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Configuration of the Control System in Public Transport Vehicles Using Industrial Communication Networks

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Abstract – **The electrical circuits and their Electronic Control Units (ECUs) in buses and coaches are essential for their good working. Drive, braking, suspension, door opening, security and communication devices must be integrated in a reliable and real time information system. The industrial communication networks or fieldbuses are a good solution to implement networked control systems for the onboard electronics in the public transport buses and coaches. The authors are working in the design of multiplexed solutions based on fieldbuses to integrate the body and chassis functions of city public transport buses. An example for the EURO5 model of the Scania manufacturer is reported in this paper. The authors are also working in the implementation of new modules based on FPGAs (Field Programmable Gate Arrays) that can be used in these networked control systems.**

I. INTRODUCTION

Nowadays, the commercial buses and coaches are more and more equipped with electronic devices that make it easier to drive the vehicle and improve their security and comfort. These electronic devices are applied to functions such as Electronic Stability Program (ESP), braking help system (ABS), gear control, light control, climate control, door opening control, navigation and guidance (based on GPS: Global Positioning System and GIS: Geographic Information System), etc. These functions require the use of reliable and real time exchange of information between the different control systems and the sensors and actuators.

With the increase of the number and the complexity of the electronic systems included in the city-buses and coaches, it is impossible to implement this exchange of information through point-to-point links because it would suppose a disproportionate length of cable, an increase of cost and production time, reliability problems and other drawbacks. Thus, it becomes necessary the use of an industrial communication network or fieldbus [1].

At the beginnings of 1980s the engineers of the automobile manufacturers assessed the existing fieldbuses systems for their using in vehicles. They came to the conclusion that none of these protocols fulfilled completely their requirements. It supposes the beginning of the development of new fieldbus protocols [2].

Each manufacturer has bet for a particular solution. For example, Bosch developed the CAN protocol, Volkswagen implemented the A-BUS (Automobile Bitserielle Universal-Schnittstelle), Renault and the PSA Consortium used the VAN protocol, BMW tried it with the M-BUS and Honda with the DLCS. The majority of these automobile manufacturers evolved and adopted for the general purpose communication the CAN standard [3] [4] [5] [6].

For other functionalities, such as low speed smart sensors, multimedia, high speed and safety applications, the manufacturers are adopting other protocols in the last years. For example, the Firewire (IEEE 1394), MOST (Media Oriented System Transport) [7] [8], D2B optical and D2B Smartwirex are used for high speed multimedia applications; TTP, Byteflight and FlexRay for high speed and safety applications; and LIN (Local Interconnect Network) for low speed smart sensor communication [9] [10] [11].

II. MULTIPLEXED SOLUTIONS

The buses and coaches used in the city public transport have a lot of onboard electronic systems (motor modules, door control, platform for disabled persons, climate, security, global management, information for driver, onboard display, bus stop display, etc.), which must be integrated in an efficient way. These systems must be connected to a single industrial communication network with a Central Electronic Control (CEC) node that manages, in real time, all the information transmitted from the control modules installed in the vehicle. Also it is necessary and very interesting to integrate this onboard communication network with the enterprise management systems, fleet management system, maintenance department and the information displays in bus stops.

There are several chassis manufacturers (Man, Volvo, Scania, Iveco-Pegaso-Irisbus, Dennis, DAF, Renault, Mercedes, etc.) and every one proposed a different multiplexed solution. But the use of the CAN protocol and other fieldbus protocols based on CAN (for example SAE J1939) [12] is a common point in these solutions.

The multiplexed networks installed in the city-buses and coaches get an important reduction of the wiring that involves a reduction in costs, less breakdown risks and a simple scalability. The maintenance is easier and the global management of the technological systems is improved. The transmission of the information is integrated with a very low error rate (high reliability). The control of the systems is in real time supporting very high elemental information traffic with command messages for actuators, data from sensors and alarm events.

A. Structure of the Network

A generic structure of communication used in the multiplexed solutions implemented currently in the city public transport buses is presented in this section.

The main problem in the public transport buses is the increase of the requirements imposed to the electronic and electrical systems. It is getting more and more difficult to find adequate places for plugging electrical and electronic components with the corresponding wiring. The installation of circuits based on relays, diodes and resistors is very complicated.

