

MONITORING OF VEHICLES WITH CONTROLLER AREA NETWORK

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Abstract - The implementation of various electronic subsystems in passenger cars and different kind of vehicles is constantly expanding. Accordingly the new vehicles, instead of being mechanical systems, become advanced mechatronical systems which development and testing call for a new approach. Possibility of using data available on vehicles network seems to be extremely powerful tool on it.

The paper deal with new approach in monitoring of vehicles systems which is based on information available on dedicated vehicles' network. Based on complexity of the system and different communication protocols on the vehicles' networks it was found as extremely practical solution to make a new approach which will be based on standards which are widely accepted by the industry.

The new approach was tested in real service. It was found that system can enable significantly less time of vehicle instrumentation before monitoring.

1 INTRODUCTION

Two approaches in vehicles' monitoring are available with nowadays technology. The first one is oriented to the vehicles without electronic unites especially electronic controllers. To enable service data acquisition on those vehicles the same have to be additionally instrumented with all necessary sensors, signal conditioning units as well as some kind of data logging systems. That process can be very time consuming, expensive and frequently related to the technical problems in transducers installation. Fore example, in the case when transmission service load has to be investigated the problem of transducers installation can be extremely difficult based that measurement has to be done on rotating part in limited space where possibilities for transducer installation and taking signals from them is related to many difficulties. This approach is already evaluated trough literature. But, the recent development in vehicle systems brings the new possibilities in the field of measurement. Reality that new vehicles are equipped with

dedicated electronic controller units opens possibility for fundamentally new approach in data acquisition.

The said possibility can be studied from Fig. 1 – top where the layout of controllers and other electronic units on up-to-date vehicles is given. The new vehicles are commonly fitted with minimum two to three electronic control units which are oriented to the engine, transmission, etc. Those controllers are interconnected trough CAN (Controller Area Network). As a part of driver information system a few terminals are provided as nodes of the CAN. Consequently, the intention for monitoring has to be oriented toward possibility that many data of interest can be acquired from vehicle's network rather than to be measured by dedicated and additionally added instrumentation.

2 CAN BASED SYSTEM FOR VEHICLE'S SERVICE LOAD MONITORING

The system which was developed for service load data monitoring on vehicles fitted with CAN bus considers a few hardware items as well as dedicated software. This chapter is related to the concept of the system. Although the system is mainly oriented to the transmission service load monitoring from the CAN bus, it would be clear that its concept enables monitoring of data which are inherent to the all other vehicle's systems.

The concept of the system is based on common situation on nowadays vehicles already fitted with electronic networks which are in use for data interchanging among different vehicle's controllers and their instruments (Fig. 1 - top). In spite of the fact that there are a few protocols which are in use on vehicles' networks it is of importance to be noted that all of them are based, mainly, on the same physical layer which is, nowadays widely accepted by all producers. That is physical layer defined through ISO 11898 or frequently named as CAN 2.0B. As it is given in Fig. 1 - bottom, all data which has to be transferred through this layer have to be organized in frames which start with SOF (Start of Frame) character, followed by 29 bits CAN identifier, RTR character, Control Field, 0 to 8 byte Data Field, CRC Field, Acknowledge Field and EOF (End Of Frame) bits.

From the message format is clear that data of interest for service load would be placed in Data Field. But, to be in position to use those data a few problems have to be solved. Those problems are mainly related to the CAN identifier (ID).

As it is defined by ISO 11898 CAN ID has to be 29 bits long. But, different protocols use that identifier in different ways. For transmission load investigation it is of importance to be oriented to the protocols which are dominant for engine and transmission controllers. As per situation in the market those controllers are mainly based on SAE J 1939 protocol. SAE J 1939 is a protocol with all 7 layers, but for the first two layers (lower two layers) it takes definition from ISO 11898 i.e. CAN 2.0B bus.

Before establishing data acquisition from CAN bus it has to be analysed in which way SAE J 1939 uses CAN's identifier. In brief, in J 1939 the first 3 bits of ISO 11898 Identifier (ID) are in use for priority (000 for the highest priority and 1111 for the lowest priority). The next 18 bits are in use for PGN or Parameter Group Number.

