# Characterization of a 16-Channel Optical/Electronic Selector for Fast Packet-Switched WDMA Networks

F. Tong, *Member, IEEE*, C.-S. Li, *Member, IEEE*,
A. E. Stevens, *Student Member, IEEE*, and Y. H. Kwark, *Member, IEEE*

***Abstract*— We report the demonstration of a 16-channel optical/electronic selector for applications in fast packet-switched wavelength division multi-access networks. The selector chip has four differential transimpedance amplifiers with each amplifier shared by four photodetectors, giving a total of 16 channels selected by two stages of MESFET switches. The channel switching time is approximately 10 ns. No appreciable crosstalk is observed from neighboring channels in the first-stage switches, and a 0.35 dB crosstalk penalty is measured through the second-stage switches at a BER of $10^{-9}$ with $-20$ dBm average optical power in the interference channel. The selector can also be reconfigured as an unswitched four-channel array receiver.**

## I. Introduction

WAVELENGTH division multiaccess networks (WDMA) require compact, low-cost wavelength selectors or tunable filters capable of covering a wide spectral range but with a narrow bandwidth [1]. In a packet-switched environment, wavelength channel reconfiguration has to be completed within a relatively short interval ($\simeq\mu$s) in order to maintain a high throughput [2]. These requirements render various existing tunable filters [3] inadequate for such networks.

One attractive tunable filter approach is to combine an optical demultiplexer with a photodetector array and electronic selector fabric. In this case, the optical demultiplexer can support a large channel capacity and a wide spectral range, and the electronic selection can be very fast. Fig. 1 shows the schematic of such a tunable filter. The optical demultiplexer is a $SiO_2$/Si planar waveguide grating [4]–[7] which diffracts and focuses the input optical signals of multiple wavelengths onto different output waveguides. Currently under development, our planar waveguide grating exhibits a total loss (including fiber coupling loss at the input waveguide) of 10–16 dB at the TE mode with a wavelength channel spacing of 7.8 Å and channel crosstalk of <16 dB. There exists, in addition, stress-induced birefringence causing a ~3 Å shift at the output between the TE and TM modes. The resolved optical channels are coupled to large area (75 $\mu$m diameter) InGaAs photodetectors via reflection by a 45° mirror (formed by polishing of the end face of the grating) and focused by a lens array. The photodetectors are connected to transimpedance amplifiers integrated with electronic switches. The channel selection scheme is based on sequential switching of the received optical signals in stages at the analog level. There are several photodetectors connected to a single transimpedance amplifier through switches, thus forming the first level of selection. The signals are further discriminated through a set of switches implemented inside the amplifiers, thus forming the second-level selection. A four-channel optical-to-electronic GaAs amplifier/selector with a single switching stage has previously been reported [8].

