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OFDM-ROF 가입자링크의 인접채널전력비 해석

(Comparative Adjacent Channel Power Ratio Analysis in an OFDM-RoF Access Link)

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요 약

본 논문에서는 광대역통합망 응용을 위하여 ROF 링크와 접속된 무선 OFDM 시스템의 인접채널전력비를 해석하였다. RF 증폭기에서 비선형 효과에 의한 인접채널전력비의 해석을 다른 기존의 결과들과 다르게 본 논문에서는 ROF 링크를 포함한 유무선통합 링크에 대하여 IEEE 802.11a의 5.8GHz OFDM 신호의 인접채널전력비를 해석하고 시뮬레이션한 결과를 보였다.

Abstract

In this paper, Adjacent Channel Power Ratio (ACPR) of wireless Orthogonal Frequency Division Multiplexed (OFDM) system interconnected with Radio over Fiber (RoF) link is analyzed for broadband convergence network applications. Unlike previous results, ACPR of the total link, which is involved with Radio Frequency (RF) amplifier as well as ROF link, at 5.8 GHz in IEEE 802.11a environment is simulated and compared at both system ends.

Keywords : OFDM, ACPR, PAPR, RoF access link

I. Introduction

OFDM, as a multi-carrier digital modulation technique, proved its robustness against time-dispersive impairments such as multi-path fading and impulsive interference and therefore is currently in use by European digital audio and terrestrial broadcasting and Asynchronous Digital Subscriber Lines (ADSL). But high Peak to Average Power Ratio (PAPR) has become an important parameter to consider for OFDM as nonlinearity distortion increases for an input signal led to the Power Amplifier (PA). The in-band and out-of-band interference created by the distortion effects of nonlinear amplification, increase Bit-Error-Rate (BER) and Spectral Regeneration (SR) respectively. Hence, the degree of SR can be characterized by ACPR and this ratio is the limiting factor on achieving high efficiency amplification[4].

Interconnection between optical and wireless networks is necessary for Broadband Convergence Network (BcN) performance as the high data rates with multiple services are expected using multi-carrier modulation techniques. Therefore, RoF is becoming an increasingly important technology for the in-building wireless connectivity.

Relevant works of optical interconnection and wireless link have been undertaken in [1-2]. Interconnecting the OFDM signal at 5.8 GHz (for IEEE 802.11a) with the optical fiber links and to observe the performance under simulated environment is a new research area to be explored

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and this paper assesses the ACPR performance under that environment with a mathematical modeling approach.

In this paper, bandpass memoryless nonlinearity effects are presented with High Power Amplifier (HPA) for ACPR performance simulation of an OFDM system. The OFDM system is then interconnected with a RoF model comprising Distributed Feedback (DFB) Laser Diode as a transmitter and Photodetector (PD) as a receiver. The ACPR performance is then simulated again at the analog Radio Frequency (RF) output and compared with the OFDM system ACPR performance.

The paper is organized as follows. In Section II, the system and channel model are described. In the next section, ACPR performances at OFDM and RoF output ends are compared by simulation and in the last section, there comes the main summarization of the paper.

II. OFDM-RoF System Description

1. OFDM System

An OFDM signal $S(t)$can be represented as [3]

$$S(t)=\sum_{i=n/2}^{n/2} d_i(t)\cos\left[2\pi(f_o-f_i)t\right] \tag{1}$$

Where f_o is a central frequency, (f_o-f_i) is a frequency of i-th subcarrier and $d_i(t)$ describes complex QAM symbols and n is the number of subcarriers. Using the modulated narrow band Gaussian input signal shown in equation (1) we can write,

$$\begin{aligned} S(t) &= x(t)\cos 2\pi f_o t - y(t)\sin 2\pi f_o t \\ &= \mathrm{Re}\left\{A(t)e^{j2\pi f_o t}\right\} = A(t)\cos(2\pi f_o t+\theta(t)) \end{aligned} \tag{2}$$

Here $|A(t)|$ is the voltage envelope of the modulated signal, $\theta(t)$ is the phase and f_o is the carrier frequency. The square root raised cosine filter $h(t)$ is used here with roll off factor β and output signal of the IFFT $m(t)$ will be passed though the filter and finally fed to the input of the HPA considered in our model.

