A Novel AOTF-Based Multichannel Add-Drop Node and its Cascadability in WDM Ring Networks

Roberto Gaudino[†] and Daniel J. Blumenthal[††]

[†]Dipartimento di Elettronica, Politecnico di Torino,
Corso Duca degli Abruzzi, 24, 10129 Torino, Italy
e-mail: gaudino@polito.it
[††]Optical Communications and Photonic Networks (OCPN) Laboratory
School of Electrical and Computer Engineering
Georgia Institute of Technology, Atlanta, GA 30332-0250
e-mail:danb@ee.gatech.edu

Abstract

A novel AOTF multichannel add/drop node is demonstrated and its cascadability in a ring network is evaluated. It is shown that an alternate channel spacing scheme produces acceptable power penalties for up to 7 cascaded nodes with channel rates of 2.5 Gbps.

Introduction: Acousto-optic tunable filter (AOTF) technology has greatly evolved over the last several years and research grade products are available for wavelength division multiplexed (WDM) applications [1]. These devices still have limitations in dense WDM systems, particularly when several RF frequencies are applied for multichannel adding/dropping functions [2, 3]. Techniques like spatial and/or wavelength dilation have been utilized to overcome these limitations [4].

In this paper, we present a novel add-drop node architecture based on two cascaded AOTFs. This node is particularly suited for circuit switched all-optical ring networks. We experimentally measure the node performance in several worst case situations in a 400 GHz (3.2 nm) spaced WDM network. Node cascadability is investigated using a recirculating loop. It is shown that the power penalty per node due to AOTF related impairments is less than 1 dB provided that adjacent channels are not simultaneously dropped/added in the same node. This constraint must be dealt with using a proper medium-access protocol (MAC) at the network management level. This architecture employs a much simpler hardware implementation compared to standard spatial or wavelength dilated architectures.

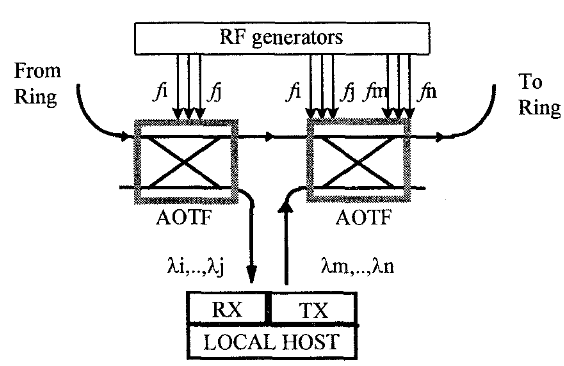

Figure 1: Add-drop node architecture

Multichannel Add-drop Node Architecture: The Multichannel AOTF add-drop node is shown in Fig. 1. The first AOTF acts as a dropping filter for wavelengths, $[\lambda_i,\ldots,\lambda_j]$ when the appropriate set of RF frequencies $[f_i,\ldots,f_j]$ are applied. The second improves the extinction ratio on the dropped channels and allows new wavelengths $[\lambda_n,\ldots,\lambda_m]$ to be added.

ECOC 97, 22–25 September 1997, Conference Publication No. 448, © IEE, 1997

Multichannel Add/Drop Experiment: We tested the multichannel performance of the node using two polarization independent, fully integrated, apodized AOTF [5] made by Pirelli Cavi S.p.A.. When used for single channel add/drop functions, the cascaded configuration exhibited better than 30 dB rejection on the dropped channel and a suppression of more than 18 dB on the sidelobes at the drop port, resulting in negligible power penalty for both coherent and incoherent crosstalk. The AOTF performance can severely degrade under multi-RF operation due to the superposition of multiple traveling wave acoustically induced gratings inside the device as shown in [2, 3]. In this situation, the input-output transfer function shows a time dependent behavior and thus time averaged spectral measurements using an optical spectrum analyzer can be misleading. Therefore, the following results are based on time domain measurements of bit-error rate (BER) or Q-values using eye-diagrams.

