High Speed NRZ and PAM optical modulation using CMOS Photonics

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Overview

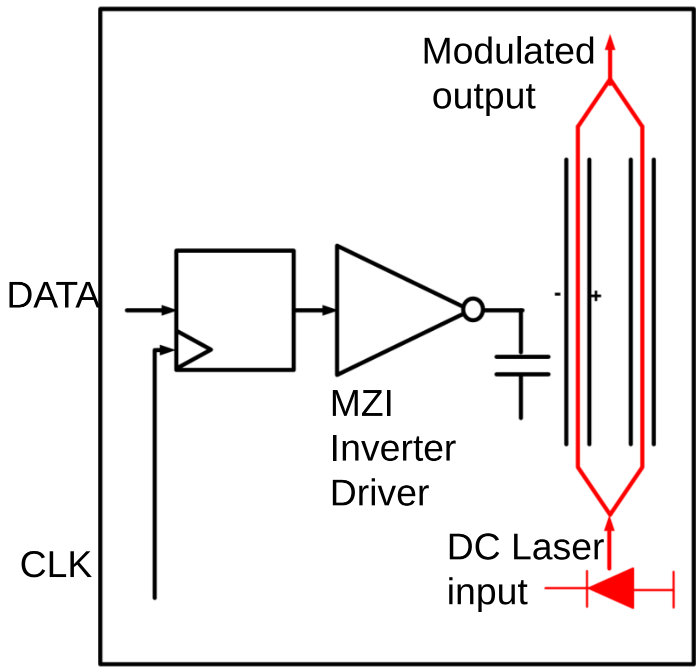
» Mach–Zehnder Interferometer (MZI) in CMOS Photonics

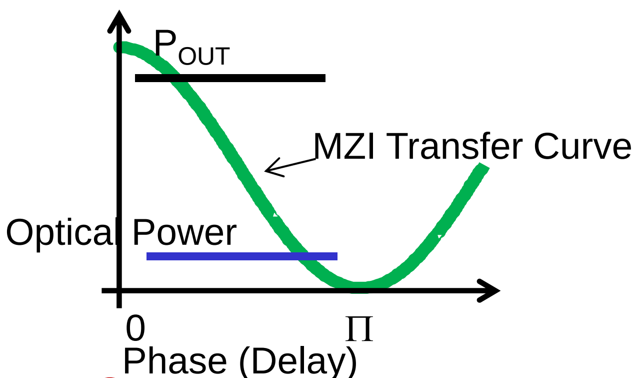
» Simulation and measurement results for NRZ optical modulation

» 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

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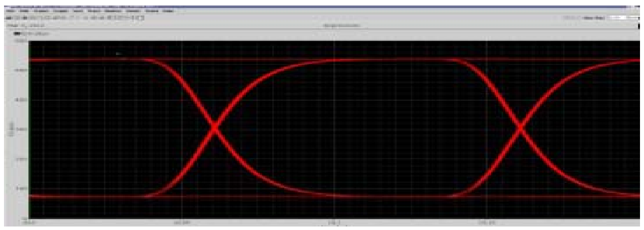
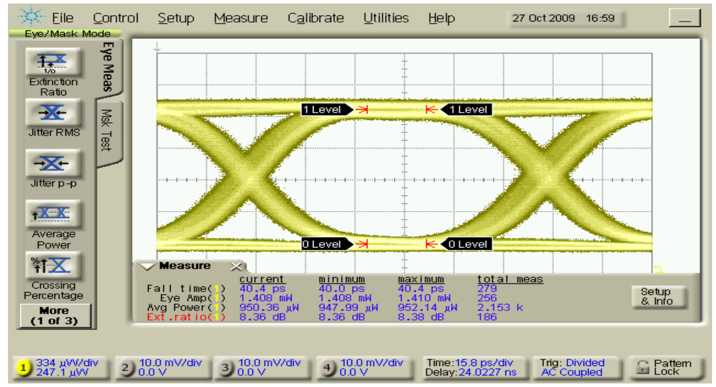
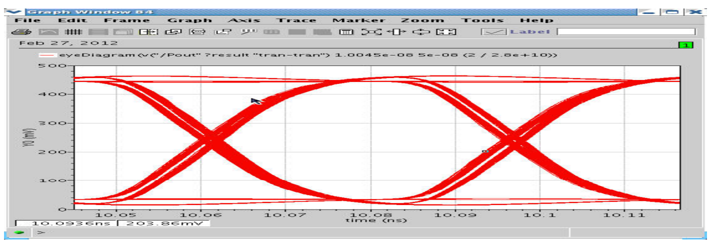
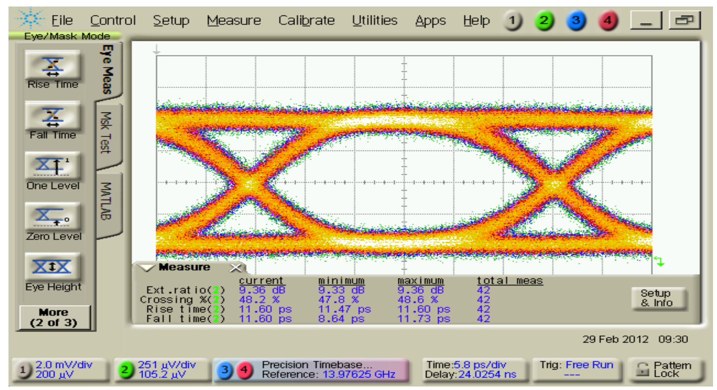




