Electronics in Automotive Engineering: A Top–Down Approach for Implementing Industrial Fieldbus Technologies in City Buses and Coaches

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***Abstract*—The electrical circuits and their electronic control units in city buses and coaches are essential for good performance. 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. Also, this trend of automotive electronics is being encouraged in the current European Union Framework Program (FP) (seventh FP), which is devoted to intelligent transportation systems, for facing the world's new challenges in environmental care and efficient fuel consumption among others. 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.**

***Index Terms*—City bus, controller area network (CAN), industrial communications networks.**

I. Introduction

NOWADAYS, commercial city buses and coaches are more and more equipped with electronic devices that make the vehicle easier to drive and improve its security [1] and comfort. These electronic devices are applied to functions such as electronic stability programs [2], braking help systems (antilock-braking system), gear control, light control, climate control, door opening control, navigation and guide based on global positioning systems and geographic information systems, etc. These functions require the use of reliable and real-time exchange of information between the different control systems and the sensors and actuators [3].

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, the use of an industrial communication network or fieldbus becomes necessary [4].

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At the beginnings of the 1980s, the engineers of the automobile manufacturers assessed the existing fieldbus systems for their use in vehicles. They came to the conclusion that none of these protocols fulfilled completely their requirements. It supposes the beginning of the development for new fieldbus protocols [5].

Each manufacturer has a bet for a particular solution. For example, Bosch developed the controller area network (CAN) protocol, Volkswagen implemented the Automobile Bitserielle Universal-Schnittstelle, Renault and the PSA Consortium used the vehicle area network protocol, BMW tried it with the M-BUS, and Honda with the data link communications system. The majority of these automobile manufacturers evolved and adopted for the general purpose communication, the CAN standard [6]–[9].

For other functionalities, such as low-speed smart-sensor, multimedia, high-speed, and safety applications, the manufacturers have been using other protocols in the last years. For example, the Firewire (IEEE 1394), Media Oriented System Transport [10], [11], D2B optical, and D2B Smartwirex are used for high-speed multimedia applications; TTP, Byteflight, and FlexRay for high-speed and safety applications; and the Local Interconnect Network for low-speed smart-sensor communication [12]–[14].

Given that automotive engineering in the manufacturer sector is starting a relevant effort for getting involved on automated-design innovations, from advanced engineering fields like military and avionics, claims about the fulfillment of automotive particular requirements from the software-tool market must be validated in real implementations. This paper describes a real CAN implementation for the Scania's EURO5 model, based on specific software tools, and is an extended version of [15] written by the authors. It is organized into six sections including this introduction. Section II gives an overview of the multiplexed solutions. Section III details the developed system. Section IV outlines the results, whereas Section V presents the future works. Finally, the conclusions are presented in Section VI.

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.

