Monitoring CAN performance in installations with high level of interference

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In some industrial applications of CAN, the influence of interference becomes substantial. The paper describes measurements of the electromagnetic compatibility of CAN. The bus was submitted to standardized EMC tests and the results were evaluated so that some recommendations for designers could be given. These comprise basic design rules which increase the electrostatic discharge immunity, and the application of devices which provide protection against high-voltage burst transients.

1. Introduction

Fieldbuses became relevant parts of control systems. CAN bus with its inherent fault tolerance and precisely defined physical and link layers ([1], [2]) represents a very universal means of interconnections, ranging from integrated circuits on one board up to large-scale control systems in industry and transport. In the case of industrial applications where high levels of electromagnetic interference must always be anticipated, the problems of electromagnetic compatibility (EMC) became crucial. Though CAN bus controllers are well equipped with error detection and correction mechanisms (automatic repeating), destruction of bus drivers by induced high-voltage pulses and a consequent failure of a controller can be dangerous for both people and technology.

At the *Faculty of Electrical Engineering,* part of the *University of West Bohemia* in Pilsen, we devote proper attention to the CAN bus - in teaching, laboratory experiments, and in research. In 1997, the *Laboratory of EMC* was established and since then we have the opportunity to investigate effects of electromagnetic interference under standardized conditions with guaranteed precision.

Several waveshapes are recommended for investigations of electromagnetic susceptibility (EMS) of decentralized control systems in industry. We selected bursts in accordance with EN 61000-4-4. Fig. 1 shows a single, exponentially shaped pulse, and a grouping of such

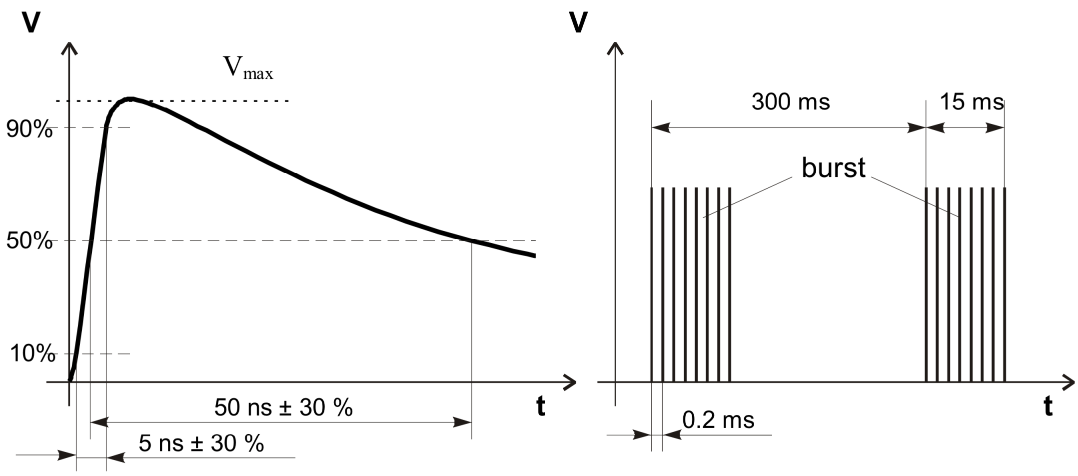

Fig. 1 - standardized pulse and burst

pulses in bursts. The laboratory is equipped with a calibrated generator providing bursts of a positive or negative polarity, with peak voltages V_{max} ranging from 200 to 4400 V. The measurements are taken with a digital oscilloscope and appropriate probes. All instruments and devices under test are placed in a shielded room [3], [4].

Having the EMC laboratory available, we tried to find the answers to the following questions:

- What is the amplitude of pulses introduced by bursts in a CAN installation with long transmission lines?
- How are the results dependent on types of cables?
- Is a shielding really necessary?
- Are voltage suppressors necessary?
- If the amplitude of interference is safe for bus drivers (due to the shielding, voltage suppressors, etc.), is a delay in transmission the only consequence of high-voltage bursts?
- Are the communication boards, used during the experiments, really interference-safe?

The answers should lead to the recommendations about the type of cable, voltage suppressors, shielding of communication boards, and software.

