Simulation of SOA-MRR-Based Equalization Technique for FSO Signals

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***Abstract*-The feasibility of combining a semiconductor optical amplifier (SOA) with a single passive microring resonator (MRR) to equalize the amplitude and phase fluctuations of the distorted signal in free space optical (FSO) communications is theoretically investigated and demonstrated. The numerical simulation conducted for this purpose allows to specify the MRR radius and detuning so that the critical performance metrics are acceptable and the signal's quality is sufficiently restored.**

I. Introduction

Free Space Optical (FSO) communications are evolving rapidly and are becoming a promising alternative over conventional fiber-based wired systems. In order to maximize the potential of this technological option and take better advantage of its attractive characteristics, it is indispensable to combat the impairment of scintillation [1]. We have recently employed a technique for mitigating the intense amplitude and phase fluctuations incurred by this performance limiting effect [2]. The technique exploits the properly perturbed gain dynamics of a semiconductor optical amplifier (SOA) in combination with the interferometric properties of a cascaded optical delay interferometer (ODI). In this paper we propose to apply this technique by replacing the ODI with a microring resonator (MRR). Compared to the ODI the MRR exhibits [3] flexibly adjustable transmission characteristics, reduced latency, efficiently and repeatedly achievable interference and relaxed operating conditions. Thus in this paper we numerically investigate and demonstrate the amplitude and phase equalization capability of the MRR-assisted scheme. This is done by formulating in Section II an appropriate model that describes the amplitude and phase response of the SOA-MRR configuration in the time and frequency domain. The conducted simulation enables to evaluate the impact of the MRR radius and detuning and to suitably select these critical parameters so that the defined performance metrics are made acceptable, as detailed in Section III.

II. Modelling

Fig. 1 depicts the simulated setup, which comprises of a SOA serially connected to MRR of radius R, field

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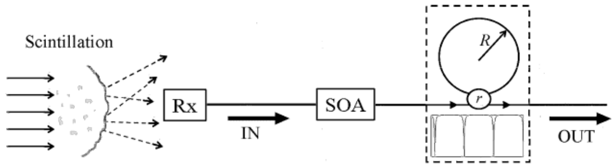

Fig. 1. Proposed SOA-MRR setup for signal equalization in FSO links.

transmission coefficient r and round-trip amplitude attenuation factor τ. The properly biased [2] SOA induces an intensity-dependent phase shift and a positive instantaneous frequency deviation, i.e. red chirp, on the scintillation-distorted signal components that arrive from different directions of propagation. Then if the MRR is properly designed to act as notch filter and the transmission peak of its spectral response is set at somewhat lower than the wavelength of the optical signal carrier it can compensate for the signal amplitude and phase fluctuations by converting them into amplitude and phase variations, respectively, of the opposite magnitude at its output [2].

In order to simulate the operation of the proposed scheme, we need to provide expressions for the power, $P(t)$, and chirp $\Delta v(t)$, at the output of the SOA and MRR. The amplified signal power, $P_{SOA}(t)$, is given by [4] $P_{SOA}(t) = |E_{SOA}(t)|^2$, where $E_{SOA}(t)$ is the signal electric field obtained from [4]

$$E_{SOA}(t) = E_{sig}(t)\exp\left[-(1+jC)\left(\tfrac{1}{2}(1-ja)h(t)\right)\right] \quad (1)$$

where a is the SOA linewidth enhancement factor, C is the initial chirp parameter and $h(t)$ is the integrated SOA power gain. $h(t)$ obeys the following differential equation [4]

$$\frac{dh(t)}{dt} = \frac{\ln(G_{ss}) - h(t)}{T_{carrier}} - \frac{P_{sig}(t)}{E_{sat}}\left\{\exp\left[h(t)-1\right]\right\} \quad (2)$$

where G_{ss}, $T_{carrier}$, E_{sat} is the SOA small signal gain, carrier lifetime and saturation energy, respectively, while $P_{sig}(t) = |E_{sig}|^2$ is the power of the input signal. The field transfer function of the MRR is [5]

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$$T_{MRR}(\lambda) = \frac{r - \tau \exp\left[j\varphi\left((\lambda - \Delta\lambda)/\lambda \right) \right]}{1 - r\tau \exp\left[j\varphi\left((\lambda - \Delta\lambda)/\lambda \right) \right]} \quad (3)$$

In this expression $r = \tau = 0.95$, which is necessary in order for the condition of critical coupling to be satisfied and accordingly for the MRR to be able to act as notch filter as efficiently as possible [5]. Also $\varphi = \left(4\pi^2 n_{eff} R\right)/\lambda$ is the MRR single-pass phase shift [5], where n_{eff} = 1.41 is the effective refractive index. Furthermore, *Δλ* is the MRR detuning and *λ* is the signal wavelength in the vicinity of 1550 nm. The signal power at the output of the MRR is $P_{MRR}(t) = \left|E_{MRR}(t)\right|^2$ where

$$E_{MRR}(t) = F^{-1}\left\{F\left[E_{SOA}(t)\right]T_{MRR}(\lambda)\right\} \quad (4)$$

The operators F and F^{-1} denote Fast Fourier transform (FFT) and its inverse (IFFT), respectively.

