable. Shielding the nodes with a grounded copper plate didn't reduce the effect to a level where reasonable measurements could be made.

To be able to place the nodes outside of the measurement cell we moved our experiment setup to a so called GTEM cell. The GTEM cell is an extended version of the traditional TEM (Transverse Electro-Magnetic). In principle the TEM cell is a tapered coaxial line, from a coaxial feeding point with an air dielectric and a characteristic impedance of 50Ω. In contrast to the TEM cell the GTEM cell, the coaxial line is terminated by a combination of discrete resistors and RF absorbers to achieve a broadband match. The outer conductor of this coax line is represented by the metal walls of the cell which provide screening for both the internal and external electromagnetic fields.

The setup of the experiment is depicted in Fig. 3. The cables of the prototype nodes are fed into the GTEM cell. The part of the cable which is measured is laid on a calibrated position on an insulator 5 cm above the hull orthogonal to the electric field. The measuring system is standardized to a standard anechoic chamber. The return of the cable was attached as close as possible to the hull to reduce disturbance. The ground wire of the unshielded cable was laid parallel to the communication cable. In this setup only the horizontal flow of the cable could be measured. Now similar to the anechoic chamber, an EMI measuring receiver is connected to the GTEM cell. It is now possible to receive the EMI of the installed cable for different frequencies.

Start frequency	30 MHz
Stop frequency	1 GHz
Step size	40 kHz
Resolution bandwidth	120 kHz
Measure time	50 μs

Table 1 Measurement Settings

The settings of the EMI receiver is shown in Table 1. The receiver always recorded the maximum values at each position. Several runs were made until the maximum values didn't increase anymore. The evaluation platforms turned out to be active amplifiers for noise in several frequencies, so we added ferrite beads to the cables to avoid the problem of transmitting noise into the cell.

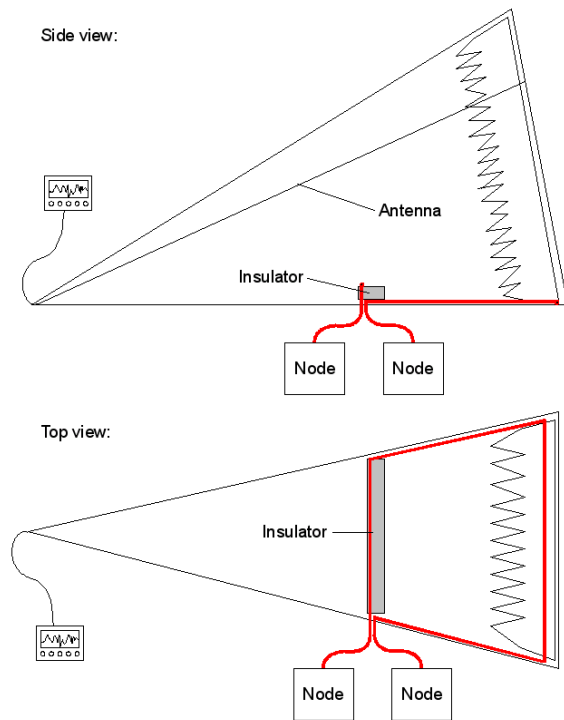


Figure 3 Setup for EMC measurement at calibrated position in the GTEM cell

3.3.2 Results

With each cable the measurements were made for three different settings of the communication:

1. off: The communication is turned off. These results represent the noise that was transmitted into the cell.
2. CAN: The communication is using High-Speed CAN. These results are used as reference.
3. CAN+: The communication is using CAN+ with 8 fast bits. Each fast bit is set on the bus for 25 ns.

An example result for the unshielded cable at the calibrated position is shown in Fig. 7. The dark plot shows the radiation while the communication is turned off. For most of the frequencies we could eliminate the noise and a comparison is possible.

