RESEARCH OF INTERFERENCE NOISE IN VDSL2 SYSTEMS WHEN OPERATING OVER TPP TYPE TELEPHONE CABLES

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Abstract. The article presents the results of the research of the interference noise in transmission systems using the VDSL2 technology when operating over TPP type telephone cables. The research was carried out by analyzing the modeling of VDSL2-systems with the frequency plan B8-6 [998-M2x-B] over TPP-0.4 type telephone cable using traditional orthogonal harmonic signals (OHS) and generalized class orthogonal harmonic signals (GC OHS). Interference noise for both downstream and upstream transmission directions was researched. Interference noise was estimated in relative values as a percentage ratio of the interference noise and signal effective values. The article presents three-dimensional diagrams of the dependence of the interference noise values distribution in channels from the integration beginning (start) moment when the line length varies from 200 to 500 meters. It was determined that interference noise is unevenly distributed in the VDSL2-system channels and their value significantly depends on the integration start sample number. The optimal values of the integration start are calculated by the criterion of the minimum of the arithmetic mean for all information channels of the interference noise value. The dependences of the interference noise distribution in the VDSL2-system channels are investigated when using traditional OHS and GC OHS with the optimal values of the integration start. The dependence of the interference noise in the VDSL2-system channels is analyzed depending on the line length, the type of the orthogonal harmonic signals and the transmission direction. The efficiency of the generalized class orthogonal harmonic signals application in comparison with traditional OHS application is proved. The significant influence of the quantity of adjacent channels on the interference noise value is determined.

Key words: VDSL2 technology, interference, transmission system, orthogonal harmonic signals, telephone cable.

ИССЛЕДОВАНИЕ ИНТЕРФЕРЕНЦИОННЫХ ПОМЕХ В СИСТЕМАХ VDSL2 ПРИ РАБОТЕ ПО ТЕЛЕФОННЫМ КАБЕЛЯМТИПА ТПП

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Анотація. У статті надані результати дослідження інтерференційних завад у системах передачі (СП) за технологією VDSL2 при роботі телефонними кабелями типу ТПП. Дослідження проводилося шляхом аналітичного моделювання роботи VDSL2-систем з частотним планом В8-6 [998-M2x-B] по телефонному кабелю типу ТПП-0,4 при використанні традиційних ортогональних гармонічних сигналів (ОГС) і ортогональних гармонічних сигналів узагальненого класу (ОГС УК). Дослідження інтерференційних завад проводилося як для низхідного, так і для висхідного напряму передачі. Залежність від інтерференційних завад оцінювалася у відносних величинах як відсоткове співвідношення ефективних значень інтерференційна завада/сигнал. У статті надані тривимірні графіки залежності розподілу по каналах значень інтерференційної завади від моменту початку
інтегрування при зміні довжини лінії від 200 до 500 метрів. Визначено, що інтерференційні завади розподілені нерівномірно по каналах СП VDSL2 і їх величина суттєво залежить від номера відліку початку інтегрування. Розраховано оптимальні значення відліку початку інтегрування за критерієм мінімуму середньоарифметичного по всіх інформаційних каналах значення інтерференційної завади. Досліджено залежності розподілу інтерференційних завад по каналах СП VDSL2 при використанні традиційних ОГС та ОГС УК при оптимальних значеннях відліку початку інтегрування. Проаналізовано залежність інтерференційних завад у каналах СП VDSL2 у залежності від довжини лінії, типу ортогональних гармонічних сигналів і напряму передачі. Доведено ефективність застосування ортогональних гармонічних сигналів узагальненого класу порівняно з традиційними ОГС. Визначено істотний вплив кількості сусідніх каналів на величину інтерференційних завад.

Ключові слова: технологія VDSL2, інтерференція, система передачі, ортогональні гармонічні сигнали, телефонний кабель.

