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K. Kamuda[1], W. Kalita[1], J.F. Kołodziejski[2]

[1]Rzeszow University of Technology,

Department of Electronic and Communication Systems, Poland

[2]Technical University of Lodz, Institute of Electronics, Poland

CANCAN-PROGRAM FOR DETERMINATION OF CONFIGURATION PARAMETERS OF CAN- BUS CONTROLLER

Досліджено методи розроблення, які забезпечують правильну конфігурацію CAN-шини. Результати досліджень підтверджують можливість розрахунку параметрів, які необхідні для вибору правильної конфігурації CANконтролера. Розроблена CANCANпрограма дає змогу розраховувати матриці R, L, C, G параметрів, що необхідно під час розрахунку часу проходження сигналу і падіння напруги в лініях. Програма дає змогу перевіряти коректність прийнятих припущень і повідомляє про області, де необхідно здійснити модифікацію, зокрема в критичних випадках.

The researches for elaboration of the method allowed to correct configuration of CAN-bus have been presented in the paper. The results of investigations have proofed the possibilities of parameter's calculation, required to choose relevant CAN controller configuration during the design. Elaborated CANCAN-program allow to calculate matrices R, L, C, G parameters, used at next step for time of the signal propagation and voltage drops in the lines, etc. in relation to wire types and their configuration. It allows checking the correctness of applied assumptions and indicates the modification areas, especially in critical cases of application.

1. Introduction

It is generally assumed that the designers of CAN-bus based systems should have sufficient experience and an intuition. Owing to them the designers can properly determine final parameters of the systems like the highest transmission speed, transmission medium type, achievable transmission range etc. at given environment conditions and specify EMC requirements. It would be therefore strongly desired to develop a method of the selection of CAN-bus operational or functional parameters on the base of mathematical line model.

The above-mentioned problems were considered as a base of the investigations aims, directed to synthesis and practical application of the method, allowing determination of configuration parameters of CAN-bus by the analysis of its structure, topology conditions and transmission properties characteristics of CAN-bus, in relation to application and disturbing signals.

2. Per-Unit-Length Parameters

The CAN-bus specification doesn't impose a specific type of conductors (Fig.1). The fundamental criterion of selection depends then on the parameters, which allow obtaining the expected signals propagation time in the bus, acceptable voltage drops and required EMC properties. The type of used wires, their geometry and cross-section area implicate per-unit-length line resistance, insulation leakage, capacitances and self and mutual inductances and wave impedance, necessary for detailed analysis. Even the wires from good manufacturers with well-known and stable initial parameters can change these parameters in a certain application (e.g. if the wires are placed on the metal supporting the structure of the building).

Fig. 1. Cross-section of the transmission line wires used for CAN-bus

Making assumption that in transmission lines of the CAN-bus the wave of TEM type (or quasi-TEM) is propagated, and assuming line homogeneity, only the mutual configuration of m+1 conductors and dielectrics has an influence on residual parameters [2].

The potential in any point P on (n+1) wire at homogenous dielectric medium with ε_r (not regarding insulation of conductor), can be determined from equation:

$$\varphi(\vec{r}_p) = \frac{1}{2\pi\varepsilon_0\varepsilon_r}\sum_{\mu=0}^{m}\oint_{s_\mu}\sigma_\mu(\vec{r}_\mu)\cdot\ln\frac{1}{\left|\vec{r}_p-\vec{r}_\mu\right|}ds_\mu, \quad (1)$$

where s_μ means wire μ cross section while r_p, r_μ result from Fig. 2. Because the conductors have the good electrical conductivity, it can be assumed that potential on the perimeter of each wire μ is constant. But distribution of the surface charge density σ_μ is dependent on wire geometrical configuration and is unknown. For wires with cylindrical symmetry this magnitude can be expressed in Fourier series form. N+1 describe number of Fourier coefficients $\alpha_{\mu k}$, and $\vartheta_{\mu k}$ (Fig. 2).

