# Regenerative Re-circulating Fiber Loop for Optical Buffering

**F. Scotti[1], G. Berrettini[2], G. Serafino[2], G. Contestabile[2]*, and A. Bogoni[1]**
*1: National Laboratory on Photonic Networks - CNIT, via G. Moruzzi 1 56124 Pisa, Italy*
*2: Scuola Superiore Sant'Anna, via G. Moruzzi 1 56124 Pisa , Italy*
**Author e-mail address: contesta@sssup.it*

**Abstract:** We propose a re-circulating fiber-loop-based optical memory exploiting regenerative amplification by cross-gain-compression in an SOA. 50 circulations giving around 150 µs buffering time with 1.2 dB power penalty every 10 rounds are reported.

**OCIS codes:** (060.4250) Networks; (230.1150) All-optical device; (250.5980) Semiconductor Optical Amplifier.

All-optical buffers will likely be key elements in future all-optical networks. Indeed, many applications would benefit from such a novel function, as examples, packet synchronization, label processing, contention management and so on. Only variable optical buffers will allow dynamical wavelength-preserving optical packet delay [2]. Among the various schemes proposed for optical buffers, semiconductor optical amplifier (SOA)-boosted re-circulating fiber loops [3, 4] show high delay-bandwidth products. However, in those schemes pattern effects and amplified spontaneous emission (ASE) noise accumulation limit the number of packet circulations and the overall buffer performance. Nevertheless, there are signal reshaping techniques that work properly with packets and that can be used to extend the number of circulations and, hence, the buffering time. Here, we report a novel re-circulating loop scheme that exploits the cross gain compression (XGC) effect in an SOA [5, 6] to obtain amplification and, at the same time, a considerable noise reduction. This new scheme allows to significantly improve the number of loop circulations with respect of previous results [4] so that tens of loop rounds are now possible having only limited signal degradation. Moreover, the regenerative behavior of the buffer is also proven studying the evolution of the signal Q-factor in case of the storage of input noisy signals.

The schematic of the regenerative re-circulating loop is reported in Fig. 1. Input packets at wavelength $\lambda_1$=1551nm are sent into the loop through a coupler. The minimum packet length is determined by the need to perform proper BER measurements. Indeed, error detector sequence acquisition time limits the minimum packet duration. For this reason, a 500m-long fiber spool has been inserted into the loop (not reported in Fig. 1) to avoid packet overlapping, giving a round trip time of about 3 µs. Once in the loop, the signal is split along two different paths. Part of the signal is coupled with a continuous wave (CW) at a longer wavelength $\lambda_2$=1558 nm. Those two signals co-propagate as a pump-probe pair in SOA1 in order to obtain a logically inverted copy of the packets at $\lambda_2$ by cross gain modulation (XGM). The inverted copy is selected by an optical band-pass filter (OBPF), and then synchronized and coupled with the original packets at $\lambda_1$. This way, by properly adjusting the two optical powers, an almost overall constant power signal is obtained and sent to SOA2. Indeed, "1s" on $\lambda_1$ correspond to "0s" on $\lambda_2$, and vice versa, and a constant power at $\lambda_2$ corresponds to the input packet guard-times. Signal power saturates SOA2 gain so that XGC occurs between opposite bits [5, 6]. This effect gives noise compression on mark levels, as well as power equalization because of constant SOA2 gain saturation. At the same time, noise compression of space levels can also obtained because of spectral modulation of the gain [6].

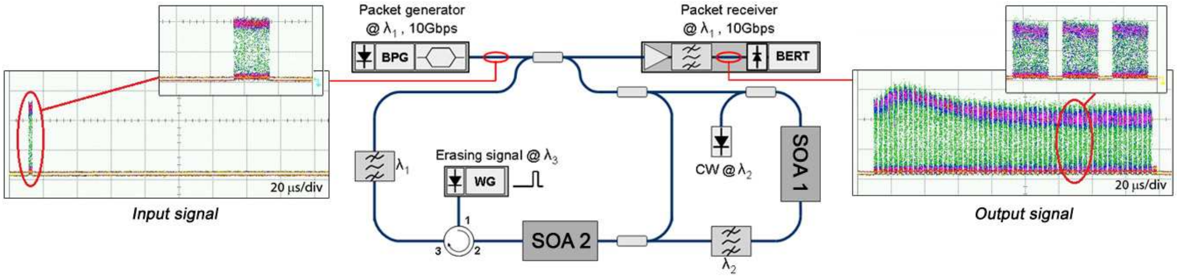
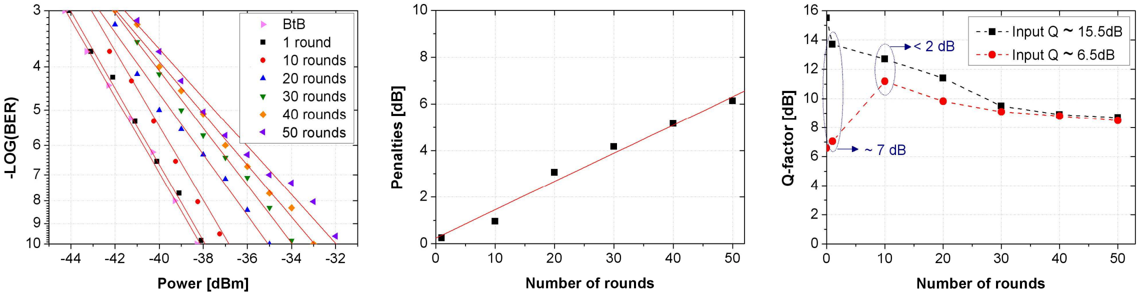