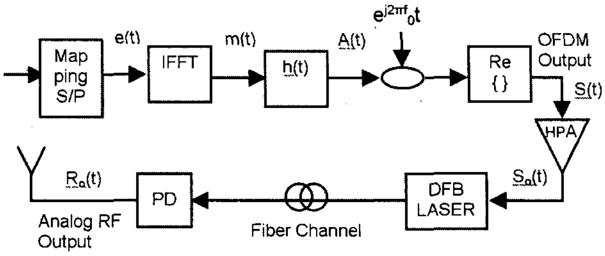


그림 1. 시스템 블럭도
Fig. 1. System block diagram.

A bandpass memoryless nonlinear amplifier model, as proposed for our system, will exhibit the output as follows when modulated signal in (2) is used as the input signal to the amplifier,

$$S_o(t)=g(A(t))\cos\{2\pi f_o t+\theta(t)+\phi(t)\} \tag{3}$$

The functions $A(t)$ and $\phi(t)$ represents AM/AM and AM/PM respectively. In a bandpass model, the in-band and adjacent channel distortions appear due to the odd harmonics only. And, we assume no AM/PM effects in this paper because it is found by computer simulation that the AM/AM effects are more significant than the AM/PM effects.

We define the power spectrum and autocorrelation of the input OFDM signal as $S(f)$ and $R(\tau)$ respectively for the amplifier.

$$R(\tau)=\int_{-\infty}^{\infty} S(f)e^{-j2\pi f\tau}df \tag{4}$$

So, the output of the power amplifier is obtained as

$$S_o(t)=g\left(\sqrt{A(t)}\right)e^{jf\left(\sqrt{A(t)}\right)}e^{j\varphi} \tag{5}$$

where g(A) and f(A) are the AM/AM conversion and AM/PM conversion of the nonlinear amplifier for the input envelope A. φ is the angle of $A(t)$. Autocorrelation of the output signals is written as

$$R_{S_0}(\tau)=0.5E[S_0(t)S_0(t+\tau)] \tag{6}$$

Fourier transform of equation (6) leads to the power spectrum for the signal component

$$S_0(f)=S(f)\left|\frac{1}{2\rho_s}\int_0^{\infty}\rho^2 e^{\frac{-\rho^2}{2}}\{g(\sigma_s\rho)e^{jf(\sigma_s\rho)}\}d\rho\right|^2 \quad (7)$$

Detailed steps of determining ρ and ρ^s (which is found by placing $R(\tau)=0$) is discussed in [5].

The third-order intermodulation (IM3) component can be found as

$$R_{S_0}^{IM3}(\tau)=\frac{1}{8}R(\tau)[R(\tau)]^2\left|\frac{1}{\sigma_s^3}\int_0^{\infty}\rho^2(\frac{\rho^2}{2}-2)e^{\frac{-\rho^2}{2}}\{g(\sigma_s\rho)e^{jf(\sigma_s\rho)}\}d\rho\right|^2 \quad (8)$$

The power spectrum of the third-order intermodulation is written as

$$S_0^{IM3}(f)=S(f)*S(f)*S(f)\left|\frac{1}{8\sigma_s^3}\int_0^{\infty}\rho^2(\frac{\rho^2}{2}-2)e^{\frac{-\rho^2}{2}}\{g(\sigma_s\rho)e^{jf(\sigma_s\rho)}\}d\rho\right|^2 \quad (9)$$

For numerical results with HPA we used the formula,

$$g(A)=\frac{A}{(1+A^{2p})^{(1/2p)}} \quad (10)$$

$$f(A)=0 \quad (11)$$

where p is the smoothness factor.

