Invited Paper

Development of hybrid-integrated tunable receivers for multi-wavelength computer networks

F. Tong*, C. S. Li and K. Liu
IBM Thomas J. Watson Research Center,
P. O. Box 704, Yorktown Heights, NY 10598, U. S. A.
kliu/csli@watson.ibm.com

*currently on leave from IBM
Information Engineering Department
The Chinese University of Hong Kong
Shatin, Hong Kong
fkong@ie.cuhk.edu.hk

ABSTRACT

We discuss the development of tunable optical receivers for packet-switched multi-wavelength computer networks. The architecture of the tunable receivers consists of a planar waveguide grating demultiplexer, photodetector array and followed by transimpedance amplifiers with selection capability. The channel selection is based on sequential switching of the received optical signals in stages at the analog level. The receivers can accommodate 32 wavelength channels at around 1.55 μm region with channel access time of less than 40 ns.

Keywords: Tunable receivers, WDMA, Optical Communication.

1. INTRODUCTION

Wavelength division multi-access (WDMA) networks require some form of tunable receivers to select individual wavelength channel from a large number of channels carried in the input optical fiber at the receiving node. In particular in computer communication environment where the data are transmitted in forms of packets (nominal size of ~4 KB), the channel reconfiguration time of the tunable receiver has to occur within ~1 ms [1] in order to maintain a high throughput, assuming a high data rate of ~1 Gbps per wavelength channel. In addition, other qualities such as ease of control, compactness, low power consumption, low loss and supporting a wide spectral range are equally essential requirements. More importantly, the tunable receiver must be of low manufacturing cost. These stringent requirements render many existing tunable filter schemes inadequate for the WDMA systems.

One simple yet powerful tunable receiver approach is to combine an optical demultiplexer with a photodetector array and electronic amplifier-selector fabric [2-7]. The optical demultiplexer separates all the wavelength channels onto photodetectors and the channel selection is achieved by electronic means. The passive optical demultiplexer can support a large channel capacity and a wide spectral range, and the electronic selection can be very fast. A four-channel [8], eight-channel [9], and a 16-channel [10] optical-to-electronic GaAs selectable amplifiers have previously been published. Based on this architecture, two types of tunable receivers have been developed. The earlier version has a lens array coupling between the demultiplexer and the photodetectors. The electronic packaging was mostly through wire-bonding. The second version eliminates the lens array and has a compact, planarized electronic packaging which allows direct contact between the package and the demultiplexer. Besides the packaging, there are more integration in the electronics and the performances of the demultiplexer are greatly improved.
2. TUNABLE RECEIVER: EARLIER VERSION

Figure 1 shows the architecture and also the packaging of our first version of the tunable receiver, revealing the grating demultiplexer, lens array, photodetector array, and the selectable amplifier chip.

![Diagram of tunable receiver](image)

Figure 1 The schematics of the our earlier version tunable receiver, showing details of the packaging.

Incoming light consists of multiple wavelength channels in a common optical fiber attaching to the input waveguide of the optical demultiplexer. The optical demultiplexer was a SiO₂/Si planar waveguide etched grating which diffracts and separates spatially the multiple wavelengths onto different output waveguides (see Fig.2). The resolved optical channels are coupled to large area InGaAs photodetectors via reflection by a mirror and focused by lenses in an array format. The photodetectors are connected to GaAs 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 switching. The signals are further discriminated though a set of switches implemented inside the amplifiers, thus forming the second level selection. Table 1 summarizes the performances of our etched grating demultiplexer. Table 2 summarizes the breakdown of the grating loss. The performances of the packaged tunable receiver are shown in Table 3.
Figure 2. (a) The top view of the etched grating demultiplexer. (b) SEM pictures showing the etched grooves.

