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Simulations of Far-end Crosstalk based on Modified Matrices of Transmission Line

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Introduction

The current access telecommunication networks still consist mostly of metallic pairs. These cables are actually used for high-speed digital transmission systems, such as digital subscriber lines (xDSL). These subscriber lines provide affordable and cheap connections mainly for residential use and small business companies [1]. The next generation of xDSL digital subscriber lines, e.g. VDSL2, could provide higher transmission bitrates, but there are several problems related with the usage of metallic lines and cables, which need to be solved first. The major problem, which appears in large metallic networks, is crosstalk [2]. It comes from unbalanced capacitive and inductive couplings between single copper pairs, their quads and multi-quads [3]. These pairs demonstrate towards themselves small irregularities, which are caused by manufacturing tolerances, deformations and other specific reasons [3]. The influence of near-end crosstalk (NEXT) can be easily limited by separating transmission directions using different frequency bands, but the reduction of far-end crosstalk (FEXT) is not so easy and therefore FEXT is a dominant source of disturbance. One of the most promising solutions for the elimination of FEXT is Vectored DMT modulation (VDMT) [4]. This modulation is an upgrade of previous Discrete Multi-tone modulation (DMT) and it offers the cancellation of FEXT crosstalk by coordinating the transmitted DMT symbols [5]. It would be possible to perform the VDMT modulation only for a limited number of the most disturbing pairs in a cable, which would simplify the whole process of coordination [6]. However, this method would require very accurate prediction of crosstalk behavior and realistic modeling of FEXT for all mutual combinations of pairs in a cable. That is why a new advanced method of FEXT modeling is necessary to implement. The present standard FEXT model [7] comes only from the averaged crosstalk values for the whole cable and it uses only one crosstalk parameter given for the whole cable. It is obvious that such model cannot be very accurate and therefore provides only approximate and not very realistic results, as presented in [8]. The accuracy of this model can be sufficient for some specific applications (e.g. summarization of many contributions), but the simple standard FEXT model is not very useful for the precise modeling of perspective VDSL2 lines using VDMT concept. The main problem represents the individual method for modeling of transmission channels and FEXT transmission functions, which is necessary for the implementation of VDMT modulation for all combinations of pairs in a cable.

This paper presents a new innovative method of FEXT modeling, which is based on simulations and calculations of capacitive and inductive unbalances between pairs in a cable and using cascade matrices of a transmission line. The paper follows authors' previous publications describing the method of using space selection of disturbing pairs among the whole cable based on their crosstalk contributions [8]. The first part brings a description and calculations of capacitive and inductive unbalances and their influence on resulting crosstalk currents for the case of two parallel pairs in a cable. Then this derivation will be compared with a formula for standard simple FEXT model to verify its mathematical correctness. Based on these conclusions, the new advanced method for FEXT simulation, using cascade description of the transmission line and unbalances, will be proposed. The results of simulations will be also compared with standard FEXT model as well as with measured results.

General expression of far-end crosstalk

The elementary unit of a standard telecommunication cable generally consists of two insulated wires twisted uniformly to form a balanced pair [3]. By twisting four insulated wires together uniformly a star-quad is formed. Several quads are typically twisted together to form a subgroup of pairs (or quads), these subgroups can be further twisted and gathered according to a cable's internal structure and they can be also covered by screening to form grounded shielding and to separate each subgroup of pairs. Interstices among pairs, quads and subgroups are usually filled with a gel or air. The resulting transmission parameters of a cable are determined according to a method of manufacturing and internal structure, types of used materials and their processing. Several parameters are to be measured and checked during the process of cable's manufacturing, and they must meet specified tolerances. Based on these tolerances, pairs, quads and subgroups in a cable demonstrate towards themselves small irregularities and unbalances. Capacitive and inductive unbalances and couplings are the main source of crosstalk among them. These capacitive and inductive couplings in a quad of four wires form an unbalanced bridge. It is possible to express resulting capacitive unbalance C_{ub} and inductive unbalance M_{ub} using the star-polygon transformation. The calculation of these unbalances based on the geometrical structure of the quad and other parameters of the materials, was presented e.g. in [3].

The far-end crosstalk is caused by disturbing currents, penetrating from the disturbing pair to the parallel disturbed pair, due to the capacitive and inductive unbalances between them, which is described below.

