# 10 Gbit/s Data Transmission Experiments over Optical Backplane Waveguides with 850 nm Wavelength Multimode VCSELs

Martin Stach *

*An optical backplane concept based on polymer waveguides, well suited to overcome the communication bottleneck caused by conventional printed circuit boards is investigated. Attenuation coefficients are determined for several waveguides on different backplanes and it is shown that 10 Gbit/s data transmission at a bit error rate of* $10^{-12}$ *is possible both for waveguides of large* ($250 \times 200\,\mu m^2$) *and smaller core size* ($100 \times 100\,\mu m^2$).

## 1. Motivation for Optical Data Transmission

With permanently increasing microprocessor clock frequencies (outreaching 2.5 GHz), this speed enhancement becomes more and more challenging for the periphery. On the high-speed chips themselves parasitics rise with the signal frequency and attenuation increases due to the skin effect,which leads to distortions of pulse shapes and limits transmission lengths. On printed circuit boards, microprocessors are interconnected over relatively great distances, entailing a bottleneck for the outgoing data due to the limited bandwidth-length-product of conventional wire lines. Still using electronic data transmission, one would have to distribute higher data rates to a corresponding number of parallel input and output lines, being followed by a growing terminal density and increasing production costs. However, the main point is that the clock frequency will continue to rise, making high-speed data transmission, e.g. to memory chips, more and more difficult, because the pin density can hardly be increased any further. The use of optical data transmission is one possibility to overcome those disadvantages. Due to photon transmission, one gets a significantly higher bandwidth-length-product, eliminates radio frequency interference, and – with proper design – there are less problems concerning crosstalk, transmission losses and pulse distortion. In ultra-short range optical datacom, distinctions are usually made between inter-rack, inter-board, inter-MCM (multi-chip module), inter-chip and intra-chip interconnection levels [1]. This contribution deals with the characterization of high-bandwidth optical waveguides to be employed in hybrid electrical-optical backplanes for inter-board communications.

*Work performed in collaboration with the DaimlerChrysler Research Center Ulm.

## 2. Optical Backplane Concept

Polymer waveguide technology can be used for transmitting data via optical waveguides both on one single opto-electronic processor board and for backplane interconnects. One possibility of implementation is the concept of the optical backplane being shown in Fig. 1.

