EXPERIMENTAL REDUCTION OF PHASE-NOISE INFLUENCE FOR AN OPTICAL CPFSK SYSTEM WITH I.F. FILTERING

Y. Jaouën, I. Roudas, and P. Gallion
Département Communications
Ecole Nationale Supérieure des Télécommunications
46, rue Barrault
75634 Paris Cedex 13, France

KEY TERMS

Optical communications, optical receivers, phase noise

ABSTRACT

Theoretical modeling and experimental analysis of the influence of i.f. filtering on performance of optical heterodyne CPFSK systems with differential detection in the presence of phase noise are compared. It is shown that for a bit rate of 1 Gbits/s with a modulation index of 1, i.f. filtering reduces phase noise influence, leading to a significant reduction of the bit-error-rate floor.

INTRODUCTION

Coherent optical systems using electrical delay-line demodulation, such as DPSK and CPFSK systems, are very attractive because they provide nearly the same receiver sensitivity as the PSK system using coherent demodulation, while no optical phase-locked loop is required. A CPFSK modulation can be obtained directly by modulation of the injection current of a semiconductor laser, avoiding the insertion loss of an external modulator.

The semiconductor laser phase noise is well known to lead to a BER floor independent of the optical power received. The theoretical BER floor is related to the i.f. linewidth $\Delta\nu_{\text{i.f.}}$ and demodulation delay time τ by

$$P_{e\ \text{floor}} = \text{erf}_c\left[\frac{1}{4}\sqrt{\frac{\pi}{a\ \Delta\nu_{\text{i.f.}}\tau}}\right], \qquad (1)$$

where $\text{erf}_c(x)$ is the complementary error function. The a parameter expresses the effect of the i.f. filtering on the phase noise and is equal to unity when i.f. filtering is negligible. For instance, in a CPFSK system, a BER of 10^{-10} without influence of phase noise is achieved when the i.f. linewidth is lower than 1% of the bit rate. The linewidth requirement is a function of the modulation index. It is possible to decrease the phase-noise influence by increasing the frequency shift, i.e., decreasing the demodulation delay time τ ($\tau = \frac{1}{2}mR_b$). This expression has been verified experimentally for $a = 1$ by the use of an optical demodulation technique [1].

In heterodyne delay-line demodulator systems, i.f. filtering minimizes the shot noise and reduces the phase-noise influence as well [2, 3]. A theoretical expression of the output phase-noise variance with a finite-time integrator filter for an heterodyne CPFSK system has been given by Jacobsen and Garrett [3]. Tight i.f. filtering also reduces the output phase shift, creating intersymbol interference whose magnitude depends on the modulation index m. For a modulation index $m = 0.5$, the presence of intersymbol interference is more important and leads to an enhancement of the error rate floor and a performance degradation [4]. However, some optimum values for i.f. bandwidth and modulation indices result in negligible intersymbol interference at the sampling instant [4]. In this case, i.f. filtering leads to a reduction of the phase-noise variance, the influence of which on $P_{e\ \text{floor}}$ is expressed by $a < 1$.

EXPERIMENTAL SETUP

The experimental arrangement is shown in Figure 1. A 1520-nm DFB laser diode, with a Lorentzian line shape of about 28 MHz linewidth, is used as FSK transmitter. The spectral linewidth is controlled by changing the biasing injection current. Optical CPFSK modulation is achieved by direct modulation of the laser injection current. The frequency deviation between the two symbols transmitted is 1 GHz, corresponding to a modulation index $m = 1$ for a bit rate $R_b = 1$ Gbit/s. The optical output power is launched into a single-mode fiber

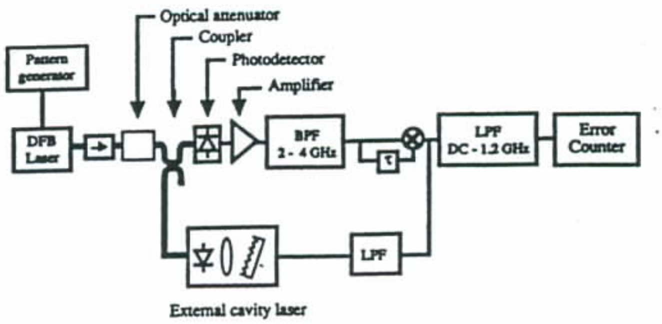

Figure 1 Experimental setup

through an optical isolator providing more than 60 dB isolation.