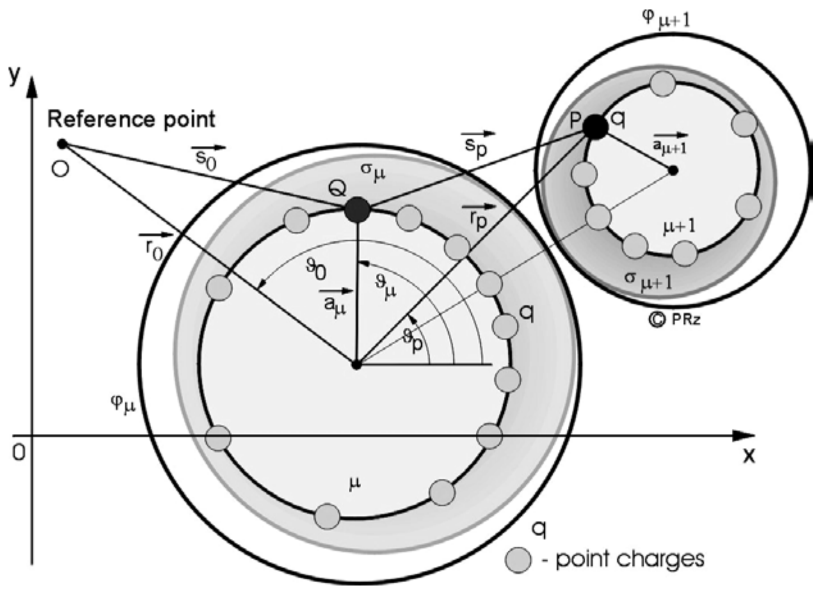

Fig. 2. Illustration of determination of per-unit-length-parameters

With a large number of coefficients it can be assumed that the charge on the wire perimeter is divided on the 2N+1 point charges and that each point participates in the creation of potential of all wires.

Additionally, if logarithm in (1) will be transformed to power series then the algebraic equations system can be obtained instead of integral equations. They can be wrote down in matrix form:

$$\begin{bmatrix} \mathbf{\Phi}_0 \\ \vdots \\ \mathbf{\Phi}_i \\ \vdots \\ \mathbf{\Phi}_m \end{bmatrix} = \begin{bmatrix} \mathbf{D}_{00} & \cdots & \mathbf{D}_{0j} & \cdots & \mathbf{D}_{0m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \mathbf{D}_{i0} & \cdots & \mathbf{D}_{ij} & \cdots & \mathbf{D}_{im} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \mathbf{D}_{m0} & \cdots & \mathbf{D}_{mj} & \cdots & \mathbf{D}_{mm} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{A}_0 \\ \vdots \\ \mathbf{A}_i \\ \vdots \\ \mathbf{A}_m \end{bmatrix}. \tag{2}$$

Φi is the potential vector of i-th wire while Ai is weight coefficients vector which allows to determine of charge distribution on i-th wire perimeter. Assuming ϕ0 ÷ ϕn potential values for system of neutral character and making inversion of **D**, the values of αik coefficients are reached. They show the role of particular point charges in total wire potential:

$$\mathbf{A} = \mathbf{B} \cdot \mathbf{\Phi}\text{, where } \mathbf{B} = \mathbf{D}^{-1}. \tag{3}$$

Resulting matrix - so called generalised capacitance matrix - is the basis for another calculations allowing finding per-unit-length capacitance matrix for considered conductors system (with selected one or more reference wire). For example, to determine the capacitances for wires placed over ground plane the calculations are carried out for 2m+1 wires, where half of them are "mirror wires". After the adequate transformation (using $\Phi_i = -\Phi'_i$ relation) the resulting matrix of per-unit-length capacitances is obtained. The general capacitance matrix is at least one order less than resulting matrix.