Another topic to take into account is the satisfaction of the customer needs in a flexible and fast way. It is difficult and expensive. A manual process according to the documentation must implement the relay switching. The electromechanical circuits have a limited lifetime. A conventional intermittent indicator relay can switch 1 million times approximately. This involves a replacement maintenance operation every 20,000 Kilometres in a city public transport bus. Thus, the use of electronic switches in power circuits is a good solution because achieve the life time of the vehicle, increasing their reliability and reducing the time out of service.

Due to the aforementioned problems, the CAN data bus is a reference into the automobile technology. Thus, an example of a multiplexed solution based on the CAN protocol for data communication in a city public transport bus is shown in the Fig. 1. Independent data fieldbuses are used for the different areas in the system:

- A 125 Kbps information bus (I-CAN) to connect the driver place with the central unit is considered.
- There are a 250 Kbps fieldbus to enable the communication of the engine control devices (EDC: Electronic Diesel Control, EBS: Electronic Brake System, gearbox, etc.) between them and with the central unit (M-CAN).
- Two 125 Kbps buses (B-CAN 1 and 2) for body functions of the classical electrical system (in and out lights, horn, wipers, etc.).
- Another 125 Kbps body bus (B-CAN 3) for the doors control, disabled persons platform control, and climate devices.

The bus manufacturers have trend towards the use of the VDV (Verband Deutscher Verkehrsunternehmen) recommendation 234 [13] for the onboard information system integrated in the dashboard. Therefore, the central unit must be equipped with a VDV interface module.

The central unit must execute the classic functions for the vehicle control and manage the data traffic from the different CAN fieldbuses. Thus, the central unit can report a full onboard diagnosis. This central unit can be implemented by a 16 bits microprocessor and a 256 Kbytes data RAM memory.

The body modules are usually implemented by a 8 bits microprocessor, which constitutes the calculation core, with peripheral extensions, a program EEPROM memory and a suitable number of digital and analog inputs and outputs.

A typical multiplexed solution must consider the integration of a video surveillance system and the information for the passengers. This integration can be implemented using a CAN network or other fieldbuses more adequate for multimedia information (J1708, WorldFIP, IEEE 1394/Firewire, etc.). An example of the levels in a complete communication system is shown in Fig. 2.

B. Reliability

The chassis and body electronic reliability is very important in the public transport buses and coaches. The central unit should not connect and disconnect any power circuit. Based on city-bus manufacturers knowledge, under this rule, the central unit will only be implicated in one of each one thousand failures.

Three body CAN buses are contemplated to communicate several body modules with the aim to reduce the consequences of a breakdown. These body modules should be protected against a global overload with two security devices. Therefore, the effects in case of failures are minimized. The modules control their outputs according to the programmed emergency function when failures are detected in the data fieldbus. In this way, the outputs can be permanent connected, permanent disconnected, intermittent connected or maintaining the last state.

