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Investigation on Noise-stability of the Optical Link by AM-VSB and *M*-QAM Signals Transmitting in HFC Communication Systems

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Introduction

Today's modern Hybrid fiber-coaxial (HFC) communication systems have the advantages of great transmission capacity, high speed and high transmission quality and so on.

Lately lots of attention is attracted to the transmission of conventional analog AM-VSB signals subcarrier-multiplexed (SCM) with the digital (MPEG) signals such as *M*-QAM over an optical fiber. The advantage of the use of digital signals is that they are more spectrally efficient and stronger than the analog signals to noise, interference and nonlinearity. For the AM-VSB/*M*-QAM HFC/CATV transmission, however the QAM signals may suffer significant performance degradation due to occasionally laser diode "clipping" [1, 2]. It is find in a multichannel system when a laser outputs nearly zero power as the input signal current to the laser drives below the laser threshold current I_{th} (Fig.1), [2].

However, power-dependent self-phase modulation (SFM) in intensity-modulated systems causes frequency chirp, which in combination with fiber dispersion generates nonlinear distortions.

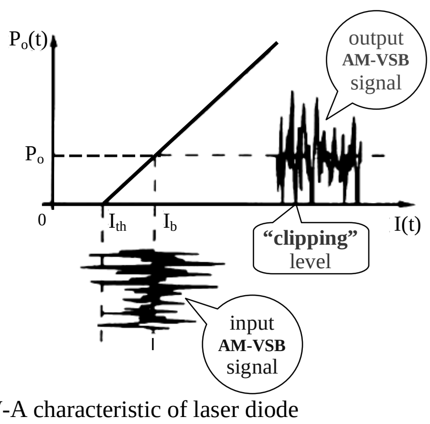

Fig. 1. W-A characteristic of laser diode

Despite the comparatively small optical fiber attenuation, in the optical link there is a presence of big losses from the ineffective transforming of the electrical power into an optical and vice versa. The typical losses from the double transforming in an optical link with direct laser intensity modulation are in the order of 20 ÷ 50 dB, and for a link with external laser modulating – from 30 dB to 60 dB. Those losses indicate even the small efficiency of light's tricking in the optical fiber, as well mismatching of electronical and optical components of the link [3]. The losses in optical link have an influence to the C/N ratio in the link output. Supporting of C/N ratio in the necessary borders, in accordance with the European standard CENELEC, requires special attention at designing of wideband cable communication systems such as HFC/CATV networks.

Moreover the coaxial part causes thermal noise, non-linear distortions, micro reflections and manmade noise. Micro reflections resulting from impedance mismatch or amplifier return loss have also been identified as a new factor impairing the digital channel, mainly in the coaxial part. These micro reflections sometime severely influence the C/N ratio of the *M*-QAM signals, but an adaptive equalizer offers a promising solution for such digital channel deterioration.

Noise sources

Noise sources in the optical link are connected to its optical devices, as well as the optical fiber itself. Distinguished are the following types of noises: relative intensity noise of the laser (*RIN*); shot noise of the photodiode; thermal noise of the receiver; interferometric intensity noise (*IIN*) and optical amplifiers' noise. The laser *RIN* and the noise, made from the optical amplifiers, are due to a spontaneous emission of photons, raising a ge-

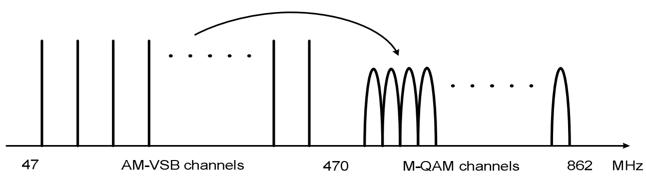

Fig. 2. Frequency spectrum of HFC/CATV system with a pointer laser "clipping" influence

neration of incoherent light. Shot noise of the receiver also has a quantum origin, while its thermal noise is raised mostly form the main amplifiers, used for amplifying of detected RF signal to the necessary level. Interferometrical intensity noise in the optical fiber is a result of it's loses, Rayleigh scattering of the light and of the functions of optical wave's length, provoked from laser chirp [3].

Level of the general noise in the link's output depends of different factors, most important of which are: the used optical devices' parameters and their regime of working; also attenuation and reflection in the fiber; the temperature; the type of transmitter signals (analog and digital), their modulations and others. Usually the expressions, by which are defined the dependences of the noise components in an optical link, do not report on the full influence of the different factors and in many cases are nor useful for an engineer applications [1, 2]. Besides, at designing of the optical link are used a parameters, which requires together reading of the noises with Gaussian distribution and noises from clipping, caused by AM-VSB channels (Fig.2) – with a pointer.

Therefore in the present paper is suggested more accurate and in the same time easy applicable noise model of the optical link when designing of the systems.