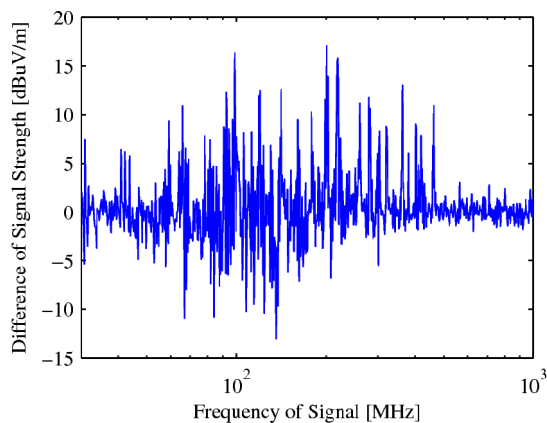


Figure 4 Difference of signal strength between CAN and CAN+ on the unshielded cable at the calibrated position

The calibration to the standard anechoic chamber allows us to compare our results above 100 MHz to the DIN EN 55025 [7]. Even though below 100 MHz the conversion is not guaranteed to be exact, it can still give an approximation of the emission. For both cables and both protocols the results are below the prescriptive limits of class 5, which is the best class in this norm.

The difference between the two protocols with the unshielded wire is shown in Fig. 4. This shows us, that sometimes CAN and sometimes CAN+ gives lower results. But in average no trend can be seen.

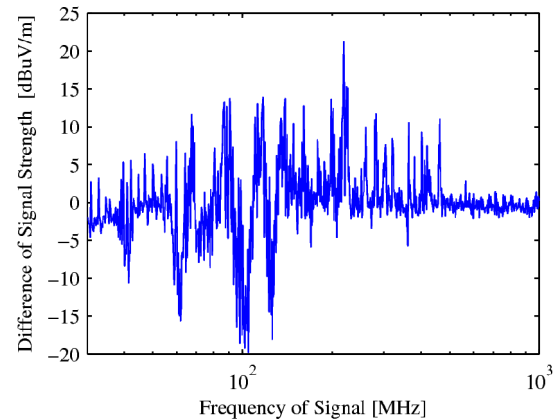


Figure 5 Difference of signal strength between the unshielded and the shielded cable at the calibrated position using CAN+

The difference between the cables is shown in Fig. 5. Here, again no trend can be detected. Therefore, simple unshielded cable can also be used for CAN+.

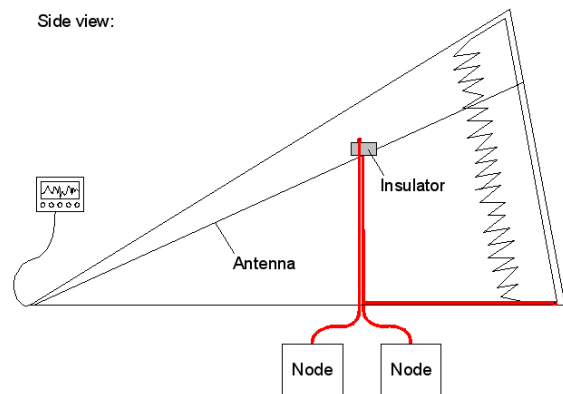


Figure 6 Setup for EMC measurement at close position to the antenna

As the difference between the cables and the protocols at the calibrated position can not be measured, we did another series of measurements with the cables positioned closer to the measuring antenna. This has the effect that the overall signal strength is increased and therefore the difference between the different cables and protocols can better be seen. The setup of these experiments is depicted in Fig. 6, the results in Fig. 8 and 9. Now it is possible to distinguish between the different cables and communication ways. As expected we now can see that the CAN+ protocol emits higher radiation than standard CAN. This effect is mainly discovered on the unshielded CAN cable.

