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A Simulator for Integrated Optoelectronic Devices

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Outline

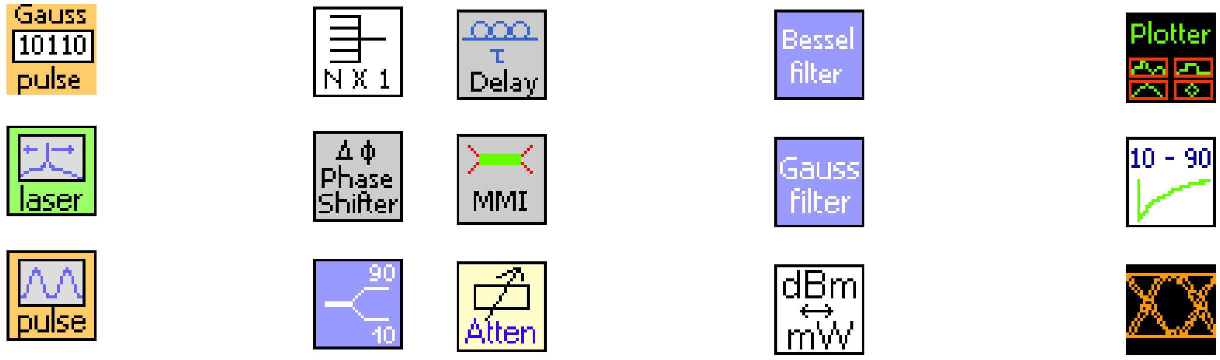
- Simulator for photonic integrated devices
- Programming language
- Application: Wavelength conversion at 40 Gb/s
- Single Gaussian pulse response
- System level simulations: PRBS signal response
- Conclusions

Simulation of new photonic integrated circuits

- New integration technology allows fabrication of sophisticated Photonics Integrated Circuits (PICs) .
- Single SW tool must be able to deal with a wide variety of complex optoelectronic integrated circuits consisting of tens or even hundreds of interconnected devices.
- Solution: implementation of building blocks, each one performing a specific data-flow oriented function onto an input optical stream.
- Result: A simulator that is Flexible, Powerful and Intuitive

Solution: Modularity + Data Flowing

- Example of simulation units:



- Desirable characteristics:
  - High modeling accuracy
  - Modular, following I-O approach
  - Short processing time and low memory requirements

Novel semiconductor optical amplifier simulator

- Uni-directional approach: easy integration into system simulator and fast execution.
- Solved via a fast single-marching algorithm and integration of propagation equation in a (1+1)–dimension rectangular grid.
- Time domain representation allows straightforward incorporation of multiple channels. It is flexible in terms of applications.
- Non-linear effects: all carrier dynamical processes relevant for bit rates from 2.5 to 160 Gb/s (and higher) are considered through rate equation approach.
- Impact of amplified spontaneous emission on carrier dynamics is included.

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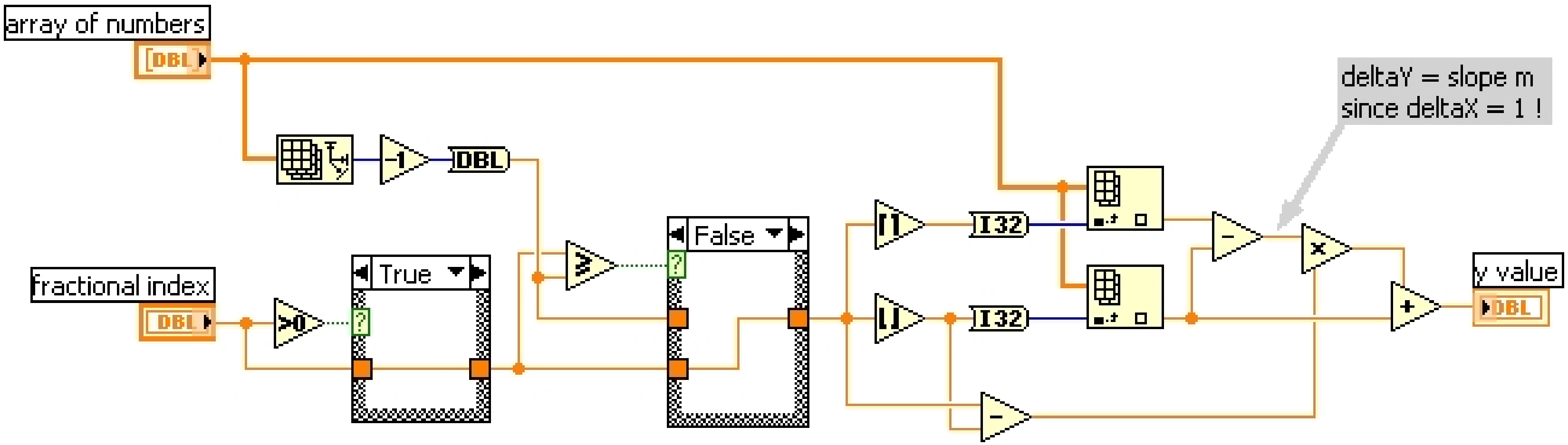
LabVIEW graphical programming language