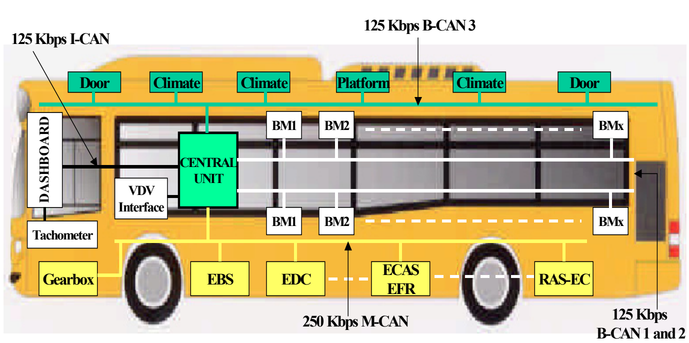

Fig. 1. An example of multiplexed solution

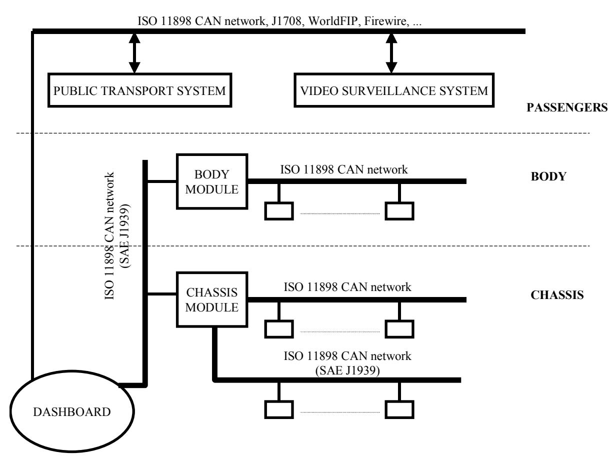

Fig. 2. Levels in a typical city public transport bus

Another important application to get a good reliability is that the body and chassis electronic system supports a wide diagnostic. The central unit should manage all the CAN networks and implement their own diagnostic of the body and chassis electronic system. Every output of the body modules should be revised periodically to check that there are not short circuits, overloads and interruptions. The inputs should be controlled according to the technical possibilities of the connected sensors. All the events detected in this diagnostic process must be stored in the central unit. Thus, the data can be used for an onboard diagnostic (for example, showing the failure in the driver's display by a VDV message) or to improve the maintenance process in the garage.

C. Challenges

Every chassis manufacturer has developed his own multiplexed solution based on CAN. The great investments made from manufacturers imply that every one wants to impose its solution. The integration problem is for the coachbuilder that works with chassis from different manufacturers (ten or more chassis). Each chassis has a different multiplexed solution and only the modules chosen by the corresponding manufacturer can be connected to the system. It involves that the coachbuilder cannot have their own CAN system (an unified management for the electrical part of the body and chassis) and must use the modules chosen by the manufacturer with a non-competitive price.

The SAE Truck and Bus Control and Communications Sub-committee has developed the J1939 standard. The aim of this association is to develop and recommend the use of standards about devices that transmit electronic signals and control information onboard. The goal of this standard is to provide an open interconnection system for different electronic systems to enable the communication between them with an unique structure.

The J1939 standard is necessary to sort the codifications that each manufacturer has used to specify the same peripheral unit (device, sensor) or the set of the units connected to the CAN network in the city-buses and coaches. Besides of the codification of the terminals, the standard defines several common parameters and data rates. Thus, the J1939 standard enables to the coachbuilder connecting different modules to the CAN system independently of the manufacturer.

III. DESIGN OF A NETWORKED CONTROL SYSTEM

The authors are working in the design of a networked control system that is a multiplexed solution to integrate the onboard electronic devices present in a typical city public transport bus. This system should integrate all the sensors and actuators present in the vehicle in an optimal way. Besides, it must resolve those particular functions that actually are not integrated in the multiplexed solutions of the chassis manufacturers [14].

The paper will describe an example of design for a real commercial vehicle of the Sweden chassis manufacturer Scania (EURO5 model). The features of the system, used modules, software and requirements that must be taken into account will be commented in the next paragraphs.

A. Implementation of the System

The aim of the project exposed in this paper is to implement an onboard network in a city public transport bus. This network allows the control of the ECUs simplifying the wiring, removing electrical components (fuses, relays, etc.), improving the reliability and the diagnostic and getting an open system with new technologies.

There are different types of modules that are necessary in the system: dashboard and chassis and body modules (Fig. 2). The dashboard is where the information about the devices of the bus is displayed to the driver and also allows to the driver the control of the system through switch packs. The dashboard is usually made up of an Information Control Unit (ICU) and a Screen Control Unit (SCU). It includes a LCD or TFT VGA display where the information is shown to the driver. It is interesting to include some video inputs for the video surveillance system. The dashboard also has multifrequency audio devices and several LEDs to give information about state of the devices and alarms. With respect to the ergonomics, the dashboard must be designed in compliance with the standard ISO 16121 (ISO/TC22/SC13).

The French firm ACTIA supplies the chassis and body modules used in this design. There are master modules or CAMUs (Central Management Units) and slave modules or IOUs (Input/Output Units) and are shown in Fig. 3. These modules have several inputs and outputs (20 inputs and 23 outputs the CAMUs and 18 inputs and 15 outputs the IOUs) of different types and implement the CAN V2.0 B protocol. These modules must be ready to work in the conditions of a vehicle in motion. Thus, the protection level must be high (IP65) and must endure the mechanical vibrations and fulfil the corresponding electromagnetic compatibility standards.

B. Inputs and Outputs

The first step in the design is the identification of the electrical signals of the bus that must be connected to the networked control system. These electrical signals must be described in detail with their location in the bus. Some of the electrical signals that were included in the control system in the Scania bus of the project are listed in Table I.