Annотация. В статье приведены результаты исследования интерференционных помех в системах передачи (СП) по технологии VDSL2 при работе по телефонным кабелям типа ТТП. Исследование проводилось путем аналитического моделирования работы VDSL2-систем с частотным планом Вь-6 [998-М2х-В] по телефонному кабелю типа ТТП-0,4 при использовании традиционных ортогональных гармонических сигналов (ОГС) и ортогональных гармонических сигналов обобщенного класса (ОГС ОК). Исследование интерференционных помех проводилось, как для нисходящего, так и для восходящего направления передачи. Интерференционные помехи оценивались в относительных величинах как процентное соотношение эффективных значений интерференционная помеха/сигнал. В статье представлены трехмерные графики зависимости распределения по каналам значений интерференционной помехи от момента начала интегрирования при изменении длины линии от 200 до 500 метров. Определено, что интерференционные помехи распределены неравномерно по каналам СП VDSL2 и их величина существенно зависит от номера отсчета начала интегрирования. Рассчитаны оптимальные значения отсчета начала интегрирования по критерiuю минимума среднееарифметического по всем информационным каналам значения интерференционной помехи. Исследованы зависимости распределения интерференционных помех по каналам СП VDSL2 при использовании традиционных ОГС и ОГС ОК при оптимальных значениях отсчета начала интегрирования. Проанализирована зависимость интерференционных помех в каналах СП VDSL2 в зависимости от длины линии, типа ортогональных гармонических сигналов и направления передачи. Доказана эффективность применения ортогональных гармонических сигналов обобщенного класса по сравнению с традиционными ОГС. Определено существенное влияние количества соседних каналов на величину интерференционных помех.

Ключевые слова: технология VDSL2, интерференция, система передачи, ортогональные гармонические сигналы, телефонный кабель.

In Ukraine, operators of the telecommunication services providing broadband access based on xDSL technologies are faced with the need to upgrade their broadband access network that was built based on the subscriber line (SL) network using multi-pair telephone cables. This is due to the need to increase access rate and improve the quality of services provided to subscribers to ensure the competitiveness of xDSL technologies in the market for provision of services for broadband access [1].

Until recently, the main technology of broadband access over SL was ADSL2+-technology, which provided data rates up to 24 Mbit/s in the downstream direction (DS) and up to 3 Mbit/s in the upstream (US). At the same time, the actual transmission rate depended on many factors: the level noise, the characteristics of the SL, and the load coefficient of a multi-pair telephone cable by transmission systems (TS) operating in parallel on this cable [2].

Increasing the access rate can be achieved by replacing the ADSL2+-technology with the VDSL2-technology, which can provide bidirectional data transmission at rate up to 200 Mbit/s in the band up to 30 MHz [3]. It should be noted that the rate increasing compared with ADSL2 + technology is achieved by reducing the length of the subscriber line. It is proved that the transmission system by VDSL2-technology can guarantee the rate in the downstream direction of 50 Mbit/s on multi-pair telephone cables such as TPP-0.4 with the SL length up to 500 meters [4].

In this case, the upgrade consists in rebuilding the broadband access network from the FTTN+ADSL2+ variant (the access node was installed at the telephone exchange) to the FTTC+VDSL2 variant (with the access node being removed to the distribution cabinet).

Research of interference noise in vdsl2 systems when operating over tpp type telephone cables
When using the VDSL2 TS on multi-pair telephone cables, the main reason for limiting the transmission rate is the far end crosstalk between systems operating in parallel [4]. To suppress crosstalk, a «vectoring» system is used, the efficiency of which over TPP cables was proved in [5], while the crosstalk is suppressed to the thermal noise level. In this case, it is necessary consider other factors affecting the transmission rate, primarily interference noise.