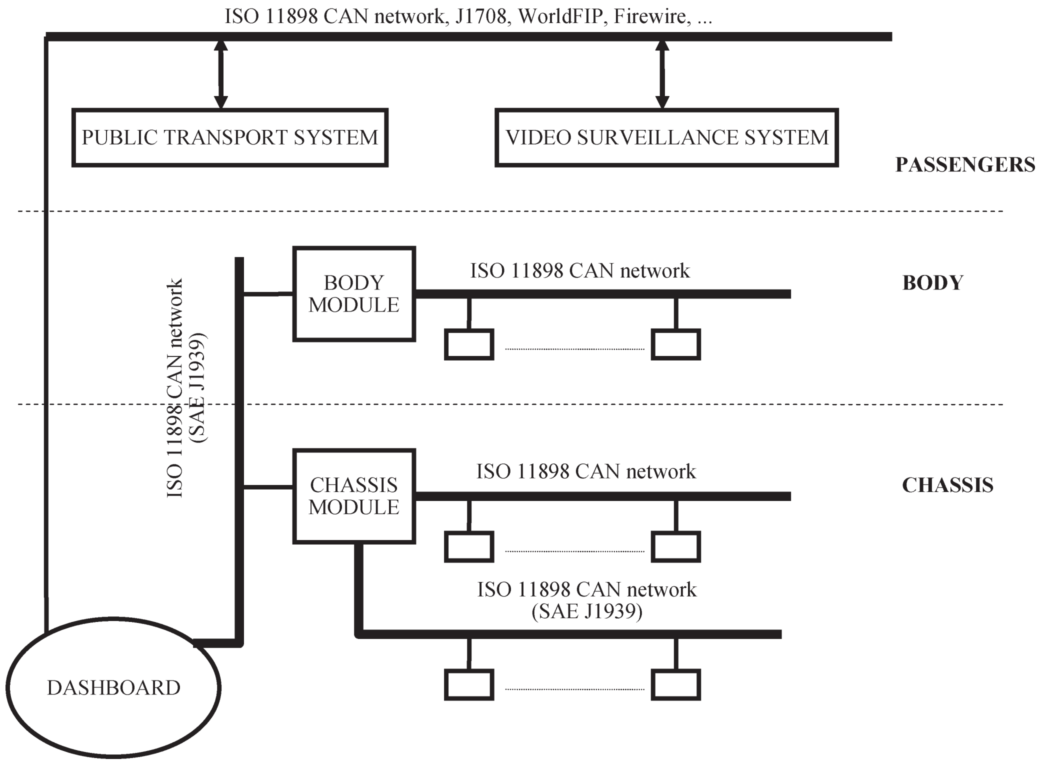

Fig. 1. Levels in a typical city public transport bus.

These systems must be connected to a single industrial communication network with a central electronic control node which 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 [16]. However, the use of the CAN protocol and other protocols based on CAN (for example, SAE J1939) [17] is a common point in these solutions.

The multiplexed networks installed in the buses and coaches provide an important reduction of the wiring that involves a reduction in costs, less breakdown risks, and easier scalability. Also, the maintenance tasks are enhanced, and the global management of the technological systems is improved. Likewise, 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. The relay switching must be manufactured by a manual process according to the documentation. The electromechanical circuits have a limited lifetime. A conventional intermittent indicator relay can switch one million times approximately. This involves a replacement maintenance operation every 20 000 km in a city public transport bus. Thus, the use of electronic switches in power circuits is a good solution because a longer vehicle lifetime is achieved, increasing their reliability and reducing the out-of-service time.

A typical multiplexed solution can consider the integration of a video surveillance system and the information for the passengers among other functionalities (Section V). This integration can be implemented using a CAN bus or other fieldbuses that are 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. 1.

The bus manufacturers have a trend toward the use of the Verband Deutscher Verkehrsunternehmen (VDV) recommendation 234 [18] for the onboard information system integrated in the dashboard. Therefore, the central unit must be equipped with an interface VDV module (Section V).

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

The body modules are usually implemented by an 8-b microprocessor, which constitutes the calculation core, with peripheral extensions, a program electrically erasable programmable read-only memory, and a suitable number of digital and analog inputs and outputs.

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 manufacturer knowledge, under this rule, the central unit will only be implicated in one of every 1000 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 permanently connected, permanently disconnected, intermittently connected, or maintaining the last state.

Another important application to get a good reliability is that the body and chassis electronic systems support wide diagnostic capabilities. The central unit should manage all the CAN networks and implement their own diagnostic of the body and chassis electronic systems. Every output of the body modules should be revised periodically to check that there are no 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. Consistently, 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 its own multiplexed solution based on CAN. The great inversions made for the manufacturers involve the fact 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 the constraint that the coachbuilder cannot have their own CAN system (a unified management for the electrical part of the body and chassis) and must use the modules chosen by the manufacturer with a noncompetitive price.

The SAE Truck and Bus Control and Communications Subcommittee 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 a unique structure.

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

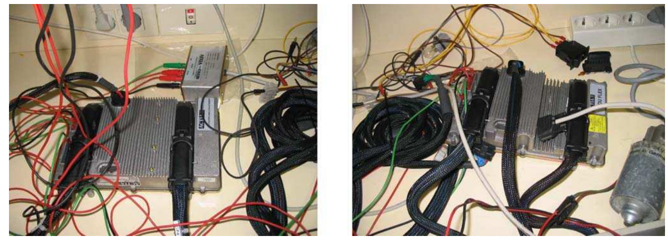

Fig. 2. Chassis and body modules (CAMU and IOU).

III. DESIGN OF A NETWORKED CONTROL SYSTEM

The authors are working on the design of a networked control system that will be a multiplexed solution to integrate the onboard electronic devices established in a typical city public transport bus. This system should integrate all the sensors and actuators present in the vehicle in an optimum way. Moreover, it must resolve those particular functions that are not currently integrated in the multiplexed solutions of the chassis manufacturers [15].

This paper will describe an example of a 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 explained in the following paragraphs.

A. Implementation of the System

The aim of the project detailed in this paper is to implement an onboard network in a city public transport bus. This network allows the control of the electronic control units (ECUs), simplification of the wiring, removal of electrical components (fuses, relays, etc.), improvement of the reliability, and the diagnostic and attainment of an open system with new technologies.

There are different types of modules that are necessary in the system: dashboard, chassis, and body modules (Fig. 1). The dashboard is where the information about the devices of the city bus is displayed to the driver and also allows the driver to control the system through switch packs. The dashboard is usually made up of an information control unit and a screen control unit. It includes a liquid crystal display or thin-film transistor video graphics array display where the information is shown to the driver. The dashboard also has multifrequency audio devices and several LEDs to give information about devices and alarm states. With respect to the ergonomics, the dashboard must be designed in compliance with the standard ISO 16121 (ISO/TC22/SC13).