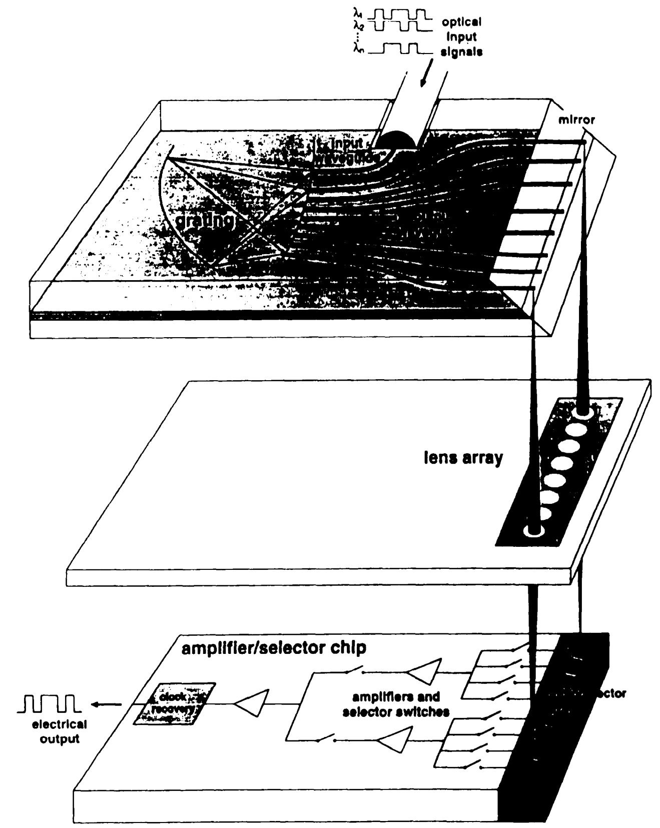



Fig. 1. Schematic of the tunable filter for WDMA networks.

## II. Selector Design

Figs. 2(a) and 2(b) show the electronic circuitry and photograph of the selector chip. The design, simulation and wafer probe results will be reported in [9]. As shown in the figures, the chip consists of four sets of differential transimpedance amplifiers and output buffers. Each of the four amplifiers is designed to accommodate four photodetectors (5 bonding

Manuscript received March 29, 1994; revised May 24, 1994.
F. Tong, C. -S. Li, and Y. H. Kwark are with the IBM T. J. Watson Research Center, Yorktown Heights, NY 10598 USA.
A. E. Stevens is with the IBM T. J. Watson Research Center, Yorktown Heights, NY 10598 USA. He is also with the Dept. of Electrical Engineering, Columbia University, New York, NY 10598 USA.
IEEE Log Number 9403618.