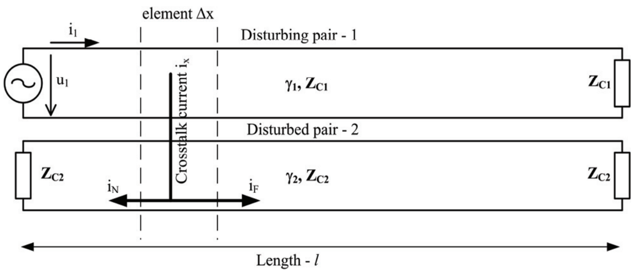

Fig. 1. The schematic situation of parallel disturbing and disturbed pairs

We are able to assume the situation with two parallel pairs in a cable, where the near-end of the disturbing pair contains the source of signal u_1 with total current i_1. The pair is correctly terminated on its far-end by the characteristic impedance of this pair Z_{C1}. The disturbed pair is properly terminated on its both ends by its characteristic impedance Z_{C2}. The propagation constants of both pairs are γ_1 and γ_2 respectively. The length of both pairs is l. The infinitely short element Δx contains a total capacitive unbalance $C_{ub}\Delta x$ through which the capacitive crosstalk current i_C propagates from the disturbing pair into the disturbed pair. This element also contains the inductive unbalance $M_{ub}\Delta x$, which causes the origination of inductive crosstalk voltage u_M in the disturbed pair. The sum of both crosstalk disturbances is the total crosstalk current i_x, which propagates along the disturbed pair to its near-end as a current i_N where it causes the near-end crosstalk, NEXT and another part propagates also to the far-end as a current i_F where it causes the far-end crosstalk, FEXT.

The crosstalk current i_{Cx}, which comes from the capacitive unbalance $C_{ub}\Delta x$ can be expressed as

$$i_{Cx} = \frac{u_{Cx}}{\dfrac{1}{j\omega C_{ub}\Delta x} + \dfrac{Z_{C2}}{2}}. \quad (1)$$

The term with Z_{C2} in the denominator may be neglected and the expression simplified. The voltage in the capacitive unbalance in the element Δx is given as

$$u_{Cx} = Z_{C1} \cdot i_1 \cdot e^{-\gamma_1 x} \quad (2)$$

and therefore the equation (1) can be expressed as

$$i_{Cx} = j\omega C_{ub}\Delta x \cdot Z_{C1} \cdot i_1 \cdot e^{-\gamma_1 x}. \quad (3)$$

This current is divided, one half propagates to the near-end, while the second half to the far-end of the disturbed pair. The current, which is caused by capacitive unbalance and appears at the far-end - i_{CF}, can therefore be calculated

$$i_{CF} = \frac{1}{2} j\omega C_{ub}\Delta x \cdot Z_{C1} \cdot i_1 \cdot e^{-\gamma_1 x} \cdot e^{-\gamma_2 (l-x)}. \quad (4)$$

It is also possible to express the crosstalk voltage u_{Mx}, which comes from the inductive unbalance $M_{ub}\Delta x$ as

$$u_{Mx} = j\omega M_{ub}\Delta x \cdot i_{Mx} = j\omega M_{ub}\Delta x \cdot i_1 \cdot e^{-\gamma_1 x}. \quad (5)$$

The crosstalk current coming from the inductive unbalance and propagating at the far-end - i_{MF} can be calculated as

$$i_{MF} = -\frac{u_{Mx}}{2Z_{C2}} = -j\omega \frac{M_{ub}\Delta x}{2Z_{C2}} \cdot i_1 \cdot e^{-\gamma_1 x} \cdot e^{-\gamma_2 (l-x)}. \quad (6)$$

Based on the previous equations (4) and (6) it is possible to derive the summary far-end crosstalk current from both unbalances originating in the element Δx

$$i_F = i_{CF} + i_{MF} = \\ = \frac{1}{2} j\omega \cdot i_1 \cdot e^{-\gamma_1 x} \cdot e^{-\gamma_2 (l-x)} \cdot \left(Z_{C1} C_{ub}\Delta x - \frac{M_{ub}\Delta x}{Z_{C2}} \right). \quad (7)$$

To obtain the standard FEXT model, it is necessary to adjust the equation (7) and to consider some simplifying assumptions, as described in [7]. Capacitive C_{ub} and inductive M_{ub} unbalances in a real metallic cable are generally varying along the cable, so they can be expressed as a function of their position x. It is possible to assume both unbalances constant and equal to their mean values for the whole length of a cable l in case of the simplified standard FEXT model, so they are constant and independent on their positions x. Thanks to this assumption, it is possible to consider the element Δx as infinitely short and to express it by using differential term dx. Another simplification considers the transmission parameters of both pairs within the same cable to be identical (γ, Z_C).