The chirp at the SOA output is mathematically described from [4]

$$\Delta\nu(t) = -\frac{1}{2\pi}\frac{d\Phi_{SOA}(t)}{dt} \quad . \quad (5)$$

where the SOA phase transfer function is [4] $\Phi_{SOA}(t) = 2\ln 2Ct^2D^2/T^2 - \alpha h(t)/2$, with $D = 4$ and $T = 100$ ps being the duty factor and repetition interval of the pulses from different signal components that are inserted in the SOA. On the other hand the chirp at the MRR output is found using the same equation as in (5) but by substituting in the phase term $F^{-1}\left\{\Phi_{MRR}(\lambda) + F\left[\Phi_{SOA}(t)\right]\right\}$, where $\Phi_{MRR}(\lambda)$ is the phase argument of the MRR field transmission factor [5]

$$\Phi_{MRR}(\lambda) = \pi + \varphi + \arctan\left(\frac{r\sin(\varphi)}{\tau - r\cos(\varphi)}\right) + \arctan\left(\frac{r\tau\sin(\varphi)}{1 - r\tau\cos(\varphi)}\right) \quad (6)$$

III. RESULTS

The numerical simulation is performed for the same input signal and SOA parameters as in [2]. The performance criteria are the signal peak amplitude fluctuation (*AF*) and chirp fluctuation (*CF*) [2]. These are evaluated against *R* and *Δλ*. We consider a realistic scenario for FSO operation where the received signal has an initial *AF* = 1 dB and *CF* = 1.5. From Fig. 2(a) we observe that with no detuning, i.e. *Δλ* = 0 nm, the *AF* is reduced for specific MRR radius values, 7 and 14 um. For these *R* values, when the detuning is increased, *AF* is reduced until *Δλ* = 0.3 nm, while it is significantly increased for other *Δλ* values. Similarly, *CF* is reduced for *R* = 7 um and *R* = 14 um. Thus, if *R* = 7 um then *CF* becomes minimum in a detuning range from *Δλ* = 0.2 nm to 0.4 nm, while if *R* = 14 um the decrease of *CF* is more pronounced for *Δλ* = 0 nm and *Δλ* = 0.5 nm. Consequently, we should make a compromise between *AF* and *CF*, which leads us to select *R* = 7 um and *Δλ* = 0.3 nm. This combination results indeed in acceptable *AF* = 0.85 dB, as opposed to *AF* = 1 dB without the equalization technique. Similarly the *CF* is dropped from 1.5 after the SOA to 1.14 after the MRR. The pulse and chirp amplitude variations become more smoothened as indicated in Fig. 3 by the vertical arrows.

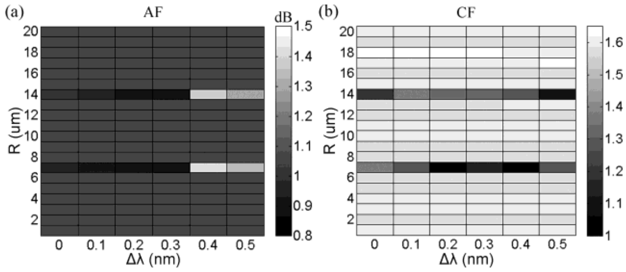

Fig. 2. (a) Peak amplitude fluctuation-*AF* and (b) chirp fluctuation-*CF* at MRR output vs. radius R and detuning *Δλ*.

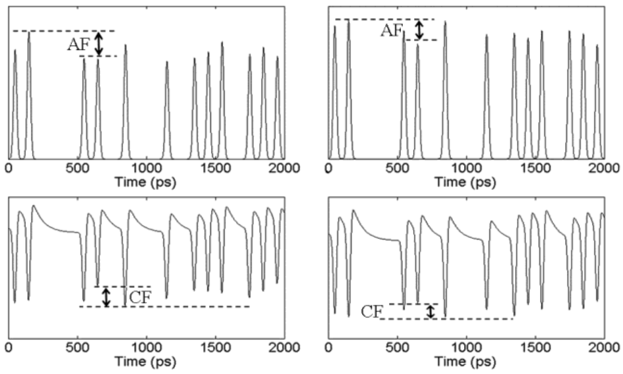

Fig. 3. Signal pulse (top) and chirp profile (bottom) without (left) and with (right) MRR-assisted equalization technique.

IV. CONCLUSION

In conclusion, the possibility of applying a technique for equalizing the signal fluctuations in FSO communications has been investigated and demonstrated by means of numerical modelling. The proposed technique relies on the combination of a SOA and MRR-based notch filter, and is capable of improving the performance of FSO communications that has been degraded due to scintillation-like effects.

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