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Heterodyne Detection of CPFSK Signals With and Without Wavelength Conversion up to 5 Gb/s

R. J. S. Pedersen, F. Ebskamp, B. Mikkelsen, T. Durhuus, M. Öberg, and S. Nilsson

Abstract—**In this letter we report detection of wavelength converted signals by a coherent CPFSK receiver. The signals are wavelength converted over 35 nm, and we measure record receiver sensitivities of −38.7 dBm at 4.0 Gb/s and −35.6 dBm at 4.8 Gb/s. Comparison between results with and without wavelength conversion, relative to theory, results in a small penalty of less than 1.5 dB.**

I. Introduction

THE coherent multichannel (CMC) technique is a promising method for implementation of multichannel frequency division multiplexing (FDM) networks [1]. Heterodyne receivers exhibit both high sensitivity and good selectivity, and they may prove to be advantageous to use in network structures, where large fan-out, narrow channel spacing, and fast channel switching are required. In this context also, high-speed all-optical wavelength converters are key components, since the flexibility and capacity of FDM systems can be greatly enhanced by reuse and reallocation of carrier wavelengths [2].

In this paper we investigate the combination of the two techniques, using the sensitivity and selectivity advantage of the heterodyne receiver and the network flexibility of the wavelength converter. Wavelength conversion of DPSK signals at 140 Mb/s was reported earlier [3], without bit error rate (BER) measurements. We report the application of a CPFSK heterodyne receiver to detect wavelength converted signals at bit rates of up to 4.8 Gb/s. Also, we include BER simulations, using an accurate CPFSK system model [4].

We have used a DBR laser as wavelength converter, since it is possible to get an all-optical conversion up to Gb/s data rates [5], [6]. The conversion is performed by an incoming AM signal through optical modulation of the carrier density in the gain section of the DBR laser. The use of optical modulation eliminates the influence of electrical parasitics, and the maximum speed of operation is determined by the intrinsic characteristics of the DBR laser. The conversion range is given by the gain bandwidth of the DBR laser, and the output wavelength range is given by the tuning range of the DBR laser.

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II. System Setup

The experimental setup for heterodyne detection of wavelength converted signals is shown in Fig. 1. A three-electrode $\lambda/4$-shifted MQW DFB laser [7] is used as a remote CPFSK transmitter. The light is launched into a fiber-based interferometer with a free spectral range (FSR) of 16 GHz. Here, the signal is FM/AM converted, resulting in an AM signal with an extinction ratio larger than 10 dB and negligible chirp. The light is coupled through a fiber coupler into the DBR laser wavelength converter [5], where the AM signal at a wavelength λ_1 = 1548 nm is converted into a CPFSK signal at a wavelength of λ_2 = 1514 nm. The wavelength conversion range is shown in Fig. 2, where the optical spectrum from the DBR laser at threshold is depicted together with the signal from the remote signal laser. The DBR wavelength is as indicated in the range 1511–1514 nm, ~ 35 nm from the wavelength of the remote signal laser. Output wavelengths of 1514.1 and 1512.5 nm have previously been used from this DBR laser [5].

The FM response of the optically modulated DBR laser is very important for a high-quality CPFSK output signal. The relative FM response is presented in Fig. 3 with the current in the gain section as a parameter. At a gain current of 100 mA, a flat FM response is obtained with a bandwidth of 3.3 GHz.

The output signal from the wavelength converter is fed through an optical attenuator and into the coherent receiver. The coherent receiver uses a balanced low-noise tuned front end [8], with an average noise spectral density of 16.9 pA/$\sqrt{\text{Hz}}$ and a common-mode-rejection ratio of more than 26 dB. The intermediate frequency (IF) is 10.3 GHz, and the IF band is from 6.4 to 14.2 GHz. A DBR laser, matched to the wavelength converter, is used as a local oscillator (LO), and it generates a total photocurrent of 1.1 mA. The IF system linewidth is measured to be 20 MHz. To match the delay in the demodulator, a frequency deviation of 3.2 GHz is required. Modulating the remote signal laser with a bit rate of 3.2 Gb/s, the obtained IF spectrum shown in Fig. 4(a) indicates a modulation index

