Journal of Physical Science and Application 11 (1) (2021) 17-21
doi: 10.17265/2159-5348/2021.01.003

DAVID PUBLISHING

Distortionin Multi-tone Modulation Fiber Systems

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Abstract: This paper analyzes the analog CATV transmission systems to investigate the interfering distortions. Here, it is considered distortions such as the composite second order, composite triple beat, and intermodulation distortion. In optical fiber-based analog CATV transmission systems, there is usually one wavelength used for the signal transmission with multiple analog RF channels modulated onto it. While BER is the most common performance metric in a digital transmission system, measurement of distortion is the critical metrics in an analog transmission system. The results of this study contains the simulations of distortion for a two tones direct modulated analog transmission system, a two tones externally modulated analog transmission system, three frequencies directly modulated together and 20-channel analog CATV system. It is shown that the modulation distortion can be considerably diminished at special frequencies if the overlap of frequencies is truly adjusted by the modulator characteristic parameters. Afterward, the optical attenuators or optical filters can serve to remove the sidebands with low intensities.

Keywords: Fiber-based CATV transmission system, intermodulation distortion.

1. Introduction

Through the last two decades, cable television (CATV) systems have been promoted from coax cable based one-way broadcast of analog video transmission to modern two-way hybrid fiber/coax (HFC) networks. The traditional one-way broadcast suffered from several cascaded RF amplifiers to overcome the high losses of coaxial cables and splitters. These in turn, affected the quality of received signal due to significant levels of noise and intermodulation distortion. Utilization of fiber optics technology in CATV transmission systems has led to a significant reduction of the number of cascaded RF amplifiers, leading to the robust transmission of signals [1-7]. In a broadband CATV transport system, the broadcast amplitude modulated optical signal at 1550 nm or 1310 nm is amplified and then combined with the broadband optical M-QAM (Quadrature Amplitude Modulation) signal for forward transmission. The broadband optical M-QAM signal carries the digital video and data, which are transmitted over different wavelengths λ_1, λ_2, …, λ_n using a (DWDM) dense wavelength division multiplexer (MUX). This hybrid optical signal is transmitted over a SMF to the respective fiber nodes. Today, these systems carry about eighty analog video channels and thirty 64/256 QAM channels. The MUX device located in the hub multiplexes the received return signals for transmission towards the head-end. At the end point, the wavelength demultiplex device (DMUX) located in the head-end demultiplexes the wavelength stream into individual wavelengths for further processing. CATV transport systems utilize the photonics devices as mentioned below in order to attaining high system performance [1-7].

Analog CATV systems contain analog DFB lasers, external modulators, optical amplifiers, analog optical receivers, and digital return technology. The analog CATV transmission must provide a high carrier to noise ratio (CNR) to achieve a fair signal quality at the receiver. Hence, requirements for DFB lasers are high output power, low RIN, high linearity, and low distortion.

The signal distortion in analog transmission systems known as Intermodulation Distortion (IMD) is determined by the nonlinearity of the power versus characteristics of a DFB laser, fiber characteristics and

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external/internal modulator properties and measured in terms of CSO and CTB levels. The CSO refers to composite second order distortions due to 2nd order nonlinearity, whereas CTB is the composite triple beat, also known as composite third order distortion, which occurs due to third order nonlinearity [8-16].

Utilization of directly modulated DFB lasers in the 1550 nm wavelength region causes severe signal distortions due to fiber dispersion and hence limits the transmission distance to a few kilometers. Thus, external modulators such as Mach-Zehnder (MZ) modulators are required to minimize these signal distortions. The main design requirement for an external modulator is that it should provide high linearity for analog transmission. The MZ modulators which were used for digital transmission cannot be readily used for analog applications and hence require some corrective design measures. Several linearization techniques or pre-distortion circuitry have been incorporated into the design of these external modulators to minimize the signal distortions [16-18]. In addition, suppression of stimulated Brillouin scattering (SBS) effects and interferometric noise were also achieved in these modulators [16-18].