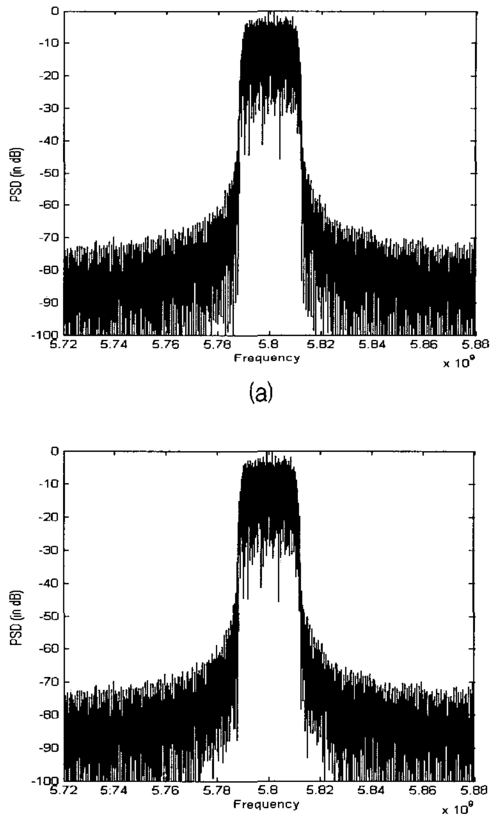
2. RoF system

In our RoF model, a direct modulated DFB Laser was used as a transmitter and a single mode fiber was taken as the fiber channel. At the receiver, a PD was responsible to convert the optical signal back to the RF signal. The complete system model has been represented as a block diagram shown in Fig. 1.

A direct-modulated laser diode is modeled by the rate equations for photon and electron densities $S(t)$ and $n(t)$, respectively [6].

$$\frac{dN}{dt}=\frac{I_A}{qV_{act}}-\frac{N}{\tau_n}-g_0(N-N_{0g})(1-\epsilon S)S \quad (12)$$

$$\frac{dS}{dt}=\left\{\Gamma g_0(N-N_{0g})(1-\epsilon S)-\frac{1}{\tau_p}\right\}S+\Gamma\beta\frac{N}{\tau_n} \quad (13)$$



(a)

(b)

그림 2. (a) 입력 OFDM 전력 스펙트럼밀도
(b) OFDM 출력 전력 스펙트럼밀도
Fig. 2. (a) OFDM input power spectral density.
(b) OFDM output power spectral density.

where N is the electron density, S is the photon density, Γ is the optical confinement factor given by the ratio of the active region volume to the modal volume, g0 is the gain slope constant, N_{og} is the electron density at which the net gain is zero, τ_p is the photon lifetime, τ_n is the electron life time, β is the fraction of spontaneous emission coupled into the laser mode, V_{act} is the volume of the active layer, q is the electronic charge, I_A is the electronic charge injected into the active layer and ϵ is the gain saturation coefficient.

The transfer function of the single mode fiber can be written as

$$H_{fiber}(f)=\int_{-\infty}^{+\infty}S(\lambda)L(\lambda)\exp[-j\omega T(\lambda)]d\lambda \quad (14)$$

where $S(\lambda)$ is the source spectrum as a function

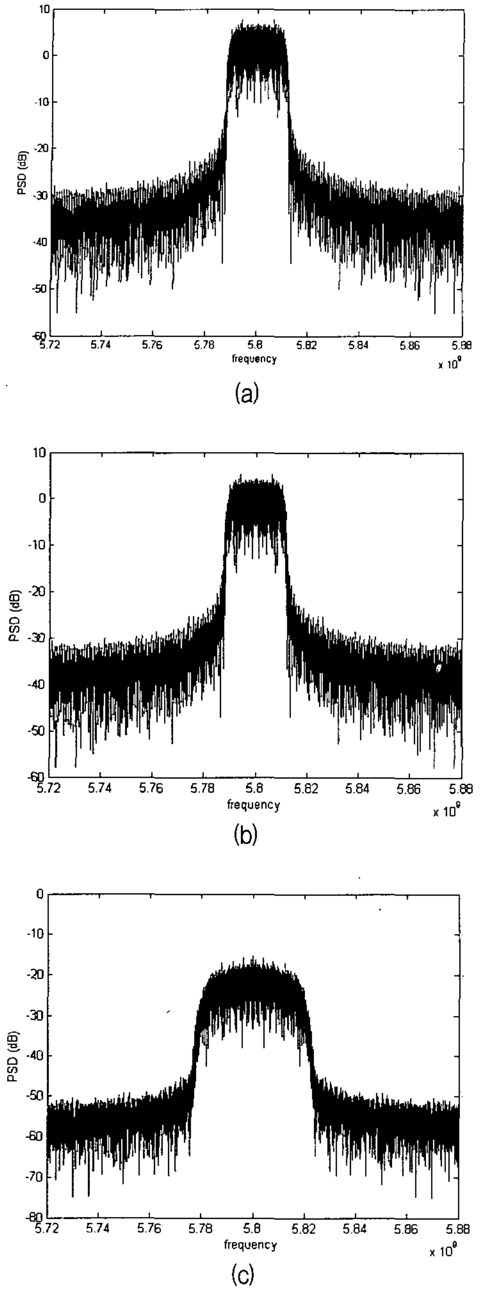


그림 3. (a) DFB 레이저 출력단의 전력 스펙트럼 밀도
(b) 광섬유 출력단의 전력 스펙트럼밀도
(c) 포토다이오드 출력단의 전력 스펙트럼밀도