The equation (7) may be modified in accordance to these simplifications as

$$i_F = j\omega \cdot \underbrace{Z_C \cdot i_1}_{u_1} \cdot \underbrace{e^{-\gamma x} \cdot e^{-\gamma(l-x)}}_{e^{-\gamma l}} \cdot \underbrace{\frac{1}{2}\left(\overline{C_{ub}} - \frac{\overline{M_{ub}}}{Z_C^2}\right)}_{\text{Summary coupling - C}'} =$$

$$= j\omega \cdot u_1 \cdot e^{-\gamma l} \cdot C'. \tag{8}$$

The FEXT power transfer function is defined by

$$\left|H_{FEXT}(f)\right|^2 = \frac{P_{FEXT}(f)}{P_1(f)}, \tag{9}$$

where $P_{FEXT}(f)$ represents the power function of far-end crosstalk and $P_1(f)$ the input power function at the near-end of a disturbing pair. The FEXT power transfer function may be obtained by an integration of crosstalk contributions (8) for the length l

$$P_{FEXT}(f) = \left|Z_C\right| \cdot i_F^2 =$$

$$= \left|Z_C\right| \cdot \omega^2 \cdot u_1^2(f) \cdot C'^2 \cdot \int_0^l -e^{-2\gamma x} \cdot dx. \tag{10}$$

It is possible to express FEXT power transfer function (9) assuming electrically long pairs and (10) as

$$\left|H_{FEXT}(f)\right|^2 = \frac{P_{FEXT}(f)}{P_1(f)} = \frac{\left|Z_C\right| \cdot i_F^2}{\frac{u_1^2}{\left|Z_C\right|}} =$$

$$= \frac{\left|Z_C\right| \cdot \omega^2 \cdot u_1^2(f) \cdot C'^2 \cdot l \cdot \left|H(f)\right|^2}{\frac{u_1^2(f)}{\left|Z_C\right|}} =$$

$$= K_{FEXT} \cdot f^2 \cdot l \cdot \left|H(f)\right|^2, \tag{11}$$

where K_{FEXT} is a crosstalk parameter (a constant for the selected combination of pairs), which represents the summary rate of capacitive and inductive couplings between specific pairs. $|H(f)|^2$ is the power transfer function of a pair, f is the frequency and l represents the length of both pairs. Following the previous modifications, it is obvious, that

$$K_{FEXT} = \left|Z_C\right|^2 \cdot 4\pi^2 \cdot C'^2. \tag{12}$$

Therefore K_{FEXT} crosstalk parameter is expressed through the integration of capacitive and inductive unbalances in (10). The equation (11) represents the standard simple FEXT model, which is presented in [7]. It is obvious that thanks to the previous simplifications and assumptions, this standard FEXT model with only one crosstalk parameter cannot be very accurate and that it provides only approximate results, which are presented as mean values of the summary crosstalk characteristics for the whole cable.

Innovative advanced FEXT model based on cascade matrices and capacitive unbalances

The previously derived standard FEXT model uses several simplifications and assumptions. The most negative circumstance is the consideration of constant capacitive and inductive unbalances and their independence on the position x. However, for accurate and realistic FEXT modeling, it is necessary to assume varying unbalances along a cable. Nevertheless, analytical expression of these functions $C_{ub}(x)$, $M_{ub}(x)$, could be mathematically quite difficult. The values of these functions are probably varying pseudo-randomly in the interval given by manufacturing tolerances and other influences in a cable. It is possible to assume that the character of these functions would behave as a normal distribution with the deviation given by these tolerances and imperfections of a cable. That’s why it is not possible to use the operation of integration of crosstalk contributions.