VDSL2 TS, as well as most broadband access systems transmit information by a set of orthogonal harmonic signal-carriers (OHS). The terms OFDM (Orthogonal Frequency Division Multiplexing) or DMT (Discrete Multi-Tone) are often used in foreign literature. In [6], using the example of G.fast-technology, it was proved that interference noise can lead to a reduction in the rate of the G.fast TS in the absence of the other noise types. But the use of generalized class (GC) OHS with the optimal shape of the signal sending envelope at the clock interval reduces the influence of interference noise compared to traditional OHS, which have a «Π»-shaped envelope of the signal sending and which use the guard interval to suppress interference noise.

There are no such research in scientific papers for domestic broadband access networks based on VDSL2-technology, therefore it is of interest to investigate interference noise when the VDSL2 TS operates over domestic multi-pair telephone cables and to evaluate the efficiency of GC OHS using.

The purpose of this article is to research interference noise in VDSL2 transmission systems when working over telephone cables of the TPP type and evaluate the efficiency of using the generalized class orthogonal harmonic signals as linear signal-carriers compared to traditional OHS.

The research was carried out by analytical modeling the VDSL2-systems operation over TPP-0.4 type telephone cable with the following parameters:

- transmission systems – VDSL2 with B8-6 [998-M2x-B] frequency plan [3];
- transmission line – TPP type telephone cable with a 0.4 mm wire diameter [4];
- the line length \((l_{\text{line}})\) varies in the range – 200...500 m;
- envelope kind of the linear signal sending – traditional («Π»-shaped) and generalized class with optimal function (with quadratic cosine fronts) [6];
- fundamental frequency (frequency separation between channels) – \(f_0 = 17.25\, \text{kHz}\);
- samples number of the orthogonality interval \((N)\) – 2048;
- samples number of the guard interval \((L)\) – 128;
- information channels number \((n)\) – \(n_{DS} = 477\) (of which downstream uses channels 16...217 and 302...492), \(n_{US} = 478\) (of these, upstream uses channels 218...301 and 493...695);
- first information channel number \((m)\) – \(m_{DS} = 16\) (downstream), \(m_{US} = 218\) (upstream).

As mentioned above, the VDSL2 TS use the OHS transmission method. In this paper, we consider the variants of the VDSL2 TS using traditional OHS and generalized class OHS. The \(l\)-th channel structural schemes of the traditional OHS TS and TS with generalized class OHS are shown in Fig. 1. The traditional OHS TS for counteracting interference use a guard interval, therefore the duration of the clock interval is defined as the sum of the duration of the orthogonality interval and the guard interval \(T = \tau_0 + \tau_p\) (Fig. 2, a). In the TS with GC OHS, in comparison with the traditional OHS TS, when forming the group signal, the additional reference signal \(u(t-pT)\) is used, which allows to form a linear signal of the duration \(T\) with cosine-quadratic fronts (Fig. 2, b). In this case, the signals are orthogonal over the all clock interval \(T\), and the term “signal expansion coefficient” is used instead of the term “guard interval”, which is calculated from the expression \(a_{ex} = L/N\) and determines the relative increase in the signal duration compared to the initial \(\tau_0\).
For the considered variants of the VDSL2 TS, interference noise was calculated by the method described in [6, 7].

In accordance with the used method for calculating interference, $g(k)$ impulse responses (IR) were calculated. The impulse responses corresponding to the transmission line lengths given by the following formulas:

$$
\sin \omega_0 (t-\tau) \cos \omega_0 (t-\tau)
$$

For the first order channel, the impulse response is given by:

$$
H(i\omega) = \sin \omega_0 (t-\tau)
$$

For the second order channel, the impulse response is given by:

$$
H(i\omega) = \cos \omega_0 (t-\tau)
$$

The impulse responses corresponding to the transmission line lengths given by the following formulas:

$$
h(t) = u(t) \sin \omega_0 (t-\tau)
$$

Where $u(t)$ is the input signal and $\tau$ is the delay time.
Initial data are shown in Fig. 3. In the interference calculations for the IR duration taken the samples number \((R)\), at which not less 99.99% of its power is concentrated.

