Optics Communications 285 (2012) 3483–3486

Contents lists available at SciVerse ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Simultaneous demodulation and dispersion compensation of WDM DPSK channels using optical ring resonator

Bishanka Brata Bhowmik [a,*], Sumanta Gupta [a], Ranjan Gangopadhyay [b]

[a] *Department of Electrical Engineering, Indian Institute of Technology Patna, Patna-800013, India*
[b] *The LNM Institute of Information Technology, Jaipur, India*

ARTICLE INFO

Article history:
Received 16 May 2011
Received in revised form 2 April 2012
Accepted 3 April 2012
Available online 14 April 2012

Keywords:
Wave length division multiplexing
Differential phase shift keying
Optical ring resonator
Chromatic dispersion
Optical fiber communication

ABSTRACT

We have introduced and comprehensively analyzed a novel scheme of simultaneous demodulation and dispersion compensation of wavelength division multiplexed (WDM) non-return-to zero (NRZ) differential phase shift keying (DPSK) optical link using an optical ring resonator (ORR) based filter. Using extensive numerical simulation we have demonstrated the transmission of 10.7 Gb/s WDM DPSK channels having 50 GHz and 100 GHz spacing over 400 km of unrepeatered reach at 20 dB optical-signal-to-noise-ratio (OSNR) to achieve a bit error rate (BER) of 10^{-3}.

1. Introduction

For the last few years differential phase-shift-keying (DPSK) signaling format becomes a much appreciated modulation format in optical fiber communication transmission technology for its higher receiver sensitivity and greater tolerance towards the impairments caused by fiber-induced nonlinearity [1]. For the demodulation of optical DPSK signals various techniques have been adopted such as the Mach–Zehnder interferometer (MZI) [1,2], narrowband optical filter (NBOF) having appropriate bandwidth (BW) [3,4]. These schemes essentially convert the phase information into the amplitude that is followed by a direct detection. Simultaneous demodulation of WDM DPSK signal by periodic Gaussian filter has been successfully demonstrated experimentally in [5,6]. Nowadays optical ring resonator (ORR) filter based DPSK demodulator has also attracted much attention due to its lower footprint, higher flexibility, lower latency and monolithic integration [7–10]. The demonstration of multi-channel 40 Gb/s NRZ-DPSK demodulation exploiting the periodic filter response of single ORR has been reported recently [11].

Moreover the capability of single channel NRZ-DPSK demodulation as well as chromatic dispersion (CD) compensation using the chirped fiber Bragg grating (CFBG) has been reported in [12]. The efficacy of a tunable CD compensator based on multiple ORRs capable of compensating a relative group delay of ~1350 ps/nm was also demonstrated [13]. Although realization of ORR based NRZ-DPSK demodulator or the CD compensator was reported separately earlier, the simultaneous demodulation and CD compensation of NRZ-DPSK by single ORR is not believed to have appeared in the open literature, to the best of the authors' knowledge.

In this paper, we have shown for the first time the efficacy of an ORR for simultaneous demodulation and dispersion compensation of WDM NRZ-DPSK signal with per-channel data rate of 10.7 Gb/s. It is revealed that 400 km of uncompensated reach can be achieved using a suitably designed ORR based dispersion compensator and NRZ-DPSK demodulator, ensuring bit-error rate BER $= 10^{-3}$.

2. Principles of optical ring resonator based NRZ-DPSK demodulator and dispersion

The schematic diagram of an ORR having N number of uncoupled rings associated with tunable phase shifter is shown in Fig. 1. Here the φ_i ($i = 1, 2..., N$) represent the round-trip phase shift of the i-th ring and κ_i and $\kappa_i^{'}$ are the power coupling coefficient between the i-th ring and the lower and upper waveguides respectively. The resonance frequency of the i-th ring can be tuned by varying φ_i and the group delay can be varied κ_i and $\kappa_i^{'}$ [14]. The field transfer function at the through port for i-th ring can be written as

$$\frac{E_{i_{through}}}{E_{i_{in}}} = \frac{\left(\mu_i - \mu_i^{'} e^{-j\varphi_{i_r}} \chi_{i_r}\right)}{\left(1 - \mu_i \mu_i^{'} e^{-j\varphi_{i_r}} \chi_{i_r}\right)} \tag{2.1}$$

where, $E_{i_{through}}$ = field at the through port of i-th ring, $E_{i_{in}}$ = input field of the i-th ring, $\mu_i = \sqrt{1-\kappa_i}$, $\mu_i^{'} = \sqrt{1-\kappa_i^{'}}$, φ_{i_r} = round trip phase of i-th

* Corresponding author.
E-mail address: bishanka@iitp.ac.in (B.B. Bhowmik).