One of the initial ideas of new model is using a space selection of disturbing sources and respecting the internal structure of a metallic cable. For that reason, extensive measurements of real metallic cables were performed. More detailed description of cables and performed measurements together with results was presented in [10]. Based on these results, several conclusions about the allocation of disturbing sources in the cable may be made [8]. The summary conclusion of performed measurements is that there are significant differences among the crosstalk levels of each category - pairs in the same subgroup, pairs in the surrounding subgroups and pairs in the distant subgroups. This dependence of FEXT crosstalk on the relative position of disturbing and disturbed pair will be further used for more accurate FEXT modeling.

Several models of FEXT crosstalk using capacitive and inductive unbalances and impedance or cascade matrices have been already presented, or models using pseudo-randomly generated components, but these models are mathematically quite complex and require many parameters typically. Proposed innovative method of FEXT modeling, which is presented here, and which is based on the description of sub-elements and sections using cascade matrices, can offer less complexity and computational demands while maintaining a sufficiently accurate method of modeling. The main idea of this advanced FEXT model is dividing the whole cable into several transmission sub-sections with transmission lines, crosstalk coupling and the bridge taps from the unused ends of both symmetrical pairs. Each section is described by its cascade matrix and the final crosstalk current is calculated by their multiplication. Several assumptions are necessary to be defined first.

The model does not include the impact of a crosstalk across the third lines, or an indirect effect of the crosstalk originating from reflections from the ends of the unused lines. Total crosstalk coupling is summarily expressed by its inductive and capacitive components, but the inductive part is approximated by the capacitive unbalance. This assumption is based on previous theoretical considerations

[3], according to which the impact of inductive coupling can be modeled by an additional capacitance unbalance and these two parts are included in the summary capacitive unbalance C' [1]. The last simplification of the model concerns the question of simulation and determination of the capacitive unbalance. It could be very complicated to express its values mathematically. Moreover, these values are usually pseudo-random and therefore are influenced by many internal and/or external effects. That is why a simple method for generating pseudo-random values using formulas of normal distribution and the proper statistical values is used in the model. Based on the previous assumptions it is possible to provide a schematic model of the whole situation, Fig. 2. Standard models for crosstalk between two pairs are usually based on the description of 4-port network, or two coupled 2-port networks, but for the basic crosstalk modeling, the simple 2-port model is sufficient.

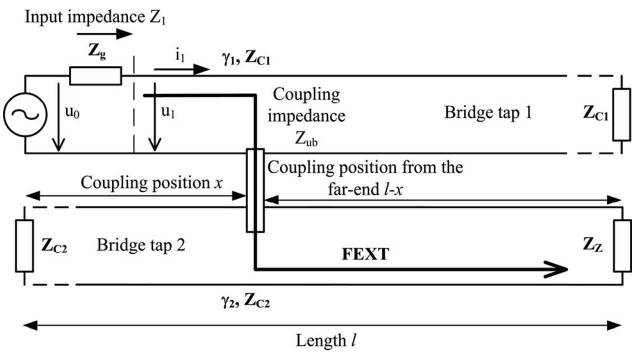

Fig. 2. The cascade elements of proposed FEXT model

The signal generator with output voltage u_0 and internal impedance Z_g is located at the input of disturbing pair. The input impedance of the whole system Z_I provides the total current i_I and voltage u_I. The summarized capacitive coupling C' represented by the impedance Z_{ub}, is situated in the position x from the near-end of a cable and l-x from the far-end of a cable, where l is the total length. This unbalance is situated in series with the generator from the perspective of FEXT crosstalk. The first bridge tap, which consists of the unused part of the disturbing pair of length l-x, is connected to the unbalance in parallel. Also the unused section of the disturbed pair, which forms the second bridge tap of the length x, is connected in parallel. The rest of the disturbed pair with length l-x is connected in series from the perspective of FEXT crosstalk. The far-end of the disturbed pair is terminated by the load impedance Z_Z. The propagation constant of disturbing pair is γ_1 and that of disturbed pair γ_2. The ends of both bridge taps are opened, but the model could be further modified by terminating the taps by impedances Z_{C1} and Z_{C2}.

