A Four-Channel Monolithic Optical/Electronic Selector for Fast Packet-Switched WDMA Networks

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***Abstract*— We report the characteristics of a four-channel monolithic GaAs optical/electronic selector for applications in fast packet-switched wavelength division multiaccess networks. The selector chip consists of four metal-semiconductor-metal photodetectors sharing a single differential transimpedance amplifier selected by four enhancement-mode MESFET switches. The channel switching time is about 2 ns and no appreciable crosstalk is observed from neighboring channels.**

I. INTRODUCTION

HIGH-SPEED packet-switched wavelength division multiaccess networks (WDMA) require compact, low-cost, high-speed wavelength selectors or tunable filters capable of covering a wide spectral range and narrow bandwidth [1], [2]. In computer networks with a packet size of ~4 KB at gigabit data rates, switching must occur within 1 μs. Other requirements include: optical bandwidth of ~30 nm, approximately 100 channels, channel access time less than 1 μs, polarization insensitivity, compactness (a few cm), low loss, low crosstalk, low power consumption and low manufacturing cost. Of equal importance is the selection control which should be discrete and should not require elaborate control schemes.

One of the more promising wavelength selector schemes is to combine a wavelength demultiplexer, photodetector array, and electronic selector fabric. This approach does not use active tuning in the optical component and channel selection is achieved by electronic means. The design of the wavelength demultiplexer can be flexible; it can be a planar waveguide grating [3]–[5], a waveguide coupler [6], or a channel dropping filter [7]. Previously, most of the emphasis has been on amplification of the received signals to the digital level and then switching [8]. However, the real estate and power consumption of the electronics for such an approach limit the number of wavelength channels to approximately 20. In order to increase the wavelength channel capacity, we have pursued a wavelength selector scheme with a planar waveguide grating as the wavelength demultiplexer [4]. The selection scheme is based on sequential switching of the received optical signals in stages at the analog level. A hybrid scheme using PIN photodiodes and FETs has been reported previously [9]. Here, we focus our report on the performance of a GaAs monolithic optical-to-electronic selector that can accommodate 4 wavelength channels. A 2-stage 16-channel selector is currently under fabrication.

II. SELECTOR DESIGN

Figures 1(a) and (b) show the schematics and the photograph of the selector chip. There are four identical metal-semiconductor-metal (MSM) photodetectors (with center-to-center separation of 140 μm) sharing the same transimpedance amplifier, with each photodetector connected to the transimpedance amplifier by an enhancement-mode MESFET switch. Only one of the four switches is activated at a given time such that only one photodetected signal can be amplified at a time. Each of the MSM photodetectors has a diameter of 100 μm and an electrode width of 0.8 μm separated by a finger spacing of 2.5 μm, yielding a measured responsivity of 0.3 A/W at 0.85 μm wavelength. The photodetectors are all biased simultaneously by a separate voltage supply. The FET switch has a gate length of 0.8 μm and a gate width of 30 μm. The transimpedance amplifier utilizes a 0.8 μm gate length with a transconductance g_m of 150 mS/mm, an 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 10 pF located at the inputs of the amplifier. The feedback and biasing resistors are 4 KΩ. and 10 KΩ, respectively. The received signals are further amplified by a 2-GHz-bandwidth amplifier in the test fixture before being converted to single-ended by a power combiner. The transimpedance amplifier circuit consumes 129 mW with a 5 V supply.

III. EXPERIMENTAL RESULTS

Figure 2 shows the results of a bit error rate (BER) measurement of a selected channel. The 0.85 μm modulated laser output (HP 83404B) is coupled to a multimode fiber and butt coupled into one of the photodetectors of the selector. Several devices from different wafers were investigated. At a transmission rate of 1 Gb/s, a nominal sensitivity of -18.5 dBm is measured at a BER of 10^{-9}, using a $2^7 - 1$ non-return-to-zero (NRZ) pseudorandom bit sequence (PRBS) and an extinction ratio of 2.7 in the optical signal. The measured BER is within the expected range (-18 to -20 dBm) from a single independent receiver without sharing of photodetectors. In these measurements, the photodetectors are biased at 6.98 V and the FET switch gate voltage is 0.48 V. An eye diagram is shown in the inset under similar operating conditions with an average optical power of -18.9 dBm coupled into the