- 10G optical eye
- Trise/Tfall = 40ps (10%-90%)
- ER = 8.3 dB





- 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

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- …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)

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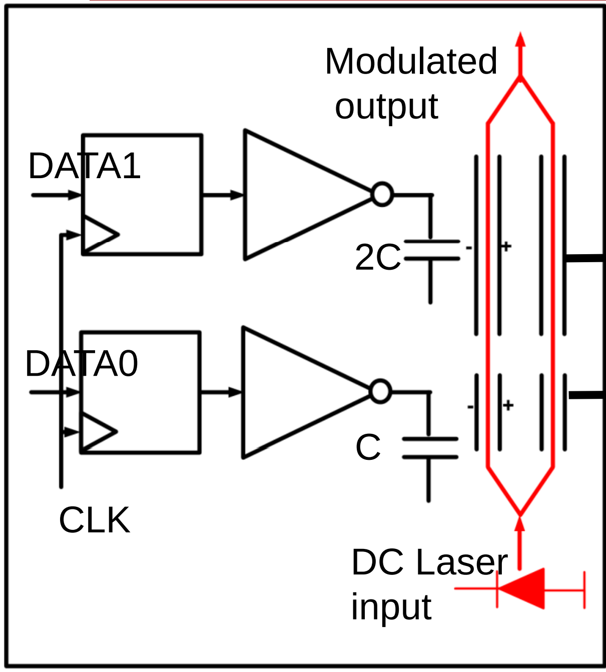
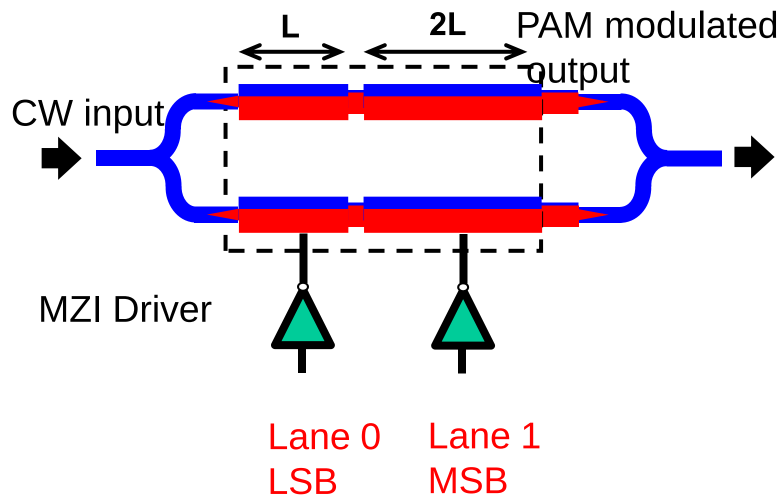
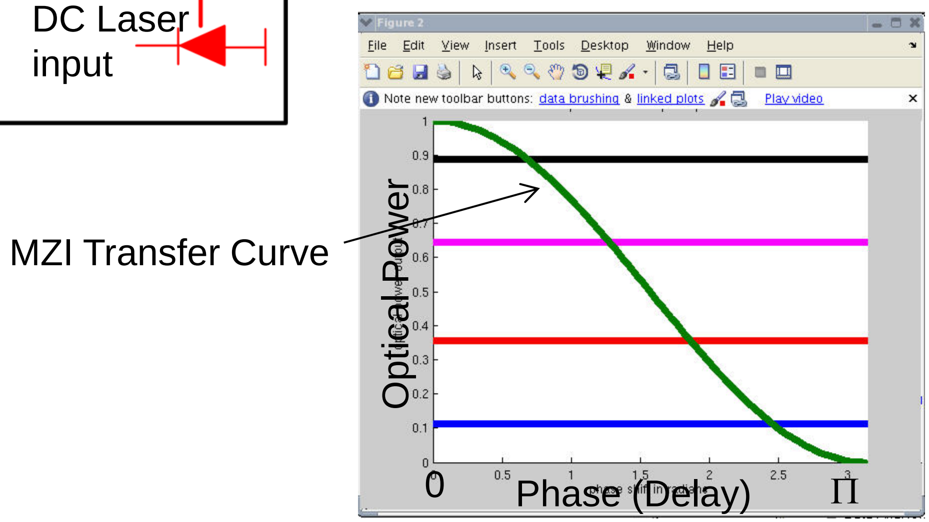