The chassis and body modules used in this design are supplied by the French firm ACTIA. There are master modules or central ActiGRAF management units (CAMUs) and slave modules or input/output units (IOUs) shown in Fig. 2. These modules have several inputs and outputs (20 inputs and

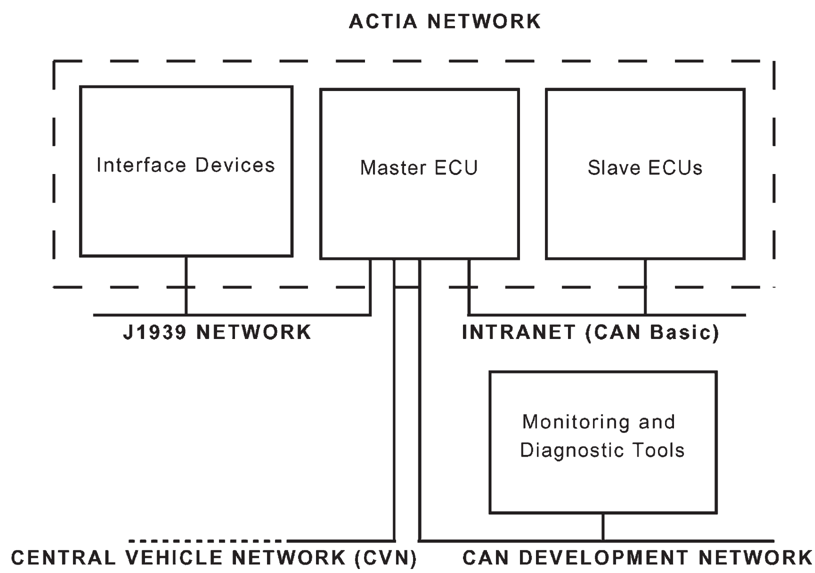

Fig. 3. Block diagram of city-bus networks.

23 outputs for the CAMUs and 18 inputs and 15 outputs for 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 fulfill the corresponding electromagnetic compatibility standards.

The architecture of the system network is shown in Fig. 3. It is composed of the ACTIA network, the CAN development network, and the central vehicle network.

The ACTIA networks (Fig. 4) are constituted by the ECUs and the interface devices. The ECUs can be IOUs and CAMUs.

The CAMU is the master ECU. Every CAN network using the ACTIA ECUs must have at least one CAMU. Each CAMU has several CAN interfaces for accessing different CAN networks. The intranet network communicates with the slave modules called IOUs that collect the available data and send them to the CAMU using standard identifiers of the CAN protocol. The CAMU can also activate outputs of the IOUs sending them the same packet type. The interface devices are in a separate network. These devices can be switches or screens used as a human interface. These devices use the J1939 standard for sending and receiving the data. For example, the SwitchPacks can send J1939 frames for advertising the ON-/OFF-state of each of its switches. On the other hand, the VDV dashboard changes the on-screen information based on the J1939 frames received by the CAN bus.

The CAMU works as a gateway between the different elements of the ACTIA architecture. It reads the state of the different inputs of the slave modules (IOUs) and the state of the interface devices and, based on the programmed functionality, can activate an IOU output, a LED of any of the switches, or show some information on the dashboard screen.

Fig. 5 shows the CAN development network. This experimental network is only used for testing and debugging purposes in the CAN fieldbus, and therefore, it is not included in the final installation of the system. The network is composed of the following elements.

1) Field-programmable gate array (FPGA). This FPGA was programmed with the complete design in very high level design language of the full implementation of a CAN controller based on the popular CAN controller SJA1000. It is used as an experimental tool for monitoring and debugging the CAN bus protocol. By means of this tool, it is possible to inject errors or force states on the CAN bus for diagnostic and testing purposes. The FPGA has a serial peripheral interface for configuring any of the CAN protocol parameters and an RS232 port for sending and receiving data.
2) Laptop and personal digital assistant (PDA). The laptop is used for monitoring and diagnostic purposes in CAN fieldbuses. The hardware used for this purpose is a PCMCIA-CAN card from National Instruments. Also, it is used for application development for both PC and PDA architectures. For PC software development, the LabVIEW graphical environment from National Instruments is used. The applications developed include: software for CAN frame monitoring, a graphical user interface (GUI) for ACTIA switch pack emulation using CAN bus, and gateway software that translates CAN frames in Bluetooth frames (using a commercial USB-Bluetooth module) that can be read from a PDA. For PDA software development, embedded C++ from Microsoft and also LabVIEW are used. The software developed for the PDA is a GUI that will complement the information offered to the driver by the display included in the dashboard of the city bus.