Multichannel drop port measurements: The effect of multichannel operation on node drop port performance was tested by dropping a 2.5 Gbps channel at λ_0=1556.8 nm and measuring the BER as a function of received power when a second RF signal $f_{RF,2}$ was applied simultaneously with the RF frequency $f_{RF,1}$ corresponding to the channel at λ_0=1556.8 nm. The results are shown in Fig. 2 for different values of $\Delta f = f_{RF,1} - f_{RF,2}$. The receiver consisted of an erbium-doped fiber amplifier (EDFA) followed by an optical filter centered around λ_0, a photodiode, a low-noise electrical amplifier and a SONET OC-48 filter. For $\Delta f = \pm 400$ KHz, which corresponds to $\Delta\lambda$=3.2 nm (the location of the filter side lobes relative to the center frequency), the penalty at P(e)=10^{-9} is greater than 2 dB. The penalty becomes small (less than 0.3 dB) for $\Delta f = \pm 600$ KHz, and negligible for $\Delta f = \pm 800$ KHz (not shown in the picture for clarity) which corresponding to an alternate channel dropping situation in a 3.2 nm spaced WDM. The slight difference between positive and negative values of Δf are due to the asymmetry in the AOTF transfer function.

Coherent interference measurements: A potentially critical situation arises when coherent interference occurs between a dropped channel at wavelength λ_0 and a new channel added on the same wavelength. This signal will be further degraded in the presence of other acoustic frequencies spaced by Δf as shown in Fig. 3. The penalty in this situation, due to optical coherent interference, is less than 0.5 dB when a single RF is applied and around 1 dB when a second frequency at $\Delta f = \pm 800$ kHz is applied,

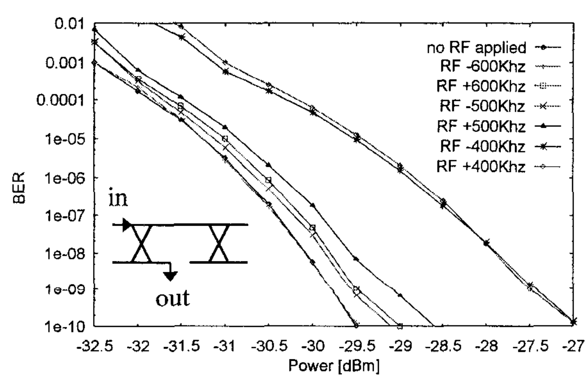

Figure 2: Effect of a second RF frequency is seen by measuring the BER for the dropped channel as a function of power at the drop port. The curves refer to different detuning frequencies between the primary and a second acoustic frequency.

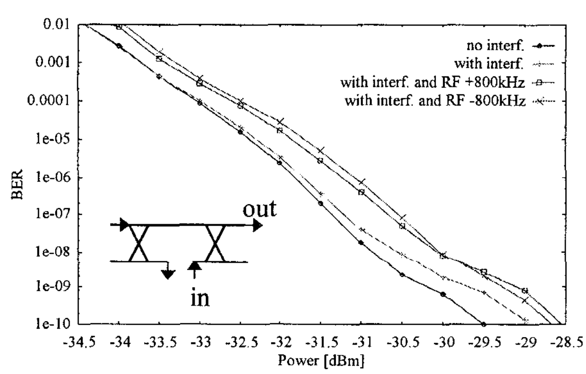

Figure 3: Effect of coherent crosstalk in the presence of a second RF frequency. The BER is measured as a function of power at the bar port, with interfering optical channel on the same wavelength. The curves refer to different detuning frequencies between the primary and a second acoustic frequency.

corresponding to the dropping of the next non-adjacent channel.

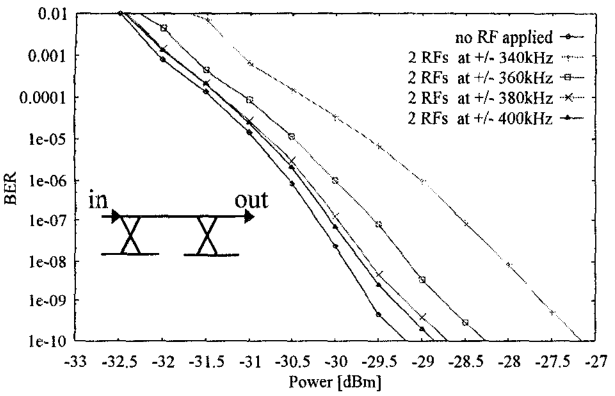

Figure 4: Multichannel BER as a function of power at the bar port.

Bar state measurements: In order to access the performance of a digital signal passing through several nodes prior to being dropped, we experimentally evaluated a channel on λ_0 passing through the bar state of a node while the two adjacent channels are dropped (using two RF signals $f_{RF,1}$ and $f_{RF,2}$ spaced by $\Delta f = f_{RF,1} - f_{RF,2}$). The results are shown in Fig. 4; the penalty for Δf=400 kHz is 0.4 dB at P(e)=10^{-9}.