2X phase delay

1X phase delay

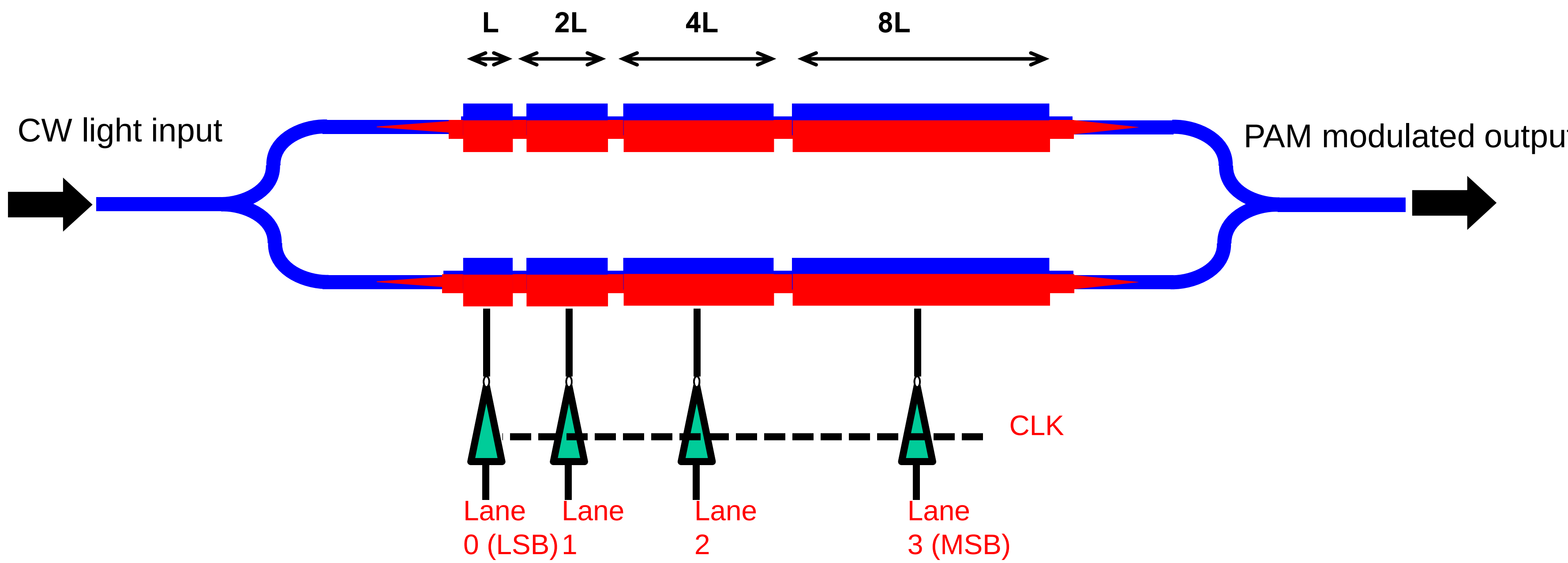




Lane 1 – Electrical MSB 0.66 ϕ	Lane 0 – Electrical LSB 0.33 ϕ	Optical Out
0	0	0
0	1	1
1	0	2
1	1	3

