BER DEGRADATION DUE TO THE PHASE NOISE SPECTRAL SHAPE IN LMDS SYSTEMS

Youngsun Kim, Jong-In Song and Kiseon Kim

Department of Information and Communications,
K-JIST,
1 Oryong-dong, Puk-gu, Kwangju 500-712 Republic of Korea.
Phone:+82-62-970-2264, Fax:+82-62-970-2204, Email:yskim@geguri.kjist.ac.kr

ABSTRACT

Phase noise of oscillator gives the performance degradation significantly when a high carrier frequency and low transmission rate are used. The BER(Bit Error Rates) degradation of QPSK(Quadrature Phase Shift Keying) transmission is analyzed with the oscillator phase noise level specified in downstream physical interface of LMDS(Local Multipoint Distribution Services) which is described in DAVIC(Digital Audio Visual Council). The model used for the phase noise is a power-law model. We also investigated the effects of the various transmission rates on system performance. For the transmission rate below 0.5 Mbps, the BER performance is severely degraded and we verified that the transmission rate, 20 Mbps, is adequate for the downstream of LMDS systems.

1. INTRODUCTION

The phase noise of oscillator is one of the main factors that degrades the system performance in the communication systems which need low cost and low bit rates. In DAVIC specifications, since the downstream channel has low bit rate link, the precise oscillator is needed[1]. A perfect oscillator will operate at one discrete frequency but any corrupting noise will spread this frequency, resulting in high power levels at near frequencies. As a result, the BER of system increases.

Typically, the stability of oscillator can be analyzed in both frequency and time domain. Also, the analysis result of both domain can be converted[2]. In the time domain, the variance of frequency instability is obtained using the real sample of frequency output. And then, time average concept is used to get the variance. There are several kinds of variances since the early 1960's and those gives different relationships between the variances and the spectral densities. To decide the number of samples for a specified duration, David Allan did a pioneering work that is so called Allan variance[3]. In the frequency domain, the performance analysis starts with the power spectral density (psd) of frequency instability. Since the psd of phase deviation is same with that of squared version of frequency deviation, the oscillator instability is main source of the performance loss in high frequency band.

In the past researches, only the white phase noise term is considered[4] and when more than one phase noises are used, the satellite broadcasting system is used[5]. Corvaja analyzed the performance in LMDS systems but he described the performance in concept of SNR penalty which is additionally needed to achieve certain required BER[6]. In this paper we mainly consider the BER as a function of SNR since the BER vs. SNR curve gives an important information to communication system designer.

The paper is organized as follows. In Section 2, we present the phase noise model described in DAVIC standards, and in Section 3, we show the BER Performance can be obtained with the oscillator's phase noise. Next, in Section 4, we analyze the degraded BER performance curves due to the phase noise. Finally, we conclude this paper.

This work is supported in part by BK-21 Project

2. SYSTEM MODEL

2.1. Downstream LMDS

DAVIC specified the physical layer interface over a radio frequency (above 10 GHz) of LMDS system[1]. Specially, we consider the specifications of the downstream LMDS. In the radio frequency unit, maximum phase noise levels are shown in Table 1. The phase noise level is expressed in dBc/Hz and that means the phase noise levels are evaluated in dB scale after normalized by a power of carrier. Even though information bit rate, 1/T, depends on the code rates of channel coding we used about 20 Mbps. Also 10 Ghz carrier

Table 1: Maximum phase noise levels in DAVIC

frequency offset [kHz]	phase noise level [dBc/Hz]
1	-51
10	-81
50	-99
100	-99
500	-109
1000	-115
2000	-121

frequency is used for analysis.

2.2. Phase noise model

Power-law spectral densities are often used to model the phase deviation of oscillators. In practice, the power spectral density of the phase deviation, ϕ, can be represented by the sum of five independent noise processes as like Eq.(1).

$$S_\phi(f) = \begin{cases} \frac{A_3}{f^3} + \frac{A_2}{f^2} + A_0 & for \quad 0 < f < f_h \\ 0 & for \quad f \geq f_h \end{cases} \tag{1}$$

where

A_n = constant
f_h = high-frequency cut-off of a low pass filter

This model is described by 3 contributions: frequency flicker noise (f^3 part), white frequency noise(f^2 part) and white phase noise(f^0 part) [2]. In Fig.1, the dashed line represents the phase noise level specified in the DAVIC standards and the solid line shows approximated power-law model for given DAVIC phase noise levels. Fig.1 shows the spectral shape of the phase noise level required by the DAVIC standard. The solid lines with slope of -30, -20 and 0 dB/decade represent A_3, A_2 and A_0. The phase noise spectrum is separated by three parts at 10 kHz and 1000 kHz.