The PGN is the key element for understanding possibilities for service data acquisition from the existing vehicle's network. Actually, all data which have to be sent to the CAN bus are organized in the groups. For example, all data relevant for the electrical transmission controller would be placed in the data message (according to the SAE J 1939 terminology: PDU i.e. Protocol Data Unit) in which PGN would be 61442 and 61445. Data available in messages (i.e. messages Data Fields) with stated PGN(s) would be: transmission selected gear, transmission actual gear ratio, percent of clutch slip, transmission input shaft speed, etc. It is clear that lot of data significant for transmission service load are already available on the vehicle bus in the messages with appropriate PGN's.

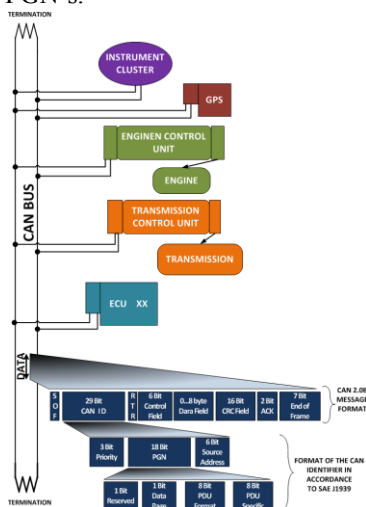


Fig. 1.: Common configuration of the vehicle's CAN bus (top) and the message format (bottom).

Out of data messages with PGN(s) related to the transmission controllers, there are other messages of the

interest. Those are mainly the messages from engine electronic controller, retarder controller, axle controller, etc.

It is clear that for the concept of service load data monitoring is essential to be familiar with the PGN concept. Unfortunately, the concept of PGN and establishing CAN identifier is not as simple as said above. Strictly speaking, PGN has 4 parts: Reserved bit, Data Page bit, PDU Format - 8 bits and PDU Specific - 8 bits. Also, it has to be recognized that PDU Specific can be defined in two different ways based on the value of PDU Format: as the Destination Address (for PDU Format values 0 to 239) or as Group Extension (For PDU Format values 240 to 255). All of this makes approach to the messages on the CAN bus (PDU) very complicated and can cause a lot of problems.

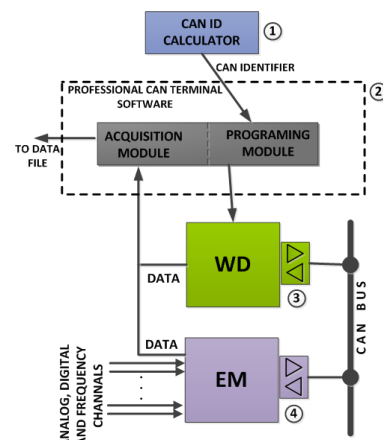


Fig. 2.: Hardware and software components developed through the project (meaning of numbers and abbreviations are given in the text).

As it was explained, defining the proper PGN is not sufficient for successful data acquisition i.e. acquiring of data of interest from the CAN bus. It is also important to know the position of the value of interest in Data Field. The Data Field is 8 bytes long and encloses different data. Their allocation in Data Field must be known for proper data extraction.

Based on explained concept of data flow trough CAN bus it is obvious that first interest in establishing the system for data acquisition has to be oriented to providing of adequate software tools for PGN, CAN Identifier (ID) and Data Field evaluation. To reduce problems i.e. to enable easier service data acquisition trough CAN bus the project which results are given in this paper considered development of a few software and hardware components which are listed below.

1. CAN Identifier (ID) Calculator – software component,
2. Professional CAN Terminal – software component,
3. Watch Dog (WD) – hardware component,
4. Extension Module (EM) – hardware component.

The scheme of functional interdependence of the developed components are given in the Fig. 2 where components are marked with appropriate numbers as given above.

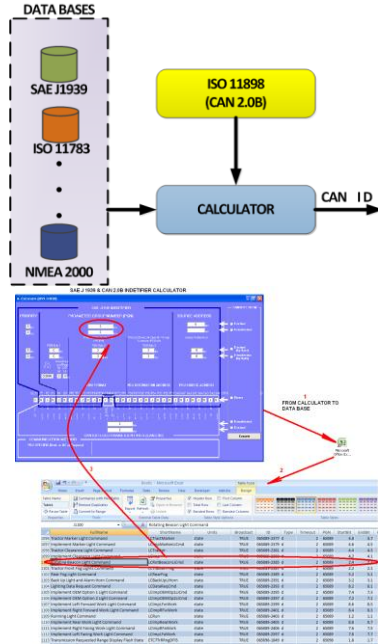


Fig. 3.: CAN Calculator; top – the software structure; bottom – the monitor page which provide support to the user to calculate CAN ID based on SAE J 1939 protocol.