0030-4018/$ – see front matter
doi:10.1016/j.optcom.2012.04.005

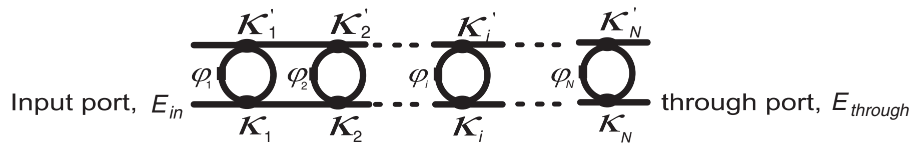

Fig. 1. Two port ORR having N uncoupled rings and phase shifters.

ring, χ_{i_r} = the round trip loss factor of the i-th ring, $\chi_{i_r} = 10^{\frac{-2\pi R_i \alpha_{i}dB}{20}}$, where R_i = radius of the i-th ring, and $\alpha_{i_{dB}}$ = loss in the i-th ring expressed in dB/m.

The through-port field transfer function normalized to the free spectral range (FSR) for i-th ring is

$$\mathrm{H}(\Omega_i) = \frac{\left(\mu_i - \mu_i' e^{-j\Omega_i}\chi_{i_r}\right)}{\left(1-\mu_i\mu_i' e^{-j\Omega_i}\chi_{i_r}\right)} \tag{2.2}$$

where, Ω_i = relative angular frequency normalized by FSR, i.e. $\Omega_i = \frac{\omega-\omega_{i_0}}{FSR}$, ω = angular frequency, ω_{i_0} = angular frequency where the i-th ring resonator is tuned.

The through-port phase response with respect to the normalized relative angular frequency is,

$$\phi(\Omega_i) = \arctan\left[\frac{\mathrm{Im}[\mathrm{H}(\Omega_i)]}{\mathrm{Re}[\mathrm{H}(\Omega_i)]}\right]. \tag{2.3}$$

Accordingly the group delay $\tau(\Omega_i)$ normalized by round trip time of T_i for i-th ring is given by

$$\tau(\Omega_i) = -\frac{d\phi(\Omega_i)}{d\Omega_i}. \tag{2.4}$$

Then the total normalized field transfer function and normalized group delay for N rings are given by

$$H(\Omega)|_{\mathrm{total}} = \prod_{i=1}^{N} \frac{\left(\mu_i - \mu_i' e^{-j\Omega_i}\chi_{i_r}\right)}{\left(1-\mu_i\mu_i' e^{-j\Omega_i}\chi_{i_r}\right)} \tag{2.5}$$

$$\tau(\Omega)|_{\mathrm{total}} = \sum_{i=1}^{N} \tau(\Omega_i). \tag{2.6}$$

It was shown that by tuning of the round-trip phase and the coupling coefficient of each ring the desired value of the negative dispersion slope could be achieved. Then the ORR becomes suitable for CD compensation for a specific length of standard single-mode fiber (SSMF) [13,15,16]. It has been noticed that by proper tuning of ORR parameters having multiple rings, the power transfer function of a periodic NBOF can be obtained having a desired 3 dB BW and FSR. So an ORR can demodulate WDM NRZ-DPSK signals if the channel spacing is made equal to or an integer multiple of the FSR of the filter [11]. Moreover the group delay response, which has the same periodicity with that of power transfer function, indicates that simultaneous demodulation and dispersion compensation of WDM-DPSK channels using ORR are possible.