3. PERFORMANCE ANALYSIS METHOD

3.1. Derivation of phase noise variance

The phase noise deviation, ϕ, over a period T is expressed by

$$\sigma_\phi^2 = \sigma_3^2 + \sigma_2^2 + \sigma_0^2 \tag{2}$$

where three terms represent three parts of the phase noise spectrum respectively. The distribution of phase increment is a zero-mean Gaussian with variance σ_ϕ^2 when there is no PLL (Phase Locked Loop). Three terms can be evaluated as:

$$\sigma_3^2 = (2\pi)^2 A_3 f_1^3 T \left(1.92 + \ln \frac{1}{f_l T}\right) \tag{3}$$

$$\sigma_2^2 = (2\pi)^2 A_2 f_2^2 T \tag{4}$$

$$\sigma_0^2 = 2A_0 B[1 - sinc(BT)] \tag{5}$$

where f_l is lower cutoff frequency, B is a bandwidth of system, $sinc(x) = \frac{\sin(\pi x)}{\pi x}$ and we set f_1=100kHz and f_2=1000kHz. Fig.2 shows the phase noise variance as a function of data rate. It can be observed that the phase noise variance increase significantly for bit rates below 0.5 Mbps.

3.2. BER calculation with noisy phase

When there is phase noise, the error probability can be obtained as

$$P_E = \int_{-\infty}^{\infty} P_E(\phi) f_\Phi(\phi) d\phi \tag{6}$$

where $P_E(\phi)$ is symbol error probability with phase deviation ϕ and $f_\Phi(\phi)$ is Gaussian probability density function(pdf) of ϕ with zero mean and variance σ_ϕ^2 as specified in Eq.(2). For QPSK data transmission,

$$\begin{aligned} P_E = & \int_{-\pi}^{\pi} \left[Q\left(\sqrt{\frac{2E_b}{N_0}}(\cos\phi + \sin\phi)\right) \right. \\ & \left. + Q\left(\sqrt{\frac{2E_b}{N_0}}(\cos\phi - \sin\phi)\right)\right] f_\Phi(\phi) d\phi \end{aligned} \tag{7}$$

where E_b is bit energy and $N_0/2$ is uniform two-sided power spectral density of noise. For simple calculation of BER performance, we assume that the Gray coding is used and signal-to-noise ratio is high. Then the BER is approximately a half of symbol error probability.

3.3. Tikhonov pdf

In this Section we consider the partially coherent communications which has the statistical information about phase deviation, the structure of the optimal receiver depends on the statistics of the phase deviation. When a PLL is used to track the incoming carrier phase, the phase deviation is given by the Tikhonov density and can be expressed as[7]

$$f_\Phi(\phi) = \begin{cases} \frac{exp(\rho_\phi \cos\phi)}{2\pi I_0(\rho_\phi)}, & |\phi| \leq \pi \\ 0, & otherwise \end{cases} \tag{8}$$

where $\rho_\phi \triangleq 1/\sigma_\phi^2$ denotes the carrier loop signal-to-noise ratio and is given by

$$\rho_\phi \triangleq \frac{P_c}{N_0 B_L} \tag{9}$$

and $I_0(\cdot)$ is the zero-order, modified Bessel function. In Eq.(9), P_c denotes the power of the unmodulated carrier (which is unrelated to the power of the information bearing signal) and B_L is the one-sided bandwidth (in Hz) of the PLL. Then, using Eq.(8) in Eq.(6), BER performance can be evaluated as a function of E_b/N_0 for various values of ρ_ϕ.