The first of developed components is “CAN identifier (ID) Calculator”, with the structure as in the Fig. 3. Through varies data bases it provides support in defining CAN identifier from different standards including SAE J 1939. The user has to approach to the date base trough Excel (Fig. 3, path mark with 1). The data base can be searched in different ways including searching based on data of interest such as engine torque, engine rpm, etc. In that way user can find out the value which he is interested in to monitor or to acquire from the bus. Once when the value of interest is defined the software defines PGN and other parts of 29 bit identifier (Fig. 3, path mark with 3) in accordance to the previously explained rules. In that way the user is in position to know which message has to be grabbed from the communication on the CAN bus and to be in position to extract appropriate value(s) from the data field in that message (i.e. from PDU).

Since data are organize in 8 bytes Data Field, for successful monitoring, it is essential to be known the position of the data of interest within Data Field. Last two columns in the data base (see Fig. 3, columns marked with “StartBit” and “EndBit”). In this way the first software component which is developed in this project enable to user the full support related to the messages on

the CAN bus even without his deep knowledge of the protocols.

The next part of the data acquisition system developed for the project was dedicated hardware (see Fig. 4 - top), named WD. Actually that is Watch Dog type hardware with the following basic specification:

- Microprocessor based mother board
- 128 dedicated memory slots,
- Two CAN based gates,
- One Ethernet gate,
- Memory block for application programs, etc. (see Fig. 5 - top).

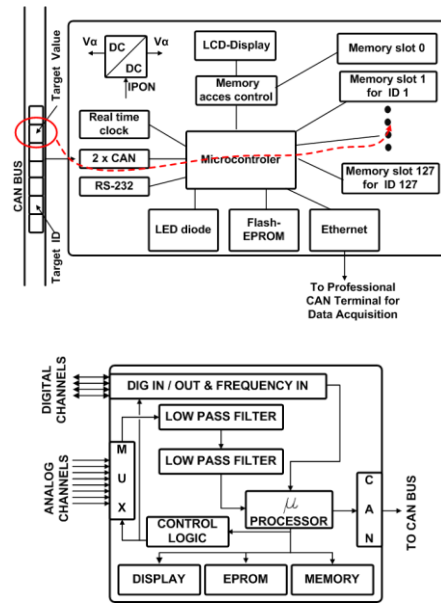


Fig. 4.: Configuration of the hardware components: top – WD (Watch Dog); bottom- EM (Extension Module).

The WD hardware was initially programmed with parameter free software developed in this project. The software drives WD to continuously listens the traffic on the CAN bus. Once when WD starts it work it asks for values for parameters. Those values have to enable WD to know CAN identifier(s) of interest, part of the data field which has to be extracted from the message with defined identifiers as well as to enable to WD to know in which memory slot the extracted value has to be downloaded. This process is visualized with red lines in Fig. 4 (top).

Once when user defines all parameters WD performs operation of grabbing data of interest from the CAN bus and places values of interest in the memory slots. The on line monitoring and data acquisition of the values are available through the Ethernet gate.

The third part of the developed system is software which enables WD programming, on line data flow monitoring and data storage for post acquisition evaluation. That software product, named “Professional CAN Terminal”

(main user page of the software given in Fig. 5) has specification as follows:

- Automatic allocation of WD within local network,
- Definition of parameters which defines data of interest from CAN bus,
- Monitoring of ongoing communication in real time and data storage,
- Possibility for sending messages to the CAN bus.

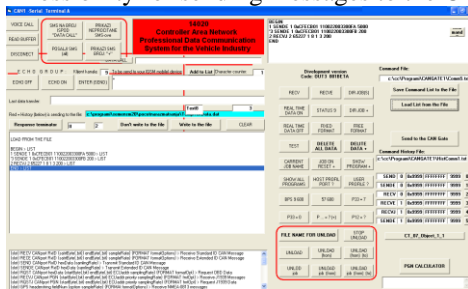


Fig. 5.: “Professional CAN Terminal” software – the main monitor page.