Analysis of the carrier-to-noise ratio (C/N)

At the HFC networks with jointly transmitting of AM-VSB and M-QAM channels, in the laser diode arise a "clipping" of SCM signal, when (Fig.1):

- Impulse noise (inherent for the frequency multiplexed signals) cause an output power drop $P_o(t)$ of the laser diode around zero;
- Input operating current of the laser diode is lower from the bias current I_b, defining its operating point.

Thus at amplitudes of the analog AM-VSB signals, exceeding the value (I_b - I_{th}), is received a restriction of the signal. As a result of that the system becomes more noise unstable and the bit-error-rate increases.

For the carrier-to-noise (Gaussian) ratio can be written the fallowing expression [4]:

$$C/N_g = TP_{av} / \sigma_g^2, \tag{1}$$

where $P_{av} = \frac{1}{2} m_q^2 \left(s\alpha P_o \right)^2 = \frac{1}{2} m_q^2 F^2$ – the average received signal power in each M-QAM channel; m_q – optical modulation index for M-QAM signal; s – sensitivity of the photodetector; α - losses in the optical fiber and F is the efficiency of the receive-transmitting link or photodetector current [4, 5]. $T = 1/B$ is the M-QAM symbol duration and B is the photoreceiver's bandwidth, respectively the bandwidth of the QAM channel.

The power spectrum density of the input Gaussian noise $n_g(t)$ is calculated by

$$\sigma_g^2 = RIN.F^2 + 2q.F + i_n^2, \tag{2}$$

where q – the electron charge (1,602 ×10^{-19} C); i_n – thermal current of the optical receiver;

For the power spectrum density of the "clipping" noise (impulsive noise) $n_i(t)$ is carried out the following expression

$$\sigma_i^2 = 2{,}4 \times 10^{-11} N_{AM}^2 \sqrt{N_{AM}}\, m_{AM}^5 F^2 exp\left(-\frac{1}{N_{AM} m_{AM}^2} \right), \tag{3}$$

where N_{AM} – the number of AM-VSB channels; m_{AM} – the AM-VSB optical modulation index.

For the carrier-to-noise ratio, indicating the Gaussian noise (RIN, shot and the thermal) and the impulsive noise (from clipping) in according to the analytical noise model (Fig.3) is work out an equation:

$$C/N = \frac{[C]_p}{[n_g]_p + [n_i]_p} = \frac{P_{av}}{(\sigma_g^2 + \sigma_i^2)B}. \tag{4}$$

In the engineering practice is more useful to be operated with logaritmic units (dB), because calculation of the values of carrier-to-noise ratio comes to an adding or/and odding. Then expression (4) can be written like this:

$$C/N[dB] = 10\lg \frac{P_{av}}{(\sigma_g^2 + \sigma_i^2)B}. \tag{5}$$

Defining of the carrier-to-noise ratio for every noise source and for the system as one

At a designing of the optical HFC network link a big problem comes to be the defining of noise power, which must be reduced for reaching settled (CENELEC) minimal C/N ratio. That requires to be used such a mathematical model of the link, which indicates not only its general noise characteristics (equations (4) and (5)), but also the noise levels of different noise sources, respective carrier-to-noise ratio for every one of them. Composing such model we are using average values for the powers disjoined on the load of optical receiver at traveling through of the detecting photocurrent and different noise sources currents.

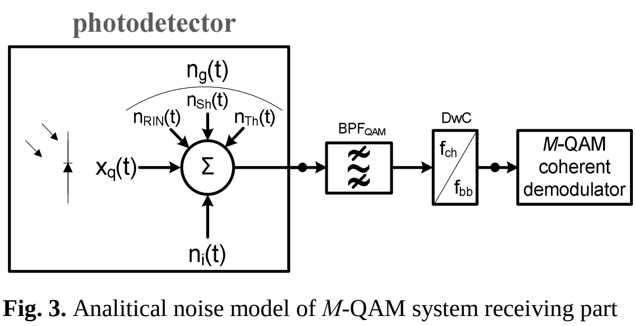

Fig. 3. Analitical noise model of *M*-QAM system receiving part

The expressions for those powers are shown in an applicable for the engineering practice form, as in the same time they guarantee enough accuracy at the process describing.

a) Carrier-to-relative intensity noise of laser ratio (C/N_{RIN})

$$C/N_{RIN}[dB] = 20\lg m_q - 10\lg B - RIN - 3. \tag{6}$$

b) Carrier-to-shot noise ratio (C/N_{Sh})

$$C/N_{Sh}[dB] = 20\lg m_q - 10\lg B + 10\lg F + 182\,. \qquad (7)$$

c) Carrier-to-thermal noise ratio (C/N_{Th})

$$C/N_{Th}[dB] = 20\lg m_q - 10\lg B + 20\lg F - 20\lg i_n - 3\,. \qquad (8)$$

d) Carrier-to-impulsive noise ratio (C/N_i)

$$C/N_i[dB] = 20\lg m_q - 10\lg B - 25\lg N_{AM} - 50\lg m_{AM} + \frac{4{,}34}{N_{AM}\, m_{AM}^2} + 103{,}19\,. \qquad (9)$$