CAMU IOU

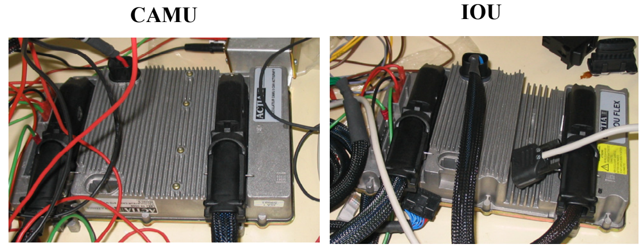

Fig. 3. Chassis and body modules

TABLE I
SOME ELECTRICAL SIGNALS IN THE SCANIA CITY- BUS

Name	Type	I/O	Power (W)
IB_MSDOOR1	VBAT ACTIVE	Input	-
IB_MSDOOR2	VBAT ACTIVE	Input	-
IB_MSDOOR3	VBAT ACTIVE	Input	-
IB_STOPREQ	VBAT ACTIVE	Input	-
IB_RAMPREQ	VBAT ACTIVE	Input	-
IB_HANDBRAKE	GND ACTIVE	Input	-
IB_ALTERNATOR	VBAT ACTIVE	Input	-
IB_SMCSEC	CAN	Input	-
OB_REARMDOOR1	VALVE	Output	25
OB_DOOR1	SIGNAL	Output	-
OB_DOOR2	SIGNAL	Output	-
OB_DOOR3	SIGNAL	Output	-
OB_POSLIGHTS1	LIGHTS	Output	25
OB_ENGINEON	INDUCTIVE	Output	240
OB_HANDBRAKEBUZZ	INDUCTIVE	Output	3

The signals are named according to a specified format. The first part of the name defines some characteristics of the signal. Some prefixes used in Table I are: IB (Input Binary) and OB (Output Binary). For example, the signal IB_STOPREQ is a binary (B) input (I) that is activated when a stop is requested. The column type shows additional information about the signals. For inputs, VBAT or GND active indicates whether the signal when activated is connected to the power supply or to the ground. For outputs there can be types like: signal (digital signals not intended for powering devices), lights, inductive (protection needed against power peaks), valve, etc.

Once the signals have been defined, the next step is to choose the number of required CAMUs and IOUs, their location in the bus and where the electrical signals will be connected (the connector pin of a specific CAMU or IOU). The designer must bear in mind the different types of inputs and outputs of the modules. The CAMUs and IOUs have the following types of inputs and outputs:

- Wake up inputs (2 in CAMUs and 2 in IOUs):
  The signals that should wake up the system are connected in these inputs.
- Logic inputs (15 in CAMUs and 7 in IOUs):
  The detection of a "0" logic is from 0 V up to 1.8 V, and a "1" logic from 7 V up to 32 V. They have a contact current of 9 mA and an internal pull up resistor of 2.2 KΩ to 20 V.
- Analog inputs to ground (5 in CAMUs and 4 in IOUs):
  These inputs have an internal pull up resistor of 2.2 KΩ to 5 V and are thought to connect a resistive load to ground. The voltage in the input of the microprocessor is directly proportional to the value of the resistive load.
- Analog inputs to positive voltage (2 in IOUs):
  There is one input of 0 V up to 32 V and other one of 0 V up to 15 V. These inputs consist in a resistive divisor.
- Frequency inputs (2 in CAMUs and 3 in IOUs):
  These inputs can be used for PWM signals, as for example the measurement of speed (tachometer). The maximum frequency is 2 KHz.
- High state and low state outputs:
  The CAMUs have a total of 23 outputs and IOUs have a total of 20 outputs. From these, 19 in CAMUs and 15 in IOUs are dedicated to loads that the microprocessor connect or disconnect to a positive voltage (battery). The other 4 in CAMUs and 4 in IOUs are to connect or disconnect the loads to ground. The maximum direct current of these outputs can be 5 A, 7A and 1.5 A in CAMUs and 9 A, 7 A, 5 A, 3.2 A and 2 A in IOUs.
- Free wheel diode outputs:
  There is one output of the IOUs that has a free wheel diode. It is dedicated to inductive loads (relays, electro valves) as for example wiper fast.
- Switched and unswitched outputs:
  The power supply of the output interface of high state signals can be unswitched (connected directly to the battery) or switched (connected after the master relay). There are 2 unswitched and 17 switched signals in CAMUs and 8 unswitched and 7 switched signals in IOUs.
- PWM (Pulse Wide Modulation) outputs:
  There are several outputs that can be used for PWM 0-100% with 10% step) or frequency (50-500 Hz with 50 Hz step) outputs.
- Bridge outputs:
  There are 8 signals in IOUs that can be configured as bridges or used independently. There are different bridge configurations and they are used for bidirectional motors (electrical windows, external wing mirror, etc.) or for current measurements.