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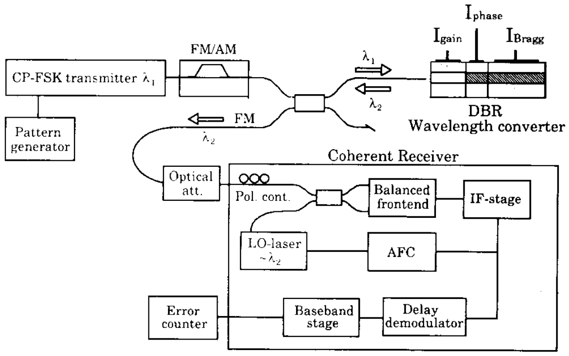

Fig. 1. Experimental setup for coherent detection of wavelength converted signals.

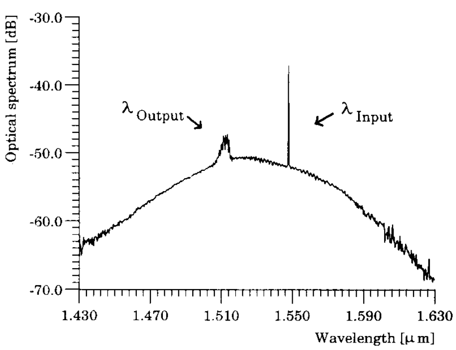

Fig. 2. Wavelength conversion range. Optical spectrum at DBR laser threshold as well as the wavelength of the remote signal laser.

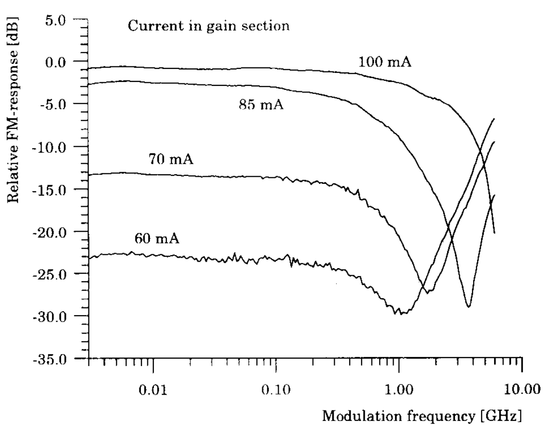

Fig. 3. Relative FM response, measured by optical modulation of the DBR laser. Current in gain section is a parameter.

of $m = 1$. This is achieved with an estimated coupled power of -1 dBm into the converter. The corresponding IF spectrum for a modulation speed of 4 Gb/s ($m = 0.8$) and 5 Gb/s ($m = 0.64$) are shown in Fig. 4(b) and (c), respectively.

As a reference, a CPFSK experiment without wavelength conversion is conducted using two three-electrode

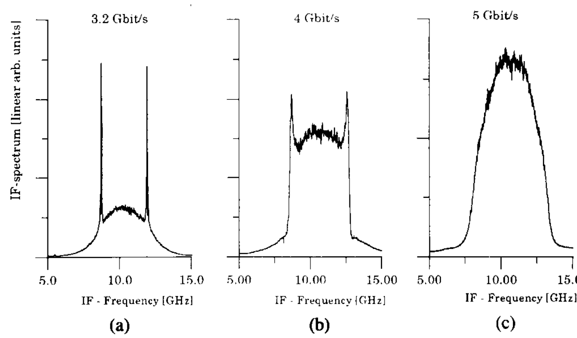

Fig. 4. Measured IF spectra for a modulation speed of: (a) 3.2 Gb/s ($m = 1$); (b) 4 Gb/s ($m = 0.8$); and (c) 5 Gb/s ($m = 0.64$).

$\lambda/4$ MQW DFB lasers, similar to the remote signal laser, as a directly modulated transmitter and local oscillator. The transmitter exhibits a flat FM response and a modulation bandwidth in excess of 5 GHz. The system linewidth with these lasers is 7 MHz, and the total photocurrent generated by the LO laser is 2 mA.

III. Results

BER measurements are done with wavelength converted signals at 4 and 4.8 Gb/s. For comparison, BER is also measured without wavelength conversion at 4 GB/s and 5 Gb/s, using the two three-electrode DFB lasers and the same heterodyne receiver.