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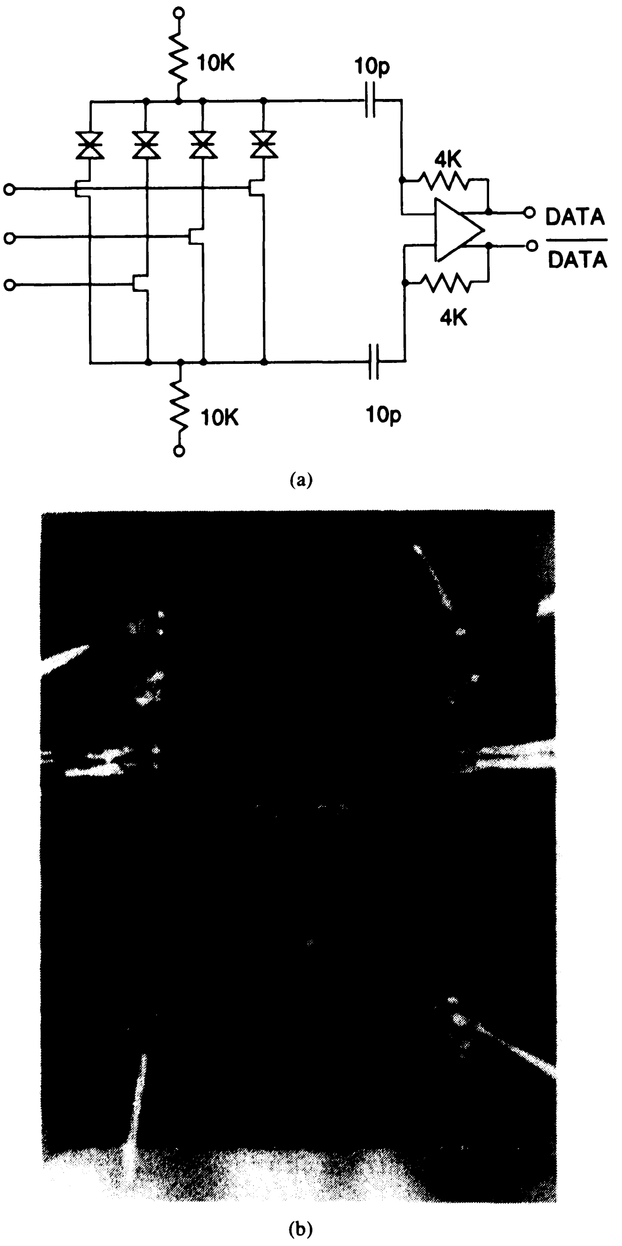

(a)

(b)

Fig. 1. (a) Schematic and (b) Photograph of the Selector Chip. Die size: 0.9 mm × . 1.2 mm.

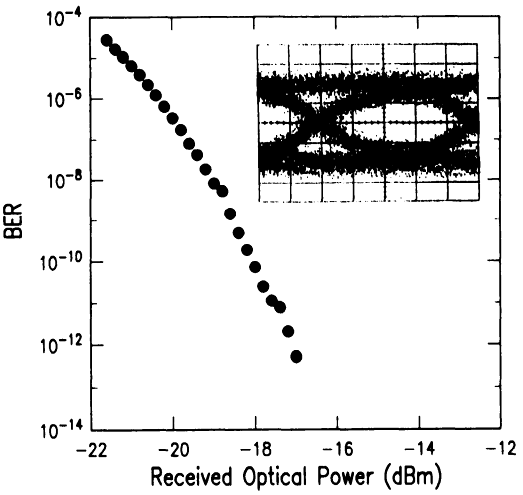

Fig. 2. The sensitivity of a typical channel. The eye diagram displayed in the inset.

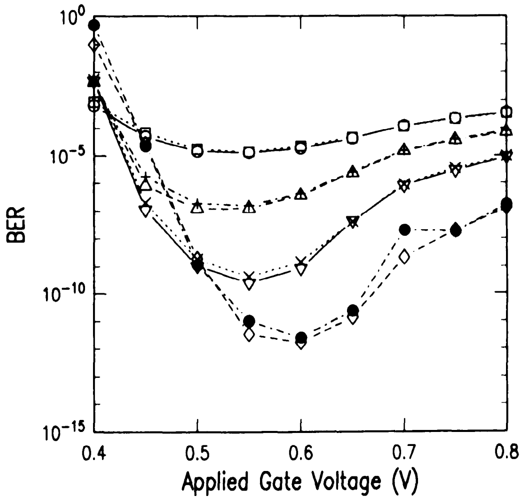

Fig. 3. BER measurement versus applied gate voltage, with and without crosstalk. The input optical intensities are -21 dBm (○, □), -19.5 dBm (Δ, +), -18 dBm (∇, ×) and -16.5 dBm (◇, •). The first element in the parentheses is measured without crosstalk channel, while the second is with crosstalk.

photodetector. The dynamic range of this receiver is found to be 5.6 dB at a BER of 10^{-9} . Because of the input coupling capacitors, data transmitted at a low bit rate (<500 Mb/s) will suffer intersymbol interference as the long strings of ONEs or ZEROs charge or discharge the capacitors, which causes a closure in the eye diagram. For lower bit rates, special coding schemes are necessary to eliminate this effect.

We also investigated the variation of BER as a function of applied gate voltage under various input optical intensities (Fig. 3). Optimal gate voltage occurs when the voltage drop across the channel is minimized. Further increase in the gate voltage introduces current from gate to drain, reducing the photogenerated current. At a given input optical power, substantial variation in the optimal gate voltage is observed among devices. This effect can be reduced by increasing the gate width (at a cost of higher noise coupling) or implementing an automatic gain control circuit.