Fig. 3. (a) DFB laser output power spectral density.
(b) Fiber output power spectral density.
(c) PD output power spectral density.

of wavelength, $L(\lambda)$ is the reciprocal of loss as a function of wavelength, l is the fiber length in kilometers and $T(\lambda)$ is the group delay function.

Finally the PD was modeled using the simplest formula

$$i_D = R_{res}(V_D)P_{OPT} \tag{15}$$

where $R_{res}(V_D)$is the responsivity of the PD.

3. Analysis of ACPR in OFDM-RoF Link

The total system model can be mathematically represented as

$$R_o(f) = E(f) \times H_{link}(f) \tag{16}$$

where $R_0(f)$ is the power spectral density of the output signal $R_0(t)$ at the end of the interconnected link, $E(f)$is the input signal to OFDM system and $H_{link}(f)$is the total OFDM-RoF link system response which is written as

$$H_{link}(f) = H_{S_0}(f) * H_{LD}(f) * H_{fiber}(f) * H_{PD}(f) \tag{17}$$

$H_{s_o}(f)$is the OFDM system response of the signal component which can be written as

$$H_{so}(f) = \left| \frac{1}{2\rho_s} \int_0^\infty \rho^2 e^{\frac{-\rho^2}{2}} \{ g(\sigma_s \rho) e^{jf(\sigma_s \rho)} \} d\rho \right|^2 \tag{18}$$

$H_{LD}(f)$is the DFB laser transfer function written as

$$H_{LD}(f) = \frac{B\omega_0^2}{(j\omega)^2 + j\omega\left\{\frac{\beta'}{P_o} + \frac{1}{\tau_n} + P_o(g_o + \frac{\varepsilon}{\tau_p})\right\} + \frac{\beta'}{\tau_n P_o} + \frac{\beta + P_o\varepsilon}{\tau_n \tau_p} + B\omega_o^2} \tag{19}$$

where $P_o$is the steady state photon intensity, $\beta' = \frac{\beta \Gamma I_{th}}{qV_{act}}$, $B = 1 - \varepsilon P_o$ and $\omega_0^2 = \frac{g_o P_o}{\tau_p}$.

$H_{fiber}(f)$ is found from equation (14) and $H_{PD}(f)$ is the transfer function found in [7] as

$$H_{PD}(f) = \frac{R_D}{a + j\omega(b - c\omega^2) - d\omega^2} \tag{20}$$

with

$$a = R_S + R_L + R_D$$
$$b = R_S R_L C_P + L_S + (R_S + R_L) R_D C_j + R_L R_D C_P$$
$$c = R_S L_S C_P R_D C_j$$
$$d = (R_S R_L C_P + L_S) R_D C_j + R_S L_S C_P + R_D C_P L_S$$

where C_j is the junction capacitance, C_P is the parasitic capacitance, L_S is the total series inductance, R_D is the diode shunt resistance, R_S is the diode series resistance and R_L is the load resistance.

In our system model, ACPR is defined as a ratio of the out-of-band signal power in the adjacent channel to the in-band signal power and thus, ACPR of wireless and optical link is defined as

$$ACPR(B)=\frac{\int_{f_0-3B}^{f_0-B} R_0(f)df+\int_{f_0+B}^{f_0+3B} R_0(f)df}{\int_{f_0-B}^{f_0+B} R_0(f)df} \qquad (21)$$

where (B,-B) is the desired in-band.

Ⅲ. Simulation and Results

Table 1 shows the simulation parameters used in the system modeling. For the DFB laser in our model, some of the worst case parameters were used to estimate maximum distortion in the link.