It is not possible to detect wavelength converted signals at higher bit rates than 4.8 Gb/s, apparently due to a combination of IF-signal jitter and FM bandwidth limitation of the wavelength converter (Fig. 3).

Experimental data are shown in Figs. 5 and 6, together with theoretical curves, using a CPFSK system simulation program, which takes shot noise, residual relative-intensity noise, equivalent input noise in the front end, phase noise, and tight IF filtering into account [4]. The measured and calculated sensitivities for a word length of $2^7 - 1$ are shown in Table I.

The sensitivities of the wavelength converted signals are the highest reported at these bit rates. Also, the 5 Gb/s CPFSK result without wavelength conversion is the best reported. The difference in theoretical sensitivities, with and without conversion, is due to different LO photocurrent and phase noise values.

The BER curves of the wavelength converted signal at 4.8 Gb/s are slightly degraded compared to 4 Gb/s, due to limited bandwidth of the wavelength converter and frequency jitter in combination with the "tight" IF filtering.

As shown in Table I, the difference between results with and without wavelength conversion, relative to the theory, is very small—less than 1.5 dB.

IV. Conclusion

We have demonstrated that a CPFSK heterodyne receiver can be applied to detect wavelength converted

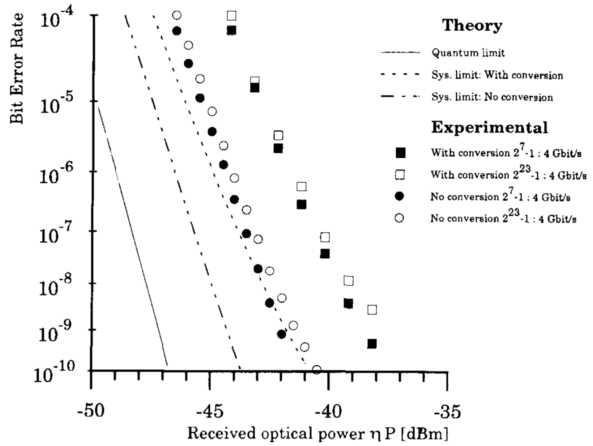

Fig. 5. Measured and calculated BER at 4 Gb/s. BER for wavelength converted signals are indicated with squares; circles represent nonwavelength-converted signals.

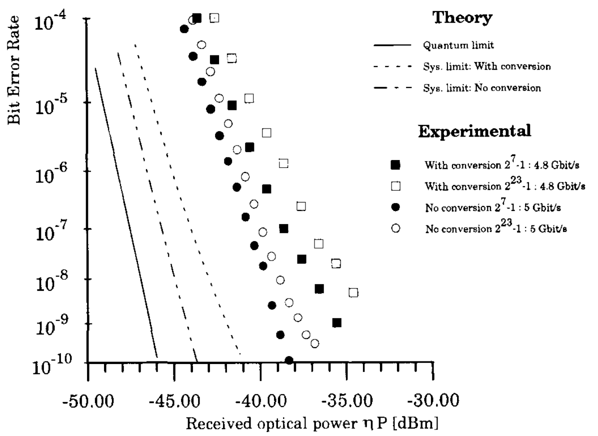

Fig. 6. Measured and calculated BER. BER for wavelength converted signals at 4.8 Gb/s are indicated with squares; circles represent non-wavelength-converted signals at 5 Gb/s.

signals, using a DBR laser as wavelength converter. The conversion is done over a range of 35 nm. We achieve a sensitivity of −38.7 and −35.6 dBm for 4 and 4.8 Gb/s, respectively. These are the highest bit rates reported to date for wavelength conversion and the best sensitivities using wavelength conversion. Comparison between results with and without wavelength conversion, relative to the theory, shows a difference of less than 1.5 dB.

TABLE I
MEASURED AND CALCULATED SENSITIVITIES OF THE HETERODYNE CP-FSK RECEIVER

Bit rate [Gb/s]	4	4	4.8	5
Wavelength conversion	Yes	No	Yes	No
ηP_s experiment	−38.7 dBm	−42.2 dBm	−35.6 dBm	−39.1 dBm
ηP_s theory	−41.8 dBm	−44.2 dBm	−42.0 dBm	−44.2 dBm
ΔP	−3.1 dB	−2 dB	−6.4 dB	−5.1 dB
Difference	1.1 dB		1.3 dB	

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