The expression of cascade matrix for standard telecommunication line may be obtained from telegraph equations [3]. The cascade matrix may be defined for a symmetrical pair with characteristic impedance Z_C, propagation constant γ and length l:

$$\begin{pmatrix} u_1 \\ i_1 \end{pmatrix} = \begin{pmatrix} \cosh(\gamma(f)\cdot l) & Z_C(f)\cdot\sinh(\gamma(f)\cdot l) \\ \dfrac{\sinh(\gamma(f)\cdot l)}{Z_C(f)} & \cosh(\gamma(f)\cdot l) \end{pmatrix} \cdot \begin{pmatrix} u_2 \\ i_2 \end{pmatrix}. \tag{13}$$

The cascade matrix for bridge tap of length l comes from the derivation for parallel impedance:

$$\begin{pmatrix} u_1 \\ i_1 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \dfrac{1}{Z_C(f)\cdot\coth(\gamma_1(f)\cdot l)} & 1 \end{pmatrix} \cdot \begin{pmatrix} u_2 \\ i_2 \end{pmatrix} \tag{14}$$

and the general cascade matrix for the impedance Z connected in series:

$$\begin{pmatrix} u_1 \\ i_1 \end{pmatrix} = \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} u_2 \\ i_2 \end{pmatrix}. \tag{15}$$

Now, it is possible to express the cascade matrices for the situation described in the Fig. 2 using previous formulas. The cascade matrix of the transmission section of disturbing pair with the length x as:

$$\mathbf{P_1} = \begin{pmatrix} \cosh(\gamma_1(f)\cdot x) & Z_{C1}(f)\cdot\sinh(\gamma_1(f)\cdot x) \\ \dfrac{\sinh(\gamma_1(f)\cdot x)}{Z_{C1}(f)} & \cosh(\gamma_1(f)\cdot x) \end{pmatrix}. \tag{16}$$

The cascade matrix of the first bridge tap, which consists of the unused section of disturbing pair with the length l-x:

$$\mathbf{O_1} = \begin{pmatrix} 1 & 0 \\ \dfrac{1}{Z_{C1}(f)\cdot\coth(\gamma_1(f)\cdot(l-x))} & 1 \end{pmatrix}. \tag{17}$$

The cascade matrix of the coupling impedance Z_{ub}:

$$\mathbf{V} = \begin{pmatrix} 1 & Z_{ub} \\ 0 & 1 \end{pmatrix}, \tag{18}$$

where the impedance Z_{ub} according to the previous assumptions may be calculated

$$Z_{ub} = \frac{1}{j\omega C'}. \tag{19}$$

The cascade matrix of the second bridge tap, which represents the unused near-end of the disturbed pair with the length x:

$$\mathbf{O_2} = \begin{pmatrix} 1 & 0 \\ \dfrac{1}{Z_{C2}(f)\cdot\coth(\gamma_2(f)\cdot x)} & 1 \end{pmatrix}. \tag{20}$$

And finally, the cascade matrix of the rest transmission part of the disturbed pair, which is terminated by the impedance Z_Z at its far-end:

$$\mathbf{P_2} = \begin{pmatrix} \cosh(\gamma_2(f)\cdot(l-x)) & Z_{C2}(f)\cdot\sinh(\gamma_2(f)\cdot(l-x)) \\ \dfrac{\sinh(\gamma_2(f)\cdot(l-x))}{Z_{C2}(f)} & \cosh(\gamma_2(f)\cdot(l-x)) \end{pmatrix}. \quad (21)$$

The resulting cascade matrix **W** may be expressed by the multiplication of cascade matrices for all sections:

$$\mathbf{W} = \mathbf{P_1}\cdot\mathbf{O_1}\cdot\mathbf{V}\cdot\mathbf{O_2}\cdot\mathbf{P_2} = \begin{pmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \end{pmatrix}. \quad (22)$$

The far-end crosstalk current, which comes from one unbalance situated in the position x, may be calculated:

$$\begin{cases} \begin{pmatrix} u_1 \\ i_1 \end{pmatrix} = \begin{pmatrix} w_{11} & w_{12} \\ w_{21} & w_{22} \end{pmatrix}\cdot\begin{pmatrix} u_{Fx} \\ i_{Fx} \end{pmatrix}, \\ \dfrac{i_{Fx}(f)}{u_0(f)} = \dfrac{Z_g + Z_Z}{Z_Z\cdot\left(Z_Z\cdot w_{11} + w_{12} + Z_g\cdot Z_Z\cdot w_{21} + Z_g\cdot w_{22}\right)} \end{cases}. \quad (23)$$