Fig. 6 shows the process for the development of the system architecture. The first steps are to specify the characteristics of the system modules for defining the system functionality and the input/output characteristics. After that, the functionality must be coded and simulated. If something is wrong, it could

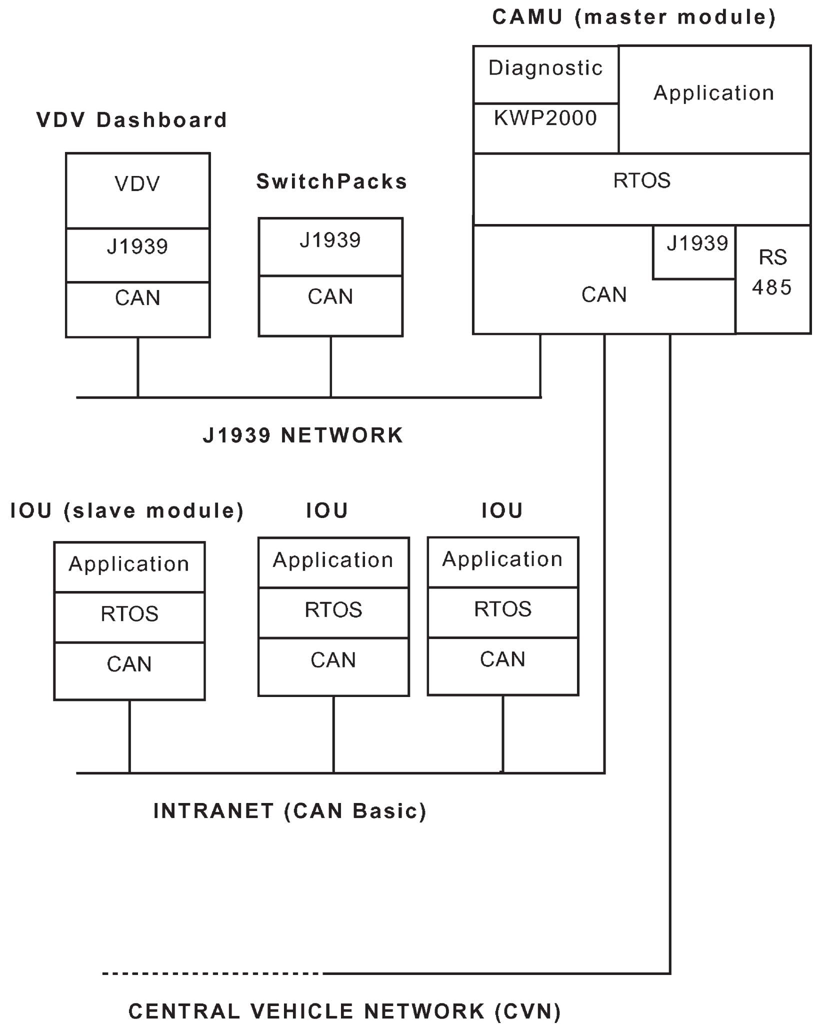

Fig. 4. ACTIA networks.

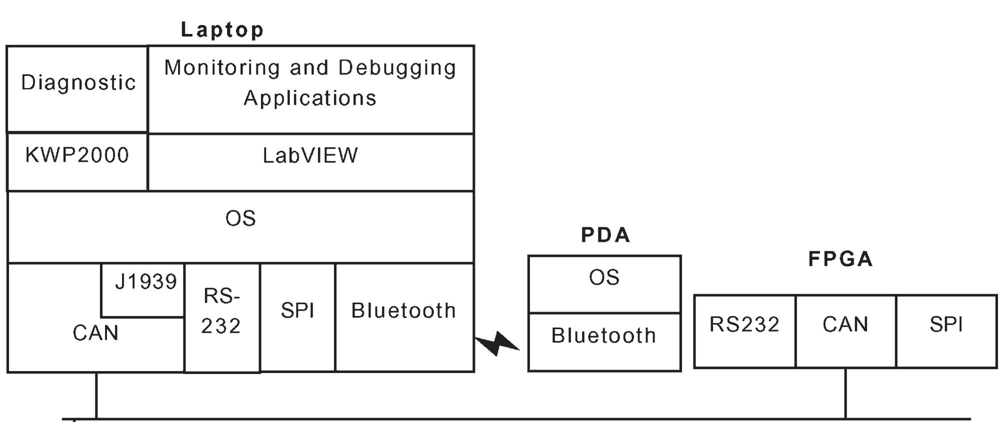

Fig. 5. CAN development network.