4. NUMERICAL RESULT

Fig.3 shows the BER for the different phase noise levels. The BER of conventional QPSK receiver is about 4×10^{-5} at $E_b/N_0 = $ 9dB. With DAVIC phase noise level, the BER is 7×10^{-5} at $E_b/N_0 =$ 9dB. To achieve BER= 10^{-5}, the coherent case needs $E_b/N_0 =$ 9.6dB and the case with DAVIC phase noise it needs $E_b/N_0 =$ 9.8dB. Thus with the phase noise level specified in the DAVIC, there is 0.2 dB loss at BER=10^{-5} comparing with coherent transmission. Another two curves are also plotted. These are obtained by increasing total noise level 10 or 20 dBc/Hz in Table 1. At $E_b/N_0 =$ 9dB, the BER is 2×10^{-4} for 10 dB leveled up and 3×10^{-2} for 20 dB leveled up. We can see as phase noise level increases, the BER is degraded severely. Clearly, the phase noise level has deep impact on the BER. Fig.4 shows the BER for a number of data transmission rate. At $E_b/N_0 =$ 9dB, as the transmission rate varies 20, 0.5, 0.4, 0.3, 0.2 and 0.1 Mpbs the corresponding BER values are about $7 \times 10^{-5}, 3 \times 10^{-4}, 5 \times 10^{-4}, 10^{-3}, 8 \times 10^{-3}$ and 8×10^{-2}. As we predicted in Fig.2, the BER performance is degraded for the transmission rate below 0.5 Mpbs. This is due to the large increment of phase noise variance in that transmission rate.

In Fig.5, we observe the phenomenon of BER performance bound in detail. For low data transmission rate (below 0.2 Mbps), as SNR is increased the BER performance is no more improved.

The BER result is plotted in Fig.6 illustrating the noisy reference effect on system performance. As E_b/N_0 increases, the BER is no more improved for low ρ_ϕ. When we compare Fig.5 and Fig.6, we can find similarity - the bound phenomenon of BER curve.

When transmission rates are 0.4, 0.2 and 0.1 Mbps with the oscillator phase noise, the BER are roughly similar with $\rho_\phi = 11$, 8, 4 dB in the parially coherent receiver, respectively. Even though both system environment are not same, the purpose to compare is to give a concrete concept how much does the oscillator phase noise degrade the BER.

5. CONCLUSIONS

This paper described the BER performance for the QPSK transmission of downstream LMDS with the oscillator phase noise specified in DAVIC. From the frequency domain analysis of phase noise, we obtained the variance of phase deviation using the power law model. Similar with the method of analysis for conventional QPSK transmission, we integrated the conditional probability density function with noisy phase. To obtain BER=10^{-5}, coherent QPSK transmission needed $E_b/N_0 = 9.6$ dB and LMDS system needed $E_b/N_0 = 9.8$ dB. As the phase noise level is increased, the BER performance is severely degraded. Also, we considered the BER performance as a function of transmission rate. The system had poor BER performance for the transmission rate below 0.5 Mbps. We verified that the transmission rate, about 20 Mbps, was adequate to mitigate the effect of oscillator phase noise. Also, we compared with the BER performance of partially coherent receiver to get the realistic concept of oscillator phase noise. Finally, we knew that the reason why 20 Mbps transmission rate was recommended in downstream of LMDS in DAVIC.

REFERENCES

[1] Digital Audio-Visual Council (DAVIC) 1.4 "Lower level protocols and interfaces"

[2] IEEE Standard Definition of Physical Quantities for Fundamental and Time Metrology (IEEE Std. 1139)

[3] D. W. Allan: "Statistics of atomic frequency standards," *Proc. IEEE*, vol. 66, pp.1048-1174, 1978

[4] R. Corvaja and S. Pupolin: "Phase noise effects in QAM systems," *Proc. ICT'99*, pp.521-525, 1999

[5] Y. W. Kim and J. H. Jo: "Phase noise allocation for digital satellite broadcasting system," *IEEE Trans. on Consumer Electronics*, vol. 43, no.3, pp.308-314, Aug. 1991

[6] R. Corvaja and S. Pupolin: "Effects of phase noise spectral shape on the performance of LMDS systems," *Proc. ICT'99*, pp.521-525, 1999

[7] W. C. Lindsey, *Synchronization systems in communication and control* Englewood Cliffs: Prentice Hall, 1972