2. Measurement of IMD and CNR

As aforementioned, the signal in practice is distorted because of a deviation from linearity which is called Intermodulation distortion (IMD). Any non-linearity in the response of the laser or in the propagation characteristics of fibers generates new frequencies of the form $f_i + f_j$ and $f_i + f_j \pm f_k$ some of which lie within the transmission bandwidth and distort the analog signals. The power level of the second and third order distortion products known as composite second order (CSO) and composite triple beat (CTB), for a specific channel are normalized to the carrier power of the channel and measured in dBc unit. The measurement technique is to use a filter which is wide enough to contain the entire range of significant products.

On the other hand one can obtain CNR as [2-15]:

$$CNR = \frac{m^2}{RIN + \frac{2h\upsilon}{P_i} + \left(\frac{h\upsilon F_n}{P_i}\right)^2 B_0 + \frac{2e}{RP_r} + \frac{i_{th}^2}{(RP_r)^2}} \frac{1}{2B_e} \quad (1)$$

where m is the Optical Modulation Depth (OMD) per channel. *RIN* is the relative intensity noise of the laser transmitter, F_n is the noise figure of the in-line amplifier, R is the receiver responsively, B_0 is the optical bandwidth of the received signal, B_e is the electrical bandwidth of each video channel, i_{th}^2 is the receiver spectral noise power density, P_i is the amplifier output power and P_r is the optical power at the receiver [2-15].

3. Results of Measuring the IMD in Fiber Optic Based CATV Systems

To investigate IMD in CATV systems, the following simulations are implemented via Standard Model of SMF in RSoft OptSim Simulating Software:

1) A Two tone direct modulated analog transmission system
2) A Two tone externally modulated analog transmission system
3) Three frequencies directly modulated together
4) And 20-channel analog CATV system

It is considered distortions of CSO, CTB, and intermodulation distortion. In fiber-based analog CATV transmission systems, there is usually one wavelength used for the signal transmission with multiple analog RF channels modulated onto it. While BER is the most common performance metric in a digital transmission system, measurements of distortions are the critical metrics in an analog transmission system.

3.1 A Two Tones Direct Modulated Analog Transmission System

In this case, there are two electrical sine-wave frequencies generated and summed. These two frequencies are at 500 MHz and 525 MHz. These are then modulated onto a direct modulated DFB laser at a wavelength of 1550 nm. This is then propagated over 40 km of single-mode optical fiber to a PIN-based optical receiver. The RF spectra can be viewed in the spectrum analyzer to measure the distortions such as composite second order (CSO) distortion, which are due to new frequencies generated at $f_1 + f_2$ and $f_2 - f_1$. Figs. 1-2 show respectively the RF spectra with power at frequencies 25 MHz and 1025 MHz as well as the original frequencies of 500 MHz and 525 MHz. Also Fig. 3 shows the modulation distortions at $2 \times f_1$ and $2 \times f_2$ at 1000 MHz and 1050 MHz respectively.

3.2 A Two Tones External Modulated Analog Transmission System

This time, two tones are externally modulated; Figs. 4 and 5 shows respectively the RF spectra with power at frequencies 25 MHz and 1025 MHz. Sidebands

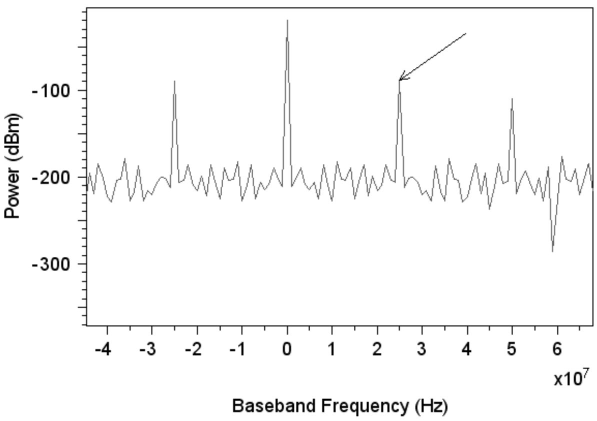

Fig. 1 RF Spectra of two tone directly modulated, CSO distortion at 25 MHz.

