Development of Vehicle On-board Communication System for Harsh Environment

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Abstract: Utilizing the already installed train interconnection cables as the physical layer of an extended intra-train communication could be a cost-effective solution. However these interconnection solutions are not optimal for the standardized digital data transfer solutions. The paper gives a brief summary of the theoretical aspects of data transmission, and experimental test results of the digital data transfer using non-standard physical layers.

Keywords: rail transport, on-board communication, network structures

1. Introduction

On-line communication, telemetry and fleet management has gained a significant role in today's modern rail transport. Such systems utilize high level integration of communication, data management and control systems. The intra-train communication network is a significant among them. To extend the information chain on the train level, a network is needed to reach all units of a train. Multiple train communication networks exist for general train control purposes, such as remote traction control to handle push-pull train operation, door and light control, or audio channels. However the need for extended services of intra-train communication has arisen.

They serve two purposes:

- First is to improve passenger satisfaction by providing real-time information about the state of the journey, i.e. current delay, estimated arrival, connections etc. This information could be displayed in passenger cars via different kinds of displays, which are supplied with reliable data from the on-board unit of the driver's stand.
- Second is to improve train information for the operator. The telemetry or the automatic enrollment of train units can be centralized on the train level with a closed communication solution, where the only connection to a central data centre of the operator is managed by the on-board unit.

There exists a standardized extension of the Train Communication Network [8] [9] in newly introduced passenger and traction units providing additional channels and protocols for these purposes. However the spread of these solutions is limited, and the operators need to handle the problem on existing units, which are intended to be in service for a long time.

This motivates the operators to implement such a communication system on their current fleet [12]. The task can be handled in two different ways of which the first is to install additional wiring and connectors on their units. This solution could result in a well-designed multi-purpose and, most importantly, closed and independent communication system. However, the installation costs are high. The other way is to use the already installed connection system of the trains. Naturally one must examine the pin allocation of the connectors of the current system and determine those wire pairs that do not carry safety-critical information in order to maintain the safety level of the train operation.

The paper deals with the problems of using the already-installed interconnection for extended communication purposes with alternative protocols. The non-standard physical layer, the non-fixed topology of the network, network length and speed are discussed.

In Section 2 the specialities of the vehicular environment are presented. The brief introduction of the transmission line theory and the differential signalling technologies are described in Sections 3 and 4 respectively. The experimental results are presented in Section 5.

2. Vehicular environment

The topology of the train units and the formation of the already installed interconnections indicate that such a communication system could only use two kinds of network topology: the chain and the bus topology, as shown on Figure 1. Since the chain topology breaks the continuity of the cable, the bus topology seems to be the suitable solution for the proposed network solution.

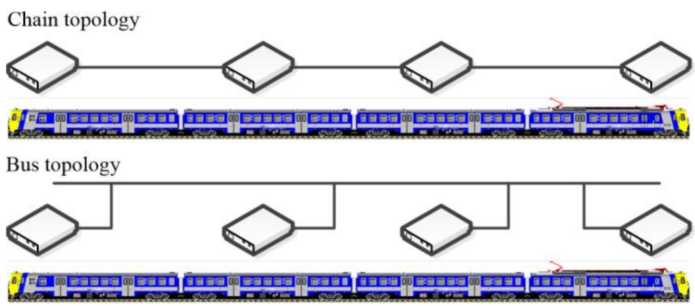

Figure 1: Train network structure

The problem becomes more complex, since the Hungarian State Railways uses four different systems for train interconnection: three old standards left from the Comecon era, and the UIC 558 [11] standard. Each system has different wiring, shielding, and termination carrying multiple kinds of analogue or digital signals on high or low voltage and current. These parameters influence the feasibility of the communication.

Moreover the network topology of the train is not fixed, since the individual units can build up different formations in length, or in the position of the traction and/or control units. This feature of the modular network poses several problems. The proper or even adaptive termination of wire pairs, the determination of achievable network speed, and the network build-up must be solved. Another problem is the separation of communication devices if the train uses the interconnection wire for its primary function. The discussion of these topics is not intended in this paper, though the examination of the physical layer and the determination of the feasible data transfer are discussed in the coming sections.

