# Novel 42.65 Gbit/s Dual Gate Asynchronous Digital Optical Regenerator Using a Single MZM

S. K. Ibrahim[1], D. Hillerkuss[1,2], R. Weerasuriya[1], G. Zarris[3], D. Simeonidou[3], J. Leuthold[2], A.D.Ellis[1]
[1] Photonic Systems Group, Tyndall National Institute, Prospect Row, Cork, Ireland.
2. Institute of High-Frequency and Quantum Electronics, University of Karlsruhe (TH), 76131 Karlsruhe, Germany.
3. Photonic Networks Research Laboratory, CES, University of Essex, Colchester CO4 3SQ, UK
Email: selwan.ibrahim@tyndall.ie

**Abstract**

*We propose and demonstrate experimentally a 42.65Gbit/s dual-gate asynchronous digital optical regenerator in a novel configuration using a single MZM, with receiver sensitivity penalty of only ~2dB.*

## Introduction

Interconnection between backbone and metro-core networks operating at different line rates is required in proposed future networks [1,2]. A requirement in such interconnection nodes is the conversion between multiple lower data rate signals and higher data rate signals, wavelength-division-multiplexed channels and higher data rate optical-time-division-multiplexed (OTDM) channels. For WDM-to-OTDM conversion, a simple means is needed to synchronize all individual WDM channels to a common reference clock before they can be aggregated to a single high data rate OTDM signal [2]. An Asynchronous Digital Optical Regenerator (ADORE) provides a solution by regenerating, reshaping, and retiming incoming asynchronous bursts of data to a local clock asynchronously [2,3,4]. Here we report the first practical implementation of a 42.65Gbit/s dual-gate ADORE with a simplified architecture and improved performance by using a single MZM with a wide data switching window which can be used for sampling two clock pulses with different phases. The optimum sampling clock phase is selected by a 2x1 optical switch. This experimental demonstration of a simplified ADORE offers a practical solution for OTDM multiplexing in future high-speed optical networks.

## Principle of Operation

Figure 1 shows a functional diagram of a dual-gate ADORE, using two optical gates to provide the two sampling clock phases. The output from the local clock at frequency ($f_L$) is applied to the inputs of the two gates, one of which is delayed relative to the other by half the nominal bit period T ($T=1/f_L$). Each bit of an RZ-ASK signal at a frequency $f_R$ is reshaped and amplified to an NRZ-ASK signal bit with a wider pulse width than the RZ pulse. This is then used to modulate the two clock pulses with a gate switching window width W. It is necessary that the gate switching window width is chosen so that for any phase delay of the incoming RZ-ASK data signal, the clock pulses should be correctly modulated by at least one of the two gates. Finally a 2x1 optical switch is used to select the optimum clock phase with appropriate delay achieving asynchronous regeneration. The additional T/2 differential delay after the upper gate is needed only if it is required to maintain bit synchronism for all the outgoing regenerated bursts; if that is not required, then the additional delay is unnecessary. The switching is achieved by a controller circuit based on a simple RF phase measurement technique to compare the phase of the incoming RZ-ASK data signal with the local clock signal to select the optimum switching path.

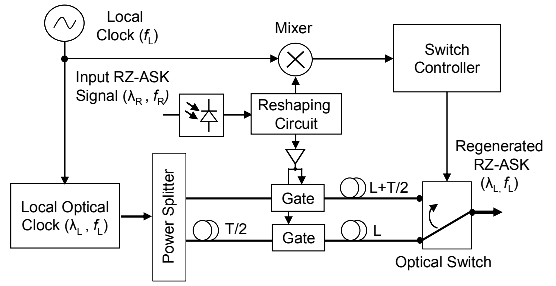


*Figure 1: Functional diagram of a dual-gate ADORE*

## Experimental Setup

Figure 2 shows the experimental setup of the dual-gate ADORE based on a single MZM configured to optimally modulate one of two half bit delayed probe pulses selected by a 2x1 optical switch.

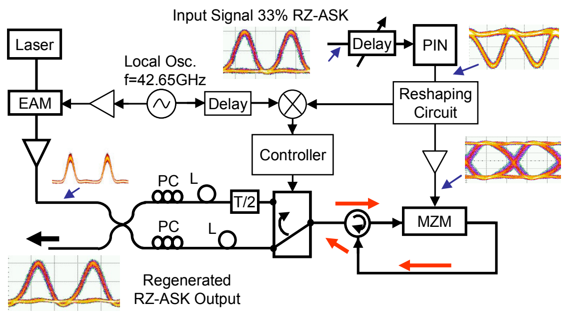


*Figure 2: Experimental setup of the 42.65Gbit/s dual-gate ADORE using a single MZM*

On the left side of figure 2 an electro-absorption modulator (EAM) was driven by a locally generated 42.65GHz clock signal in order to generate ~5ps full width half maximum (FWHM) probe pulses at the