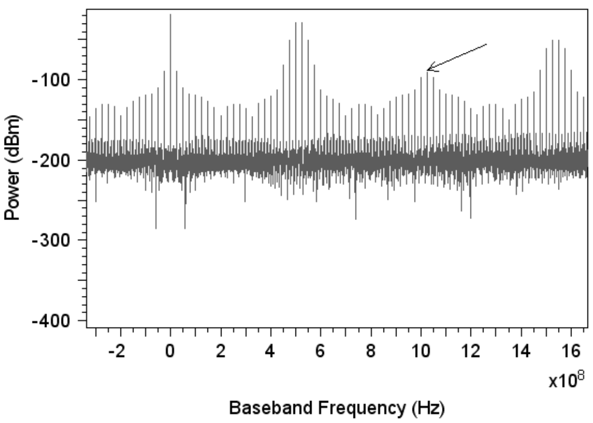

Fig. 2 RF Spectra of two tone directly modulated, CSO distortion at 1025 MHz.

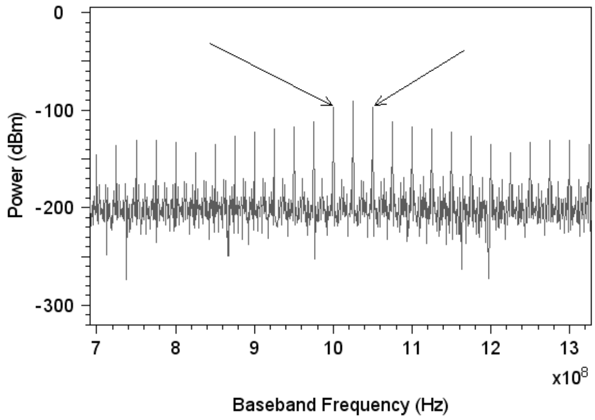

Fig. 3 RF Spectra of two tone directly modulated; IMD at 1000 MHz &1050 MHz.

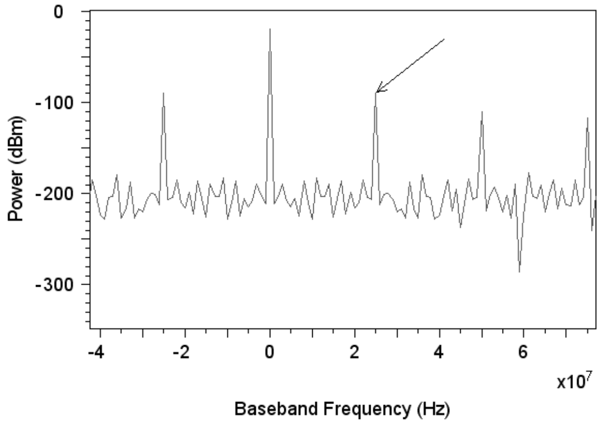

Fig. 4 RF Spectra of two tone externally modulated, CSO distortion at 25 MHz.

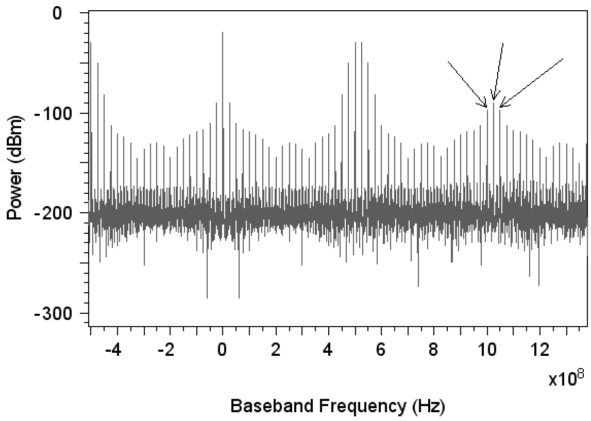

Fig. 5 RF Spectra of two tone directly modulated; CSO distortion at 1025 MHz, IMD at 1000 MHz &1050 MHz.

around in Fig. 5 shows again the modulation distortions at 1000 MHz and 1050 MHz respectively; the most striking difference between this and the direct modulated example are the additional distortions at a number of additional frequencies.