3. System description

The simulation system setup which has been used in this paper is shown in Fig. 2. A 10.7 Gb/s WDM-NRZ unrepeatered transmission link using standard single mode fiber (SSMF) (G. 652) and having 5 channels with either 100 GHz or 50 GHz channel spacing uses 1550 nm wavelength as the center channel. The SSMF is assumed to be linear, which is practical unless the launched power per channel or the channel count is high. The dispersion coefficient and the dispersion slope of the SSMF are assumed to be 17 ps/nm/km and 0.057 ps/nm^2/km respectively. Different DPSK demodulators using NBOF, MZDI and ORR are also shown in Fig. 2. At the end of the DPSK link the signal is amplified and amplified spontaneous emission (ASE) noise is loaded to achieve a required optical signal-to-noise ratio (ROSNR) measured over a 0.1 nm resolution bandwidth. The demultiplexer (DEMUX) selects the desired channel and suppresses the out-of-band ASE noise in front of the MZDI based demodulator. The NBOF or ORR themselves acts as a noise blocker and the role of DEMUX is only to select the desired channel. After the photodetection the current is filtered using a fifth order low-pass electrical Bessel filter having 3 dB BW equal to 80% of the bit rate. In this study we have selected NRZ-DPSK based on MZDI having 1-bit delay in one of its arm, Gaussian optical filer (GOF) having BW equal to two-thirds of the bit rate according to [4], and the transfer function of the ORR based DPSK demodulator is tailored to compensate the CD for a specific length of SSMF. The optimization of ORR's transfer function is done by minimizing the BER value at a given ROSNR value for a desired length of the SSMF. Here we have designed two ORRs. The first one is optimized to compensate for the CD of 200 km of SSMF, and other to compensate for the CD of 300 km of SSMF. The FSR of both ORRs are kept equal to 25 GHz. The numbers of uncoupled optical rings used for these two filters are six and seven respectively. The field coefficients and the round-trip phase shift values which are used for the simulations are summarized in Table 1(a) and (b). The 3 dB BW and the group-delay slope of the first ORR filter (ORR1) which is designed for 200 km of SSMF are 7.15 GHz and −1245 ps/nm respectively as shown in Fig. 3(a). The 3 dB BW and the group-delay slope of the second ORR filter (ORR2) have the values 5.19 GHz and −3993 ps/nm as depicted in Fig. 3(b).

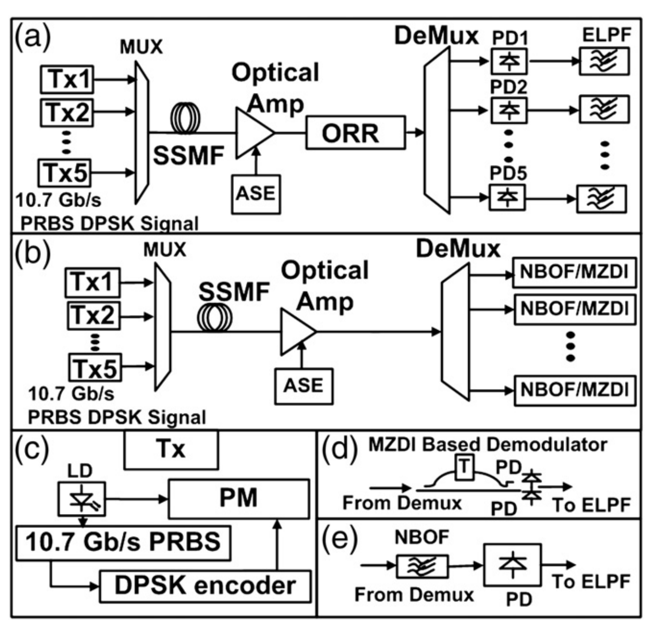

Fig. 2. Simulation system model. Tx: transmitter, LD: laser diode, PM: phase modulator, NBOF: narrowband optical filter, PD: photo detector, ELPF: electrical low pass filter, Optical Amp: optical amplifier. (a) Simultaneous setup assisted with ORR based DPSK demodulator, (b) transmission link NBOF and MZDI based demodulator, (c) DPSK transmitter, (d) MZDI based DPSK demodulator, and (e) NBOF aided DPSK demodulator.