2. Surges on a bus

The target of these experiments was to find the peak voltages of interference measured at the inputs of bus drivers. The interference was produced as bursts with V_{max}=1 kV in accordance with standards for industrial environment, using a calibrated generator and a digital oscilloscope with a bandwidth 350 MHz and sampling frequency 100 MHz. Interference was introduced into the transmission line through the capacitive coupling clamp of a standardized type - see Fig. 2.

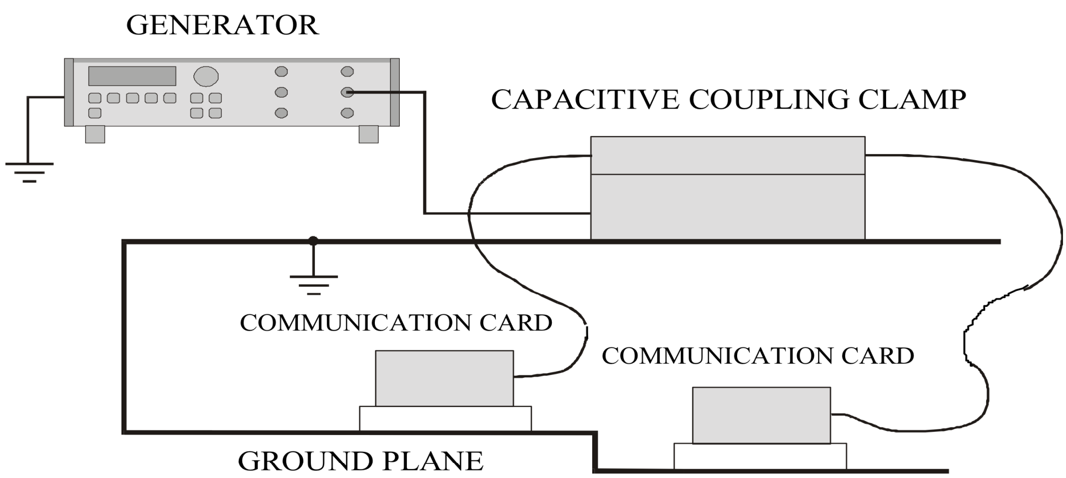

Fig. 2 - arrangement for laboratory tests

To lower the material losses, we decided to experiment at this phase with models of bus drivers rather than with real ones. We presumed the arrangement with galvanically isolated drivers compatible with ISO 11 898 standard. The models were designed as RC equivalents of currently used drivers - see Fig. 3.