3.3 A Three Frequencies External Modulated

This case is a frequency combination of three frequencies at 62.5 MHz, 125 MHz, and 187.5 MHz. These three frequencies are then modulated together onto a DFB laser with wavelength 1550 nm and propagated over 40 km of standard single-mode fiber (SMF-28) to a PIN-based receiver. The RF spectrum at the receiver can be viewed to analyze the composite second order, composite triple beat, and other distortions in the system. As shown in Fig. 6, the CSO = -36 dBc (at $f = f_1 + f_2$ =250 MHz and $f = f_2 + f_3$ = 312.5 MHz), and the CTB = - 41 dBc (at $f = f_1 + f_2 + f_3$ = 375 MHz).

As it is evident in Fig. 6, with increasing the number of frequencies, IMD will increase.

3.4 20 Channel Analog CATV System

Now considering a 20-channel analog CATV system and starting at 500 MHz with a frequency step of 6 MHz and focusing on the distortions, one can observe the distortions at many frequencies by zooming the RF Spectra as shown in Fig. 7.

4. Discussion

Referred to Figs. 4 & 6, one can deduce that the modulation distortion can be considerably diminished at special frequencies if the overlap of frequencies is truly adjusted by the modulator characteristic parameters. Afterward, the optical attenuators or

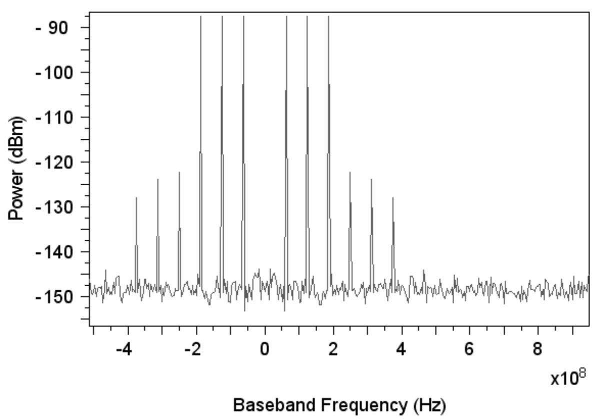

Fig. 6 RF Spectra of to three frequencies directly modulated.

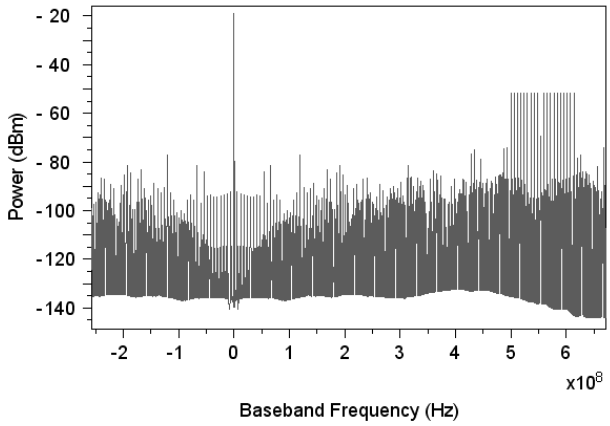

Fig. 7 RF Spectra of to 20 channel directly modulated.

optical filters can serve to remove the sidebands with low intensities.

5. Conclusions

IMD in fiber optic based CATV multichannel system is recognized by second and third harmonics sidebands of power spectra. Increasing the channel numbers leads to increase the number of sidebands and also IMD. This is because of the configuration specifications of external modulator which carries the signal of data, optical fiber non-linearity and laser instability which arises from the sensitivity to laser beam and modulation voltage in the case of utilizing external modulator. IMD is inevitable in optical fiber based analog CATV systems; however distortion is much less than coaxial cable based CATV systems. In order to decrease IMD in optical fiber based CATV systems, tuning the characteristic parameters of the modulator can be effective.

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