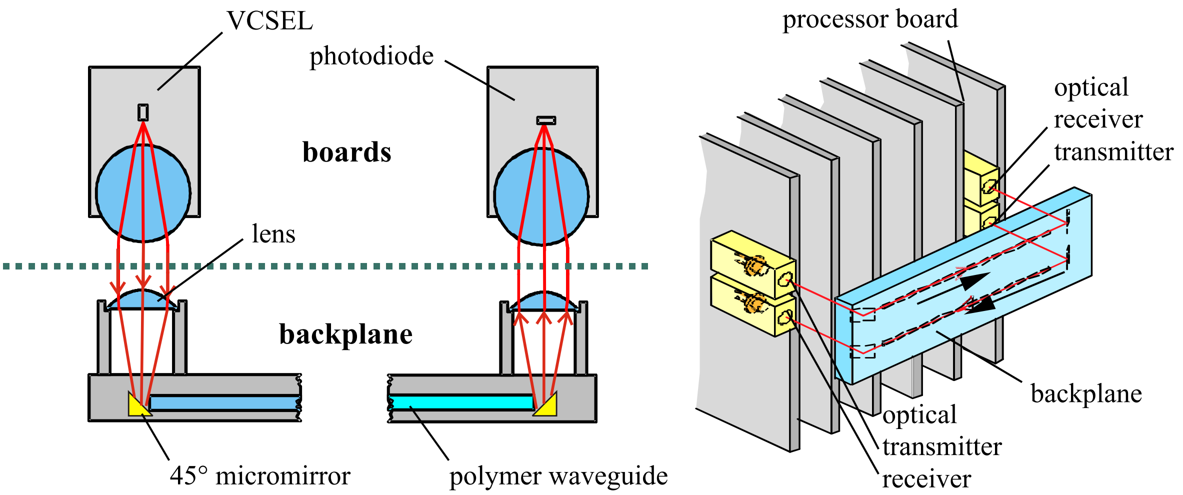


**Fig. 1:** Concept of the optical backplane developed by DaimlerChrysler and example of implementation [2].

The left part of Fig. 1 depicts the principle of the optical backplane: The main components are at first low-loss polymer waveguides which can be fabricated, e.g. from foil layers on arbitrary substrates (e.g. aluminum) by the hot embossing technique [3] or by laser writing so that the refractive index of the waveguides is increased in comparison to the surrounding material. Next there are integrated highly reflective micromirrors each with a tilt angle of 45°. The transmitter contains a vertical-cavity surface-emitting laser diode (VCSEL), where the divergent light beam is focused on one micromirror via a suitable lens system. On the opposite side the beam leaving the second micromirror has to be guided to a receiver, which contains a large-area but sufficiently fast metal-semiconductor-metal (MSM) photodiode. Using large core multimode waveguides, e.g. $250 \times 200\,\mu\text{m}^2$, with integrated mirrors and lenses, a high alignment tolerance in excess of $\pm 500\,\mu$m for 1 dB loss has been achieved [2], which helps to reduce cost and increase system reliability. VCSELs are ideal transmitters for such short-distance optical interconnects due to several advantages in comparison to edge emitters, in particular circular near field, low beam divergence and inexpensive fabrication. These laser diodes show excellent modulation behaviour, low threshold current, high wallplug efficiency, operation over a wide temperature range and the possibility of heterogeneous integration with electronics and micro-optics.

## 3. Parameters of the Laser Diode Transmitter

Top-emitting GaAs based 852 nm emission wavelength transverse multimode VCSELs fabricated by solid source molecular beam epitaxy are used for the transmission experiments. An AlAs layer included in the top mirror is selectively oxidized to define a current aperture of 12 $\mu$m. As seen in Fig. 2, threshold current and threshold voltage are 1.8 mA and 1.7 V, respectively. The differential resistance at 10 mA current amounts to 60 $\Omega$ and the maximum output power at a bias current of 18.3 mA is 7.1 mW. The output spectra for a CW driving current of 9 mA and under modulation with a 10 Gbit/s $2^7 - 1$ pseudo random bit sequence (PRBS) signal are highly multimode and centered around 852 nm. In both cases the root mean square spectral width is less than 0.4 nm. The measured 3 dB bandwidth is 8.6 GHz at 9 mA which makes the device capable for 10 Gbit/s data transmission.

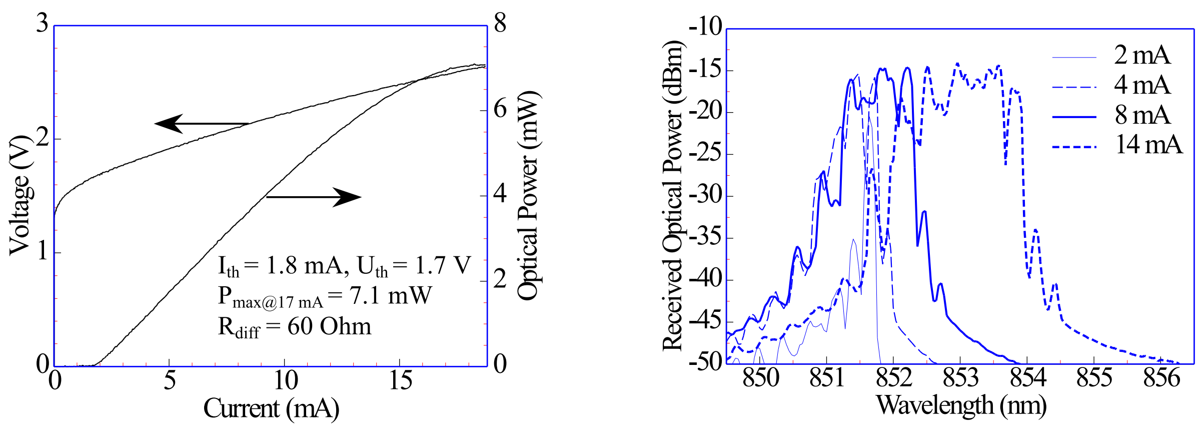


**Fig. 2:** Operation characteristics of a 850 nm wavelength multimode VCSEL (left) and spectra at CW operation with different bias currents (right).

## 4. Dimensions of the Optical Backplanes

Three optical backplanes provided by the DaimlerChrysler Research Center have been investigated. The backplane *sample A* has a total width of 12.5 cm and a length of 35.8 cm. The cross-sectional area of the waveguide core is 250 $\times$ 200 $\mu\text{m}^2$. There are four different waveguide types, all with a numerical aperture (NA) of 0.35. Backplane *sample B* has a total length of 191.5 cm and a width of 15.0 cm. As on *sample A*, some of the waveguides are intersecting, and cross-section and NA of all waveguides are as mentioned before. On the backplane itself one can find five different waveguide types. Finally an optical backplane *sample C* with a spiral waveguide was investigated. The core area of this 1 m-long waveguide is only 100 $\times$ 100 $\mu\text{m}^2$, NA is 0.3 and the minimum radius of curvature is about 4 cm.