The second hardware component which was developed in this project was “Extension Module” or EM (the configuration given in Fig. 4 – bottom). The EM, among others, performs two essential services:

- Analog to digital conversion of the analog values and
- Broadcasting CAN based messages with converted values.

The necessity for development of the module comes from the circumstance that not all values of interest were available on the CAN bus. It is common situation that there are some values of interest for acquisition which are broadcasting by no one electronic control unit connected to the vehicle’s bus. In such cases there are two possibilities for acquiring data of interest: (i) to use separate (additional) data acquisition system or (ii) to provide the system which will measure the value(s) of interest and make up the PDU(s) with Data Field in which data of interest (measured values) would be incorporated. The second noted way has some advantage. It enables utilization of the already existing data acquisition system which is oriented to the CAN bus, for acquisition of all needed data and makes needless any additional measurement and acquisition unit. In this project the second of two stated approaches was used.

3 CAN BASED SYSTEM APPLICATION

As it is noted in the introduction, one of the important advantage of data acquisition through CAN bus is to provide accurate service load data for the system which has to be developed, by using data from already existing systems. This chapter deals with that kind of the new data acquisition system application i.e. its application in designing a tractor transmission.

For the purpose of designing the new agricultural tractor transmission it was necessary to make in detail investigation of gear box input power (actual input rpm and torque) as well as front and rear axle input torque and rpm. All those data was needed as the input for precise design calculation of the new tractor transmission.

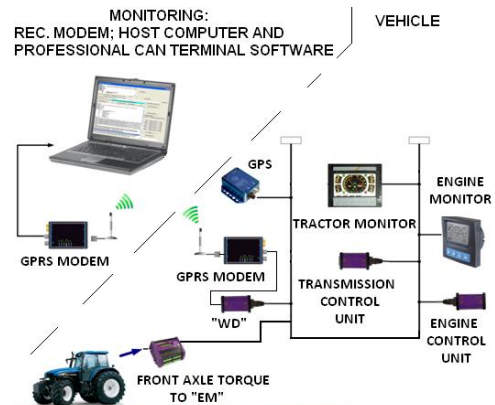


Fig.6: System for service load data acquisition through CAN bus: top – configuration of the system, bottom left – EM built in the tractor; bottom middle – GPRS modem built in the tractor, bottom right – installation of the WD unit.

It was found that vehicle with close the same specification as the new vehicle (in this example that was agricultural tractor) which had to be developed existed on the market. Based that the existing tractor was “CAN based” it was found as cost and time effective to provide transmission service load data by utilization of CAN based data acquisition system on existing tractor. Consequently, it was brought out as possible to avoid making of the prototype of the new tractor for the purpose of service data investigation.

The existing tractor was instrumented in the way that WD was installed on its CAN bus (see Fig. 6). For real time data monitoring WD’s Ethernet port was connected to Ethernet port of GPRS modem i.e. it was establish data channel from CAN bus to GPRS network. Monitoring station was fitted on the local computer with Professional CAN Terminal software and with another GPRS modem (receiver).

For acquiring data which were of interest for this investigation and which were found as missing in CAN bus traffic (broadcasted by no one ECU on the network) the Extension Module (ED) was connected to the bus. Since the front axle input torque was not-broadcasted

value of interest the additional front axle torque measurement line was established on tractor's propeller shaft and the analog signal from the torque conditioning unit was directed to the EM.

Before data acquisition, it was necessary to find out appropriate PGN(s) part of Data Field in PDU(s) and ID for the values of interest. That was done with previously developed CAN Calculator software. The following text gives in detail explanation of that process. Given explanation is of general importance since it provides guidance for other researcher and facilitates their work on data acquisition through CAN bus.