When each conductor of wire is surrounded by insulation coat of εrμ permittivity, the additional effect related to dielectric polarisation should be taken into account in calculations. As the result of electrostatic induction, the summarised charge accumulated on the μ-wire, represents difference between free charge on wire surface and induced charge on coat surface. It leads to a modification of matrix equations, describing the dependence between ϕ and α:

$$\begin{bmatrix} \mathbf{\Phi} \\ \mathbf{0} \end{bmatrix} = \begin{bmatrix} \mathbf{D}_{11} & \mathbf{D}_{12} \\ \mathbf{D}_{21} & \mathbf{D}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{A} \\ \mathbf{A}^* \end{bmatrix} \Rightarrow \mathbf{\Phi'} = \mathbf{D'} \cdot \mathbf{A'}, \tag{4}$$

where **A*** is potential coefficients matrix for charges induced in dielectric. Taking into consideration the boundary conditions and their influence on value of ϕ potential the **D** matrix is extended with additional sub-matrixes concerned with polarisation of dielectric coat. Making **D'** matrix inversion and multiplying it by potential vector, the Fourier coefficients matrix for wire and coat is obtained. Using elements of $\mathbf{D'}^{-1}$ matrix the general matrix of capacitances is determined (similarly to the system with homogenous dielectric) and - after transformation - its resulting matrix. With assumption that only transverse electromagnetic wave is propagated in the transmission lines of considered bus it is easy to determine the inductance and leakage matrix on the basis of obtained capacitance matrix:

$$\mathbf{L} = \mu_0 \varepsilon_0 \mathbf{C}_0, \tag{5}$$

where C0 is C matrix determined at an assumption εr=1, and:

$$\mathbf{G} = 2\pi \cdot f \cdot tg\delta(f) \cdot \mathbf{C}, \tag{6}$$

when tgδ(f) is determined for f frequency or for its harmonics.

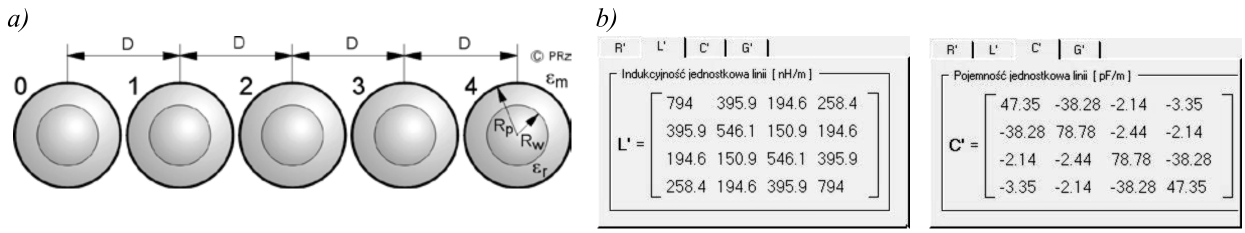

Fig. 3. PCV ribbon wire: a) cross-section: D=1.56mm, rw=0.37mm, rp=0.78mm, b) per-unit-length parameters L and C calculated as example using elaborated program (ref. wire – 2)

On the basis of the above-mentioned considerations the program (in Math-CAD environment) was elaborated. It allows determining per-unit-length line parameters based on their configuration and measurements of fundamental geometrical dimensions (Fig.3). The received results were verified by measurements using RLC-bridge and necessary calculations.

3. Multiconductor Transmission Line Equations

With the aim of estimation of the effects of complicated phenomena appearing in transmission lines and for determination of the voltages and currents at the front and end of the lines, adequate differential equations should be solved (Fig. 4). Additional difficulty in CAN-bus lines makes disadvantageous wires coupling and manufacturing asymmetry. They cause possibility of the mutual generation and penetration of disturbances.