![Figure 3](image)

**Figure 3** – Impulse responses of the transmission line of the VDSL2 TS when working over TPP-0.4 cable

Interference noise was estimated in relative values as the interference and signal effective values percentage ratio and was represented as a discrete function, the argument of which is the channel number (carrier) of the VDSL2 TS, \(h_l\)% . Further, the interference and signal effective values percentage ratio \((h)\) will be called interference noise.

The three-dimensional diagrams of the interference noise values distribution on channels dependence from the integration (signal processing at the receiver) beginning (start) moment (sample number), when the line length \(l = 200\) and \(500\) m, respectively, for traditional OHS TS are shown in Figs. 4 and 5.

Similar results for the TS with GC OHS are shown in Figs. 6 and 7.

In figures: \(l\) – the channel number (carrier); \(k_T\) – integration (signal processing at the receiver) start sample number; \(h_{l,k}\) – Interference noise as a function of two variables: the channel number and the integration start sample number.

Analyzing the results presented on three-dimensional diagrams (Figs. 4 ... 7), it can be concluded that interference noise is unevenly distributed on VDSL2 channels and their value significantly depends on the integration start sample number \(k_T\) (can differ by tens or even hundreds of times). Therefore, to minimize interference noise, it is important to choose the start moment of the signal processing at the receiver. We will consider the \(k_{T_opt}\) optimal moment at which the \(h_{l,k}\) arithmetic mean interference noise value all information channels will be minimal.
For further analysis of the calculation results the interference integral estimates is performed, which is expressed in determining the arithmetic mean of the interference noise value $h_k$ all information channels as a function of the integration start sample number value $k_T$. According to the $h_k$, functions minimum the $k_{T_{opt}}$ optimal integration start sample number value, are determined for all variants given by the initial data (when using traditional OHS and GC OHS, when transmitting in the US and DS direction, for different line lengths $l_{line}$).

The results of the determining $k_T$ optimal values are presented in Table 1, and the corresponding $h_k$ arithmetic mean values at the $k_{T_{opt}}$ optimal value are presented in Table 2. Diagrams of the $h_l$ interference noise in the VDSL2 TS channels when using traditional OHS corresponding to the $k_T$ optimal value are shown in Fig. 8. Similar results for the VDSL2 TS when using the GC OHS are shown in Fig. 9.
Figure 6 – Diagram of the function $h_{l,k}$ for VDSL2 TS with GC OHS ($l_{line} = 200$ m; TPP-0.4; $L = 128$; transmission direction: a) DS; b) US)

Figure 7 – Diagram of the function $h_{l,k}$ for VDSL2 TS with GC OHS ($l_{line} = 500$ m; TPP-0.4; $L = 128$; transmission direction: a) DS; b) US)

Table 1 - The optimal values of the integration start sample number $k_{Topt}$ sample

<table>
<thead>
<tr>
<th>$l_{line}, m$</th>
<th>Traditional OHS</th>
<th>GC OHS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>DS</td>
</tr>
<tr>
<td>200</td>
<td>130</td>
<td>139</td>
</tr>
<tr>
<td>300</td>
<td>203</td>
<td>163</td>
</tr>
<tr>
<td>400</td>
<td>189</td>
<td>209</td>
</tr>
<tr>
<td>500</td>
<td>204</td>
<td>247</td>
</tr>
</tbody>
</table>
Table 2 – Arithmetic mean of the interference noise $h_k$ at the optimal value of the integration start sample number $k_{T_{opt}}$, %