# 5. Measurement Results

## 5.1 Waveguide attenuation

Since the waveguides are optimised for wavelengths around 850 nm, a VCSEL as described in Sect. 3 was used for attenuation measurements. The attenuation is determined with optimum coupling of the VCSEL light via two lenses and with a large-area photodetector placed directly above the output port. Figure 3 shows the attenuation values of the waveguides on backplane *samples A* and *B*.

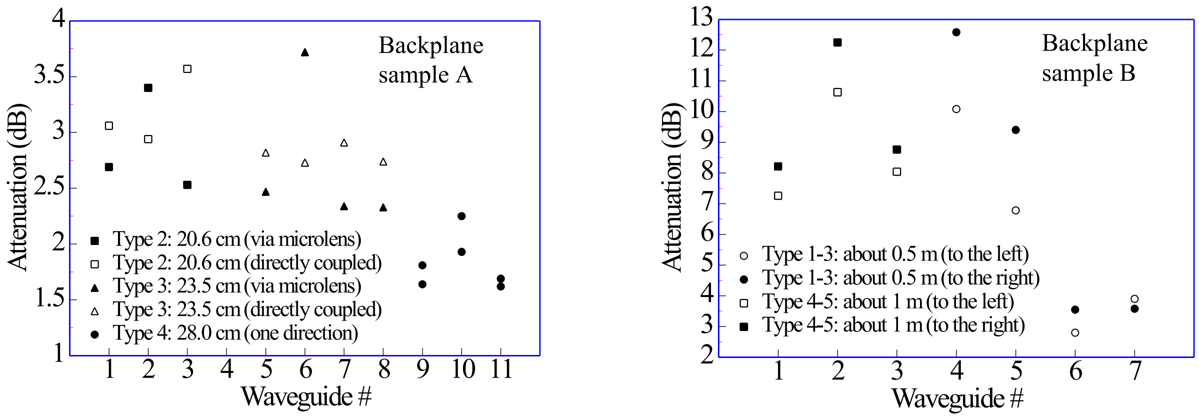


**Fig. 3:** Attenuation values of waveguides of backplane *sample A* (left) and *sample B* (right) at 850 nm wavelength.

The observations can be summarised as follows:

*Sample A*: The longest waveguides (type 4) incorporate no bends and microlenses and thus show the lowest attenuation ($<$ 2.25 dB). Assuming an insertion loss of 0.5 dB per mirror [2], the measured minimum attenuation coefficient is as low as 2.2 dB/m.

*Sample B*: Except for waveguide #7, the attenuation is higher or lower if the light is coupled into the left or right waveguide end, respectively, which can be explained from the mirror fabrication process. The straight waveguide #6 of 50 cm length shows the minimum attenuation of 2.8 dB, which results in an attenuation coefficient of 3.6 dB/m if the insertion loss of two times 0.5 dB is taken into account.

*Sample C* (spiral waveguide): The attenuation coefficient is the lowest one being measured here because of an improved fabrication process. The attenuation of 3 dB results in an attenuation coefficient of only 2 dB/m. This value is even smaller than the total loss of 5 dB of a comparable 1 m-long spiral with 250 × 200 $\mu m^2$ core size [4].

## 5.2 Digital data transmission

For data transmission the VCSEL was driven at 9 mA bias. Transmission experiments have been carried out with a PRBS non-return-to-zero signal of $2^7 - 1$ word length (peak-to-peak voltage: 0.8 V; Bessel lowpass filter: $f_c$ = 7 GHz) at a data rate of 10 Gbit/s.

An InGaAs (p-i-n)-photoreceiver with either 50.0 $\mu$m or 62.5 $\mu$m multimode fiber (MMF) input was employed, where the larger fiber provides a higher coupling efficiency. The influence of backreflection is negligible with measured average backreflection levels on *sample A* of −15.1 dB and −14.7 dB with and without microlenses, respectively. The mean backreflection levels on backplane *sample B* and on the backplane spiral are −15.7 dB. The eye diagrams are very similar for all experiments, so that the diagram corresponding to the transmission over the backplane spiral is quite representative (Fig. 4). The eye is wide open and essentially does not differ from the recorded eye diagram of the back-to-back (BTB) measurement. In both cases the received optical power is −13.7 dBm entailing a bit error rate of BER $< 10^{-12}$.