3. Transmission line principle

The term transmission-line in electromagnetics is commonly reserved for those structures which are capable of guiding Transverse Electromagnetic (TEM) waves. Transmission-lines are a special class of the more general electromagnetic waveguide. TEM waves can only exist in structures which contain two or more separate conductors. Coaxial lines, parallel plates, and two-wire lines are examples of practical transmission-lines [3]. Practically a transmission line is a two-port network (see Figure 2) connecting a generator circuit at the sending end to a load at the receiving end.

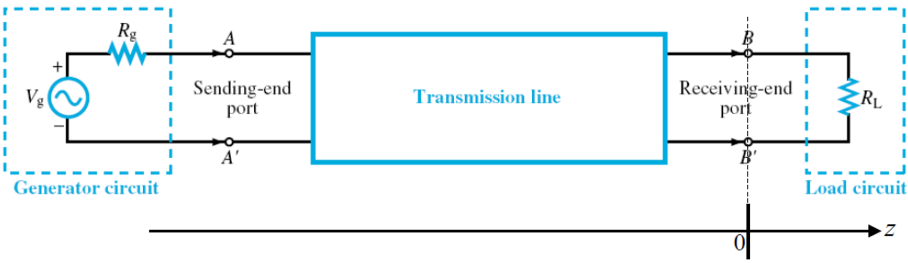

Figure 2: General transmission line [4]

One can analyse the transmission lines using circuit theory concepts breaking the line into small sections so that the circuit element dimensions will be much smaller than the wavelength. To do this, the transmission-line is described by a series resistance per unit length R, series inductance per unit length L, shunt conductance per unit length G, and shunt capacity per unit length C. A small section of the transmission-line with length dz thus has the following equivalent circuit as shown in Figure 3. This concept is also known as distributed parameter representation.

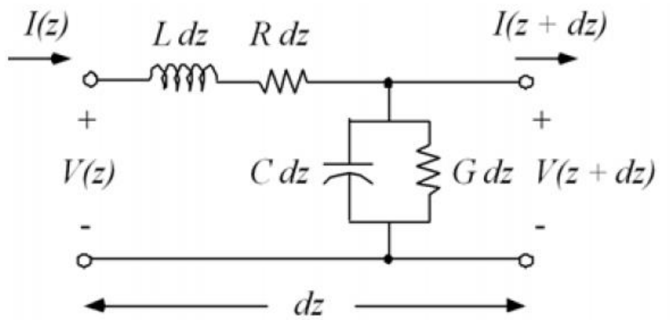

Figure 3: Transmission line section [3]

The following parameters are related to the physical properties of the material filling between the wires:

$$LC = \mu\varepsilon \,, \; \frac{G}{C} = \frac{\rho}{\varepsilon} \,,$$

where μ, ε, ρ are the permittivity, permeability, conductivity of the insulator of the wires respectively. The characteristic impedance Z_0 is the most important parameter of the transmission line. It depends on the distributed parameters (which depend on the material of the conductor and the surrounding of the wires) and ω:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

For lossless transmission lines $R = G = 0$ and it can be proved that the frequency dependence of the characteristic impedance will cease thus we can approximate $Z_0 \approx \sqrt{L/C}$.

3.1. Reflections in transmission lines

In subsequent analyses, only lossless transmission lines will be considered. Take a finite length transmission (see Figure 4) terminated with load impedance Z_L at the end.

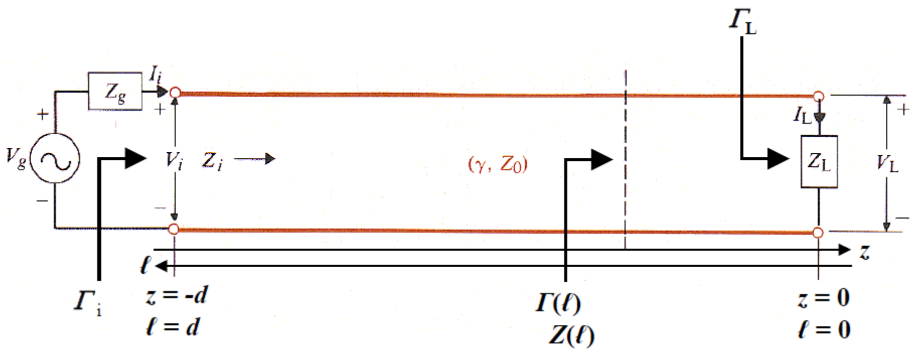

Figure 4: Terminated transmission line circuit [4]