A tunable 10 kHz-linewidth external cavity laser was used as local oscillator. A polarization controller is used to match the state of polarization of the two lasers. The two optical fields were combined with a 1:1 fiber coupler and detected with a PIN photodiode. The oscillator power level at the photodetector is $P_{\text{ol}} = -5.3$ dBm. The i.f. signal is amplified and filtered, and is demodulated using a delay-line discriminator having a 3.05 GHz zero crossing. The i.f. filter is centered at 3 GHz and has a bandwidth of $B_{\text{i.f.}} = 2$ GHz. The low-pass filter (LPF) suppresses the second harmonic components of the intermediate frequency. The cutoff frequency of the LPF is selected for no phase-noise filtering influence [5].

EXPERIMENTAL RESULTS

Calculations for the theoretical BER floor as a function of the i.f. linewidth-delay time product $\Delta\nu_{\text{i.f.}}\tau$, using Eq. (1), are plotted in Figure 2. The solid line corresponds to the BER floor without i.f. filtering influence; i.e., for $a = 1$. The dotted curve is for a BER floor with $a = 0.68$, corresponding to a modulation index $m = 1$ with an equivalent i.f. bandwidth $B_{\text{i.f.}} = 2R_b$ [4]. The dotted curve is plotted taking into account i.f. filtering on phase noise variance reduction, relaxing in the linewidth requirement.

For an ideal finite-time integrator filter with equivalent bandwidth $B_{\text{i.f.}} = 2R_b$, the integration time is equal to $T_b/2$ where T_b is the bit time. For a modulation index $m = 1$, the delay time of discriminator is also $\tau = T_b/2$. Clearly, there is a sampling instant for which no intersymbol interference occurs. This is obvious because the discriminator compares two samples corresponding to an integration time over the same bit period.

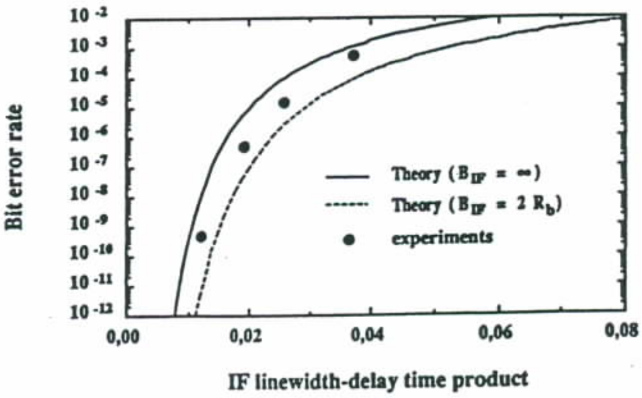

Figure 2 BER floor over i.f. linewidth product $\Delta\nu_{\text{i.f.}}\tau$ for a modulation index $m = 1$

Experimental data are obtained for a 1-Gbit/s system using a 2^7-1 binary sequence. Increasing the received optical power does not improve the BER. Thus, we consider that the performances are only limited by phase noise. We observe a good agreement between theory and experiment. The difference between experimental results and theoretical curve is attributed to the presence of residual intersymbol interference due to the nonideality of the i.f. filter used.

BER in the presence of intersymbol interference can be obtained by quasianalytical techniques using computer simulation. Optimum values of i.f. filter bandwidth can be given as a function of laser linewidths and modulation indices [4].

CONCLUSION

We have presented an experimental setup which investigates the influence of i.f. filtering on phase-noise variance reduction. We have evaluated the linewidth requirements for optical CPFSK systems, including the influence of i.f. filtering. For a modulation index $m = 1$ and i.f. bandwidth $B_{\mathrm{i.f.}} = 2R_b$, better performances and higher phase noise immunity are obtained.

REFERENCES

1. R. Pedersen, G. Schiellerup, G. Jacobsen, and E. Bodtker, "Direct Optical Characterisation of DFB Lasers for CPFSK System Applications," *Electron. Lett.*, Vol. 25, No. 17, Aug. 1989, pp. 1108–1110.
2. E. Patzak and P. Meissner, "Influence of IF-Filtering on Bit Error Rate Floor in Coherent Optical DPSK-Systems," *IEE Proc.*, Pt. J, Vol. 135, No. 5, Oct. 1988, pp. 355–357.
3. G. Jacobsen and I. Garrett, "Crosstalk and Phase-Noise Effects in Multichannel Coherent Optical CPFSK Systems with Tight IF Filtering," *IEEE J. Lightwave Technol.*, Vol. LT-9, No. 9, Sept. 1991, pp. 1168–1177.
4. I. Roudas, Y. Jaouën, and P. Gallion, "Optimum IF Bandwidth of Optical Heterodyne CPFSK Systems with Differential Detection in the Presence of Phase Noise," unpublished.
5. L. Kazovsky, "Impact of Laser Phase Noise on Optical Heterdyne Communications Systems," *J. Opt. Commun.*, No. 7, 1986, pp. 66–78.

Received 8-11-93

Microwave and Optical Technology Letters, 6/16, 903–905

CCC 0895-2477/93