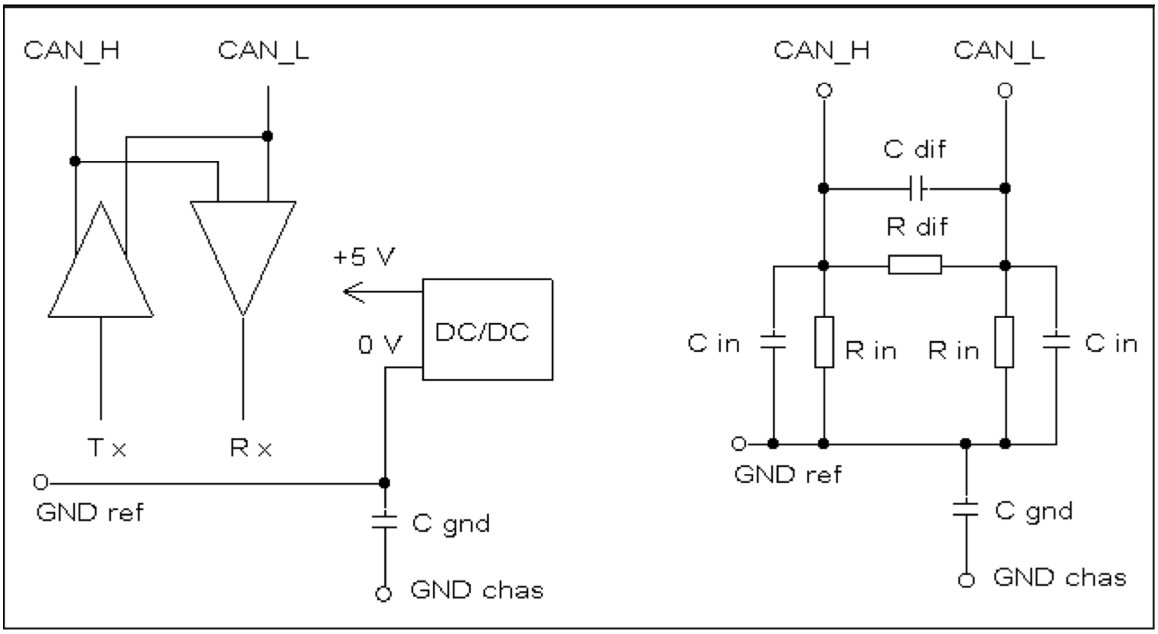

Fig. 3 - bus driver and equivalent circuit

The models of two types were used: „Low Load“ representing 1 driver, and „High Load“ representing 15 drivers in parallel. The values of R and C are summarized below:

Low Load:	C_{dif}=5 pF,	R_{dif}=56 kΩ,	C_{in}=10 pF,	R_{in}=22 kΩ,	C_{gnd}=10 pF
High Load:	C_{dif}=82 pF,	R_{dif}=3.9 kΩ,	C_{in}=150 pF,	R_{in}=1.5 kΩ,	C_{gnd}=150 pF

All the capacitors are rated for 1 kV. The capacitor C_{gnd} is an equivalent of a typical DC/DC converter capacity between input and output ports.

Bursts were introduced at the end and at other places at the cable. The whole arrangement is shown in Fig. 4. At this phase, the communication cards marked in the figure were replaced by their models and no computer was connected.

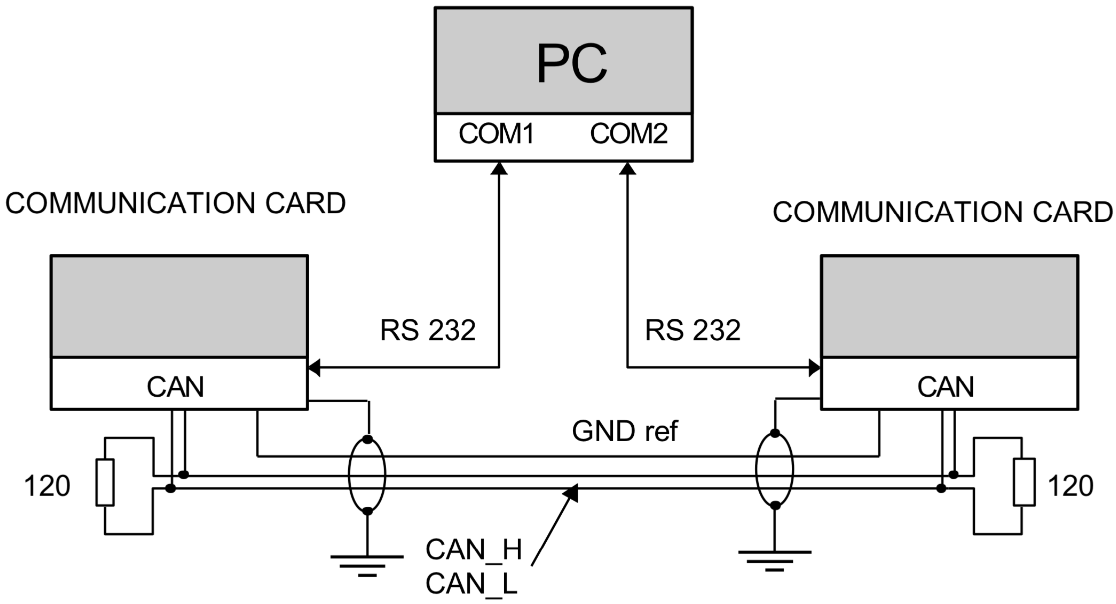

Fig. 4 - bus configuration for tests

The common conductor GND_{ref} was isolated from chassis GND_{chas}, which was connected with safety earth. Waveforms taken at the inputs of the bus-driver models during a single pulse are shown in Fig. 5, where V_p is a peak voltage between the specified wire and GND_{chas} .