be necessary to return to the initial specification steps. When the functionality is tested, the assignation of ECUs takes place. This procedure provides the number of ECUs to use and the input/output pin assignment. If the input/output pins are not enough, it could be necessary to add more ECUs and return to the previous development step. Once the ECUs are defined and all the inputs/outputs assigned, the application and wiring code is generated and loaded into the ECUs. The application is verified and validated using test banks (Fig. 7). These emulate the different devices of a city-bus system. The test banks are made up of several switches, resistor loads, LEDs, and input/output connectors. The step *System Validation* and *Verification* in Fig. 6 is achieved using these test banks. By means of these test banks, some particular functionality can be checked using the electrical switches as inputs to the system and checking if the corresponding output LEDs get active. In complex systems,

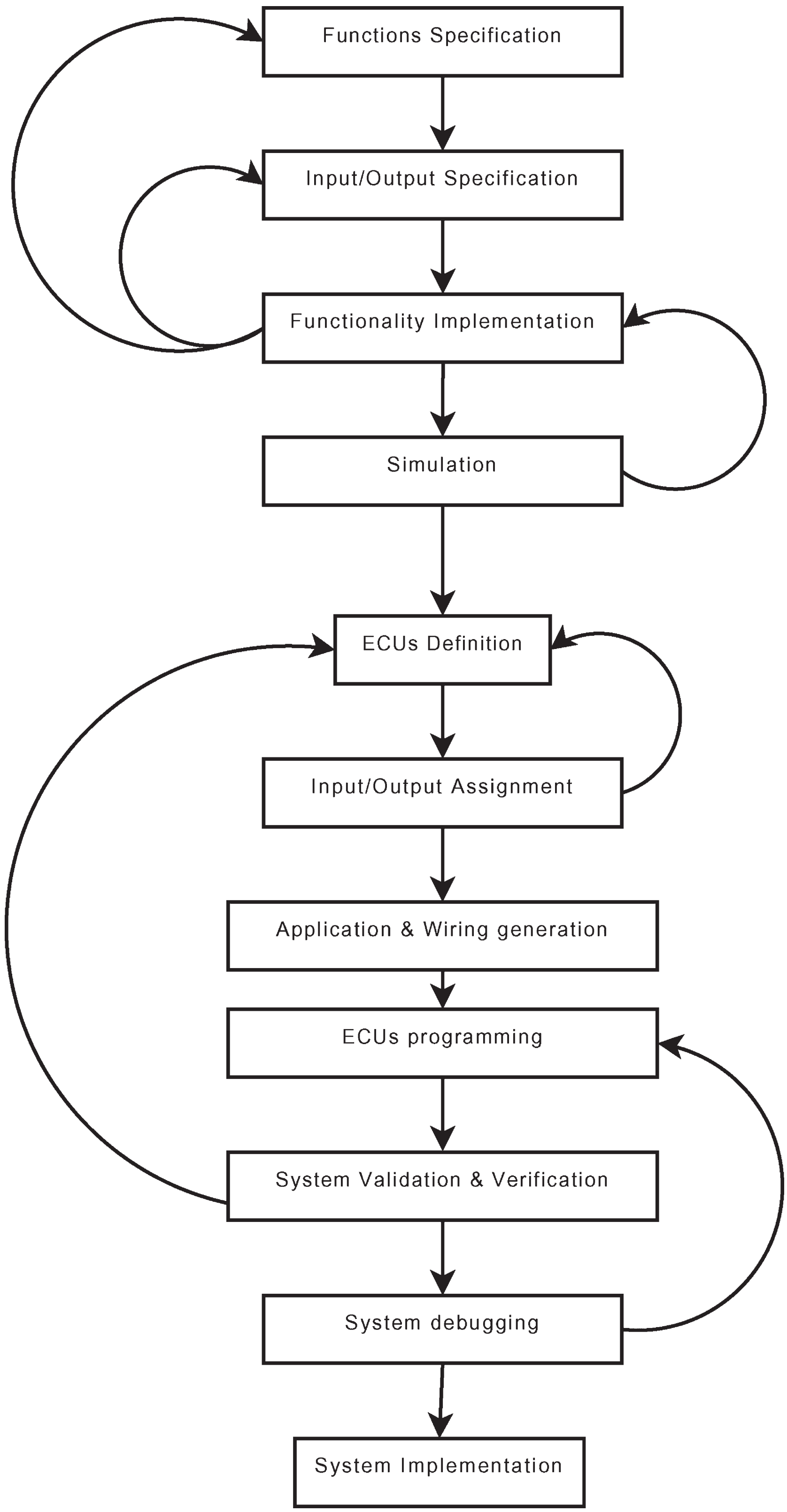

Fig. 6. Development steps using the application software tools.

the verification of all input combinations is sometimes impracticable; therefore, it is necessary to establish a limited set of input combinations to verify. Currently, the verification of the functionality is made by hand, with the possibility that some input combinations were not tested, leading to an unexpected result. A possible automated solution is presented in Section V. If the validation step is wrong, the ECUs and inputs/outputs must be revised. The final steps are devoted to debug the full application on a system prototype, and if all goes right, the final version is implemented.