- Friendly graphical user interface (graphical source code).
- Modularity and interconnectivity of subroutines (VIs).
- Efficient management of libraries.
- Dataflow–oriented: data processing along wires.
- Allows interfacing with other programming languages.

Is LabVIEW fast Enough? - YES

- Identical SOA simulators written in LabVIEW and Matlab: code optimized to each programming language.
- Benchmark: amplification of 40 Gb/s PRBS of Gaussian pulses 6.25ps FWHM. Δt=0.0976 ps, N=2^n bits long.

LabVIEW (LV)				Matlab (ML)			
Runge-Kutta				Runge-Kutta		ODE15s	
Interp1 Library	Interp2 Self-W			Interp1 Library	Interp2 Self-W	Interp1 Library	Interp2 Self-W

Identical simulators

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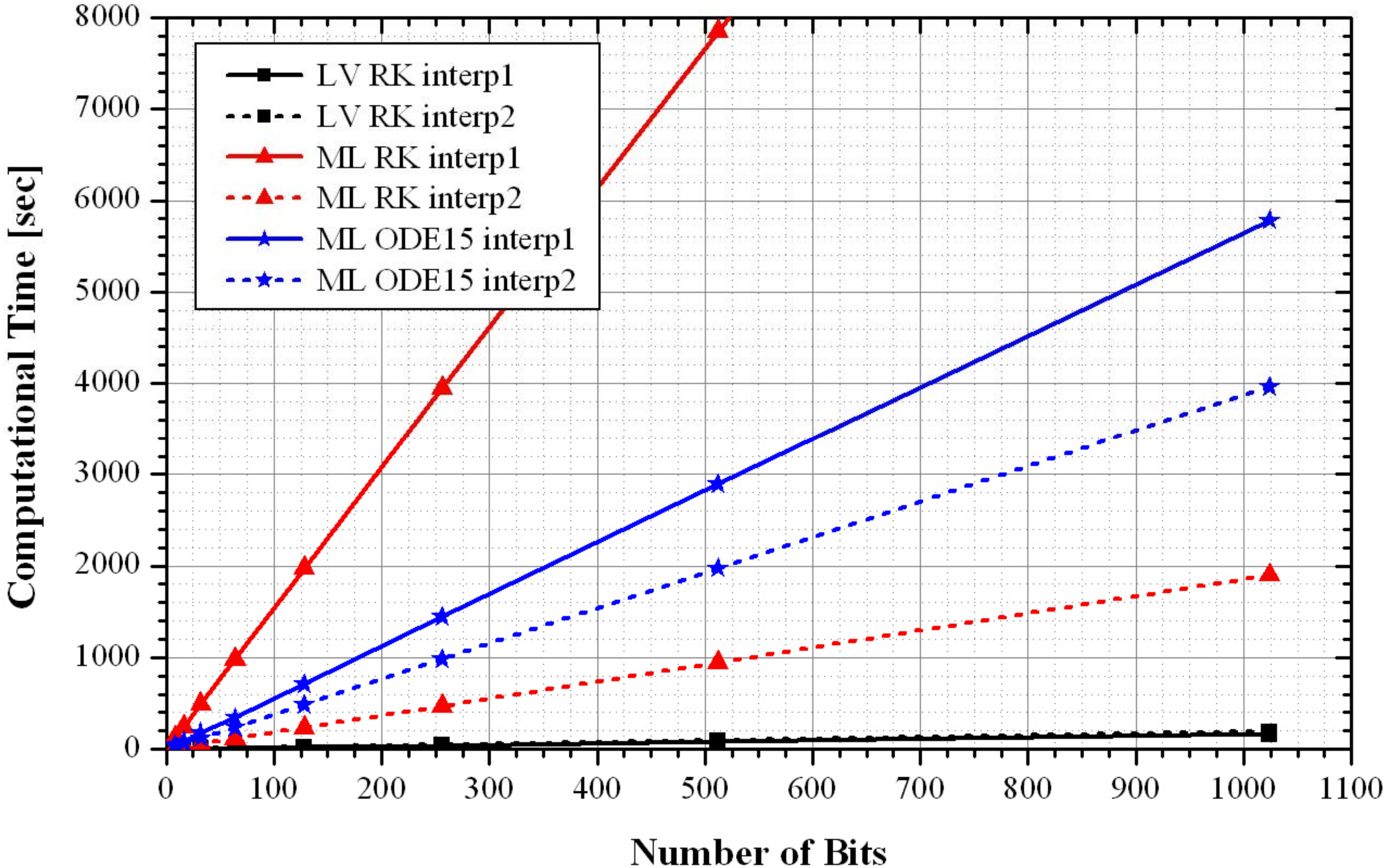
LabVIEW 7.1 versus Matlab 7.0.1