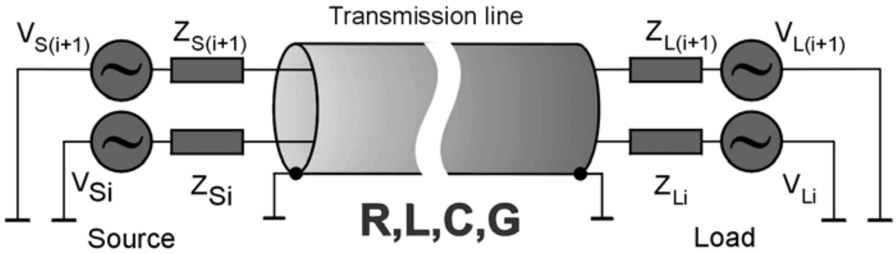

Fig. 4. General view of transmission line

The signal propagation analysis in differential lines of CAN-bus has been made - in the considered case, based on previous investigations in area of transmission lines modelling – with selection the operator method. Its idea lays on conversion from time to frequency domain, solving of differential equations for assumed harmonics and making the back conversion to the time domain.

$$\begin{cases} \dfrac{d^2}{dz^2}\underline{\mathbf{U}}(z,s) = \underline{\mathbf{Z}} \cdot \underline{\mathbf{Y}} \cdot \underline{\mathbf{U}}(z,s) \\ \dfrac{d^2}{dz^2}\underline{\mathbf{I}}(z,s) = \underline{\mathbf{Y}} \cdot \underline{\mathbf{Z}} \cdot \underline{\mathbf{I}}(z,s) \end{cases} . \tag{7}$$

With assumption that u(z,t), i(z,t) are voltage and current vectors, respectively, while R, L, C, G – per-unit-length matrices of transmission line (determined in the above-mentioned way) the equations can be expressed as (according to the operational calculus):

$$\underline{\mathbf{U}}(z,s) = \mathbf{L}\ (u(z,t)),\ \underline{\mathbf{I}}(z,s) = \mathbf{L}\ (\mathbf{i}(z,t)), \tag{8}$$

where $\mathrm{L}\left(\dfrac{\partial}{\partial t}\right) = j\omega = s$. After substitution $\underline{\mathbf{Z}} = \mathbf{R} + s\mathbf{L}$, $\underline{\mathbf{Y}} = \mathbf{G} + s\mathbf{C}$ and assuming $\underline{\mathbf{U}}$(z,0)=0, I(z,0)=0 we can get the system of equations uncoupled in relation to voltage and current vectors. Such equation, as second-order differential equation with constant coefficients, has a solution for one-element impedance and admittance matrixes. For multiconductor lines the solution is possible (providing that the transformation allowing separation of equations connected by matrixes $\underline{\mathbf{Z}} = \mathbf{R} + s\mathbf{L}$, and $\underline{\mathbf{Y}} = \mathbf{G} + s\mathbf{C}$ will be introduced). Using transformation these matrixes by analogy can be reduced to the diagonal form:

$$\underline{\mathbf{z}} = \mathbf{T}_U^{-1}\underline{\mathbf{Z}}\mathbf{T}_I = \begin{bmatrix} z_1 & 0 & \cdots & 0 \\ 0 & z_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & z_M \end{bmatrix},\quad \underline{\mathbf{y}} = \mathbf{T}_I^{-1}\underline{\mathbf{Y}}\mathbf{T}_U = \begin{bmatrix} y_1 & 0 & \cdots & 0 \\ 0 & y_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & y_M \end{bmatrix}. \tag{9}$$

Taking into account the long-lines property (product of admittance and impedance diagonal matrixes gives a matrix of squares_of constant propagation $\boldsymbol{\gamma}^2$) and knowing the general solution of such differential equations type we can write algebraic equations system in a form showing below for currents:

$$\underline{\mathbf{I}}_{mi}(z,s) = \exp(-\gamma_i \cdot z)\cdot \underline{\mathbf{I}}_{mi}^{+} - \exp(\gamma_1 \cdot z)\cdot \underline{\mathbf{I}}_{mi}^{-}. \tag{10}$$