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



Lane 3 MSB	Lane 2	Lane 1	Lane 0 LSB	Optical Out
0	0	0	0	0
0	0	0	1	1
-	-	-	-	-
1	1	1	1	15

» Electrically -> 4 inverter drivers driving 4 capacitors

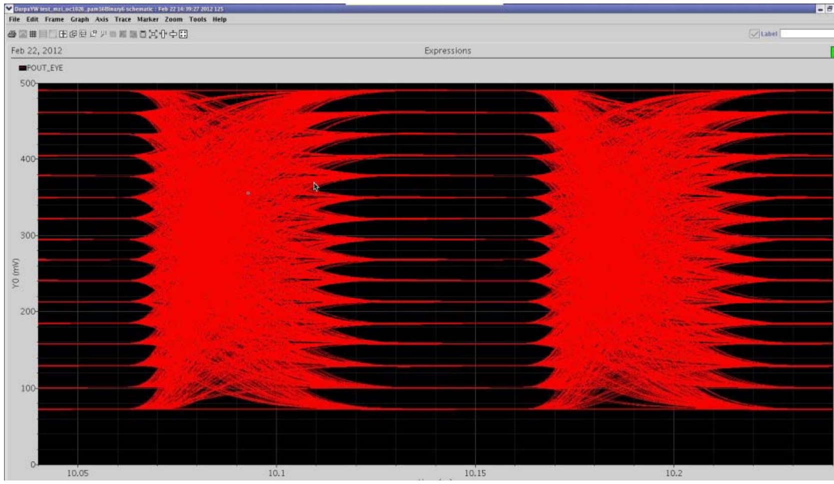
» Optically -> Continuous waveguide, where 4 segments contribute phase shift proportional to their length

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

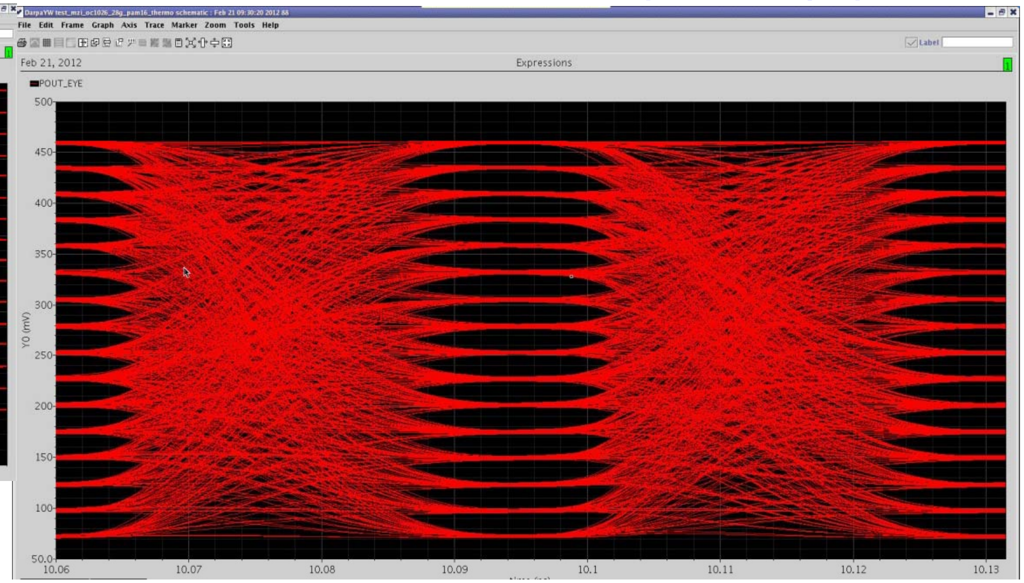
Single segmented MZI modulator provides all 16 PAM levels