At the position of the load (l=0) the voltage is V_L and the current is I_L thus:

$$V_0^+ + V_0^- = V_L$$

$$V_0^+ + V_0^- = V_L$$

$$\frac{V_0^+}{Z_0} + \frac{V_0^-}{Z_0} = I_L$$

$$\frac{V_L}{I_L} = Z_L$$

where V_0^+, V_0^-, I_0^+, I_0^- are the wave amplitudes in the forward and backward directions at z=0 and γ is the complex propagation constant given by $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$. By solving the above equations the following expression is obtained:

$$\Gamma_L = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Finally, the summary of the special cases yield the following results:

- Short circuit: Z_L=0→Γ_L=−1
- Open circuit: Z_L=inf→Γ_L=+1
- Matching termination: Z_L=Z_0→Γ_L=0

From a practical point of view it can be stated that when the data rate is low or the cables are short, termination may be unnecessary. As data rates increase, termination becomes important. Since any device on the bus can transmit, it is probable that a node within the middle of the bus will transmit requiring that termination be applied to both ends of the bus segment. The termination impedance must match the characteristic impedance of the wire. Using high frequency communication the imaginary part of the impedance is negligible thus a normal resistor (termination resistor) can be used.

4. Differential signaling technologies

During the review of the possible solutions the constraints of the vehicular environment must be considered, which fundamentally affect the technological possibilities.

- The train interconnections are considered as a transmission line, which consists of shielded and twisted wire fours.
- The maximum bus length is 500 m.
- Bus topology will be used.
- Harsh environment (extreme temperature, humidity and mechanical stress).
- Standard communication technology will be used.

Based on the above the solution could be one of the differential signalling technologies. Two of the collision domain segment network buses can satisfy all of these requirements: EIA-485 and Controller Area Network.

4.1. TIA/EIA RS-485-A

One of the more popular technologies for interconnecting devices on a network is TIA/EIA-485-A, known throughout industry as RS-485, see [1] [2]. According to the standard it specifies the characteristics of the generators and receivers used in a digital multipoint system. It does not specify other characteristics such as signal quality, timing, protocol, pin assignments, power supply voltages or operating temperature range.

An EIA-485 bus usually consists of two or more communication controllers each powered by a separate power source. At a minimum, a single shielded or unshielded twisted-pair cable interconnects the various controllers in a daisy-chain fashion. In some instances a short stub is allowed; however, higher speed networks usually do not allow stubs. Star topology is definitely not recommended. Termination is usually applied to the ends of the network.

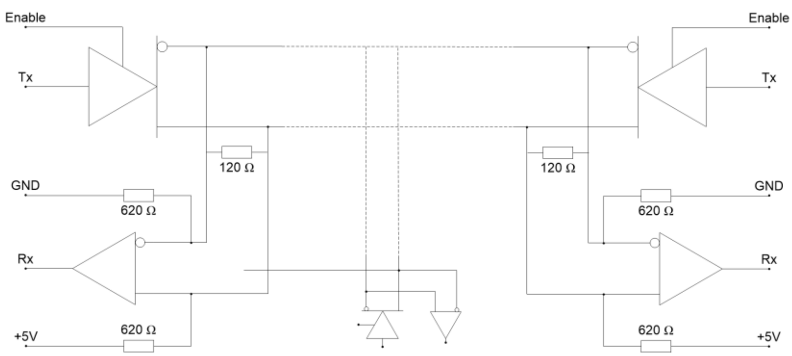

Figure 5: EIA-485 network structure

The standard basically specifies the parameters (unit load, output drive, common mode voltage etc.) of the drivers, receivers and transceivers attached to the network. Basically a driver must be able to source at least 1.5 volts differentially into 60 ohms (two 120 ohm terminators in parallel along with 32 unit loads) under a common mode voltage range of -7 to +12 Vdc. Data rates are not specified and there is a wide range of devices that conform to the standard but are intended either for high speed (up to 50 Mbps) or low speed (skew rate limited). In terms of the Open Systems Interconnection Reference Model (OSI), EIA-485 only defines the lowest layer â€” the physical layer. It is used by several higher layer protocols such as Profibus, ARCNET and other token-based protocols. There are several key topics that must be considered when deploying EIA-485 networks such as termination, fail-safe bias, connectors, grounding, cabling and repeaters. Form our point of view the most important parameters are the termination and the cabling. Terminating a data cable with a value equal to its characteristic impedance reduces reflections that could cause data errors. The most popular approach is DC termination although this approach results in higher power dissipation. Resistive terminators typically have values of 120 to 130 ohms although twisted-pair cable impedances can be as low as 100 ohms. An 100 ohm termination resistor is too low for the EIA-485 drivers. A value closely matching the cable impedance must be applied at some convenient location as close to the ends of the cable segment as possible.