The number of CAMus and IOUs must be choice taking into account the distribution of the signals in the bus and also the power consumption, because the modules define the maximum dissipated power by group of outputs, the maximum total dissipated power with the corresponding derating curve limit and the maximum permanent current switched and unswitched. Therefore, 1 CAMU and 4 IOUs have been required in the design of the Scania bus exposed in this paper. The location of the modules in the bus and the distribution of the signals are shown in Fig. 4.

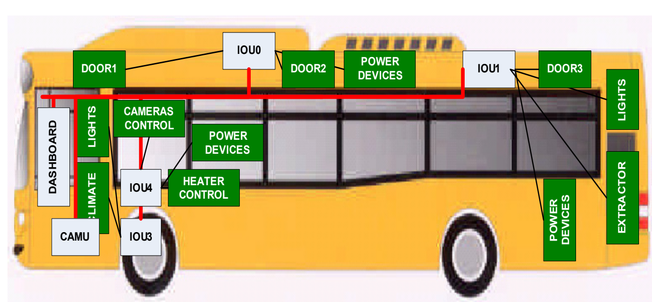

Fig. 4. Structure of the networked control system onboard the bus

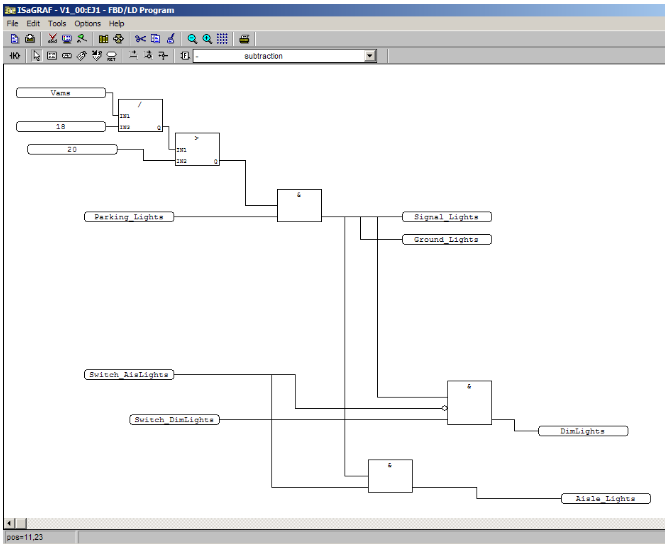

Fig. 5. Example of the specification of a function in a bus using the ISaGRAF tool.

C. Software Tools

There are several software tools that are used for the coding of the modules, validation and their installation:

- ActiGRAF: used for the wiring definition and inputs/outputs assignment.
- ISaGRAF: used for the functions specification and implementation. It is the environment for developing automation applications.
- Multitool: used for the diagnostic of the ECUs and the CAN nodes (IOUs).
- Telemux: used for programming the ECUs.

For the design of a networked control system, ActiGRAF is the project manager and ISaGRAF is the software programming environment. Thus, ISaGRAF is a tool used for ActiGRAF for developing the embedded software in the CAN modules (CAMUs and IOUs) of the control system. ISaGRAF supports the whole programming languages of the IEC 61131 standard (SFC: Sequential Function Chart; FC: Flow Chart; FBD: Function Block Diagram; LD: Ladder Diagram; ST: Structured Text; IL: Instruction List).

An example of how the specification and implementation of functionality is made using Function Block Diagram (FBD) programming language is shown in Fig. 5. The user indicates the activation condition of the outputs depending on the state of the inputs with typical function blocks as for example logic gates (and, or, not, etc.). Fig. 5 shows a programming example where the aisle lights of the bus are switched on if there is battery voltage higher than 20 V (the master relay has been activated), the parking lights are turned on and the switch of the aisle lights is activated.