After determination of the integral constants $\mathbf{I}_m^+, \mathbf{I}_m^-$ from the boundary conditions, the real currents flowing in wire system can be calculated (after reverse transformation). In similar procedure, the solution of voltage equations can be obtained. Finally we have:

$$\begin{aligned}\underline{\mathbf{I}}(z,s) &= \mathbf{T}_I\cdot\underline{\mathbf{I}}_m(z)=\mathbf{T}_I\left(\exp(-\gamma\cdot z)\cdot\underline{\mathbf{I}}_m^+ - \exp(\gamma\cdot z)\cdot\underline{\mathbf{I}}_m^-\right)\\ \underline{\mathbf{U}}(z,s) &= \underline{\mathbf{Z}}_C\mathbf{T}_I\left(\exp(-\gamma\cdot z)\cdot\underline{\mathbf{I}}_m^+ + \exp(\gamma\cdot z)\cdot\underline{\mathbf{I}}_m^-\right)\end{aligned}, \tag{11}$$

where $\underline{\mathbf{Z}}_C$ is the matrix of characteristic impedances of transmission line system.

The presented (in broad outline) method of telegraphers' equation solution is the basis of elaboration of the program of signal propagation process calculations in transmission lines.

To find the system response on defined input function, in the frequency domain U(ω), it requires multiplying of the system transmittance H(ω) by frequency representation of the input signal $U_G(\omega)$. Inside the assumed discrete frequency spectrum of the analysed signal, the module |H(ω)| and phase $\varphi_H(\omega)$ of transfer function can be calculated (for frequencies of harmonics and their number Nh). Those values allow calculating the signal representation in time domain with the help of inverse Laplace transforms:

$$\begin{aligned}u(t) &= \mathbf{L}^{-1}U(\omega)=H(0)\cdot U_G(0)+\sum_{n=1}^{Nh}\left|H\left(n\frac{2\pi}{T}\right)\right|\cdot\left|U_G\left(n\frac{2\pi}{T}\right)\right|\cdot\\ &\cos\left(n\frac{2\pi}{T}t+\varphi_H\left(n\frac{2\pi}{T}\right)+\varphi_G\left(n\frac{2\pi}{T}\right)\right)\end{aligned}. \tag{12}$$

4. Transmission Line Networks

The above-mentioned considerations are insufficient in the case of real CAN-bus line. CAN-bus is the heterogeneous system, which consists of many segments having different properties related to signal propagation. It results from the non-restrictive selection role of various types of transmission lines, users adopted topology for, random bus node placement, etc.

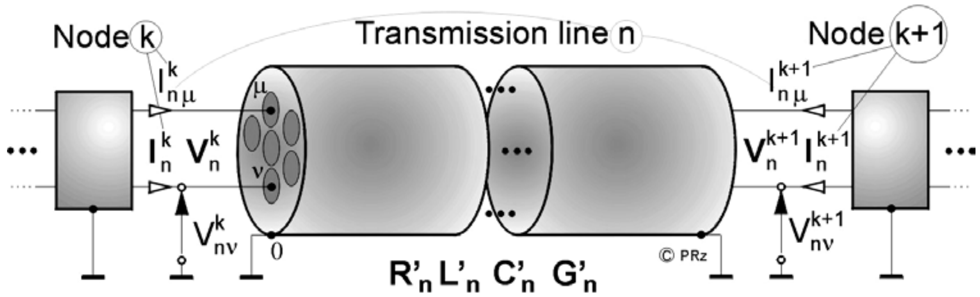

Fig.5. Illustration of dividing principle of heterogeneous line into homogeneous segments

From the point of view of the propagation parameters simulation in such transmission lines, the most important are following aspects:

- location of nodes in particular points of network in relation to current requirements; it causes that system sets the connection of many different transmission lines with nodes which play the role of loads in particular network segments;
- use of different network topologies (bus, star, mixed systems), possible application of different types of wires in various manners installed in the same network;
- node connections in the form of branches, connection with measuring and service devices;

Taking into account those factors it should be noted that CAN-bus, may be divided into N-segments. Each segment can be represented by homogenous model of transmission line with parameters possible to be established.