20 MHz bandwidth was used for the OFDM signal with a carrier frequency of 5.8 GHz for IEEE 802.11a system. The Power Spectral Densities (PSD) at the OFDM system input and output are shown in Fig. 2. In Fig. 3, PSDs at DFB laser output, fiber channel and PD output are also shown. It can be seen from Fig. 3 that DFB laser incorporates some gain in the system while HPA fed OFDM output was passed through it.

As the signal is passed through the fiber channel and PD, some more distortions are added in the system due to the inherent non-linearity effects from gain compression, clipping, power output saturation, transfer characteristics and photoresponsivity. Fiber channel includes approximately 5 dB distortion at the frequency of 5.72 GHz while passed through itself after the DFB laser diode and after the PD, approximately 25 dB loss is there than that of DFB laser output signal. Optical losses due to the coupling

표 1. 시뮬레이션을 위한 파라메터 값

Table 1. Parameters for simulation.

Parameter	Value
OFDM Data Rate	156250 Symbol/s
Number of Subcarriers	128
Carrier Frequency	5.8 GHz
Roll of Coefficient for Power Amplifier	0.22
Threshold Current for DFB Laser Diode	40 mA
Nonlinear Gain Saturation Parameter	4e-23 m^3
Confinement Factor	0.3
Fiber Path Loss	0.266 dB/km
Fiber Length	100 m- 40 km
Responsivity of the Photo Detector	1 A/W
Photo Detector Load	50 ?

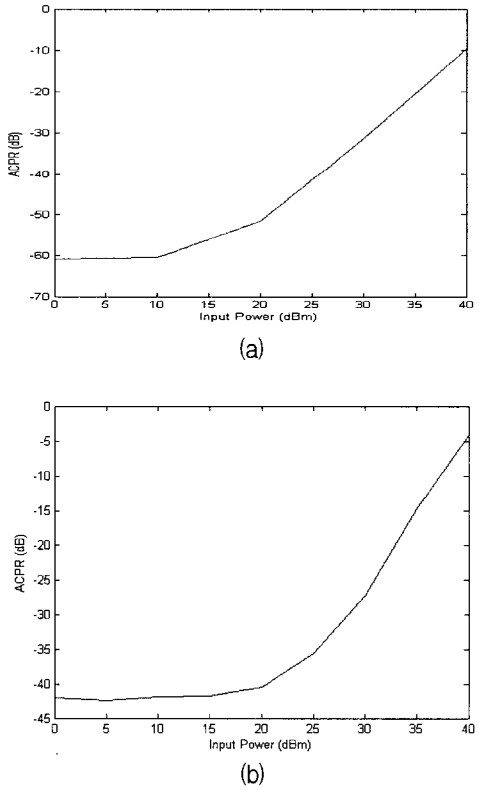


그림 4. (a) HPA 출력단에서 입력 전력에 대한 ACPR 값
(b) 포토다이오드 출력단에서 입력 전력에 대한 ACPR 값

Fig. 4. (a) ACPR vs. Input Power at HPA Output.
(b) ACPR vs. Input Power at PD Output .

between laser and fiber, and fiber and photo detector, are neglected and the shot and thermal noise in the PD were not taken into consideration for simplicity in our system.

Finally, the ACPR versus input power plot at the OFDM amplifier output and at the RF output of the PD (end of the wireless and optical link) are shown in Fig. 4 (a) and (b) respectively. It is found from Fig. 4(a) and (b) that a 22 dB ACPR performance degradation takes place initially (for input power 0 dBm)for transmitting the OFDM signal through the fiber model which comes down to approximately 5 dB distortion if 30 dBm input power is applied in the system.

Gradually increased distortion (spectral regrowth) of maximum 25 dB was observed for varying fiber length from 100 meter to 40 km. This is because; laser nonlinearity dominates for the cause of distortion at low fiber spans whereas dispersion governs distortion effects mostly for higher fiber lengths.

Ⅳ. Conclusion

This paper suggests a 5.8 GHz IEEE 802.11a OFDM wireless and optical link interconnect performance under a simulated environment with a mathematical analysis. The results showed important observations for measurement of distortion experienced due to nonlinearity by the system modeled. Maximum input power can be determined from this work in the future that can be applied to the RoF system to meet the IEEE 802.11a system specification for ACPR and thus design suitable optical links with wireless interconnection.

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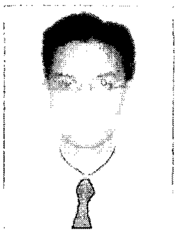

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