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

- 28G Simulations
- Further design optimization possible

- IC includes PAM-16 MZI + more structures

** Darpa Contract

Summary

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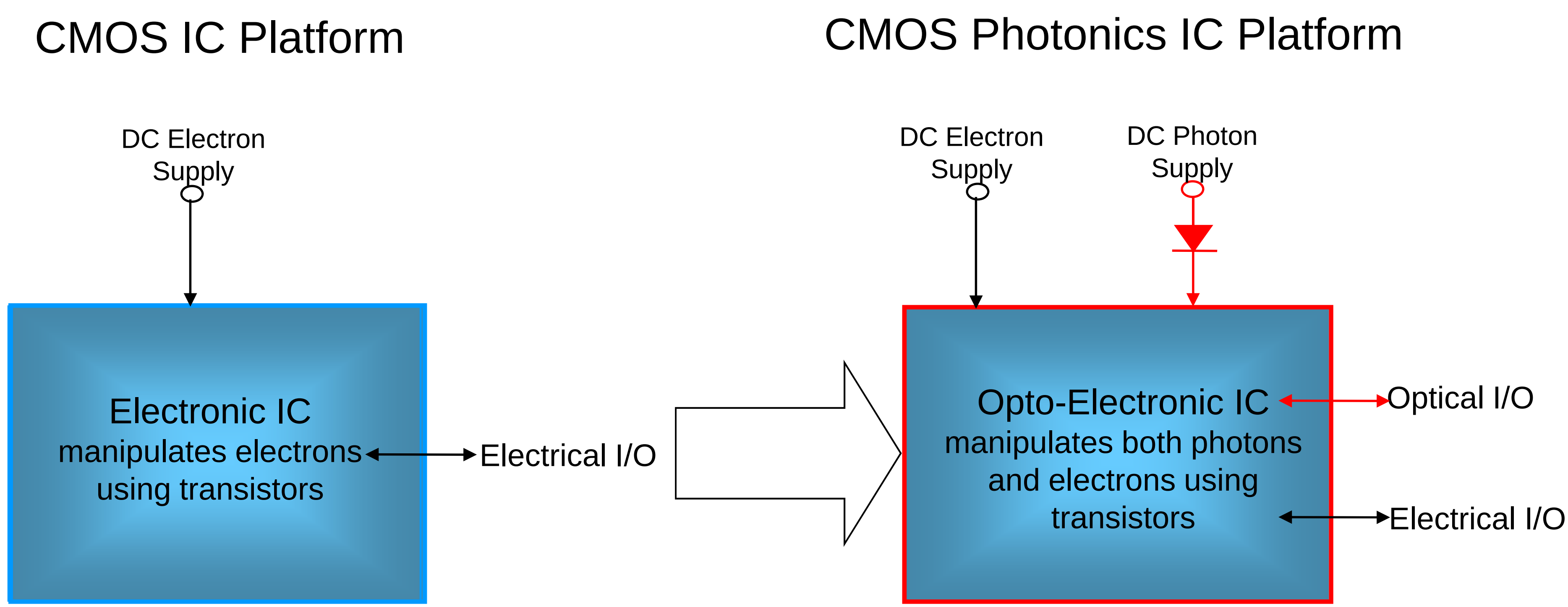
- SiPhotonics enable very efficient implementation of Multi-level modulation
- Excellent correlation between simulation and measurements
- High speed modulation using CMOS photonics shown
  - Required rise time / fall time performance demonstrated
- Simulation show 100G PAM-16 optical modulation realizable using current technology
- 40G PAM-16 optical modulation silicon measurement results soon

Additional Reference Slides

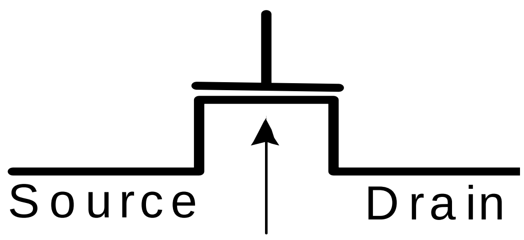
CMOS Photonics Introduction



CMOS Photonics IC Platform leverages existing multi-billion dollars of investment, Infra-structure and discipline of the CMOS IC industry to manipulate both Electrons & Photons to achieve desired Opto-Electronics functions using External DC Sources

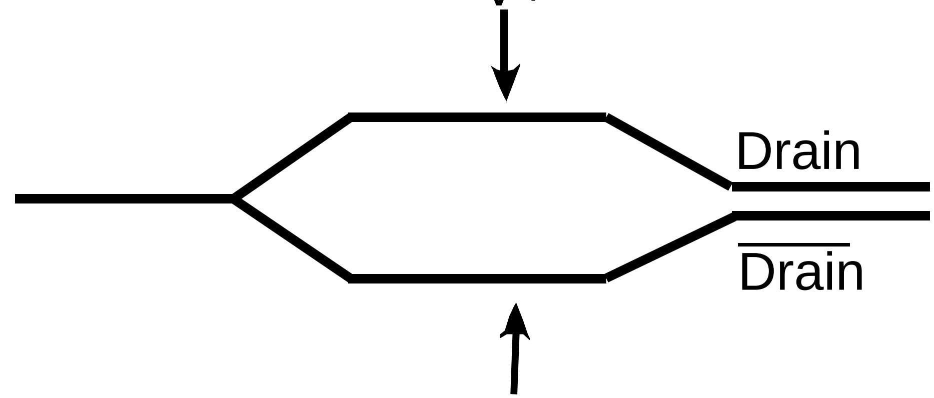
Fundamental Technology

MOS Transistor



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.