Crosstalk from neighboring channels is investigated by measuring the BER of a selected channel while a second optical signal is introduced as interference on an adjacent channel. The interfering channel is modulated by an asynchronous sine wave at 1 GHz with an extinction ratio of 2.5 and an average coupled optical power of -0.1 dBm (Fig. 3). In this experiment, two multimode fibers are placed together and butt coupled to two adjacent MSM photodetectors. The fiber diameter is 128 μm and matches well with the photodetector spacing of 140 μm. Only the FET switch connected to the selected channel is activated during the test and all remaining switches are off. In a typical sample, as shown in Fig. 3, the measured BER with the crosstalk channel is slightly higher than that obtained

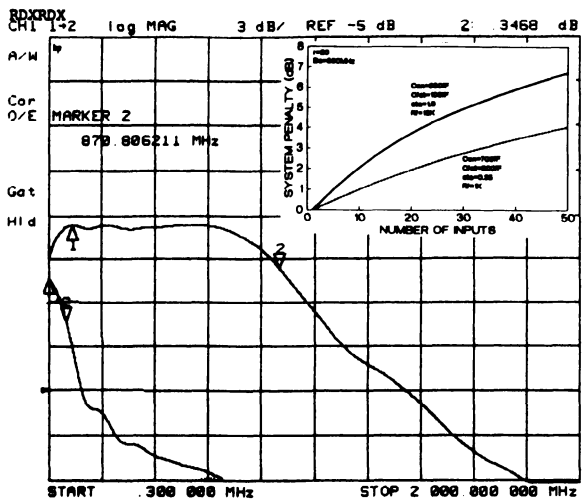

Fig. 4. The frequency response of the selector when one FET (upper trace) and two FETs (lower trace) are activated. The inset shows the calculated system penalty versus the number of MSM photodetectors sharing a single transimpedance amplifier (see text).

without the interfering channel. In most cases, the two BERs are indistinguishable.

Fig. 4 shows the frequency response of the selector at an incident average power of -15.9 dBm, with the photodetector biased at 6.5 V and the applied gate voltage at 0.8 V. As shown in the figure, the response curve is flat to ~800 MHz (-3 dB at 870 MHz). When two FETs are activated, the frequency response drops dramatically (lower curve), displaying the capacitance loading effect of the additional photodetector. Thus, the parasitic loading of the FET switches will set the upper limit on the number of photodetectors sharing the same transimpedance amplifier. System penalty incurred by the capacitive loading is evaluated assuming an operational bandwidth of 800 MHz and an extinction ratio of 20. The results are shown in the inset of Fig. 5. In the inset, C_{on} is the capacitance of the individual detector with responsivity η, C_{fet} is the capacitance of the MESFET switch, and R_F is the feedback resistor. The corresponding values are given in the inset. Two sets of values are provided for the upper and lower bound estimates. For a 1-dB system penalty, the number of allowed photodetectors is between 4 and 10.

The channel switching speed has also been investigated and the nominal switch-on and switch-off time (10%–90%) is found to be 330 ps (Fig. 5). As shown in the figure, the spiking effect generated from the sharp turn-on further limits the dead time to be 1–2 ns, after which the eye-pattern from the pseudo-random bit sequence is visible. In this measurement, the data is transmitted under similar conditions as previously described, with an average optical power of -18.9 dBm coupled to the photodetector. In addition, in order to simulate real data reception, a bit synchronizer (BCP model 50B) was connected at the circuit output. The total delay (between switching signal and ECL data regeneration) was ~100 ns, which is adequate for packet-switching applications.

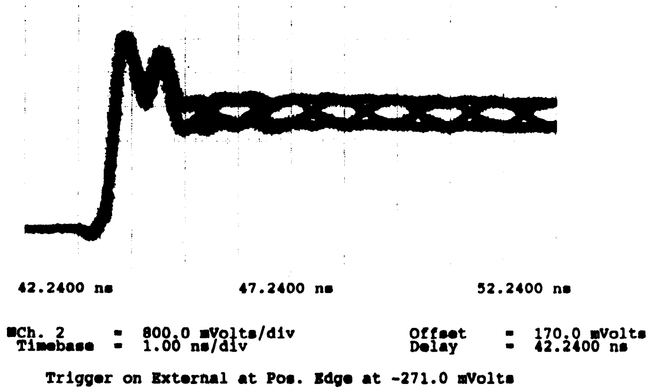

Fig. 5. Channel switching time. The eye pattern appears approximately 2 ns after the switch is activated.

IV. SUMMARY

In summary, we have investigated the characteristics of a 4-channel GaAs monolithic optical/electronic selector. The channel switching time is about 2 ns, which is adequate for fast packet-switched WDMA networks. There is no appreciable crosstalk from neighboring channels. The sensitivity of the selector is -18.5 dBm at a BER of 10^{-9}. The authors would like to acknowledge C. -S. Li, F. J. Canora and S. G. Walker for technical assistance and P. E. Green for his encouragement and support.

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