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LabVIEW 7.1 versus Matlab 7.0.1 … cont'd

Method	Slope	Slope Error	Rel. Speed factor
LV RK Interp1 ___	0.1608	7.8E-05	1.0
LV RK Interp2	0.1884	1.0E-05	1.17
ML RK Interp1 ___	15.298	1.6E-02	95.1
ML RK Interp2	1.8611	1.7E-03	11.6
ML ODE15s Interp1	5.6578	8.7E-03	35.2
ML ODE15s Interp2	3.8703	5.2E-03	24.1

- 10 times outperformance of LV over ML for identical sims.
- LV interpolant speeds up, ML interpolant slows down.
- Best LV simulator is 11 times faster than any ML simulator.
- Fastest ML simulator: entirely self-written (ML RK Interp2).

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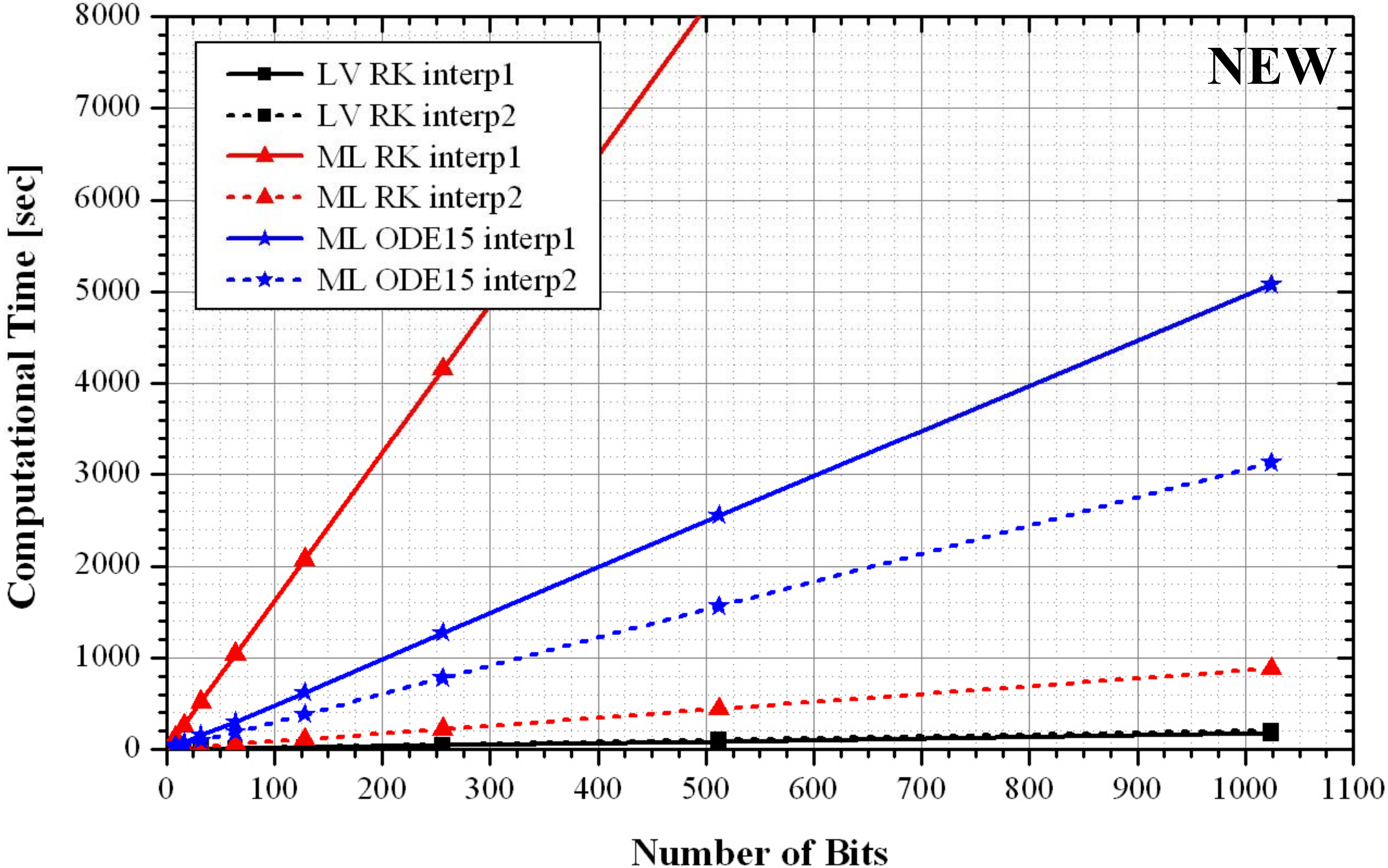
LabVIEW 8.2 versus Matlab 7.2.0.232 - Update