One of the more critical decisions to make is the selection of cable. Cable selection depends on several factors including data rate, signal encoding and distance desired. Cables attenuate the transmitted signal and introduce distortion of the signal waveform itself. Additional distortion occurs by the way receivers are biased. Jitter can occur when the receiver attempts to recover the distorted data. Intersymbol interference results when a new signal arrives at the receiver before the last signal reached its final value. Therefore, the two successive symbols interfere with one another resulting in a time shift in data recovery which is called jitter. Some jitter is usually acceptable, however, if it is excessive, the only solution is to obtain better cable, reduce the modulation rate or reduce the distance.

4.2. Controller Area Network

The Controller Area Network (CAN) [6] is a serial communications protocol which efficiently supports distributed real-time control with a very high level of security. Its domain of application ranges from high-speed networks to low-cost multiplex wiring. In automotive electronics, engine control units, sensors, anti-skid-systems, etc. are connected using CAN with bitrates up to 1 Mbit/s.

CAN is a multi-master bus with an open, linear structure with one logic bus line and equal nodes. The number of nodes is not limited by the protocol. Physically the bus line (Figure 6) is a twisted pair cable terminated by termination network A and termination network B. The locating of the termination within a CAN node should be avoided because the bus lines lose termination if this CAN node is disconnected from the bus line. The bus is in the recessive state if the bus drivers of all CAN nodes are switched off. In this case the mean bus voltage is generated by the termination and by the high internal resistance of each CAN nodes receiving circuitry. A dominant bit is sent to the bus if the bus drivers of at least one unit are switched on. This induces a current flow through the termination resistors and, consequently, a differential voltage between the two wires of the bus. The dominant and recessive states are detected by transforming the differential voltages of the bus into the corresponding recessive and dominant voltage levels at the comparator input of the receiving circuitry

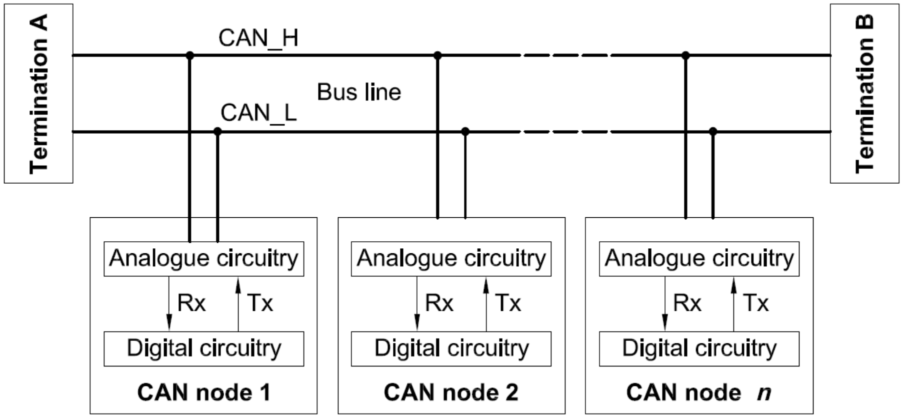

Figure 6: CAN bus structure [7]

The CAN standard [7] gives specification which will be fulfilled by the cables chosen for the CAN bus. The aim of these specifications is to standardize the electrical characteristics and not to specify mechanical and material parameters of the cable. Furthermore the termination resistor used in termination A and termination B will comply with the limits specified in the standard also.