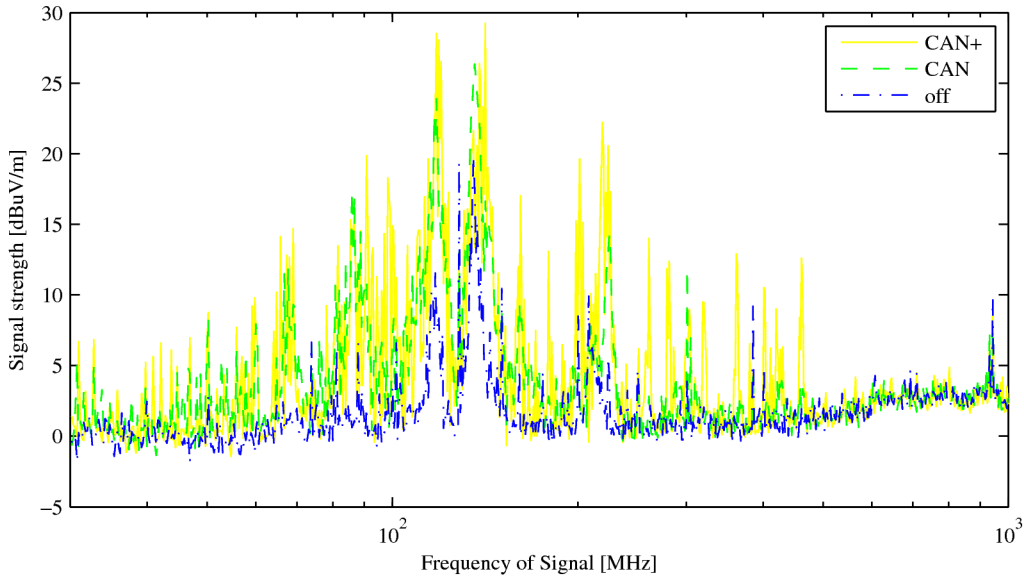


Figure 7 Signal strength at calibrated position in the GTEM cell for different communications

However, on the shielded cable the effect is negligible. This behavior might originate in the optimization of the unshielded cable for CAN, whereas on the shielded cable both results are bad. This suggests that it might be possible that a cable manufacturer can produce a cable that is optimized for CAN+ and will therefore reduce the radiation.

to 200 V/m. Unfortunately it was only possible to calibrate our amplifier to transmit at 150 V/m, even though we used the setup where the CAN cable is very close to the transmitting medium. However, as we are only doing relative measurements this is not a problem.

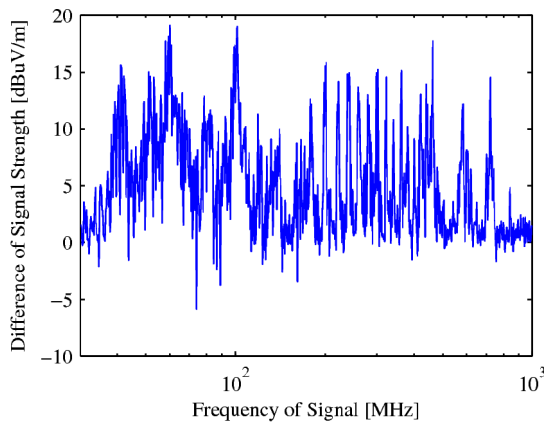


Figure 8 Difference of signal strength between CAN and CAN+ on the unshielded cable at the close antenna position

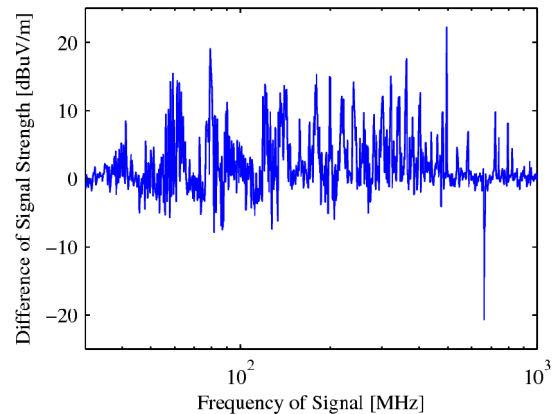


Figure 9 Difference of signal strength between CAN and CAN+ on the shielded cable at the close antenna position

3.4 Electromagnetic Susceptibility

We also wanted to compare the electromagnetic immunity of CAN+ with that of standard CAN. This was done by reproducing the tests different car manufacturers impose to their suppliers. For confidentiality reasons we are not allowed to give detailed descriptions of these tests. We used the same setup as for the emission test, but used the antenna to transmit a disturbance signal on our unit under test. In our case the unshielded wire served as the unit under test. The wire was positioned as depicted in Fig. 6. The car manufacturers demand a disturbance signal strength of up