To calculate FEXT attenuation, it is necessary to summarize all contributions of crosstalk currents for the whole length l as

$$\frac{i_F(f)}{u_0(f)} = \sum_l \frac{i_{Fx}(f)}{u_0(f)}, \quad (24)$$

therefore, the FEXT attenuation can be expressed as

$$A_{FEXT}(f) = 20\cdot\log\left|\frac{1}{Z_Z(f)\cdot\sum_l \dfrac{i_{Fx}(f)}{u_0(f)}}\right| \quad [dB]. \quad (25)$$

The results obtained by the presented method for FEXT crosstalk modeling are presented for metallic cable with the specification TCEPKPFLE 75x4x0.4 and length l = 400 m. The primary parameters may be simulated using British Telecom model; it is necessary to obtain the characteristic impedances of pairs Z_{C1}, Z_{C2} and the propagation constants γ_1 and γ_2. The next step requires dividing the cable into several sub-sections with different crosstalk couplings. For this reason, the whole cable was divided into sections of 1 m each, which means 399 capacitive unbalances (400-1) for the whole cable of the length 400 m. Then the crosstalk currents derived from all sections are summarized. It is possible to calculate the summary capacitive unbalance from the crosstalk parameter K_{FEXT} in accordance with (12). Based on the previous conclusions about the influence of internal structure of a cable on resulting FEXT crosstalk, the K_{FEXT} parameter may be calculated for three main categories - the pairs within the same subgroup, pairs from surrounding subgroups and pairs from distant subgroups. The value of capacitive unbalance C' for each category may therefore be calculated using the measured K_{FEXT} parameter and equation (12). The K_{FEXT} parameter is usually derived for a cable with the length of 1000 m that's why it is necessary to provide recalculation for the situation of capacitive unbalance for sections - 1 m in this case. The equation (12) could be hence modified to get the capacitive unbalance for the reference length of 1 m

$$C'\left[F/\sqrt{m}\right] = \frac{C'\left[F/\sqrt{km}\right]}{\sqrt{1000}} = \sqrt{\frac{K_{FEXT}}{|Z_C|^2\cdot 4\pi^2\cdot 1000}}. \quad (26)$$

The values of the summary unbalance, calculated according to (26) for TCEPKPKFLE cable, are presented in the next table.

Table 1. The calculation of capacitive unbalances

The recalculation	K_{FEXT}	C´ [F/√m]
Pairs within the same subgroup	9.9462.10^{-17}	5.0194.10^{-13}
Pairs from surrounding subgr.	1.292.10^{-17}	1.8090.10^{-13}
Pairs from distant subgroups	3.2040.10^{-18}	9.0087.10^{-14}

As it was described before, the behavior of capacitive unbalance is varying along the cable in the interval of values with characteristic, which can be predicted using the formulas for normal distribution. Therefore, the values of capacitive unbalance C' in the Tab. 1 were subsequently used as a standard deviation for generating the character of capacitive unbalance $C'(x)$ with the zero mean value. The values of parameter K_{FEXT} were obtained from measured characteristics of TCEPKPFLE cable as well as by using statistical processing. Based on previous equations of proposed advanced FEXT model (22), (23), (24) and (25) together with the pseudo-randomly generated $C'(x)$ characteristic, several examples of results were obtained. These results were compared with the measured characteristic and also with the standard FEXT model expressed by (11). The comparisons for different internal categories are presented in the following Fig. 3 and 4.