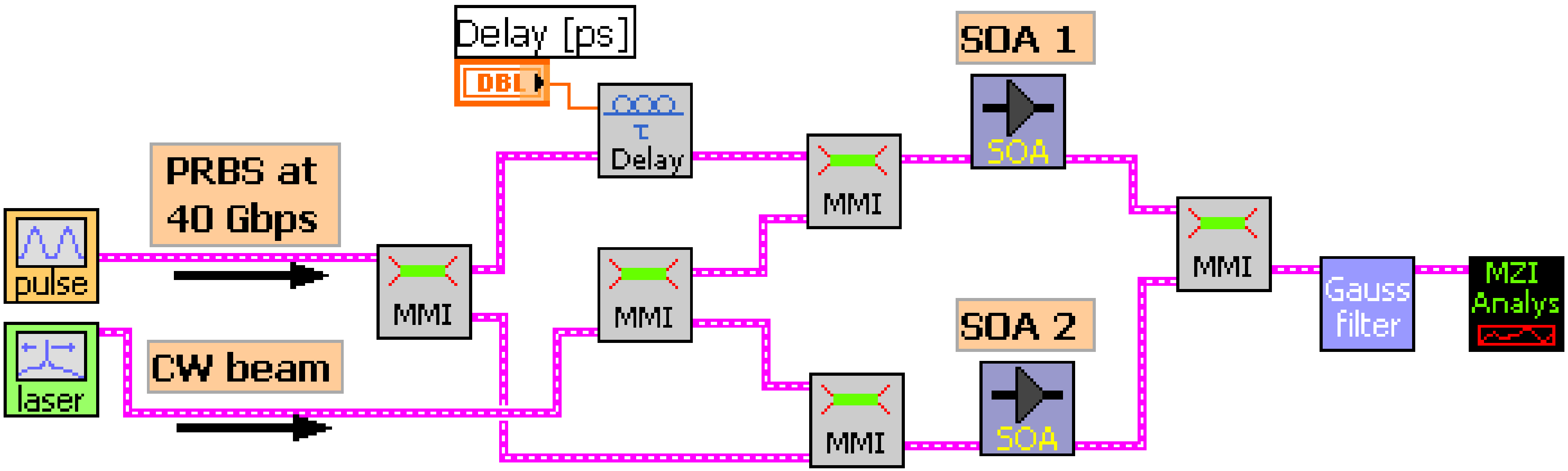


LabVIEW 8.2 versus Matlab 7.2.0.232 … cont'd

Method	Slope	Slope Error	Rel. Speed factor
LV RK Interp1	0.1723	2.0E-05	1.0 —
LV RK Interp2	0.2011	6.0E-05	1.2 —
ML RK Interp1	16.2746	8.7E-02	94.5 —
ML RK Interp2	0.862	1.3E-03	5.0 ↓
ML ODE15s Interp1	4.9668	8.5E-03	28.8 ↓