1041-1135/94$04.00 © 1994 IEEE

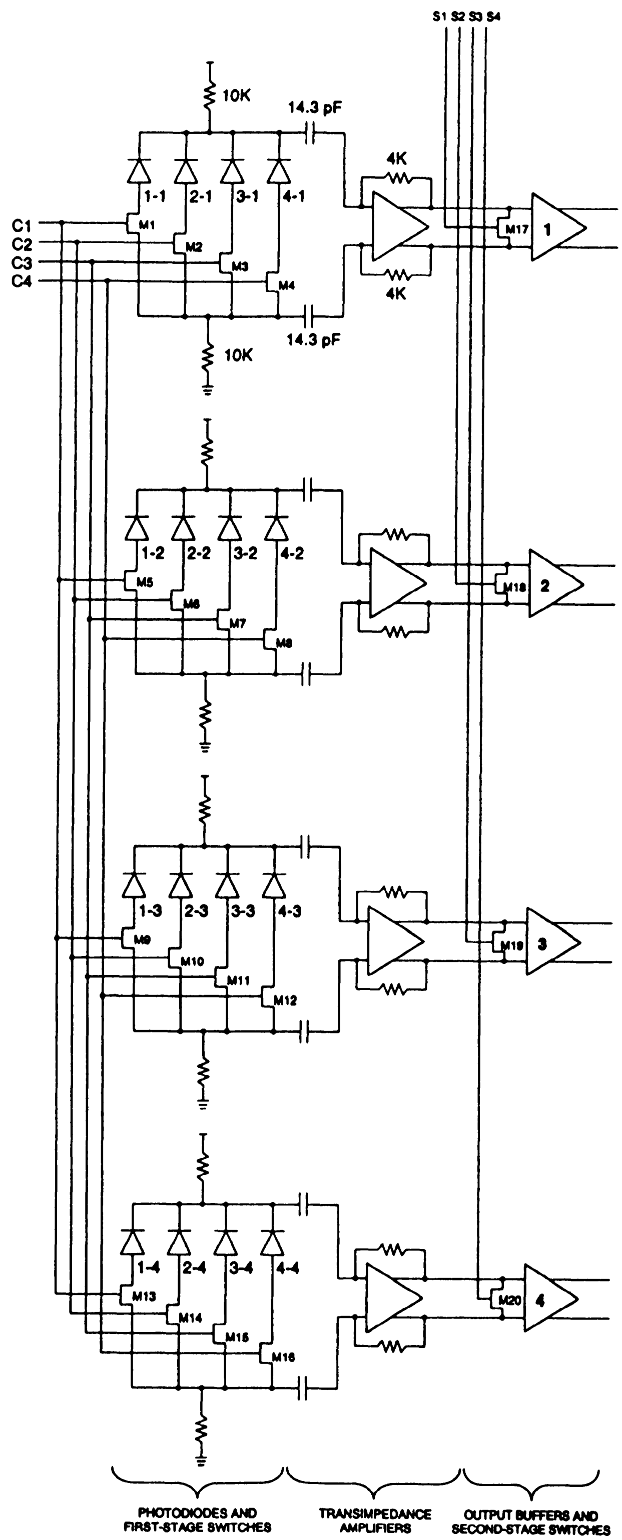



Fig. 2(a). Schematic of the selector chip (die size 2.7 mm × 2.1 mm).

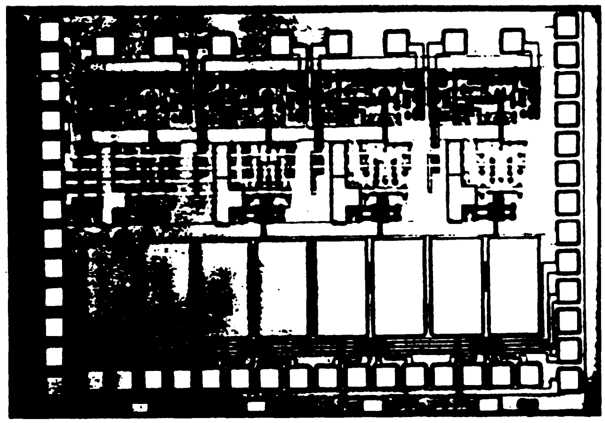


Fig. 2(b). Photograph of the selector chip (die size 2.7 mm × 2.1 mm).

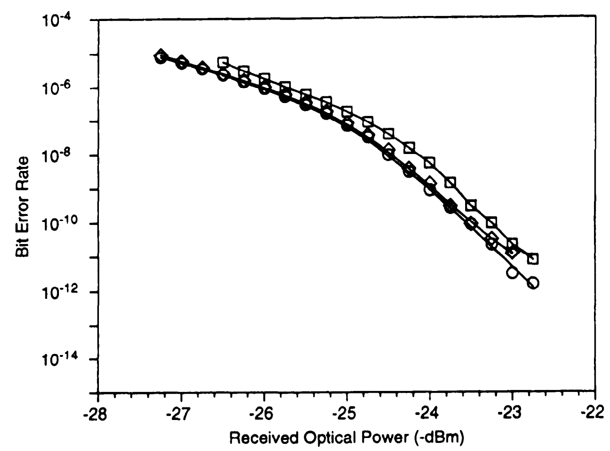
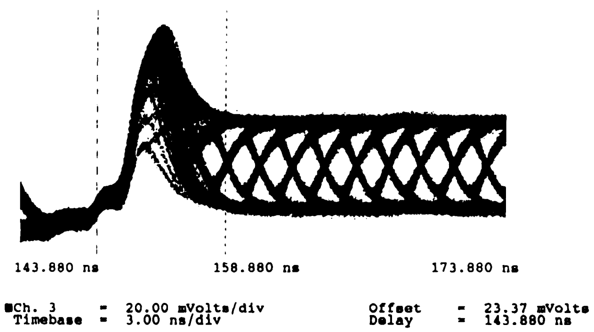


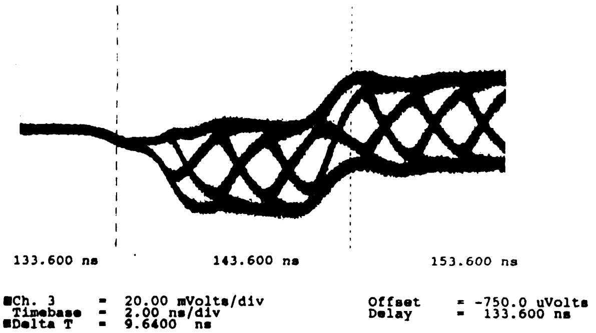

Fig. 3. Sensitivity of signal channel 4-4 without (○) and with the influence of crosstalk channel 4-1 (◇ for −25 dBm crosstalk and □ for −20 dBm crosstalk).