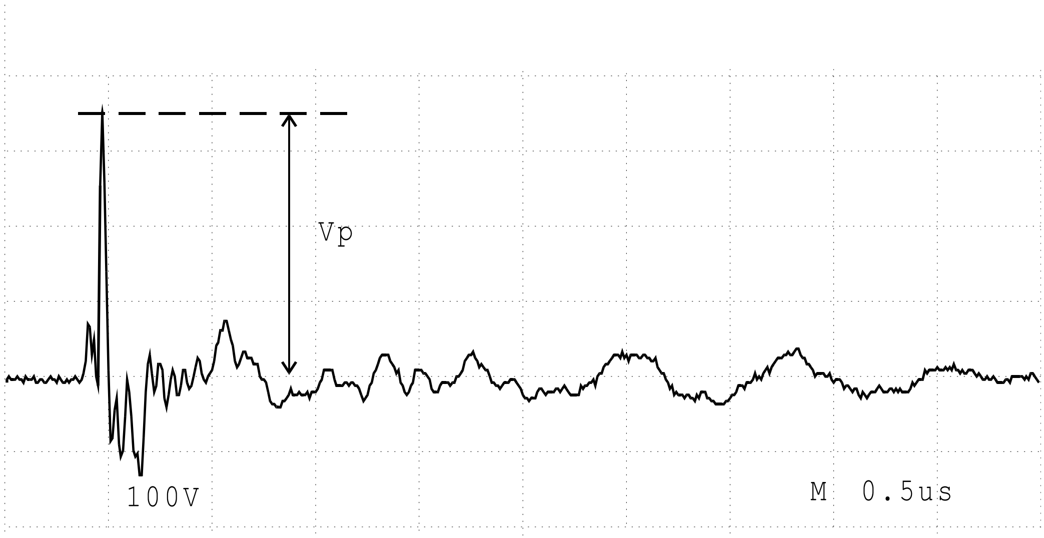

Fig. 5 - interference on a bus

Table 1 summarizes results of measurements of peak voltages between CAN_H/CAN_L and GND_{chas} for various arrangements and cables of two types, both 200 metres long:

- Unshielded cable - SYSTIMAX 1010 LAN (4 pair, AWG 24).
- Shielded cable - LAM 6 x 0.22 (3 pair, shielded by a longitudinal aluminium stripe).

cable	**load**	**position of clamp**	**near station V_p [V]**	**far station V_p [V]**
unshielded	low	end	170	50
unshielded	high	end	120	40
unshielded	low	1/2 length	40	40
unshielded	high	1/2 length	20	20
unshielded	low	1/4 length	90	50
shielded	low	end	13	not measured

Tab. 1 - induced peak voltage between CAN_H/CAN_L and GND_{chas}

For the unshielded cable, all unused pairs were left unconnected. With those pairs connected with GND_{chas} , all voltages were approx. 25% lower. Peak voltages observed at the shielded cable were very low and therefore the measurements were terminated. However, the quality of grounding is here substantial.

Table 2 shows results of measurements of peak voltage between GND_{ref} and GND_{chas} (i.e. between input and output ports of a DC/DC converter). The unused pairs were left unconnected.

cable	load	position of clamp	near station V_p [V]	far station V_p [V]
unshielded	low	1/4 length	350	100

Tab. 2 - induced peak voltage between GND_{ref} and GND_{chas}

All the above results indicate the danger of a break-down for currently used bus drivers and the need for overvoltage protectors.

3. Measurements with real circuits

To prevent the input circuits from a damage, the drivers were protected by overvoltage suppressors connected as indicated in Fig. 6. Commonly used bus drivers allow for maximum transient voltage -150 to +100 V between CAN_H/CAN_L and GND_{ref}, while the peaks detected during the measurements with models were higher. Many suppressing devices are now available: varistors, Zener diodes, transils, etc., which can be applied individually, in combinations, or in combinations with inductors. A single bi-directional transil with a voltage limit (U_{BR}) approx. 5.6 V between CAN_H a CAN_L was considered sufficient for our case where energy of absorbed pulses is relatively low. Two transils (U_{BR} = 15 V) protect CAN_H/CAN_L lines regarding to the chassis ground, which is connected with the safety reference (earth).