The voltages and currents for adequate segments of presented lines can be made_dependent on each other. For each node the equation is as follows:

$$..+\underline{\mathbf{Y}}_i^n\cdot\underline{\mathbf{V}}_i^n+\underline{\mathbf{Z}}_i^n\cdot\underline{\mathbf{I}}_i^n+\underline{\mathbf{Y}}_j^n\cdot\underline{\mathbf{V}}_j^n+\underline{\mathbf{Z}}_j^n\cdot\underline{\mathbf{I}}_j^n+..=\underline{\mathbf{P}}^n\cdot \tag{13}$$

Making a number of transformations those expressions can be presented in matrix form:

$$\left[(\underline{\mathbf{Y}}_i^n + \underline{\mathbf{Z}}_i^n \mathbf{Y}_{Si})\ldots(\underline{\mathbf{Y}}_j^n + \underline{\mathbf{Z}}_j^n \mathbf{Y}_{Sj})\ldots(\underline{\mathbf{Z}}_i^n \mathbf{Y}_{Mi})\ldots(\underline{\mathbf{Z}}_j^n \mathbf{Y}_{Mj})\right]\begin{bmatrix}\underline{\mathbf{V}}_i^n \\ \underline{\mathbf{V}}_j^n\end{bmatrix} = \left[\underline{\mathbf{P}}^n - \underline{\mathbf{Z}}_i^n \mathbf{I}_{Si}^n - \underline{\mathbf{Z}}_i^n \mathbf{I}_{Si}^n\right]. \quad (14)$$

From those relations the boundary conditions for particular line segments can be found by transformation, as was described above.

5. CAN-Bus Line Calculations and Measurements

On the basis of conducted considerations, the algorithms for practical application of the solution of the particular partial problems have been produced. Thanks to them it was possible to elaborate the CANCAN program (***C**ontroller **A**rea **N**etwork **C**alculator **AN**alyser*) for signal propagation analysis in CAN-bus transmission lines. For the sake of complexity of the particular procedures and from the need of use of advanced mathematical functions they were applied in MathCAD program. Only the data windows were made in Visual C++ (Fig.6).

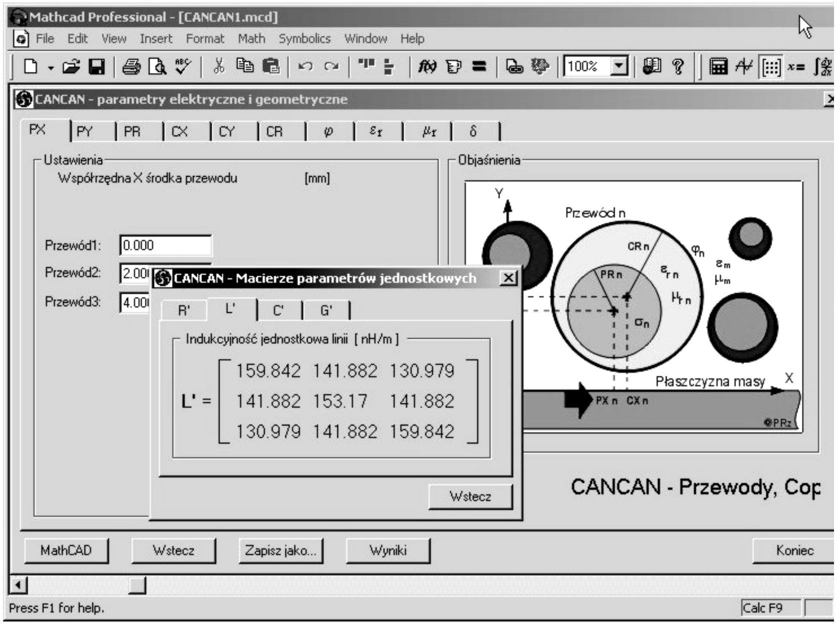

Fig. 6. General view of main data acquisition and resulting windows of CANCAN-program

