High Speed NRZ and PAM optical modulation using CMOS Photonics

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Overview

» Mach–Zehnder Interferometer (MZI) in CMOS Photonics

» Simulation and measurement results for NRZ optical modulation

» 40G & 100G PAM optical modulation using CMOS photonics

» Additional Reference Material
  • CMOS Photonics Introduction
  • Mach Zehnder Interferometer (MZI) overview
Lightwire’s Mach–Zehnder Interferometer (MZI)

- MZI -> MOS capacitor
- MZI Driver -> CMOS Inverter
- Well characterized using standard CMOS electrical IC techniques
- Use of standard IC design tools to design and simulate
- Excellent match between simulation and measurement – just like CMOS
- Leverage mature IC technology -> results in predictable performance
- Use of low cost reliable CW laser

Converting an electrical signal to an optical signal is as simple as a CMOS inverter charging & discharging a MOS capacitor
Tx Optical Eye Simulation vs. Measurement

- 10G optical eye
  - Trise/Tfall = 40ps (10%-90%)
  - ER = 8.3 dB

- 28G optical eye
  - Trise/Tfall = 12ps (20%-80%)
  - ER = 9.3 dB

- First pass matching results at 10Gbps & 28Gbps
- Extinction Ratio and Rise Time / Fall Time are adjustable design parameters

Excellent correlation between simulation and measurement
This is a digital system

- Digital drivers – driving 1 or 0
- Lithography defined MZI
- High speed digital

No magic here, straightforward high speed digital design in CMOS
CMOS Photonics enables design confidence

» …Just like CMOS electronics

» This is a new approach to optics design, but no different than traditional CMOS design

» CMOS Photonics - same CMOS design process

» Library is well characterized that results in high confidence correlation between simulation of design and actual performance

Successfully demonstrated 28+Gbps NRZ optical modulation
Rise Time / Fall Time < 12ps, ER > 8dB
Achieving PAM Signaling in MZI (e.g. PAM-4)

Segmented MZI + Simple digital drivers provide built-in DAC function for PAM
Much simpler digital drivers -> PAM optical outputs
Segmented MZI concept extended to PAM-16

Electrically -> 4 inverter drivers driving 4 capacitors

Optically -> Continuous waveguide, where 4 segments contribute phase shift proportional to their length

Need to line-up electrical transitions of all 4 lanes (minimize clock skew across 4 lanes)

Single segmented MZI modulator provides all 16 PAM levels
TX Optical PAM-16 Realization

PAM16 @10 Gbaud (40Gbps) **  PAM 16 @ 28 Gbaud (112 Gbps)

- 10G TX Optical Simulations
- Design completed
- Measurement results soon
- IC Size: ~2mm x ~1mm

- IC includes PAM-16 MZI + more structures

- 28G Simulations
- Further design optimization possible

** Darpa Contract
Summary

» SiPhotonics enable very efficient implementation of Multi-level modulation

» Excellent correlation between simulation and measurements

» High speed modulation using CMOS photonics shown
  • Required rise time / fall time performance demonstrated

» Simulation show 100G PAM-16 optical modulation realizable using current technology

» 40G PAM-16 optical modulation silicon measurement results soon
Additional Reference Slides
CMOS Photonics Introduction

CMOS IC Platform

Electronic IC manipulates electrons using transistors

Electrical I/O

CMOS Photonics IC Platform

Opto-Electronic IC manipulates both photons and electrons using transistors

Optical I/O

Electrical I/O

CMOS Photonics IC Platform leverages existing multi-billion dollars of investment, infrastructure and discipline of the CMOS IC industry to manipulate both Electrons & Photons to achieve desired Opto-Electronics functions using External DC Sources.
By controlling the voltages on terminals, MOS Transistor controls the flow of electrons from source to drain. Today, 100s of millions can be placed on a single electronics chip.

Just like the transistor is the basic building block for all ICs, Broadband Modulator is the basic building block for all high speed optical interconnects.
Mach Zehnder Interferometer (MZI)
Modulator overview

\[ E_L = \frac{E_{in}}{\sqrt{2}} \]
\[ E_R = \frac{E_{in}}{\sqrt{2}} \]

Left arm
\[ E_{left} = e^{i\theta_L} e^{\alpha_L} E_L \]

Right arm
\[ E_{right} = e^{i\theta_R} e^{\alpha_R} E_R \]

\[ P_{out} = |E_{out}|^2 = |E_{in}|^2 \left[ 1 + \cos(\theta_R - \theta_L) \right] \frac{1}{2} \]

» Control left and right arms to be in phase (optical 1) and out of phase (optical 0) by applying voltage across the length of the MZI

» Phase v/s output optical power in raised cosine relationship

» \( V_{\pi L\pi} \) = Measure of voltage and length required to get full \( \pi \) phase shift

MZI deployed in optical systems for over 20 years
Lightwire’s MZI

» $V_{\pi}L_{\pi} < 2 \text{ Vmm}$

» What does this mean?
  • Between two arms we need $< 1\text{Vmm}$
  • Enables smaller length modulators (in 100s of microns)
  • Enables cmos compatible drive voltages ($< \sim 1\text{V}$)
  • Implemented in CMOS process

» Uses CW (DC) lasers rather than direct modulation

CMOS photonics enables small size, low power MZI modulators