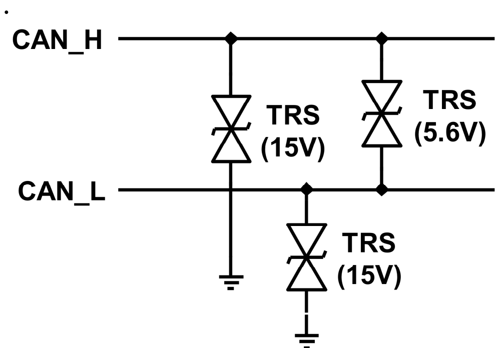

Fig. 6 - overvoltage protection

Communication cards selected for this experiment have been used for some time in a students laboratory and have never failed in spite of rather a harsh treatment. The card contains a microcontroller with a 2.0 A CAN channel, galvanically isolated, and with analogue inputs and digital inputs/outputs. The card can be fully autonomous and also can cooperate through an RS 232 channel with a PC. The program, stored in a FLASH memory, has a simple function - to receive the frame and immediately send it back. The transmitted data represent a frame counter, which is incremented when the frame was successfully received. This way a missing frame could be easily detected.

One of the digital outputs of the controller serves as a generator of time marks. Every time when one hundred frames have been received, the output changes state (toggles); then a short break is inserted and the whole process is repeated. Activity of boards is monitored by observing these time marks with an oscilloscope. Their length is proportional to the average transmission rate. Delayed pulses would indicate defective frames corrupted by interference - see also Fig. 7.

In fact, no errors have ever been detected when interference was absent. However, presence of burst interference always resulted in a crash-down of one or both communication cards without any damage to the bus drivers or other circuits. This was evidently due to disturbances in the programs running in the microcontrollers. This way the investigation of EMS of the CAN bus system was reduced to that of the controller cards. It should be emphasized that the boards were not shielded but only protected by plastic cases. This experience obviously proved the crucial importance of EMS of all electronic devices utilized in the industry. The next step was to enhance the interference immunity of the communication boards.

4. Results with shielded communication cards

Better interference immunity was achieved by careful shielding and grounding of the communication boards, respecting common recommendations - see also [5], [6]:

- Metallic box with no holes, side plates connected preferably by welding, minimum of screwed joints.
- All connectors shielded.
- Connectors close to each other, all on one side of the box.
- Low ground impedances, reliable connection of a cable shielding with the box (screwed connectors).
- Very short leads to overvoltage suppressors.

In the laboratory, both station were separately grounded to the common ground plate by the shortest possible conductors.

Both stations were left autonomous, as the EMC of the PC was found too low and could not be improved. Function of the programs was the same as described in the previous paragraph. Possible errors in transmitted data were signalled by a LED. Activity on the bus was observed by an oscilloscope - see Fig. 7, upper trace.