<table>
<thead>
<tr>
<th>$l_{line},m$</th>
<th>Traditional OHS</th>
<th></th>
<th>GC OHS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US</td>
<td>DS</td>
<td>US</td>
<td>DS</td>
</tr>
<tr>
<td>200</td>
<td>0.027</td>
<td>0.094</td>
<td>0.01</td>
<td>0.054</td>
</tr>
<tr>
<td>300</td>
<td>0.045</td>
<td>0.301</td>
<td>0.036</td>
<td>0.115</td>
</tr>
<tr>
<td>400</td>
<td>0.355</td>
<td>0.742</td>
<td>0.216</td>
<td>0.256</td>
</tr>
<tr>
<td>500</td>
<td>1.304</td>
<td>1.565</td>
<td>0.91</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Figure 8 – Diagram of the function $h_l$ at the optimal $k_T$ for VDSL2 TS with traditional OHS (TPP-0.4; $L = 128$; transmission direction: a) DS; b) US

Figure 9 – Diagram of the function $h_l$ at the optimal $k_T$ for VDSL2 TS with GC OHS (TPP-0.4; $L = 128$; transmission direction: a) DS; b) US)

Analyzing the results, we can draw the following conclusions.

1. Note that the general nature of the interference noise dependence in the VDSL2 TS on the transmission line characteristics and transmission system parameters is confirmed by the research results obtained in [6, 7] for the ADSL2+ and G.fast systems. Therefore, we consider only the
2. From the results presented in Tab. 1 and 2, the optimal values of the integration start sample number \( (k_{\text{opt}}) \) and the arithmetic mean values of the interference noise \( (h_k) \) differ for the upstream and downstream transmission directions. This is due to the following reasons:

- linear distortions increase with increasing frequency, respectively, the interference in different channels (at different frequencies) will be different, while the value of \( k_{\text{opt}} \) will be different for different channels also;
- according to the frequency plan, VDSL2 downstream channels occupy DS1 = 0.276…3.76 MHz and DS2 = 5.2…8.5 MHz, frequency bands, and upstream channels occupy US1 = 3.76…5.2 MHz and US2 = 8.5…12 MHz. Accordingly, the working channels quantity (frequencies on which information is transmitted) for the downstream transmission direction is 30 % more than for the upstream direction. But at the same time, the DS1 and DS2 bands contain approximately the same channels quantity, and for the upstream direction, the US2 band contains about 2.5 times more channels.

3. The interference noise value in the VDSL2 TS with a line length of up to 400 m for most DS and US channels does not exceed 1% both when using GC OHS, and when using traditional OHS.

4. With the increase in the line length, the interference noise in the DS channels increases by approximately 2…3 times for every 100 meters, both when using traditional OHS and GC OHS. For the US, there is the sharp increase in interference (8 times for traditional OHS and 6 times for GC OHS) with the increase in the line length from 300 m to 400 m.

5. The use of GC OHS allows reducing interference noise 1.25…2.7 times for US and 1.7…3 times for DS, depending on the transmission line characteristics.

6. From the results presented in Figs. 8 and 9, the number of adjacent channels, which is more important than the frequency band in which these channels operate, has a significant influence on the interference noise value. Thus, the US1 channels are located higher in frequency than the DS1 channels, which means that the linear distortions in the US1 frequency band are greater, respectively, the interference noise should be greater (the average between the interference for DS1 and DS2 channels). But the results of the research showed that the interference noise for US1 channels is 3…10 times less than for DS1 channels when using traditional OHS. When using GC OHS, the difference is even more – the interference noise for US1 channels is 10…25 times less than for DS1 channels. This discrepancy can be explained by the fact that the frequency band US1 contains 2.4 times less channels than the frequency band DS1.

Conclusions

The completed research allowed us to estimate the value of the interference noise in VDSL2 transmission systems when working over TPP type telephone cables. In the future, the results are planned to be used to estimate the effect of the interference on the VDSL2 transmission rate. Also, the efficiency of using generalized class orthogonal harmonic signals as the linear signal-carriers, which, compared to traditional OHS, allows to reduce the interference noise value by 1.25…3 times, depending on the transmission line characteristics, is proven. It is important to note the significant influence of the quantity of adjacent channels on the interference noise value.

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