Optical Interconnects Using Short Optical Pulses

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INTRODUCTION

Conventional optical interconnects offer numerous benefits over their electrical counterparts, including the potential for dense arrays with large numbers of interconnections, essentially no distance-dependent signal loss or degradation, and immunity to electromagnetic interference. However, while virtually all optical interconnects use continuous wave (cw) lasers, either driven directly or externally modulated, we demonstrate the use of a modulator-driven chip-to-chip optical interconnect using short optical pulses to remove jitter and skew.

When employing a short (sub-picosecond) pulse laser for optical interconnection, we can use two different aspects of the laser output to our advantage. First, the short pulse duration allows us to sample the data on the output modulators instantaneously (as shown in Figure 1), enabling the removal of jitter in output data streams and the removal of inter-channel skew at the modulators. Second, the low jitter output from the laser provides a low jitter signal for clock distribution and, provided the data are also transmitted optically, enables easy synchronization between clock and data. Though some features of short pulse interconnects have been briefly discussed before [1], to our knowledge this represents the first demonstration of such a system.

EXPERIMENT

The chips used in this experiment are fabricated in 0.5 μm silicon HP CMOS. The optical devices are GaAs multiple quantum well diodes, flip-chip bonded by Lucent Technologies. The diodes serve as both modulators and detectors, have a pitch of 62.5 μm, and are placed in lx20 arrays with 125 μm spacing. Channels are differential, an architecture allowing better system performance with low voltages. The modulators are operated with a 3.3 V bias, providing a contrast ratio of approximately 2:1, centered near 850 nm.

The optical layout is a simple free-space setup on milled stainless steel slotted baseplates that were first described in [2]. From the incoming interconnect laser beam (either short pulse or cw), a linear array of 20 beams is created using a diffractive optical element. These beams are reflected in free space from the modulators on the transmitter chip to the detectors on the receiver chip. Our short pulse laser is a Spectra-Physics Tsunami mode-locked Ti:sapphire femtosecond laser, with a repetition rate of approximately 82 MHz. The transmitter chip is driven with electrical signals from an HP 8133A pulse generator, frequency locked to the laser pulse rate. The detectors on the receiver chip drive receiver circuits that in turn drive additional modulators; these modulators enable high-speed readout of the received signal with a dedicated cw laser beam. This final modulated beam is analyzed using a Tektronix P6701 optical detector with a signal bandwidth of 700 MHz, and the output is recorded using an HP 54750A digital oscilloscope. This short pulse interconnect allows us to make comparisons between cw and pulsed operation to demonstrate benefits of the short pulse system, including the removal of single-channel jitter and inter-channel skew.

RESULTS

With the introduction of up to ± 3/8 bit of jitter on the electrical input of a modulator channel, we see that the jitter is transferred to the receiver when using a cw laser-based interconnect. However, when we use a short optical pulse (temporally centered in the electrical bit), all the jitter is removed as shown in Figure 2. In both cases, a cw laser is used to read the channel state at the receiver chip. The receiver optical output circuitry is neither clocked nor latched, so the receiver output can be seen to relax to the off state with a characteristic time constant.

Electrical data signals can be simultaneously applied to multiple transmitter channels in the array. Figure 3 shows the modulator outputs from two of these channels, which are skewed by 3/8 of a bit relative to one another.

We monitor one reflected beam from each differential pair, first for the cw and then the short pulse interconnect. While the inter-channel skew remains for the cw-based interconnect, the short pulses effectively remove all skew.

SUMMARY

We demonstrate the removal of up to ± 3/8 bit of jitter and inter-channel skew at a data rate of 82 Mb/s through the use of a short pulse-based optical interconnect. The maximum speed of this interconnect is currently limited by the repetition rate of the laser, but tests of the individual modulator and receiver circuits show significantly higher system speeds are possible. Recent advances in mode-locked laser diodes and mode-locked fiber lasers suggest compact sub-picosecond pulse sources will soon be available, making short pulse optical interconnects a feasible alternative to conventional cw interconnects.

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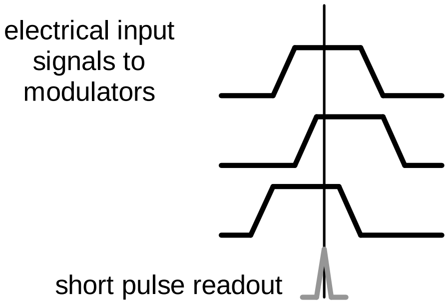

Figure 1. Conceptual illustration of modulator skew and jitter removal using short pulses with a modulator-based interconnect.

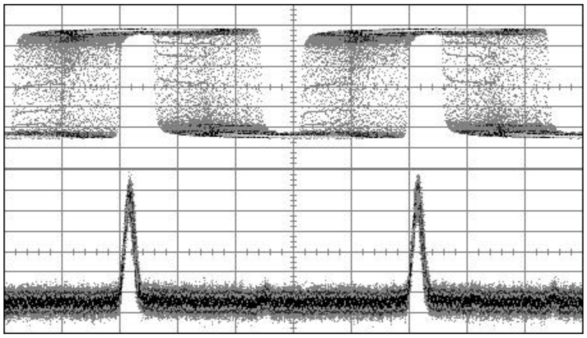

Figure 2. Demonstration of jitter removal from a single interconnect channel, at a clock rate of 82 MHz. Upper trace is the electrical input signal; lower trace is the receiver circuit optical readout.

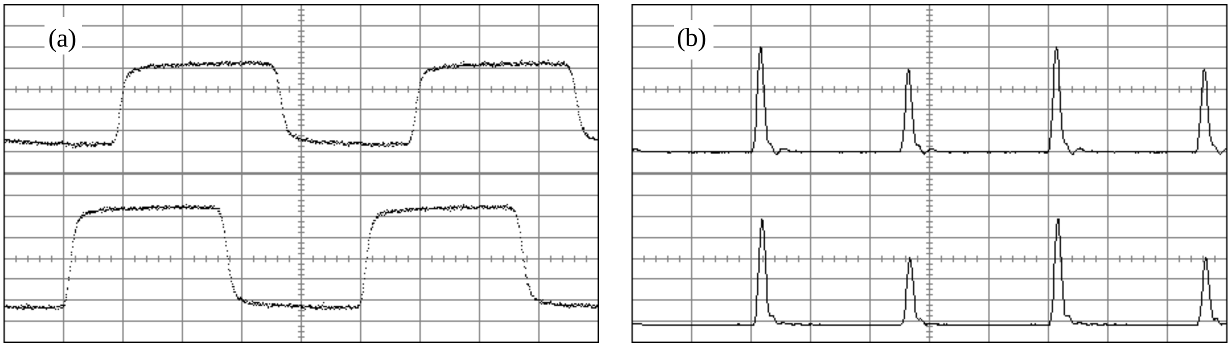

Figure 3. Transmitted signals from two channels operating at 82 MHz, whose electrical inputs are skewed by 3/8 of a bit. Readout is performed with (a) a cw laser, and (b) a short pulse laser. Skew is removed by the use of the short optical pulses.