Fig. 7. Test banks used in the verification of the system.

B. Inputs and Outputs

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

In this table, 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 the table are IB and OB. The first is for a binary input and the second for a binary output. 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 city 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.

1) Wake up inputs (two in CAMUs and two in IOUs). The signals that should wake up the system are connected in these inputs.
2) Logic inputs (15 in CAMUs and 7 in IOUs). The detection of a "0" logic is from 0 to 1.8 V and a "1" logic from 7 to 32 V.
3) Analog inputs to ground (five in CAMUs and four in IOUs). The voltage in the input of the microprocessor is directly proportional to the value of the resistive load.
4) Analog inputs to positive voltage (two in IOUs). There is one input of 0–32 V and another one of 0–15 V. These inputs consist in a resistive divisor.
5) Frequency inputs (two in CAMUs and three in IOUs). These inputs can be used for frequency signals as, for example, the measurement of speed (tachometer). The maximum frequency is 2 kHz.
6) High- 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 connects to or disconnects from a positive voltage (battery). The other four in CAMUs and four in IOUs are to connect or disconnect the loads to ground. The maximum direct current of these outputs can be 5, 7, and 1.5 A in CAMUs and 9, 7, 5, 3.2, and 2 A in IOUs.
7) Free wheel diode outputs. There is one output of the IOUs that has a free wheel diode. It is dedicated to inductive loads (relays and electrovalves) as, for example, wiper fast.
8) 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 eight unswitched and seven switched signals in IOUs.
9) Pulsewidth modulation (PWM) 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.
10) Bridge outputs. There are eight 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 chosen taking into account the distribution of the signals in the city bus and also the power consumption, because the modules define the maximum dissipated power by the group of outputs, the maximum total dissipated power with the corresponding derating curve limit, and the maximum permanent current switched and unswitched. Therefore, one CAMU and four IOUs have been required in the design of the Scania city bus exposed in this paper. The location of the modules in the city bus and the distribution of the signals are shown in Fig. 8.

C. Software Tools

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

1) ActiGRAF. It is used for the wiring definition and inputs/outputs assignment.
2) ISaGRAF. It is devoted for the function specification and implementation. It is the environment for developing automation applications.
3) Multitool. It is intended for the diagnostic of the ECUs and the CAN nodes (IOUs).
4) Telemux. It is oriented 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

TABLE I
ELECTRICAL SIGNALS OF INTEREST IN THE SCANIA EURO5 CITY BUS

Name	Type	I/O	Power (Watts)
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	VBAT_ACTIVE	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

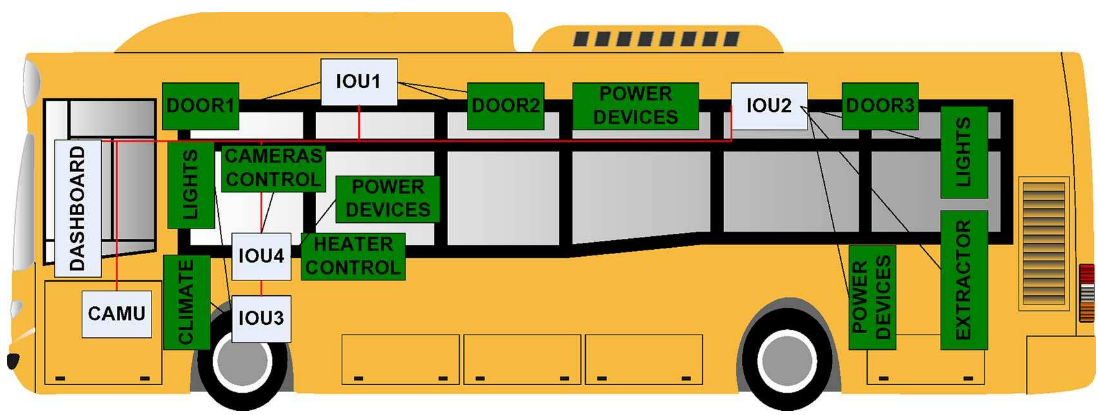

Fig. 8. Structure of the networked control system onboard the city bus.

(sequential function chart, flow chart, function block diagram (FBD), ladder diagram, structured text, and instruction list).