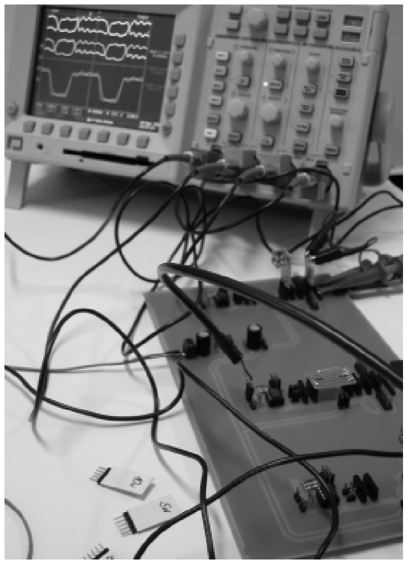

Fig. 7. View of elaborated CAN-bus testing stand

With the aim of verification of the performed investigations the voltage measurements were made in test circuit of CAN-bus together with calculations of adequate waveforms with the help of elaborated programs. The experiments were carried out for bus made from the strapped flat wires with node limitation to 3 (Fig.7). The source node was supplied from HP34120A generator by signal with transmission frequency relevant for required speed (for example for 1Mb/s f=500kHz). The signal parameters transmitted in bus lines were logged and measured using digital oscilloscope Tektronix TDS3242 type. The selected results of investigations are presented in Fig.8.

During laboratory tests it was revealed that applying of matched resistors (with recommended value equal 120□) didn't give the desirable results because the characteristic impedance of used wires was equal about 172 □. The tolerance it is observed with 25% tolerance value. The bus loading by nodes causes the deterioration of line matching, so it can be eliminated by correction of matching element values. In spite of significantly reshaping (deformed) signals of CAN-H and CAN-L lines, the differential signal revealed small changes of the voltage value (2-3%).

The influence of bus loading with increased number of nodes on the bus operation has been checked (especially on an increase of signal propagation time) – Fig.8. For example - with 20 nodes placed at the end of bus the increase is about 25ns (it responds to line lengthen to additional 9m for line with propagation time about 5ns/m). The investigations for determination of the ground potential shifts of the particular nodes and cross talks in supplying line have been also made. The significant influence of the currents in supplying and ground line on the ground potential (for example the last node) has been proved. Similarly, with the increasing of the supplying line load the increase of the cross-talk in this line has been observed.

a) *b)*

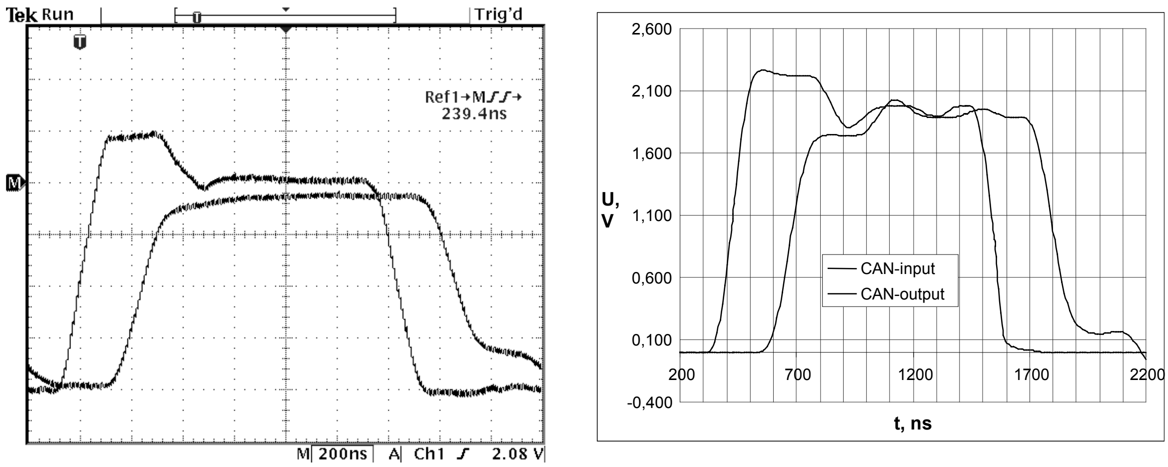

Fig. 8. An example of measurements (a) and simulations (b) results of CAN-bus loaded with 20. nodes at the end of 40m length line with terminations RT=120Ω (input and output)

