# Performance Assessment of A Complete Packaged Sub–Gbps WDM Receiver

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*The performance assessment of a complete packaged four-channel WDM receiver for operating in the sub-Gbps bitrates is presented. The WDM receiver consists of an eight-channel arrayed-waveguide grating demux and eight planar waveguide photodetectors, monolithically integrated in an InP-based chip. The chip has been hybridly mounted and connected to an array of RF-preamplifiers on a temperature stabilized AlN printed circuit board. Receiver sensitivities of approximately –17 dBm for 311 Mbps and –13 dBm for 622 Mbps were measured.*

## Introduction

The rapid progress of optical communication systems employing wavelength division multiplexing (WDM) architecture has spurred device research toward array technologies. Several architectures which are being investigated today require multi-channel transmitters and receivers. Monolithic integration technologies have progressed sufficiently that arrays of lasers and photodetectors are being envisioned as key device components which enable novel architectures. In particular, optoelectronic integrated circuit photodetector arrays have been actively researched worldwide for such applications. Amersfoort et al. [1] has demonstrated a four-channel WDM receiver consisting of an arrayed-waveguide grating (AWG) demultiplexer and four PIN photodiodes. Using the same concept, an 8×10 GHz WDM receiver was succesfully fabricated and tested [2]. A more complex device has included RF-preamplifiers in order to increase sensitivity and thereby reduce the effect of the thermal noise. An 8-channel WDM receiver with an array of front-ends, i.e. a combination of photodiodes and RF-preamplifiers, has been demonstrated in a WDM field trial [3]. In this paper, we present the performance assessment of a 4-channel WDM receiver which has been realized by monolithically integrating a demultiplexer and photodiodes on an InP-substrate. The AWG demultiplexer was based on the concept presented in [4]. Four commercial low-noise amplifiers were RF-connected to four photodiodes. The realized WDM receiver was then packaged for performance testing at sub-Gbps bitrates.

## Multi-wavelength Receiver

The packaged receiver for detecting four wavelength optical signals is shown in Fig. 1. The demultiplexer was designed for a channel spacing of 400 GHz (3.2 nm), with a free spectral range of 4.8 THz. When four-wavelength signals ($\lambda_1,...,\lambda_4$) are launched simultaneously into the input fiber, the AWG demultiplexer spectrally resolves the four-wavelength signal, sending one wavelength into each of the output waveguides. The signal is then coupled into a PIN photodiode and the photocurrent is amplified by a RFpreamplifier mounted on an AlN printed circuit board (PCB). Finally, output voltages ($V(\lambda_1)$,...,$V(\lambda_4)$) are generated for the four wavelength signals. The package is equipped with several electrical pins for fine tuning the response of the AWG demultiplexer and

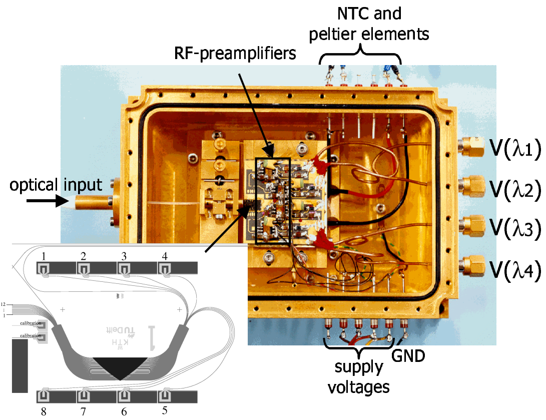



**Figure 1:** WDM receiver for detecting four-wavelength signals. The chip size is $5{\times}3mm^2$ and the package is $130{\times}90{\times}50mm^3$.

for supplying voltages to the four front-ends.

## Experiments and Results

Static characterization of the WDM receiver revealed that only four out of eight photodiodes, corresponding to wavelengths 1544.6, 1547.8, 1551.1, and 1567.2 nm, show normal diode characteristics whereas the others generate too much leakage currents. Three channels were used for the data and the fourth channel was for controlling the coupling mechanism. Two DFB lasers of wavelength 1547.8 and 1551.1

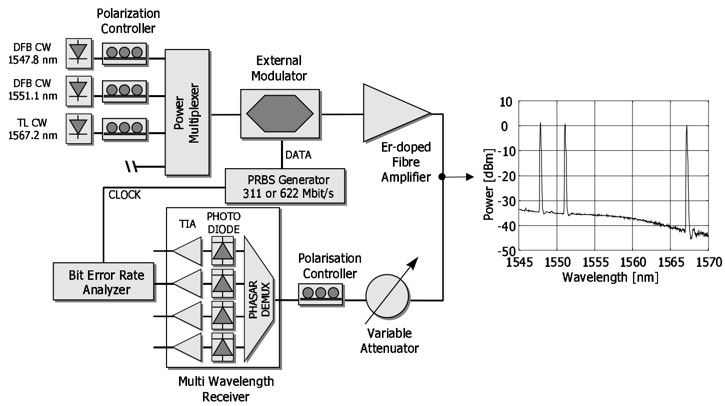
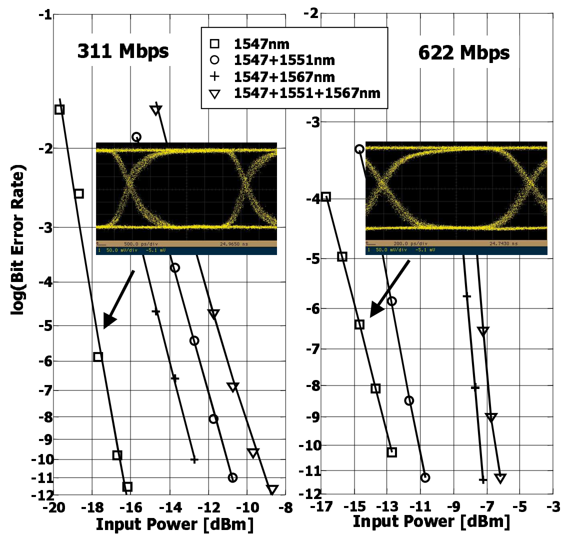