For the engine speed which is (when the vehicle's clutch is engaged i.e. while the transmission is loaded) equal to the transmission input speed, the relevant PGN is 61444 and 2 bytes long data of engine rpm starts in 4th byte in Data Field. It was found that engine control unit on the tractor had address 0. Based on SAE J 1939 i.e. with help of CAN Calculator software it was found that corresponding CAN identifier which of interest as ID = 00DE0400_{hex}. The whole process can be given in symbolic way as follows:

Engine speed:
Priority Level: 3 >>>> ID = 011xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61444_{dec} 00F004_{hex} = xxx001111000000000100xxxxxxxx_{bin}
Source: 0_{dec} = 0_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000000_{bin}
Result ID = 217056256_{dec} = 00DE0400_{hex}
Start position in Data Field: 4th byte
Length: 2 byte

The next value of interest is engine torque or transmission input torque which is broadcasted by the engine electronic controller, with the same PGN. The calculated output torque of the engine is transmitted as indicated torque in percentage of reference engine torque. Consequently, from CAN calculator software it was found that the ID of the message which contains data relevant for torque was 217056256_{dec} or given in-deal:

Engine torque
Priority Level: 3 >>>> ID = 011xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61444_{dec} 00F004_{hex} = xxx001111000000000100xxxxxxxx_{bin}
Source: 0_{dec} = 0_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000000_{bin}
Result ID = 217056256_{dec} = 00DE0400_{hex}
Start position in Data Field: 2nd byte
Length: 1 byte

Even the torque level is transmitted in percentage of reference engine torque one can easily find out the actual torque. That is possible based on the engine characteristic which is always defined in ECU memory as rpm/torque matrix. The matrix can be given in one of three modes. Mode 1 provides a complete curve of speed and torque points while modes 2 and 3 provide a partial curve of speed and torque points and a separate end speed governor characteristic. Data from the matrix loaded in ECU can be asked by sending the request with PGN 65251.

Here, we have to recall the part in which the Professional CAN Terminal software was described. As one can

recognize in given specification of that software its main purpose is to help in WD programming, to enable monitoring of the traffic on the CAN bus and to support data acquisition. But, as it was given in the software specification, it also has capability to send messages to the CAN bus. Here it is clear the purpose of that (sending request with PGN 65251).

Before starting data acquisition it is essential to send request with PGN 65251 to CAN bus. That request would be served by engine control unit. The ECU will replay with message with multi-data field (total length 39 bytes) which will be matrix data. Only in that way one will be in position to find out torque value (in Nm). The actual torque level would be found based on torque value in percentage which would be transmitted with ID 00DE0400_{hex} as explained above and from the data which would be enabled through request with PGN 65251.

The next values of interest were actual or engaged gear ratio and actual transmission range. Taking together, those two values give information of overall transmission ratio. Both are defined in data field of the messages with the PGN 61445, as follows:

Transmission actual gear ratio:
Priority Level: 6 >>>> ID = 110xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61445_{dec} 00F005_{hex} = xxx001111000000000101xxxxxxxx_{bin}
Source: 2_{dec} = 2_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000010_{bin}
Result ID = 418383106_{dec} = 18F00502_{hex}
Start position in Data Field: 2th byte
Length: 2 byte

Transmission current range:
Priority Level: 6 >>>> ID = 110xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 61445_{dec} 00F005_{hex} = xxx001111000000000101xxxxxxxx_{bin}
Source: 2_{dec} = 2_{hex} = xxxxxxxxxxxxxxxxxxxxxx00000010_{bin}
Result ID = 418383106_{dec} = 18F00502_{hex}
Result ID = 418383106_{dec} = 18F00502_{hex}
Start position in Data Field: 7th byte
Length: 2 byte

In addition, it was needful to provide data for real tractor speed. That is extremely important since there is no other way to find out wheel slip (and to give input design time for development of differential locks) out of measuring the real vehicle speed and each wheel rpm.

Real vehicle speed value, in nowadays tractors, is provided based on GPS based Doppler transducer which broadcast measured value to CAN bus with PGN 65256 in according to concept as given below. The priority and position of the data in data field are:

Navigation-Based Vehicle Speed (real tractor speed):
Priority Level: 6
ID = 110xxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 65256_{dec} = 00FEE8_{hex} = xxx001111101101000xxxxxxxx_{bin}
Source: 10_{dec} A_{hex} = xxxxxxxxxxxxxxxxxxxxxx00001010_{bin}
Result ID = 419358730_{dec} = 18FEE80A_{hex}
Start position in Data Field: 3rd byte
Length: 2 byte