978-1-4244-2229-6/08/$25.00 ©2008 IEEE

wavelength of 1549.7nm. Then an Erbium Doped Fiber Amplifier (EDFA) was used to amplify the optical pulses before being split by a 3dB coupler and passed through two optical paths containing polarization controllers and a differential optical delay of half a bit period (T/2) equivalent to about 11.72ps. The two probe pulses were then passed to a 2x1 optical switch which was automatically controlled by a circuit that selected the probe pulse giving the best sampling point. A 42.65 Gbit/s 33% RZ-ASK data signal with a Pseudo Random Binary Sequence (PRBS) length of $2^7$-1 at a wavelength of 1558.7nm and back to back sensitivity of ~32.2dBm was generated using an external cavity laser and two Mach-Zehnder modulators. This signal was passed through a variable optical delay line, and amplified to a total power of +4.5dBm before being detected using a high speed PIN photodiode. The detected RZ-ASK signal was then reshaped to an NRZ-ASK signal by using a high speed comparator. This reshaping function guarantees a wider switching window for the ADORE. The signal was then electrically amplified and applied to the electrodes of a $LiNbO_3$ Mach-Zehnder modulator (MZM) biased at the quadrature point. Depending on the configuration of the 2x1 switch, the MZM modulated one of the probe pulses resulting in a regenerated RZ-ASK signal with the same wavelength and pulse width of the probe pulses. The regenerated RZ-ASK signal returned to the switch through a circulator and passed through the same path of the probe signal resulting in delay of 2L or 2L+T depending on the switch position. The one-bit relative delay T between the two cases is of no importance provided it is much smaller than the minimum switching time of the switch (T~23.4 ps < switching time ~400 ns). The controller circuit used the output of an RF phase detector to configure the 2x1 switch to select the probe signal that was optimally modulated in the MZM. The phase detector circuit was constructed using a double balanced mixer with the local oscillator port connected to the local clock and radio frequency port connected to the incoming data signal after it has been detected.

## Results

The performance of the ADORE was evaluated by measuring the BER curves of the regenerated signal for different phases between the incoming data signal and the local clock. The automatic channel selection control of the switch ensured that error free performance was achieved for the whole range of delay phases. The maximum degradation in receiver sensitivity was measured to be ~2dB as shown in figure 3. This degradation in the receiver sensitivity occurred when the sampling probe pulse was close to the edge of the gating window. The penalty depended on various factors such as the MZM bias voltage, driving signal and the width of the probe pulses.

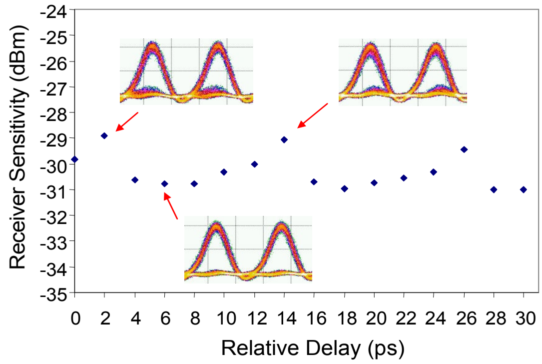


*Figure 3: Variation in receiver sensitivity as a function of input data phase delay*

Figure 4 confirms that the ADORE can operate error free over a wide range of input data signal wavelengths (1541.6-1569.6nm) with a maximum penalty of ~1.2 dB.

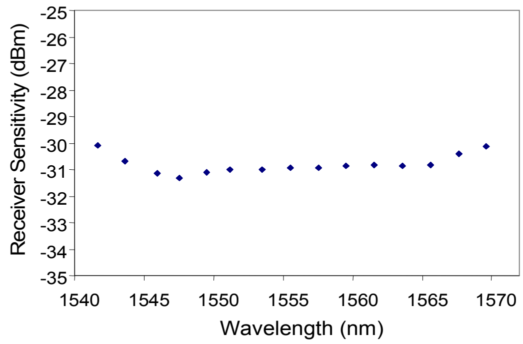


*Figure 4: Variation in receiver sensitivity as a function of input data wavelength*

## Conclusions

In this paper, we report the first demonstration of a dual-gate asynchronous digital optical regenerator based on a single MZM. At a bit rate of 42.65Gbit/s, the overall receiver sensitivity penalty was ~2dB with automatic selection of the optimum channel. This ADORE configuration offers error free retiming of an incoming optical RZ-ASK signal with any phase delay over a wide range of wavelengths (1541.6-1569.6nm) without the use of any clock recovery. It offers a practical solution for retiming burst or packet-switched data signals for WDM to OTDM conversion applications.

This work was supported by the Science Foundation Ireland under grant 06/IN/I969 and the European Commission under TRIUMPH project IST-027638 STP.

## References

1. I. Tomkos, et al, Proc. ICTON'06, Mo.B1.5
2. CW Chow, et al, Opt. Exp, (15), 8507-8512, 2007
3. D. Cotter, et al, IEEE JLT, (16), 2068-2080, 1998
4. D. Phillips, et al, IEEE PTL, (11), 892-894, 1999