Besides the physical layer the CAN standard also specifies the ISO/OSI data link layer as well. CAN uses a very efficient media access method based on the arbitration principle called "Carrier Sense Multiple Access with Arbitration on Message Priority", see [7]. Summarizing the properties of the CAN network the CAN specifications are as follows [6]: ű

- prioritization of messages
- guarantee of latency times
- configuration flexibility
- multicast reception with time synchronization
- system wide data consistency
- multi-master
- error detection and signalling
- automatic retransmission of corrupted messages as soon as the bus is idle again
- distinction between temporary errors and permanent failures of nodes and autonomous switching off of defect nodes

These properties result in significant advantages over the EIA-485 standard.

4.3. Experimental verification

In this section the result of our experimental verification is presented. It is assumed that the ends of the network cannot be terminated because in practice one should switch the termination resistors at both ends of the train during every train composition. Thus every node on the locomotives must have its own termination which cannot have a standard value because more than two nodes may be connected to the bus. In this case the equivalent resistance of the parallel resistors may be too small, which could cause the overload of the transceivers. In these laboratory tests the effects of the non-standard termination resistor with different cable lengths and data rates on a CAN bus are examined.

The effects of an order of magnitude higher termination resistors were tested with different cable lengths and baud rates. The test setup was composed of standard UTP cable (Z_0=120Ω) with switchable termination resistors at both ends and USB-CAN interfaces. During the measurements 10 different messages with extended ID and 8 data-bytes were sent with a suitable frequency causing approx. 100 % bus load. In every test case 10 000 messages were sent from the one end and logged on the other end of the network. In Table 1 the termination type and value are signed: -/-: open circuit, 120/-: termination at one end, 120/120 termination at both ends. Firstly entirely unshielded twisted pairs (U/UTP) cables were used with different bus lengths, then shielded twisted pairs (F/UTP) were used with fixed length. The measurements found that at lower baud rates the bus can work without termination, but using only one termination resistor can result in significant improvement in the communication. Of course the measurements verified that the highest baud rates can be achieved with standard termination at both ends.

The most important result is related to the non-standard termination resistors. In this case 1500 ohm resistors (weak termination) were used, which resulted in a sufficiently high equivalent resistance with more than two nodes. These tests found that the maximum baud rate decreased to a quarter of the standard values, but it is twice the open circuit values. These tests were performed with 1200 ohm resistances with the same results. It is also remarkable that in a borderline scenario the CAN protocol detected the errors (15 error frames) and resent the messages.

Table 1: Laboratory test results

Length	**Termination (Ω)**	**Baud rate**	**Error rate**	**Cable type**
10m	-/-	250K	0%	UTP Cat. 5
10m	-/-	500K	100%	UTP Cat. 5
10m	120/-	1M	0%	UTP Cat. 5
20m	-/-	125K	0%	UTP Cat. 5
20m	-/-	250K	100%	UTP Cat. 5
20m	120/-	1M	0%	UTP Cat. 5
40m	-/-	100K	0%	UTP Cat. 5
40m	-/-	125K	100%	UTP Cat. 5
40m	120/-	500K	0%	UTP Cat. 5
40m	120/-	1M	100%	UTP Cat. 5

40m	120/120	1M	15.17%	UTP Cat. 5
80m	-/-	50K	0%	FTP Cat. 6
80m	-/-	100K	100%	FTP Cat. 6
80m	120/-	250K	0%	FTP Cat. 6
80m	120/-	500K	0%+15% error frame	FTP Cat. 6
80m	120/120	500K	0%	FTP Cat. 6
80m	120/120	1M	100%	FTP Cat. 6
80m	1500/-	100K	0%	FTP Cat. 6
80m	1500/-	125K	100%	FTP Cat. 6
80m	1500/1500	125K	0%	FTP Cat. 6
80m	1500/1500	250K	100%	FTP Cat. 6

4.4. Conclusion

In this paper the first step of our research was presented focusing on on-board vehicle communication systems in a special environment. The motivation for using train interconnection cables was explained. The theoretical basis of the transmission line and the differential signaling technologies were briefly introduced. For its significant advantages the CAN standard was chosen for further examination. It was stated that the network would be terminated only with non-standard termination resistors because of the variable topology. The aim of the tests was the verification of the behavior of such a CAN bus. The laboratory experiments found that the network with non-standard termination could operate with twice the data rate of the open circuit. The next step will be the field test using the train interconnection cable with maximum required length. With this "weak termination" method the maximum reliable data rate will be located in the real environment. Based on the results possible further research will be conducted for increasing the data rate.

5. Acknowledgement

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