<table>
<thead>
<tr>
<th>Table 1</th>
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<tbody>
<tr>
<td>Number of Channels</td>
</tr>
<tr>
<td>Channel Width</td>
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<tr>
<td>Loss</td>
</tr>
<tr>
<td>TE/TM Polarization Offset</td>
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<tr>
<td>Birefringence</td>
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<tr>
<td>Crosstalk</td>
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<th>Table 2</th>
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<tr>
<td>Theoretical Throughput</td>
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<tr>
<td>Input Fiber Coupling</td>
</tr>
<tr>
<td>Waveguide Loss (including bend loss)</td>
</tr>
<tr>
<td>Tilt of Grating Reflector 2.5</td>
</tr>
<tr>
<td>Curvature of Grating Reflector</td>
</tr>
<tr>
<td>Rounding of Inner Grating Apex (into different orders)</td>
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<tr>
<td>Rounding of Outer Grating Apex</td>
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<tr>
<td>Focusing into Output Waveguide</td>
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<tr>
<td>Scattering</td>
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<tr>
<td>Total</td>
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Table 3

<table>
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<tr>
<th>Bit Rate</th>
<th>700 Mbps</th>
</tr>
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<tbody>
<tr>
<td>Sensitivity</td>
<td>-28.4 dBm</td>
</tr>
<tr>
<td></td>
<td>-4.5 dBm</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>8.7 dB</td>
</tr>
<tr>
<td>Operating Wavelengths</td>
<td>1540 nm-1590 nm</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>0.4 nm</td>
</tr>
<tr>
<td>Channel Spacing</td>
<td>1 nm</td>
</tr>
<tr>
<td>Channel Switching Time</td>
<td>&lt; 40 ns</td>
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<tr>
<td>Power Consumption</td>
<td>215 mA at 5 V</td>
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3. TUNABLE RECEIVER: CURRENT VERSION

Figure 3 shows the second version tunable receiver module, displaying the optical demultiplexer based on SiO₂ technologies, the input fiber and the backside of the packaged receiver electronics. Similarly, the output facet of the optical demultiplexer is polished at an angle for total internal reflections. Instead of the etched grating demultiplexer, an array waveguide grating (AWG devices) [11] with better performances is used. Also, a single two-staged 32-channel GaAs amplifier and selector chip replaced the two 16-channel amplifier chips. With the selection circuits implemented in the amplifier, we can select any one channel over 32 input wavelength channels in two stages of switching. The hybrid electronics package offers a planarized surface such that direct coupling with the grating demultiplexer is feasible, i.e., the lens array for the coupling between the demultiplexer and the photodetectors can be eliminated. The demultiplexer is attached to a copper heat sink and the unit is thermally controlled by a thermo-electric cooler. Thermal control is necessary as the wavelength shift by temperature of SiO₂ is ~0.15 A/C [7] and the typically temperature range of operation is specified between 4-44 C. A thermister is embedded into the copper substrate to monitor the temperature.

Figure 3 The packaged 32-channel tunable optical receiver.
The 32-channel AWG devices have a channel spacing and a 3-dB width of 100 GHz and ~30 GHz, respectively. The first wavelength channel transmits at 1537.2 nm and the 32nd channel at 1526.0 nm, in accordance to the ITU draft standard. The demultiplexer has been corrected for its birefringence by an insertion of a quarter-wave plate and has a typical loss of 3.75 dB at the center waveguide and 6.25 dB at the extreme waveguide. The neighboring crosstalk is generally better than -25 dB. The detector array and the amplifier array are packaged with High Density Interconnect packaging [12] (see Fig. 4). The flat surface of the electronic packaged module allows direct coupling between the optical demultiplexer. Several of these receiver modules was packaged. Typical performances are listed as below.

![Image](image.png)

Figure 4 The packaging of the electronics including the GaAs transimpedance amplifiers integrated with selectors and InGaAs photodetector array.

<table>
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<th>Table 4</th>
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<tr>
<td>Bit Rate</td>
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<tr>
<td>Sensitivity</td>
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<tr>
<td>Dynamic Range</td>
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<tr>
<td>Operating Wavelength</td>
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<tr>
<td>Channel Bandwidth</td>
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<tr>
<td>Channel Spacing</td>
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<tr>
<td>Overall Crosstalk Penalty</td>
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<tr>
<td>Max. Channel Switching Time</td>
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<tr>
<td>Physical Dimension</td>
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4. SUMMARY

In summary, we have developed two versions of the tunable receivers designed for WDMA packaged switched networks. Our second version tunable receiver demonstrates good performances and can be put on trials in network testbeds.

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5. Reference