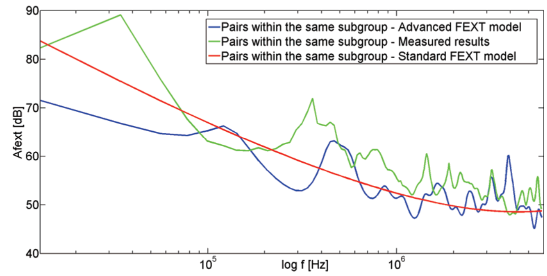

Fig. 3. The comparison of advanced FEXT model, standard FEXT model and measured results for pairs inside the same subgroup

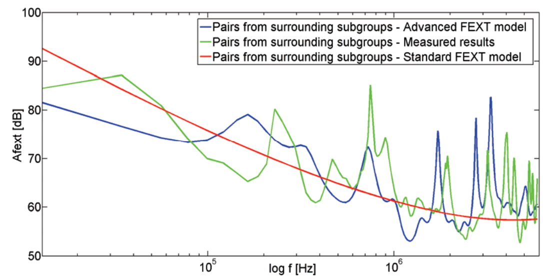

Fig. 4. The comparison of advanced FEXT model, standard FEXT model and measured results for pairs from two surrounding subgroups

Previous characteristics in the Fig. 3 and 4 give an example of presented advanced FEXT method of modeling, standard FEXT model and measured results for the frequency band to 6 MHz. It is obvious that unlike the standard FEXT model (presented in the graphs as a red line), the proposed advanced modeling method provides more precise and realistic results. The standard model uses only average values of crosstalk for the whole cable, the innovative advanced method based on the varying function *C′(x)* of both unbalances together with the influence of internal structure of the cable provides final results very close to the characteristics in real applications. The proposed advanced model reaches more realistic shapes of the transmission and crosstalk characteristics in a cable.

Conclusions

This paper presents new advanced method of far-end crosstalk modeling in metallic cables. Today, crosstalk represents the most serious disturbance factor in the current xDSL lines and it mostly limits the maximum transmission speed of these systems. It comes from the capacitive and inductive unbalances among pairs, quads and subgroups of pairs in a cable. These unbalances are caused mainly by manufacturing inaccuracies of a cable, internal and/or external deformations and other specific reasons. The full elimination of FEXT will probably come with the implementation of VDMT modulation. However, the reduction of crosstalk by VDMT is not possible in present systems due to its overall complexity and demands on computational units in DSLAMs. Therefore, it will be necessary to implement advanced methods for FEXT modeling to obtain accurate and realistic predictions of the crosstalk behavior in a cable. Thanks to that, it would be possible to apply VDMT only for a limited number of the most disturbing pairs to simplify the whole process.

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Far-end crosstalk (FEXT) is the dominant source of disturbance in digital subscriber lines. One of the most promising solutions for FEXT cancellation is Vectored Discrete Multi-tone modulation (VDMT). However, this process of elimination by VDMT is mathematically very complex and it causes high computational demands in multiplexors and terminals. The promising solution would be performing VDMT only for a limited number of the most disturbing pairs in a cable. However, this method would require very accurate and realistic simulations of FEXT and its individual prediction for each pair in a metallic cable. The standard simple FEXT model is not very accurate and does not provide realistic results. That’s why a new advanced method for modeling of FEXT was developed and is presented here. This advanced FEXT model is based on the modified transmission matrices together with calculation of capacitive and inductive unbalances between pairs in a cable and it also respects cable’s internal structure. This paper includes mathematical derivation of the advanced FEXT model as well as examples of obtained results, which are also compared with standard FEXT model and with measured characteristics. Ill. 4, bibl. 8, tabl. 1 (in English; abstracts in English and Lithuanian).

P. Lafata, J. Vodrazka. Kryžminių trikdžių imitavimas perdavimo linijos modifikuotų matricų pagrindu // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 10(116). – P. 39–44.

Nutolę kryžminiai trikdžiai (NKT) yra pagrindinis trikdžių šaltinis skaitmeninėse abonento linijose. Vienas iš perspektyviausių NKT panaikinimo sprendimų yra vektorinė diskrečioji multitoninė moduliacija (VDMT), Tačiau šis procesas yra labai sudėtingas matematiškai ir reikalauja daug skaičiavimo sąnaudų multiplekseriuose ir terminaluose. Priimtiniausia būtų atlikti tik riboto skaičiaus labiausiai trikdomų kabelio laidų porų VDTM. Standartinis NKT modelis yra nepakankamai tikslus ir neduoda realių rezultatų. Todėl buvo sukurtas naujas patobulintas NKT modeliavimo metodas. Išplėstinis NKT modelis pagrįstas modifikuota matricų transmisija. Išplėstinio modelio rezultatai palyginti su standartinio NKT modelio ir eksperimentiniais rezultatais. Il. 4, bibl. 8, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).