Here, we have to recall the part in which the Professional CAN Terminal software was described. As one can

The special interest in new transmission development was oriented to the ratio of slip between left and right wheels on the same axle. For that purpose in addition to measurement of real tractor speed, it was necessarily to provide data related to wheels speed. It was demonstrated that even those values can be measure without installation of additional transducers i.e. from the CAN bus. Those information are available from torque distributor or ASR controller or/and ABS controller. Tractor which was under the test was fitted with torque distributor controller which was also used as differential lock controller. It was found that controller follows SAE J 1939 protocol. Consequently, all needed data were located in the messages with PDU 65134. Through CAN calculator it was found:

Actual wheel speed (High resolution wheel speed)
Priority Level: 2 >>> ID=010xxxxxxxxxxxxxxxxxxxxxxxxxxxx_{bin}
PGN: 65134_{dec} 00FE6E_{hex}=xxx00111111001101110xxxxxxxx_{bin}
Source: 3_{dec}=1_{hex}=xxxxxxxxxxxxxxxxxxxxxxxx00000011_{bin}
Result ID=150892035_{dec}=08FE6E03_{hex}

Start position in Data Field—Front left wheel: 1th byte
Length: 2 byte

Start position in Data Field—Front right wheel: 3th byte
Length: 2 byte

Start position in Data Field—rear left wheel: 5th byte
Length: 2 byte

Start position in Data Field—rear right wheel: 7th byte
Length: 2 byte

Till now the paper discussed possibilities of measurement and data acquisition of the transmission service load without any additional instrumentation out of controllers which already exists on the vehicle under the test. But, it can happened that some values of interest are not available on vehicle's CAN bus. In such cases it is necessary to install appropriate measurement system for that (those) value(s). As per nowadays technology all signals for additionally measured values have to be directed to analog to digital converters and after that transferred to the files. That situation opens the problem of time base synchronization. In practice, system which collects data from CAN bus has its own time base and time stamping of data acquired from CAN bus take this time base as the reference. All other signals which come from additionally installed measurement equipment have their own time base. In the cases where all measured data have to be analyzed with the same time base that can open the problem.

To avoid problem of time synchronization of acquired data it was decided to make an extension of existing CAN on the tractor. That was done by implementation of previously explained EM. Basically speaking the system had function to transfer analog measured values to the CAN messages and to broadcast same on existing tractor's CAN bus. In that way the WD was in position to acquire missing (front axle torque) data from CAN bus in the same way as all other values and all of them would be acquired with the same time reference.

4 CONCLUSION

The process of vehicles monitoring has pass through significant changes which are caused by dramatically improvement in vehicles' technology. Instead to be oriented to the dedicated measurement systems which are added on vehicle for measurement purpose only, up-to data monitoring systems have to be oriented to the vehicles' networks, where service load data already exist. That create demand for the appropriate – the new platform which will be used for testing and verification of the vehicles. The new platform has to be network oriented data acquisition systems. The paper proposes the advanced measurement and data acquisition system of that kind.

It was shown that CAN based approach in monitoring of service load can significantly reduce time for vehicle instrumentation and enable to development engineer to make whole testing in the already existing vehicle before making the prototype of the new vehicle or system under development. The concept is accomplished by building up dedicated hardware and software. Totally two hardware and two software components were developed. The results of initial testing of all developed components indicate their good performances. Through initial testing of the development platform it was accomplished accurate measurement of vehicle's transmission service load in real service conditions.

5 REFERENCES

- [1] Olaf Pfeiffer, Andrew Ayre, Christian Keydel (2008) *Embedded Networking with CAN and CANopen*. Copperhill Media Corporation, Greenfield, Massachusetts, USA
- [2] Wolfhard Lawrenz (2007) *CAN System Engineering: From Theory to Practical Applications*. Springer, New York, NY, USA
- [3] Wilfried Voss (2008) *A Comprehensive Guide to J1939*. Copperhill Media Corporation, Greenfield, Massachusetts, USA
- [4] Konrad Etschberger (2001) *Controller Area Network*. IXXAT Automation GmbH, Weingarten, Germany
- [5] Dominique Paret (2007) *Multiplexed Networks for Embedded Systems*. John Wiley & Sons, Ltd., Chichester, West Sussex, England.

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