The disturbance signal is a sinus wave of the adjusted frequency which is amplitude modulated by a sinus wave with the frequency of 1 kHz with the depth of 80%. The modulation is used, because this way real disturbances are better emulated. The frequency of the disturbance signal ranged from 100 MHz to 1 GHz. Again, the two prototype boards were connected to the bus wire and communicated by sending 1111 messages per second. The errors that occurred were measured in two ways. First, the standard CAN error messages, and second, the data errors were counted. The standard CAN error messages could be easily counted, since they are specified in the standard. The sending node dropped the message, when an error occurred during transmission. A data error occurs when the transmitted data and the received data are not the

same. In standard CAN, data errors are protected by a checksum. Therefore, it is almost impossible to produce a data error without triggering an error message. At the moment, CAN+ is not protecting the fast bits. So, it is possible to get a data error without recognizing it. The data errors can be counted at the receiver, because we are sending a counter that is incremented by one every message. Therefore, the receiver knows what it should receive and can compare it to the actually received data.

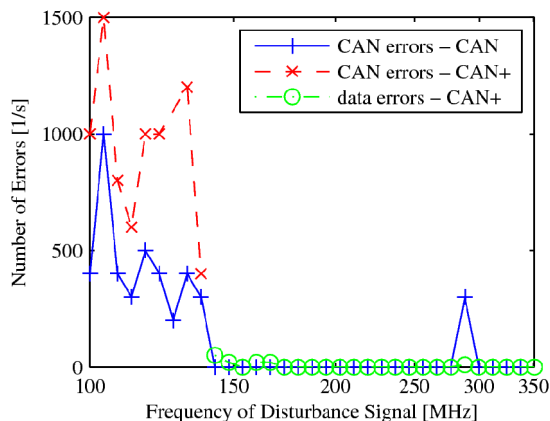


Figure 10 Number of errors that occurred when irradiating the communication with different frequencies

The results of the immunity test are shown in Fig. 10. While testing the standard CAN, only CAN errors occurred. In contrast to that during the CAN+ tests, above a disturbance frequency of 140 MHz only data errors occurred. Below 140 MHz much more CAN errors occurred than data errors, but some data errors were caused by CAN errors. So, it was impossible to distinguish between data errors that could be traced back to CAN errors and errors that only appeared in additional CAN+ bits.

Comparing the two protocols in their susceptibility behavior, we have to divide the results of Fig. 10 into three regions: below 140 MHz, between 140 MHz and 170 MHz and above 170 MHz. Below 140 MHz both protocols are heavily influenced. On CAN+ the disturbance signal is causing roughly twice as much CAN errors as on CAN. This behavior is difficult to explain, since errors in the fast bits don't cause CAN errors. However, we can imagine that the influence of the disturbance signal could cause a time displacement of the fast bits, which in consequence leads to CAN errors. Between 140 MHz and 170 MHz the CAN protocol is not influenced at all and only the fast bits of CAN+ are influenced. The results here show that the maximum number of data errors per second is 50. This number is really small compared to the amount of data that is additionally transmitted. Above 170 MHz neither CAN nor CAN+ show any errors, except at 288 MHz. There, the standard CAN protocol showed more errors than CAN+. This behavior must be very specific to our setup and some resonance frequencies of the prototype board might be hit.

In summary, the results of the electromagnetic susceptibility test showed that the new CAN+ protocol is

more sensible, but the amount is very low compared to the amount of speedup.

4 Conclusion

In this paper, we compared the EMC properties of CAN+ to the ones of CAN. The results showed that the difference is very small. This result fortifies the usability of CAN+, which solves the bandwidth dilemma of CAN.

Two ways of measuring EMC were applied. The first way is to measure the emission of the protocols. Here, difference between the two protocols could only be detected by moving the cable very close to the antenna. The measurements showed that both protocols emission was within the appropriate norm. The second way of measuring EMC was by irradiating the communication cables and look at the errors that occur. Again, CAN+ only showed minor differences to the standard CAN. These errors are mainly in the additional data that is transmitted. In further extensions this additional data could be protected by using redundant information.

Future work needs to look further into the applicability of CAN+. On the one hand, costs of creating the transceiver and the controller need to be evaluated. On the other hand, other physical constraints such as signal damping over long distances or controller and transceiver accuracy need to be considered.

5 Acknowledgment

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6 Literature

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