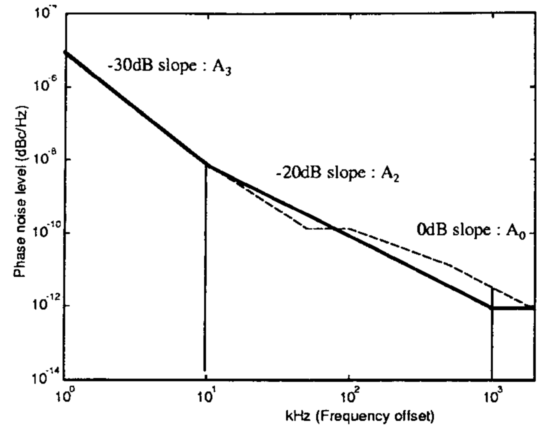

Figure 1: The spectral shape of phase noise specified

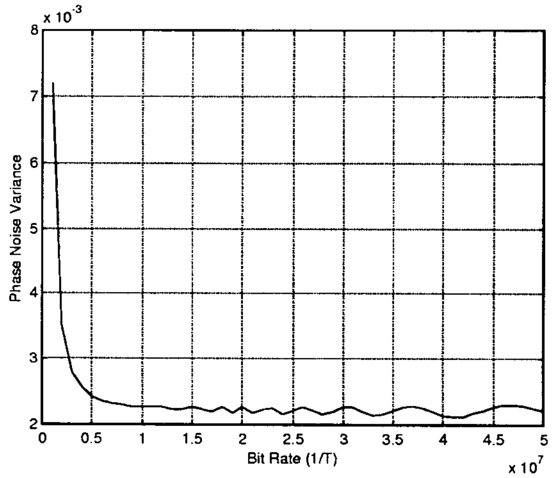

Figure 2: Phase noise variance vs. symbol rate

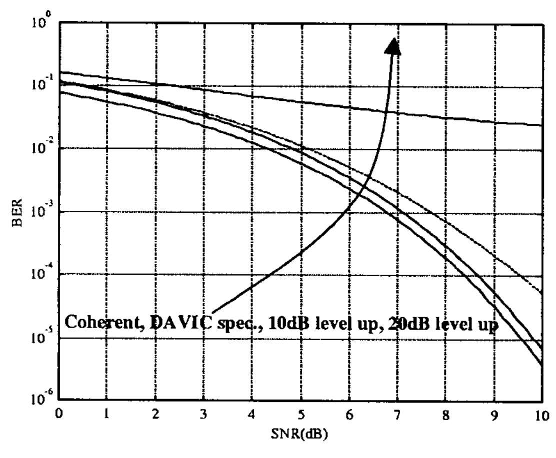

Figure 3: BER performance with varying phase noise level

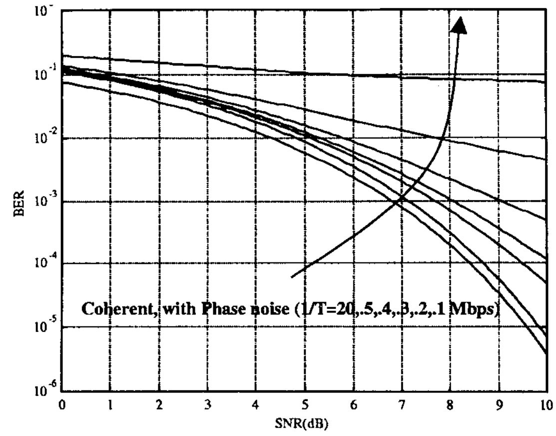

Figure 4: BER performance with varying symbol rate

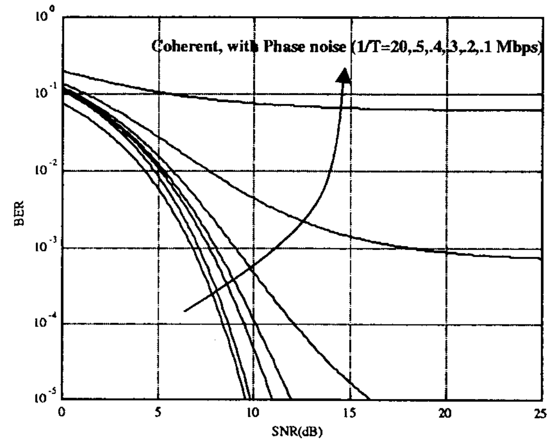

Figure 5: BER performance with varying symbol rate (Performance bound)

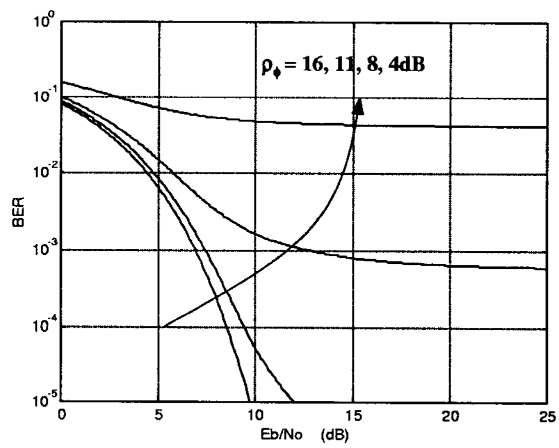

Figure 6: BER performance QPSK transmission with Tikhonov pdf