The obtained results – in spite of a certain imperfection (especially regarding the program for signal propagation analysis) – allow drawing some conclusions about the correctness of assumptions in realising the configuration of CAN controllers. First of all, the signal propagation times between particular nodes can be determined. It was proofed that the times are dependent on number of nodes and their placement. It plays a very important role for proper system configuration. It is also possible to calculate the voltage drops in transmission lines and ground wire to determine if the received values are not too large to provide adequate voltage levels for proper transceivers operation.

By analysis of the characteristic impedance matrixes of transmission lines the selection of differential mode termination can be modified and – if necessary – proper common mode termination can be introduced.

6. Conclusions

The results of investigations have proofed the possibilities of parameters calculation, required to choose relevant CAN controller configuration during the design. Elaborated CANCAN-program allow calculation of time of the signal propagation and voltage drops in the lines in relation to wire types and their configuration. It allows checking the correctness of applied assumptions and indicates the modification areas. These calculations are expected to be most useful in critical cases (max. speed, max. length, number of nodes). Actually the programs are suitable rather for the easiest practical cases, however conducted investigations are aimed to extend the CAN-bus analysis on any real configuration or any data transmission buses, e.g. USB and J-1394 “Fire-wire”.

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З.А. Дутчак, Г.О. Павлова, Л.М. Ракобовчук, Б.М. Яворський
Національний університет "Львівська політехніка",
кафедра електронних приладів

ЕЛЕКТРООПТИЧНІ ВЛАСТИВОСТІ КОЛОВОЇ ТЕКСТУРИ НРК

Отримана оригінальна текстура НРК, в якій молекули розташовані своїми довгими осями по дотичних до концентричних кіл у площині шару рідкого кристала або під деяким кутом до неї. Досліджено електрооптичні властивості отриманої колової текстури в поляризованому світлі. Виявлено, що за похилого падіння світла в схрещених поляризаторах в зростаючому електричному полі спостерігалось виникнення та напрямлений рух темних секторів симетрично до осі повороту текстури. Наведена модель, на основі якої пояснені властивості колової текстури.

The original texture of NLC, in which molecules locate by the long axes on tangent to the concentric circles in plane of liquid crystal layer or under some corner to ones, was got. The electro-optical properties of this circle texture in the polarized light were investigated. It was determined that at the sloping falling of light in crossed polarizes in the growing electric field there was the appearance and directed motion of dark sectors symmetric to the turn axis of texture. The resulted model on the basis of which the circle texture properties was explained.

Для визначення структури і властивостей рідких кристалів (РК) важливе значення має дослідження їх під мікроскопом в природному та поляризованому світлі. Спостережувані при цьому картини – текстури дають змогу судити про ступінь орієнтації молекул у зразку і приналежність його до того чи іншого типу РК або його модифікації.

У нематичних рідких кристалах (НРК) розрізняють декілька принципових груп текстур, що найчастіше зустрічаються: ниткоподібну, гомогенну, гомеотропну, закручену, мармурову і шлірен-текстуру [1–3]. Всі перераховані текстури, окрім першої, утворюються в тонких (10–50 мкм) шарах НРК і своїм походженням зобов'язані переважно взаємодією з обмежувальними поверхнями – підкладками.

Отримана колова текстура НРК, яка володіє оригінальними електрооптичними властивостями. У цій текстурі молекули рідкого кристала розташовуються своїми довгими осями по концент-