An example of how the specification and implementation of a functionality is made using the FBD programming language is shown in Fig. 9. 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. 9 shows a programming example where the aisle lights of the city 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 city bus, the ActiGRAF tool is used to specify the central network of the vehicle (all the master modules or CAMUs), the intrasystem network (all the slave modules or IOUs), the intersystem network, and other networks that can be required according to the specifications for the electrical architecture of the vehicle. Then, 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 city bus using the more adequate programming language aforementioned.

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 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 real-time operating system 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. RESULTS

The authors have developed a full multiplexed system that has been installed on a real working city bus. This city bus is being currently used in urban transport. Fig. 10 shows the pictures of the modules installed on the city bus.

The system was developed following the guidelines in Fig. 6. After specifying the functionality and signal characteristics (location inside the city bus, power consumption, etc.), it was concluded that the modules needed were the following.

1) One CAMU. It is the master module (upper left picture in Fig. 10).
2) Four IOUs. They are the slave modules (upper right and lower right and left photographs in Fig. 10).

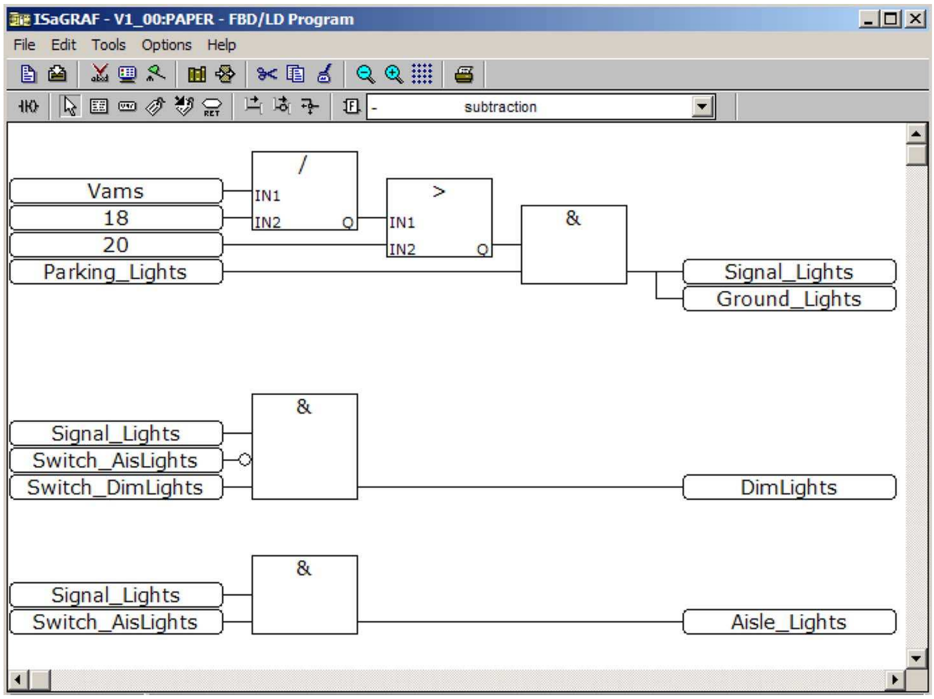

Fig. 9. Specification example of a function in a city bus using the ISaGRAF tool.

Fig. 10. Photographs of the modules installed onboard the city bus.

3) Three switch packs. They replace the traditional switches using the CAN bus for reporting the switch states.

The location of the modules is shown in Fig. 8.

One of the advantages of the multiplexed system is the unification of the electronic equipment. In current commercial city buses, there can be many different and independent ECUs which are not multiplexed. When possible, the same or better functionality can be achieved, exploiting specific available resources in some of the multiplexed ECUs, without needing to assign a full ECU to this particular functionality. The resources are shared as needed, thus cutting costs. For example, in this implementation, the city bus has one independent controller for each door (three controllers) and another controller for the ramp control. These controllers were replaced successfully without loss of functionality while gaining flexibility.

Another advantage of the implemented system is the diagnostic support. Using the software diagnostic tools, it is possible to monitor the current state of the inputs and outputs and also to change the output states. With a traditional wiring system, the diagnostic is very difficult to accomplish efficiently. There are so many and very long wires, and the identification of a faulty wire or a broken device can be an unbearable task. With the multiplexed system, the wire length is reduced, and with the diagnostic tools, the identification of a faulty part is easily achieved.

Although the initial development of this system needed much more time than a traditional system, it must be said that most of this implementation can be reused in other similar vehicles. The reusability of the implementation was taken into account, developing a very general vehicle system software with all the possible devices and functionality present in current city-bus systems. Extending this implementation to other different systems only involves deleting unused software modules and rebuilding the wire definition.