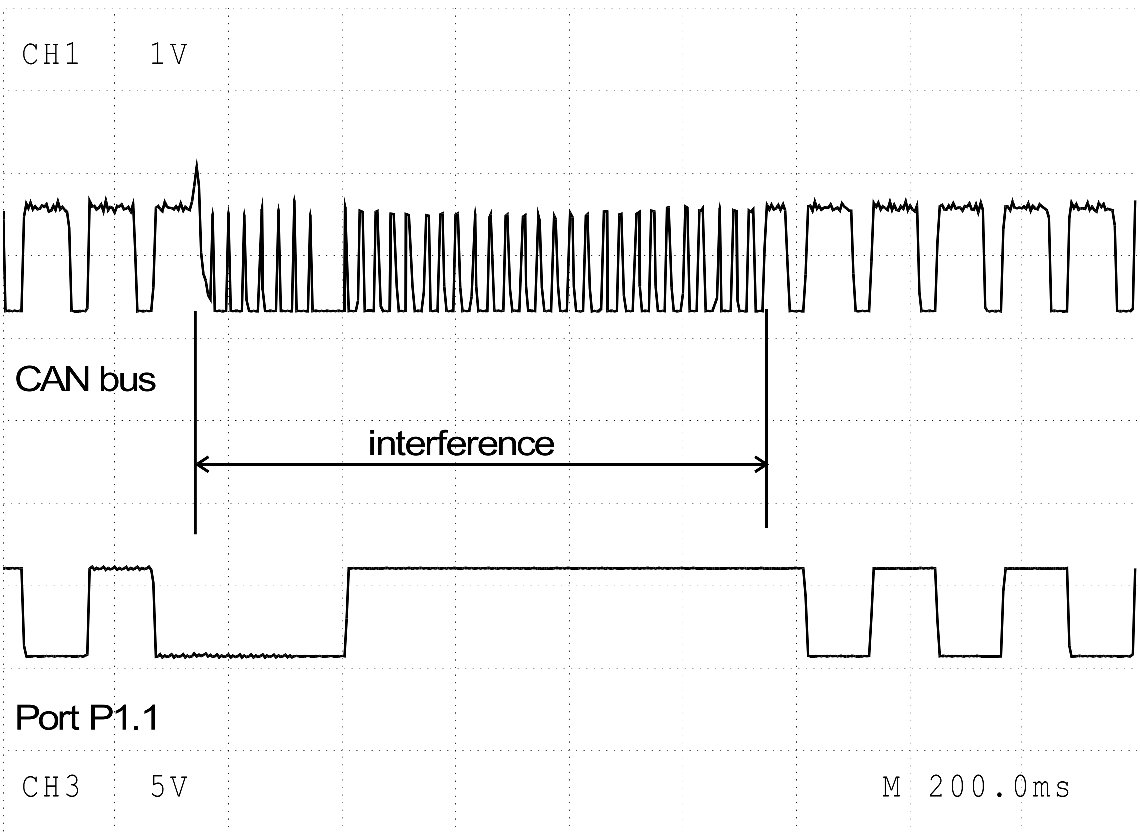

Fig. 7 - degradation of bus performance

Without interference, frames were exchanged regularly. Horizontal resolution of the oscilloscope was not sufficient to recognize details of the frames, so that a group of 100 transmitted frames looks like a pulse of higher voltage. Frames, corrupted during the burst, were automatically repeated and therefore the series of 100 frames took longer time.
The lower trace shows time marks. Every low state and alternately high state indicate a group of 100 frames. These time marks gave sufficient information on the average transmission speed and were used throughout the whole experiment.

Results:

We used standardized bursts 1 kV according to Fig. 1 and in arrangement according to Fig. 2. Though the prescribed standard length of a burst test is 1 minute, we prolonged it to 5 minutes and repeated 10 times. No incorrect data were detected during the whole experiment with both shielded and unshielded cables.

The best results were achieved with the bus completely isolated from chassis ground by optrons between bus drivers and communication controllers, and by DC/DC converters. However, for very high level of interference a good ground return path for induced charges must be provided. Transils according to Fig. 6 are a safe and inexpensive solution.

Transmission speed was not an object of this research and we did not try to reach its maximum. Clock frequency was set to 100 kHz.

5. Conclusion

Our experiments revealed the importance of the design for EMC. High level of interference can jeopardize reliability of distributed CAN systems in industry in spite of their excellent intrinsic diagnostics. It is, however, difficult to give recommendations of universal validity. Exact values, measured in the laboratory, are correct only for one specific arrangement and one type of test. Grounding and shielding in the laboratory will certainly be different from those in practice. Interference in real conditions will not exactly copy the shape of standardized bursts. Therefore, the following should be considered more as hints and observations, rather than strict rules:

- Mind the EMC of CAN stations, as it will be very probably the main source of problems.
- An unshielded cable can work quite well, but overvoltage suppressors are necessary. Connect spare conductors (if any) with chassis ground.
- If a shielded cable is used, connect the shielding with very good ground/earth. Quality of grounding is crucial.
- The whole bus and all the drivers should be isolated, bus ground should be isolated from chassis ground.
- Allow the bus to float and apply surge suppressors to prevent an eventual charging of the whole bus system and to provide a low-impedance ground return for induced charges.

References

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