CMOS Photonics Modulator



By controlling the voltages of the two arms of the modulator, one controls the flow of photons from source to drain with one major difference – Photons cannot be stopped and hence the unwanted will go to Drain. A large numbers of these can be integrated on a single 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

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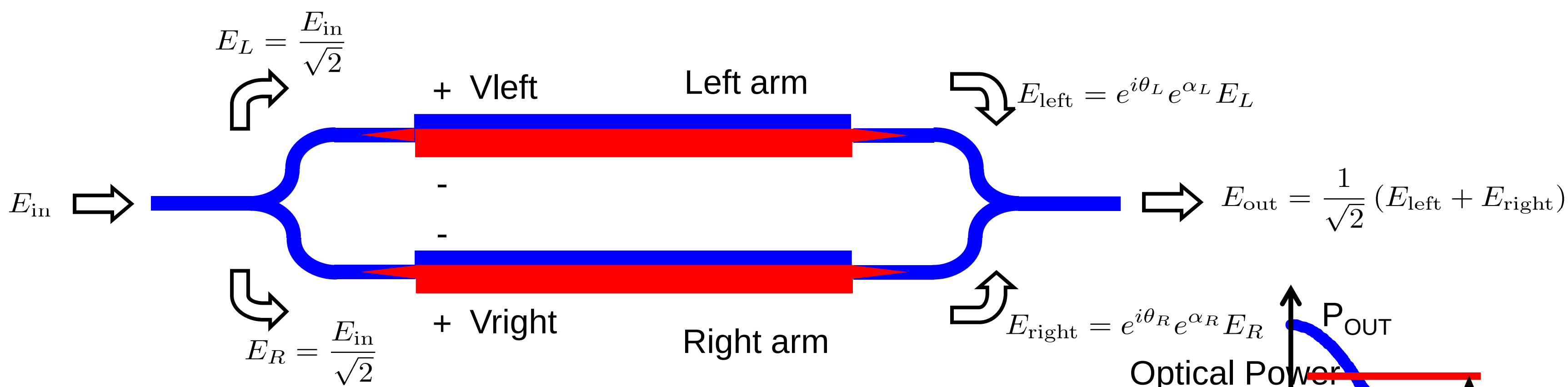

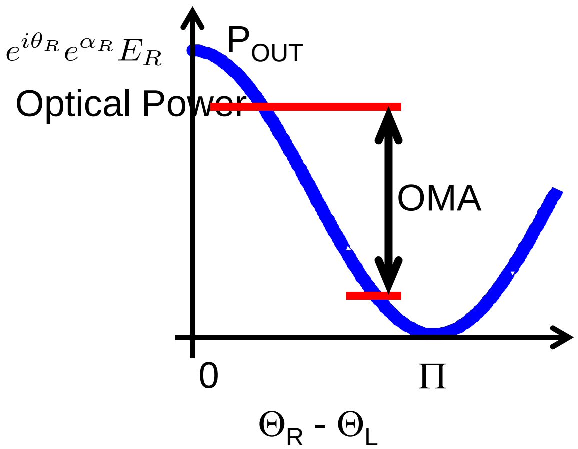

$$P_{out} = |E_{out}|^2 = |E_{in}|^2 \left[\frac{1 + \cos(\theta_R - \theta_L)}{2}\right]$$

- » 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
- » VπLπ = Measure of voltage and length required to get full π phase shift

MZI deployed in optical systems for over 20 years

Lightwire's MZI

» **$V\pi L\pi$ < 2 Vmm**

» What does this mean?

- Between two arms we need < 1Vmm
- Enables smaller length modulators (in 100s of microns)
- Enables cmos compatible drive voltages (< ~1V)
- Implemented in CMOS process

» Uses CW (DC) lasers rather than direct modulation

CMOS photonics enables small size, low power MZI modulators