According to equations (6) to (9) for the carrier-to-noise ratio (C/N) of the full system can be written the following formula

$$C/N[dB] = -10\lg\left[10^{\frac{-C/N_{RIN}}{10}} + 10^{\frac{-C/N_{Sh}}{10}} + 10^{\frac{-C/N_{Th}}{10}} + 10^{\frac{-C/N_i}{10}}\right]. \qquad (10)$$

Studying the C/N ratio for every noise source

Upper brought out equations for C/N allows us to investigate the influence of different noises in optical link. That was made for different values of the DFB-laser diode, photodiode, optical fiber parameters and OMI of the transmitted signals. The results are shown on Fig. 4, Fig. 5, Fig. 6 and Fig. 7. Some of those parameters when increasing of their values improve the respective carrier-to-noise ratio. Such are *F* and m_q. Other as *RIN*, i_n and m_{AM} aggravate the respective C/N.

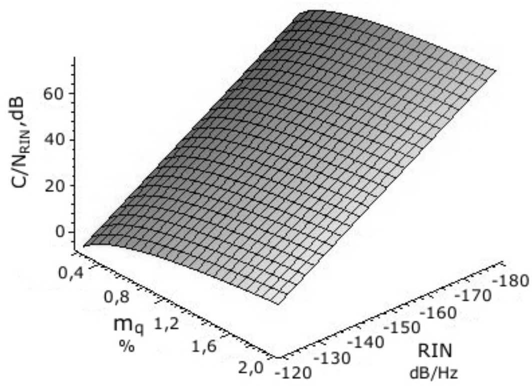

Fig. 4. The graphical dependence of C/N_{RIN} = func (m_q, RIN)

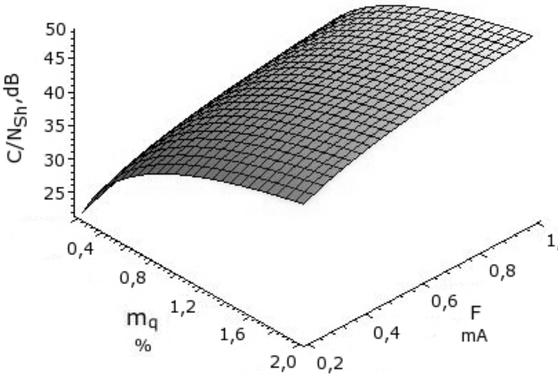

Fig. 5. The graphical dependence of C/N_{Sh} = func (m_q, F)

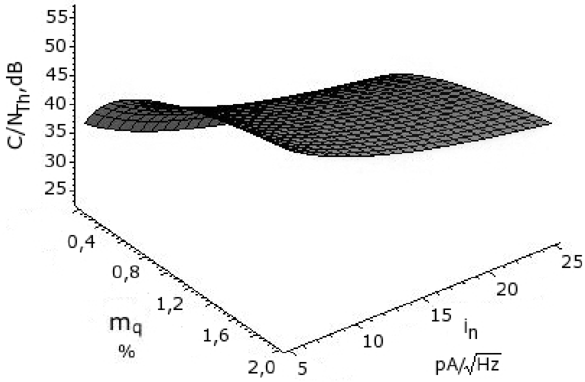

Fig. 6. The graphical dependence of C/N_{Th} = func (m_q, i_n)

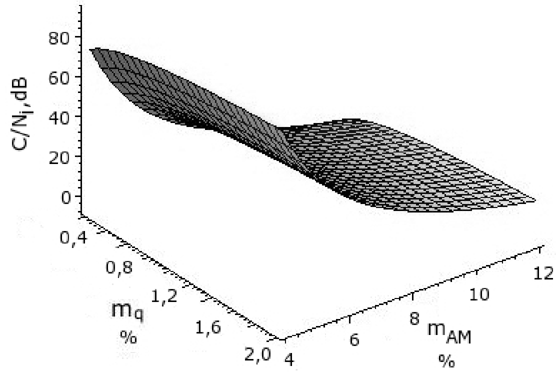

Fig. 7. The graphical dependence of C/N_i =func (m_q, m_{AM})

Studying the C/N ratio depending on the transmitting AM-VSB channels number and the modulation index