**Figure 2:** Experiment setup for performance assessment in a single- and multi-channel operation.

nm and one tunable laser tuned to 1567.2 nm were used as light sources for the setup as shown in Fig. 2. These channels were simultaneously modulated by a $LiNbO_3$ external modulator, that is driven electrically by a $2^{31}$-1 NRZ PRBS generator. A polarization controller after each laser was necessary to obtain maximum extinction ratio in the lightwaves through the polarization-sensitive external modulator. We could obtain an extinction ratio of 15 dB average per channel. An $Er^{3+}$-doped fiber amplifier (EDFA) was used to compensate for losses due to the splitting (6 dB) and modulator (3 dB). The peak power of each channel was set to 0 dBm. The EDFA was followed by an optical variable attenuator to adjust optical power detected by each front-end. Wavelength selection and optical noise suppression were performed by the AWG demultiplexer whose bandwidth is 1.3 nm and side-channel suppression is about 25 dB. Since the demultiplexer was slightly polarization dependent (1 dB), another polarization controller was located at the input port to minimize the demux loss (5-6 dB). Bit error rate (BER) measurements were performed by comparing the detected bits to the transmitted bits as a function of the input power into the WDM receiver. Two measurement schemes were made in order to evaluate the effect of optical and electrical crosstalk: single-channel (only one front-end is switched on) and multi-channel operation (all front-ends are activated). To make the paper brief, we focus the discussion only on the channel 1547 nm operating under influence of the other two channels. The performance of this channel is summarized by the BER curves in Fig. 3 for bitrates 311 Mbps and 622 Mbps. The eye patterns are presented for the single-channel operation. The patterns show clear eyes which indicate an excellent detection performance for both bitrates.




(a) (b)

**Figure 3:** BER performance for (a) 311 Mbps and (b) 622 Mbps.

Nevertheless, the eye pattern for 622 Mbps has a longer rise and fall time caused by a limited receiver bandwidth. Longer transient time results in a slower response to the dynamics of optical pulses, which in turn will cause an increased sensitivity penalty. At a bitrate of 311 Mbps the receiver sensitivity for BER=$10^{-9}$ is measured –17 dBm and at 622 Mbps the sensitivity is degraded by 4 dB to –13 dBm. Activating more than one front-end simultaneously will induce electrical crosstalk among the front-ends. The performance of an optical front-end was no longer determined by its intrinsic performance alone, but it was subject of distortion generated by the other front-ends in its perimeter. The distance between the front-ends is very small (≤5mm) and the interference within such a small distance inside the package could be devastating for the performance. Crosstalk will cause sensitivity penalties and the penalties increase with increasing signal levels in the adjacent channels increases. In order to have a fair sensitivity comparison, all front-ends received equal optical power. Therefore, only the intrinsic properties such as module responses and electrical wiring will have an impact on the performance. The BER values increased as the other modules were also switched on. We measured in channel 1547 nm a penalty of 7-8 dB for both bitrates. We have observed that the BER performance is different among the front-ends. In addition, the effect of crosstalk is the most with the wavelength channel 1551 nm at the bitrate 622 Mbps. This channel shows a BER floor of $10^{-7}$. We believe that the crosstalk is purely electrical in nature because optical crosstalk is negligible thanks to the demux performance. The crosstalk originates in the supply voltage lines of the photodiodes and from the ground loops on the PCB. The photodetector must be RF-connected to supply lines of very low resistance to avoid reflections between the photodiodes and bondwires. The signal path to ground must be kept short and the bondwires must be isolated electrically to prevent flow of signal current from one module to another that may result in severe crosstalk.

## Conclusion

An InP-based chip has been designed and fabricated containing an eight-channel AWG demultiplexer with a wavelength spacing of 3.2 nm and eight planar waveguide photodiodes. The photodiodes are arranged symmetrically around the demultiplexer perimeter. The chip is hybridly mounted and the four best-performing photodiodes are connected to four RF-preamplifiers on a temperature stabilized AlN PCB. The packaged receiver module has one optical input fiber and four electrical output connectors. Auxiliary inputs are available for active temperature stabilization and for the individual bias arrangement of the front-ends. The performance has been characterized for a single and multi-channel operation. The best receiver sensitivities were about –17 dBm for a bitrate of 311 Mbps and –13 dBm for 622 Mbps.

## Acknowledgment

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