Fig. 1. Re-circulating fiber loop scheme. Left inset: input packet; Right inset: output packet replicas.

At SOA2 output a band-pass filter centered at $\lambda_1$ selects the original packets that can circulate again or exit the buffer. An optical gate signal at $\lambda_3$, lasting at least as the packet duration, is sent counter-propagating into SOA2 to erase the loop before a further storing process begins. This avoids cross-talk of re-circulating residual replicas on new packets entering the buffer. SOA1 and SOA2 are both multi-quantum-well devices with around 30 dB gain, 13 dBm output saturation power and 17 ps gain recovery time when biased at 300 mA.



(a) (b) (c)

Fig. 2. a) BER curves as a function of the signal power at the receiver input, b) power penalties, and c) Q-factor as a function of the number of rounds.

From the insets of Fig. 1, which show input and output packets including a zoom around the 30th replica, we see that the noise levels are nicely constant even at large round count.

The performance is evaluated by BER measurement carried out as a function of the optical power at the pre-amplified receiver. Results are reported in Fig. 2 (a). The overall BER degradation in 50 rounds, corresponding to 150 µs buffering time is around 6 dB, having an average power penalty at BER=$10^{-9}$ of about 1.2 dB every 10 rounds. The penalty trend is reported in Fig. 2 (b), for 1, 10, 20, 30, 40 and 50 packet circulations in the loop, showing a linear trend. We underline that packet length was determined by the lab equipments, in detail by the error detector recognition and synchronization time. In principle, shorter packets will require buffers made by shorter loop that are suitable for photonic integration. This will also increase the memory access frequency and, most likely, significantly increase the maximum number of circulations.

We also investigated the robustness of the buffer to the case of noisy input signals and, indeed, it results that the scheme properly works even in this case, taking advantage of the regenerative amplification in SOA2.

Performance in terms of Q-factor evolution as a function of the number of rounds is studied in two different cases: a clear signal with 15.5 dB Q-factor and a noisy signal with 6.5 dB Q-factor. Results are reported in Fig. 2 (c). The Q-factor difference between the two cases tends to reduce as the number of circulations increases. As pointed out in the figure, the difference between the two curves is around 7 dB for the first round but it is reduced to only 1.7dB at the 10th round, and become negligible from the 30th circulation on. Fig. 2 (c) indicates that, because of the regenerative element inserted in the loop, from some tens of circulations on, the performance of the proposed optical re-circulating loop converge to a limit condition, even when the input signal quality is reduced.

This work is partially supported by the Pan-European Photonics Task Force Integrating Europe's Expertise on Photonic Subsystems (EUROFOS) and GOSPEL project.

## References

[1] Y. Shun, B. Mukherjee, S.J.B. Yoo, S. Dixit, "A unified study of contention-resolution schemes in optical packet-switched networks," *JLT,* vol. 21, pp. 672- 683 (2003)

[2] F. Songnian, P. Shum, Nam Quoc Ngo; Chongqing Wu, Yajie Li, C.C. Chan, "An Enhanced SOA-Based Double-Loop Optical Buffer for Storage of Variable-Length Packet," *JLT,* vol. 26, pp. 425-431 (2008)

[3] E.F. Burmeister, J.P. Mack, H.N. Poulsen, J. Klamkin, L.A. Coldren, D.J. Blumenthal, J.E. Bowers, "SOA Gate Array Recirculating Buffer for Optical Packet Switching," *OFC/NFOEC 2008*, 24-28 (2008)

[4] G. Berrettini, G. Meloni, L. Potì, A. Bogoni, "All-Optical Variable Buffer Based on Semiconductor Optical Amplifier," *IEEE JQE,* vol. 47, pp. 510-516 (2011)

[5] G. Contestabile, R. Proietti, M. Presi, S. Gupta E. Ciaramella; "All-optical 40 Gbits/s packet regeneration by means of cross-gain compression in a semiconductor optical amplifier," Opt. Lett., vol. 33, pp. 1470-1472 (2008).

[6] G. Contestabile, R. Proietti, N. Calabretta, E. Ciaramella, "Cross-Gain Compression in Semiconductor Optical Amplifiers," *JLT*, vol. 25, pp. 915–921 (2007)