Up composite mathematical model of the optical system (5) is used of illustrations visual aids of its noise-stability variation at given parameters of the optical transmitter, optical receiver and the single mode optical fiber. The graphical dependence (Fig. 8) is shown in the 3D space, as the carrier-to-noise ratio is studied in dependence of the transmitted AM-VSB channels number and their modulation index $m_{AM} = (4 \div 12)$ %. Digital signals are MPEG and are modulated with a quadrature amplitude modulation (QAM), which modulation index is m_q=1%. The other parameters of the optical link are: *RIN = -150dB/Hz;* $i_n = 24\times 10^{-12}\, A/\sqrt{Hz}$ *; F = 0,69 mA;* $N_{AM} \le 50$*; B=8 MHz; M = 16;* f_H *= 47 MHz;* f_K *= 470 MHz.*

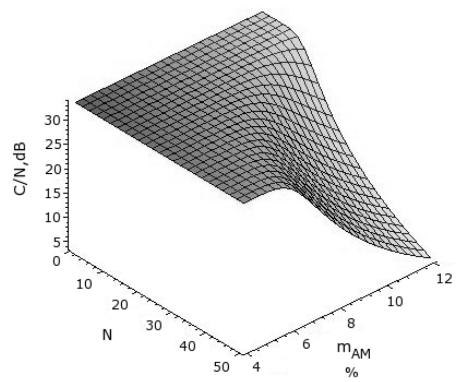

Fig. 8. The graphical dependence of C/N=func(N, m_{AM})

Conclusion

Presented mathematical models of the optical link of HFC network (equations (5) and (10)) give the opportunity to be defined its noise-stability in dependence of the building elements' parameters, transmitted channels number and the modulation depth. At a joint transmitting of analog (AM-VSB) and digital (*M*-QAM) signals as a result of the laser "clipping" is being watched change for the worse of the *C/N* ratio, which is visible from the graphic on Fig.8. When the modulation index of the analog signals have a small values ($m_{\mathrm{AM}} < 6\%$), independently of the RF channels number, the *C/N* ratio stays the same (*C/N* = 35 dB). This is like that because the Gaussian noise predominates ($\sigma_g^2 >> \sigma_i^2$). When $m_{\mathrm{AM}} > 10\%$, impulse noise from the "clipping" defines the *C/N* ratio, which reaches low values in dependence of the RF channels number. At $N_{AM} = 50$ *C/N* ratio fell to 5 dB. In this case $\sigma_g^2 < \sigma_i^2$.

Normal operating regime of the Hybrid fiber-coaxial network, transmitting AM-VSB and *M*-QAM signals at the given parameters of laser and photodiode, such as the number of AM-VSB channels is possible, when:

- m_{AM} is ≤ 7% at variance of N_{AM} to 50;
- m_{AM} is > 7%, but N_{AM} is changing to 15. At a big values of RF channels number ($N_{AM} = 40 \div 50$) is necessary m_q to be increasing as getting values upon 2%.

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The influence of analogue AM-VSB signals on the transmission of digital signals such as M-ary quadrature amplitude modulation (QAM) over an optical fiber is analyzed. Up to the 450-500 MHz is spectrum for AM-VSB signals, while for M-QAM signals he is up to 862-1000 MHz. In these networks with jointly transmitting AM-VSB and M-QAM signals are used subcarrier multiplexing (SCM) and there are favorable conditions for laser "clipping". In this case carrier-to-noise ratio of M-ary QAM can be significantly affected and BER rise. Ill. 8, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

О. Б. Панагиев. Исследование шумоустойчивости оптического канала при передачи AM-VSB и *M*-QAM сигналов в коммуникационных системах HFC // Электроника и электротехника. – Каунас: Технология, 2009. – № 1(89). – С. 69–72.

Представлено исследование шумоустойчивости оптического канала гибридной волоконно-оптической сети. Анализируется влияние аналоговых AM-VSB сигналов на цифровые сигналы (M-QAM). Спектр AM-VSB сигналов расположен в диапазоне 450–500 MHz, а M-QAM сигналов – до 862–1000 MHz. В этих сетях для совместной передачи сигналов используется поднесущее мултиплексирование, при котором в лазере получается "клиппинг". Вследствие этого значительно понижается отношение несущая–шум и повышается BER. Ил. 8, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

O. B. Panagiev. Triukšmo stabilumo perduodant AM-CSB ir M-QAM signalus optiniu HFC komunikacinės sistemos kanalu tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 1(89). – P. 69–72.

Analizuojama analoginių AM-VSB signalų įtaka skaitmeninių signalų, tokių kaip M-ojo laipsnio kvadratūrinė amplitudės moduliacija, perdavimui optiniu kabeliu. AM-VSB signalai užima 450–500 MHz spektro diapazoną, o M-QAM signalams tenka 862–1000 MHz diapazonas. Šiais tinklais perduodant AM-VSB ir M-QAM signalus tuo pačiu naudojamas nešlio multipleksavimas (SCM). Šiuo atveju nemažai pakinta M-QAM signalo nešlio ir triukšmo santykis ir padaugėja klaidų. Il. 8, bibl. 5 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).

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