In this way, it is expected that a new chassis for an experimental hybrid electric vehicle will be an extension of this initial implementation. The two independent electric engines directly coupled to the rear wheels have an electronic CAN control module provided by SIEMENS. According to the authors' experience, the module integration time in the onboard communication system could have a significative reduction.

Another interesting result about this implementation, besides the aforementioned advantages, is the experience gained by the authors using the software tools (Section III). New advanced software environments from competitive providers, in the field of automotive electronics, like Mentor Graphics, Vector, and others, have been evaluated by the authors in order to reduce or enhance some top–down design and verification steps (i.e., *Simulation* or *System Validation* in Fig. 6). This applied research is starting a reengineering process by the city-bus manufacturer.

Some of the limitations of the used ECUs involve the use of relays in several inputs and outputs; given the few positive digital inputs that these ECUs have, a relay is devoted to invert the signal. In the outputs, when the power source of the ECUs is not enough, the output has to be controlled by a relay. These drawbacks could be solved using ECUs from other manufacturers providing more positive inputs and outputs with enough power, rejecting completely the use of relays.

Therefore, the achievements from the authors in this industrial electronics research are the following:

1) validation of a software tool over a real CAN implementation, getting a know-how for assessing other similar products from providers like Mentor Graphics [19], Vector [20], and others which are currently under experimentation;
2) design and implementation of an original electronic test bank for the system validation and verification according to our top–down design model about development steps (Section III);
3) design and implementation of an original CAN development network for testing and debugging purposes (Section III);
4) proposal of an automated testing module by means of an FPGA (Section V).

V. Future Work

The authors are working in the implementation of modules based on FPGAs [21] to integrate some chassis and body functionalities in the multiplexed system of city public transport buses and coaches. They are using, as development platform, the Spartan-3 2000 FPGA platform from the firm Nu Horizons Electronics Corporation. This platform is based on a Xilinx Spartan-3 XC3S2000 FPGA. Each board is a complete development environment, allowing the design engineer to evaluate multiple system designs on a single platform. Each system platform is feature rich with a 16-MB SDRAM, 32-Mbit Flash, as well as the footprint for a 32-Mbit SSRAM. For industrial and automotive applications, this development platform includes the STMicroelectronics L9616 CAN 2.0B physical layer device. The analog to digital (A/D) converters with 10-/12-/14-b resolution and sampling rates from 10 to 135 Msps included in the board are also very useful.

The modules based on reconfigurable circuits [22], [23] 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 surveillance TV (images of doors and the city-bus rear side), 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, the development of a system to integrate in the dashboard of the city buses a PDA with the VDV protocol which complements the information offered by the display included in the dashboard is interesting. 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 implemented with an FPGA that includes the CAN protocol in accordance to the J1939 standard which manages the communication of a simple Bluetooth device [24]–[25].

As previously reported in Section III, the verification of the functionality is made by hand using the test banks. It would be necessary to develop an automated process to accomplish this task. An automated testing module could be implemented by means of an FPGA and some additional devices (D/A and A/D converters, multiplexers, etc.). This testing module could be fed from a PC with the inputs/outputs test vectors previously generated offline in order to check the right system operation.

For PDA integration in the body bus CAN network, the authors are developing a CAN–Bluetooth gateway using a C505CA 8-b microcontroller with the full CAN version 2.0B integrated on-chip, from Infineon, and a WT11 Bluetooth Class 1 module from BlueGiga. This gateway will be installed as a new CAN node in the J1939 bus of the Actia CAMU. Using this new module, specific CAN frames could be sent from CAMU to a PDA when information, warning, or error messages with text and/or graphics need to be displayed to the driver.

Another important improvement to be taken into account in the design of these modules is the possibility of the integration of the localization and fleet management systems by general packet radio service, global system for mobile communications, radio, etc. The integration of these systems enables the localization of the vehicles from the head office, the automation of the displaying systems for the driver and passengers (into the bus and also out of 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.

VI. Conclusion

The main objective of the work detailed in this paper is the improvement of the control system onboard public transport buses. For this purpose, the authors designed 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 the following:

1) development of a networked control system which satisfies the maximum demands of any public transport enterprise;
2) reduction of cables (60% according to coachbuilder sources) and number of electrical components (relays, fuses, etc.);
3) unification of the whole electronic equipment;
4) central memory for the registration of alarms and periodic maintenance control;
5) autodiagnostic of the system with alarm indications in the driver display;
6) improvements in the vehicle working control and the maintenance management;
7) improvements in the comfort of drivers and passengers;

8) best reliability of the electrical and electronic components in the installation;
9) less maintenance costs;
10) flexible and modular system.

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

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