Cascadability measurements: Cascadability was studied by placing the add-drop node in the recirculating loop shown in Fig. 5. The loop consisted of a 2x2 coupler, a 75 Km long dispersion shifted fiber, 3 EDFAs, the cascaded add-drop node and a broadband optical switch (required to synchronize the loop and gate buildup of ASE). The results, in term of Q-value as a function of the number of recirculations, are shown in Fig. 6. After 7 recirculations we were able to obtain Q>6 (corresponding to P(e)=10^{-9}) with a small penalty observable on the eye diagram when the RF signals are applied, thus demonstrating the cascadability of our add-drop node. For more than 7 recirculations, the loop performance was limited by ASE accumulation.

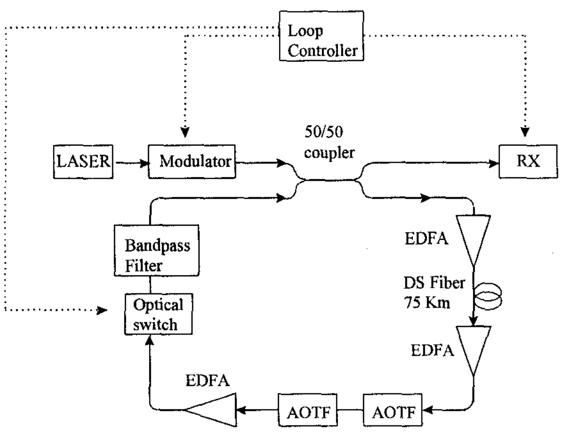

Figure 5: Recirculating loop schematic.

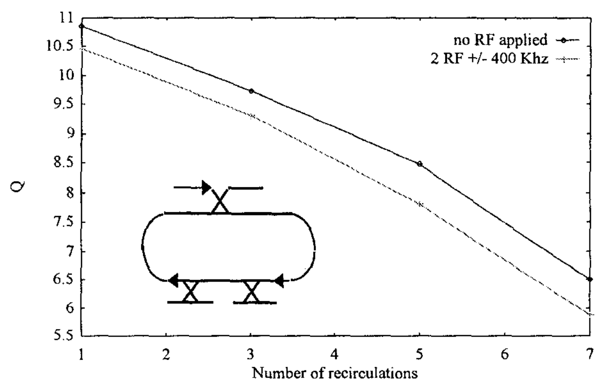

Figure 6: Bar-State Loop results. Q-factor as a function of the number of recirculations.

Conclusions: We have introduced and experimentally demonstrated a novel AOTF multichannel add-drop node. We have tested its performance using state-of-the-art AOTF devices in several worst case situations, showing that the power penalty per node in a 3.2 nm spaced WDM is always less than 1 dB in an alternate channel adding/dropping situation. The node cascadability was demonstrated in a recirculating loop experiment, where the AOTF induced penalty was shown to be neglegible after 7 recirculations.

The proposed architecture employs a much simpler hardware implementation than standard spatial and/or wavelength dilated architectures. Improvements in the characteristics of AOTF devices, such as reduced bandwidth and sidelobes suppression, will eventually allow to remove the alternate channel constraint and/or to use denser WDM. Future researches will deal with the development of a multi-channel electronic driver for the AOTFs, with further investigation on the node cascadability in more complex situations than the one considered here and with the possibility to add EDFA gain equalization functions.

Acknowledgments: This work was founded by an NSF National Young Investigator Award and a DARPA DURIP Award #DAAH04-96-1-0346.

Bibliography

[1] D. A. Smith et al., "Evolution of the acousto-optic wavelength routing switch", *J. Ligthwave Technol.*, vol. 14, no. 6, June 1996.
[2] F. Tian, H. Herrmann, "Interchannel interference in multiwavelength operation of integrated acousto-optic filter and switches", *J. Ligthwave Technol.*, vol. 13, no. 6, June 1995.
[3] M. Fukutoku, K. Oda, "Optical beat induced crosstalk of an acousto-optic tunable filter for WDM network applications", *J. Ligthwave Technol.*, vol. 13, no. 11, Nov. 95
[4] J. Sharony, K. Cheung, T. Stern, "The wavelength dilation concept in ligthwave networks- implementations and system considerations", *J. Ligthwave Technol.*, vol. 11, no. 5/6, May/June 1993.
[5] S. Morasca, D. Scarano, S. Schmidt, "Applications of $LiNbO_3$ acousto-optic tunable switches and filter in WDM transmission networks at high bit rates", in *8th Tyrrenian International Workshop on Digital Communications*, Lerici (SP) Italy, Sept. 96.