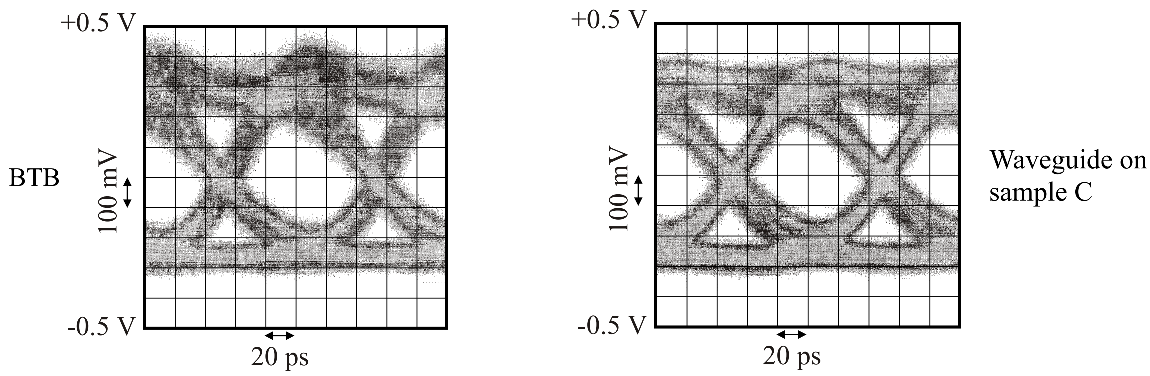


**Fig. 4:** Eye diagrams recorded for a BER $< 10^{-12}$ at 10 Gbit/s data rate for BTB transmission (left) and over the backplane spiral (right).

In Fig. 5 BER curves are depicted for several different waveguides.

*Sample A* (250 × 200 $\mu$m$^2$): The lowest observed power penalty compared to the BTB measurement is 0.3 dB for waveguide #7 (23.5 cm) and for one of the waveguides #9 (28 cm). The required optical power is −14.9 dBm and −15.7 dBm for waveguide #7 and for the straight waveguide #9, respectively.
*Sample B* (250 × 200 $\mu$m$^2$): The power penalty is 0.9 dB both for the straight waveguide #6 and for waveguide #7.
*Sample C* (spiral waveguide, 100 × 100 $\mu$m$^2$): 10 Gbit/s transmission was possible over even 1 m length which is consistent with a bit rate-length-product of more than 10 Gbit/s·m as extracted from small-signal measurements. The power penalty of 1.5 dB is relatively high compared to only 0.5 dB for the 250 × 200 $\mu$m$^2$ spiral in [4].

## 6. Conclusion

The attenuation and data transmission characteristics of polymer waveguides for optical backplane applications have been investigated. Quasi error-free transmission of a 10 Gbit/s PRBS over 50 cm and 1 m-long waveguides has been demonstrated. The power penalty at a BER of $10^{-12}$ compared to BTB transmission was 0.9 dB for the larger

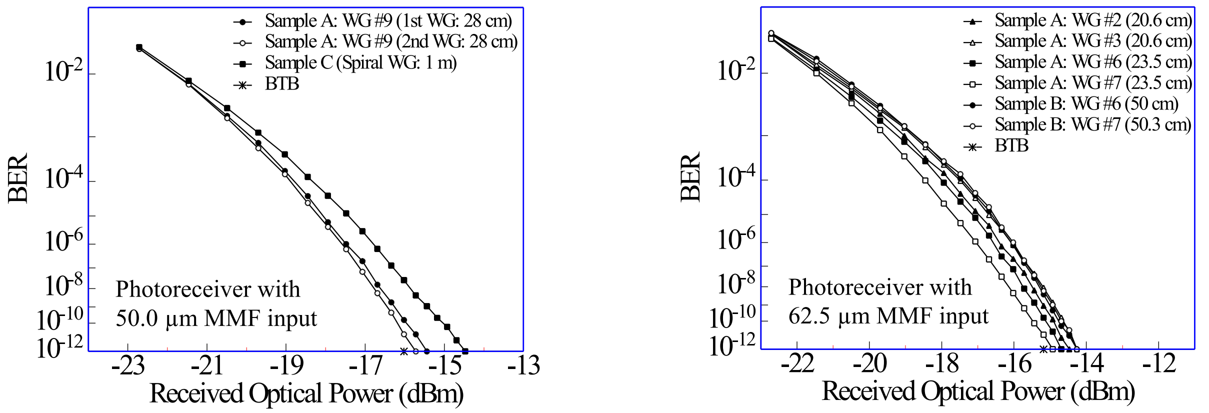


**Fig. 5:** BER characteristics for $2^7 - 1$ word length PRBS transmission at 10 Gbit/s data rate over several waveguides (WGs), employing two different photoreceivers.

core waveguide and 1.5 dB for the smaller core waveguide. The attenuation of the spiral waveguide has been the lowest one of all measured waveguides and is only about 2 dB/m at 850 nm wavelength. With regard to regular backreflection, no impact on the data transmission characteristics has been observed at measured backreflection levels below −14.7 dB.

## References

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