pads) separated by 140 $\mu$m through four enhancement-mode MESFET switches. The MESFET switches are shared by common controls. Thus, selection is made simultaneously for channels 4-1 (detector 4 connected to amplifier 1), 4-2, 4-3, and 4-4 via MESFET switches M4, M8, M12, and M16 by activating control signal C4. The outputs from the amplifiers can further be selected through four individually controlled MESFET switches (transistors M17–M20 via signals S1–S4), thereby forming the second stage switching. The second-stage switches are nominally open; the amplifier is disabled by shorting the differential signals at the input of the buffer stage. When the four amplifier outputs are connected in parallel, this circuit allows a 16:1 selection of the optical input signals. Thus, to select channel 3-2, first-stage switch M7 is closed and second-stage switches M17, M19 and M20 are also closed. Because the signals from the amplifiers are combined external to the selector chip, the chip can also function as reconfigurable four-channel array receiver. Note that the control and power-supply pads for the circuitry are duplicated on both sides of the amplifier/selector chip (Fig. 2(b)) such that several selector chips can be cascaded sideways, i.e., a selector with multiples of 16 channels can be implemented [9].

The transimpedance amplifiers utilize a gate length of 0.8 $\mu$m with a transconductance $g_m$ of 150 mS/mm, $f_T$ of 15 GHz and combined $C_{gs}$ (gate-source capacitance) and $C_{gd}$ (gate-drain capacitance) of 500 fF. Note that because of the differential design, there are AC coupling capacitors of 14.3 pF located at the inputs of the amplifier. The feedback and biasing resistors are 4 K$\Omega$ and 10 K$\Omega$ respectively. The selector/amplifier circuit consumes 77 mA with a +5 V supply.




(a)




(b)

Fig. 4. (a) Switch-on time for first-stage switch. (b) Switch-on time for second-stage switch. The eye pattern appears approximately10 ns after the switch is turned on.

For initial testing purposes, three InGaAs PIN photodetectors (channels 4-1, 3-4 and 4-4) were wire bonded to the selector/amplifier chip. This configuration allowed measurement of the crosstalk generated from a neighboring channel connected to the same amplifier (channel 4-4 and 3-4) and crosstalk generated through different amplifiers but with identical controls (channel 4-4 and 4-1) in the first-stage switch. Each PIN detector has a diameter of 75 $\mu$m and a responsivity of 0.88 A/W at $\lambda = 1.5$ $\mu$m.

## III. Experimental Results

Bit error rate measurements were performed for channel 4-4, with and without the influence of crosstalk channels 3-4 and 4-1. In these measurements, the channel was modulated at 531 Mbps with an extinction ratio of 4.48, using a $2^7 - 1$ nonreturn-to-zero (NRZ) pseudorandom bit sequence (PRBS). The interference channel was modulated asynchronously at 531 Mbps with an extinction ratio of 4.71, again using a $2^7 - 1$ NRZ PBS. The measurement was performed with the optical power of the interference channel varied between $-20$ and $-25$ dBm. The photodetectors were biased at 5 V. In order to control the switches, the gate voltages of the first-stage MESFETs were optimally biased at 0.495 V (on) or 0 V (off) [8]. The second-stage switches were optimally biased at 4.3 V (on) or 0 V (off). The 3-dB bandwidth of the amplifier chip was measured to be 260 MHz, with high frequency cutoff at 280 MHz.