When the user designs the networked control system of a bus, the ActiGRAF tool is used to specify the central network of the vehicle (all the master modules or CAMUs), the intra-system network (all the slave modules or IOUs), the inter-system network and other networks that can be necessaries according to the requirements for the electrical architecture of the vehicle. After, the opening of the communication ports should be made (enable the CAN and J1939 drivers) and the input and output signals should be declared. The ISaGRAF tool is used to define the whole functionalities of the chassis and body functions of the bus using the more adequate programming language of the above mentioned.

Once the whole functionality and the wiring are defined, it is necessary to build the application that will be executed inside the modules. ActiGRAF uses a C compiler for compiling the source code generated by ISaGRAF. The wiring specification is also compiled into binary code. The compiler used for these tasks is from the Keil Company. The used version is for the C166 platform along with the RTX166, a basic RTOS (Real-Time Operating System) included with the Keil development tool that performs round-robin and cooperative multitasking. The binary code generated by the compiler is loaded using the Telemux application. Only the CAMU is reprogrammed with the binary code. As soon as the system is restarted, the CAMU automatically sends the new application and wiring data to all the IOUS of the system.

IV. FUTURE WORKS

The authors are working in the design and implementation of new communication modules to improve the multiplexed networks used currently in city public transport buses. These modules should integrate all the sensors and actuators in an optimal way. Besides, these modules must resolve those particular functions that are not integrated in the multiplexed solutions of the chassis manufacturers.

These new communication modules will be designed using reconfigurable circuits technology as for example FPGAs (Field Programmable Gate Arrays) [15]. This technology enables the implementation of a complete system in a single integrated circuit (SoC: System on Chip).

The implementation of communication processors for fieldbuses using FPGAs has a lot of advantages on account of their reconfiguration ability [16]. The research and development of communication processors with FPGAs and their application in the networked control system in public transport buses is a very interesting project.

The modules based on reconfigurable circuits will be designed to enable the integration of the whole functions existent in the public transport buses and to add other new ones that are interesting for the coachbuilder such as closed-circuit TV (images of doors and the rear of the bus), infrared control for doors and disabled person platform, modules with outdoor connection to obtain statistical data about the working of the vehicle for maintenance, etc.

All these new functions must be integrated in the driver display. For this purpose, it is interesting the development of a system to integrate in the dashboard of the city-buses a PDA (Personal Digital Assistant) with the VDV protocol and that complements the information offered by the display included in the dashboard. The PDA could be integrated in the CAN networked control system using a VDV node that transmits the information to the PDA using a Bluetooth link. The VDV module can be designed with a FPGA that implements the CAN protocol in accordance to the J1939 standard and that manage the communication of a simple Bluetooth device [17].

Other important improvement to be taking into account in the design of these modules is the possibility of integration of the localization and fleet management systems by GPRS, GSM, radio, etc. The integration of these systems enables the localization of the vehicles from the head office, the automation of the displaying systems for driver and passengers (into the bus and also out the bus), the notification of next stop, estimated time to arrive to the bus stop, control systems of the traffic regulation devices to give priority to the public transport, etc.

V. CONCLUSIONS

The main objectives of the work exposed in this paper is the improvement of the control system onboard the public transport buses. For this purpose, the authors design a networked control system based on modules with CAN communication. Thus, the advantages and profits of this system used to integrate the electronic devices in a real time and reliable information system are:

- Development of a networked control system that satisfies the maximum demands of any public transport enterprise.
- Reduction of cables (60% according to coachbuilder sources) and number of electrical components (relays, fuses, etc.).
- Unification of the whole electronic equipment.
- The system has a central memory for the registration of alarms and periodic maintenance control.
- Autodiagnostic of the system with alarm indications in the driver display.
- Improvements in the vehicle working control and the maintenance management.
- Improvements in the comfort of driver and passengers.
- Best reliability of the electrical and electronic components in the installation.
- Less maintenance costs.
- A flexible and modular system is obtained.

The design of modules based on FPGAs and fulfilling the J1939 standard and the VDV recommendation 234 is a very interesting solution for the coachbuilders. Accordingly, they can have their own CAN networked control systems and install in the public transport buses their own compatible devices to control the different chassis and body functionalities.

ACKNOWLEDGMENT

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