In the absence of crosstalk, channel 4-4 exhibits a sensitivity of $-24$ dBm at a BER of $10^{-9}$ while channel 4-1 exhibits a sensitivity of $-24.5$ dBm, a 0.5 dB variation from amplifier 1 to amplifier 4. The dynamic range of the receiver is about 8.7 dB at a BER of $10^{-9}$. Because of the input capacitors, data transmitted at a low bit rate (<100 Mbps) will suffer intersymbol interference as the long ONEs or ZEROs charge or discharge the capacitors, which cause a closure in the eye diagram. To measure the effect of crosstalk from the next neighboring channel (first-stage switching), the BER of channel 4-4 was measured while an optical signal was introduced at photodetector 3-4. Both photodetectors share transimpedance amplifier 4, but only the first-stage MESFET switch connected to photodetector 4-4 is activated. The BER measurements with and without the presence of crosstalk (optical power upto $-20$ dBm) are indistinguishable from each other and are identical to BER measurements without crosstalk in Fig. 3. The crosstalk effect resulting from the leakage of signal through the second stage of switching was also investigated. In the experiments, only outputs from transimpedance amplifiers 1 and 4 were combined together. Signals from photodetectors 4-1 and 4-4 are connected to transimpedance amplifiers 1 and 4 by activating first-stage switches M4 and M16 and also closing second-stage switch M17, thereby disabling amplifier 1. With channel 4-1 as the crosstalk channel, the BER measurements reveal that there is a system penalty of 0.04 dB when the crosstalk channel is set at $-25$ dBm and of 0.35 dB at $-20$ dBm (Fig. 3).

The switching speed at the first- and second-stage switches has also been investigated by driving control signals C4 and S4 with a pulse generator. Using a 1-ns rise- and fall-time, the channel switch-on times for both stages are found to be approximately 10 ns (Fig. 4(a) for first-stage switching, Fig. 4(b) for second-stage switching), after which the eye-pattern from the PRBS is visible. In these measurements, the optical input power is set at $-20$ dBm, $2^7 - 1$ NRZ PRBS at 500 Mbps.

## IV. Summary

We have characterized a 16-channel GaAs optical/electronic amplifier/selector chip which is capable of random access selection of a single channel for fast packet-switched WDMA networking applications. The amplifier/selector chip can also function as reconfigurable array receiver for applications in WDM links and optical interconnects.

The authors would like to acknowledge S. G. Walker, M. Cina and F. J. Canora for many useful discussions and technical assistance, and P. E. Green and J. Jaffe for their encouragement and support.

## References

[1] See *IEEE J. Lightwave Technol.*, vol. 11, no. 5/6, May/June 1993.
[2] C. S. Li, M. S. Chen and F. Tong, "POPSMAC: A medium access protocol for packet-switched passive optical networks using WDMA," *IEEE J. Lightwave Technol.*, vol. 11, no. 5/6, May/June 1993.
[3] P. E. Green, *Fiber Optic Networks*. Englewood Cliffs, NJ: Prentice Hall, 1993.
[4] J. B. D. Soole, *et al.*, "Monolithic InP/InGaAsP/InP grating spectrometer for the 1.48–1.56 $\mu$m wavelength range," *Appl. Phys. Lett.*, vol. 58, pp. 1949–1951, 1991.
[5] K. Liu, F. Tong and S. W. Bond, "Planar grating wavelength demultiplexer," in *Proc. SPIE Conf. on Multigigabit Fiber Com. Sys.*, vol. 2024, p. 278, July, 1993.

[6] G. Grand, *et al.*, "16-channel Optical wavelength multiplexer/demultiplexer integrated on Si substrate," *E-FOC Proceeding,* pp. 264–267, 1991.

[7] C. Cremer, *et al.*, "Grating spectrograph integrated with photodiode array in InGaAsP/InGaAs/InP," *IEEE Photon. Technol. Lett.*, vol. 4, no. 1, pp. 108–110, 1992.

[8] F. Tong, Y. H. Kwark, and A. E. Stevens, "A four-channel monolithic optical/electronic selector for fast packet-switched WDMA networks," *IEEE Photon. Technol. Lett.*, vol. 6, no. 1, pp. 68–70, 1994.

[9] C. -S. Li, F. Tong, Y. H. Kwark, H. Ainspan, and S. G. Walker, "Design, simulation and testing of fast reconfigurable multichannel GaAs receivers for WDM networks," to be submitted to *IEEE J. Lightwave Technol.*