ML ODE15s Interp2	3.0566	3.8E-03	17.7 ↓

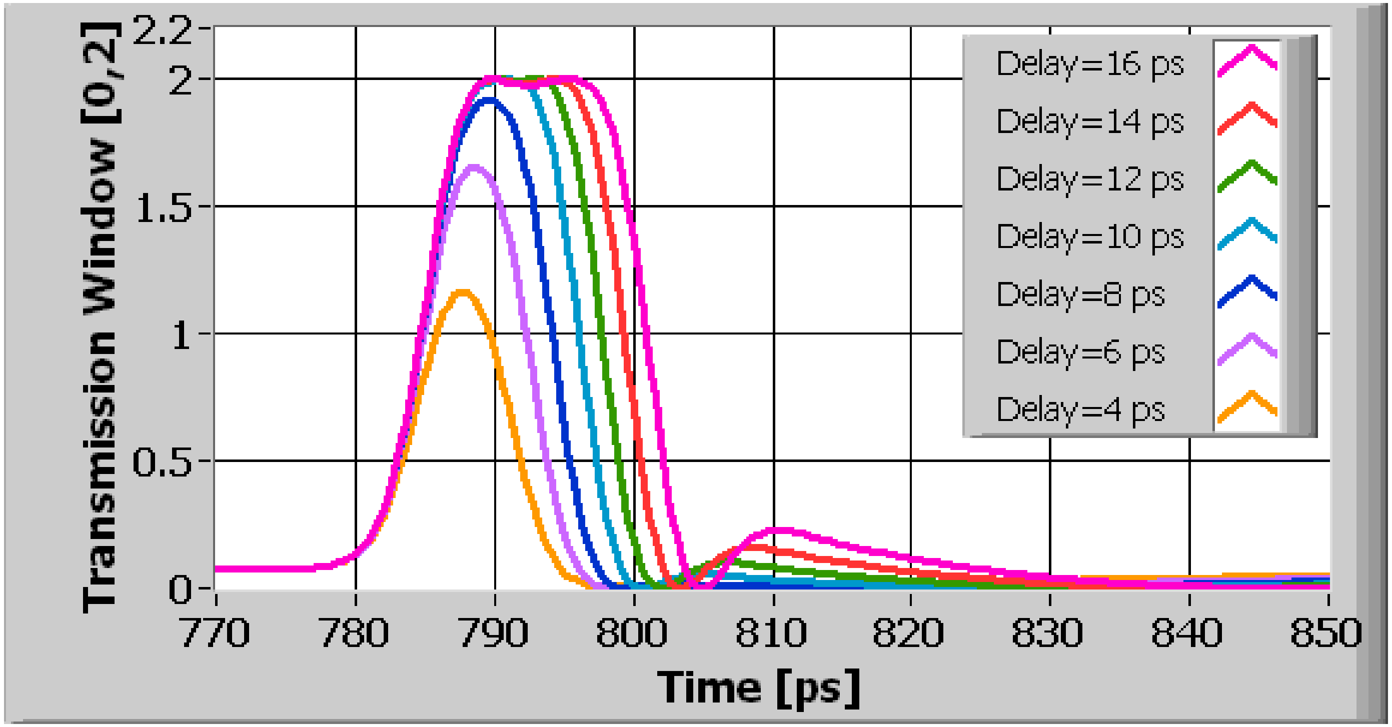
- Qualitative results remain the same.
- ML shows appreciable improvement in contrast to LV.
- For identical sims. LV still outperforms ML, now by 4.16.
- Apparently ML interpolant is still a bottleneck.

Active Mach-Zehnder interferometer: LabVIEW code



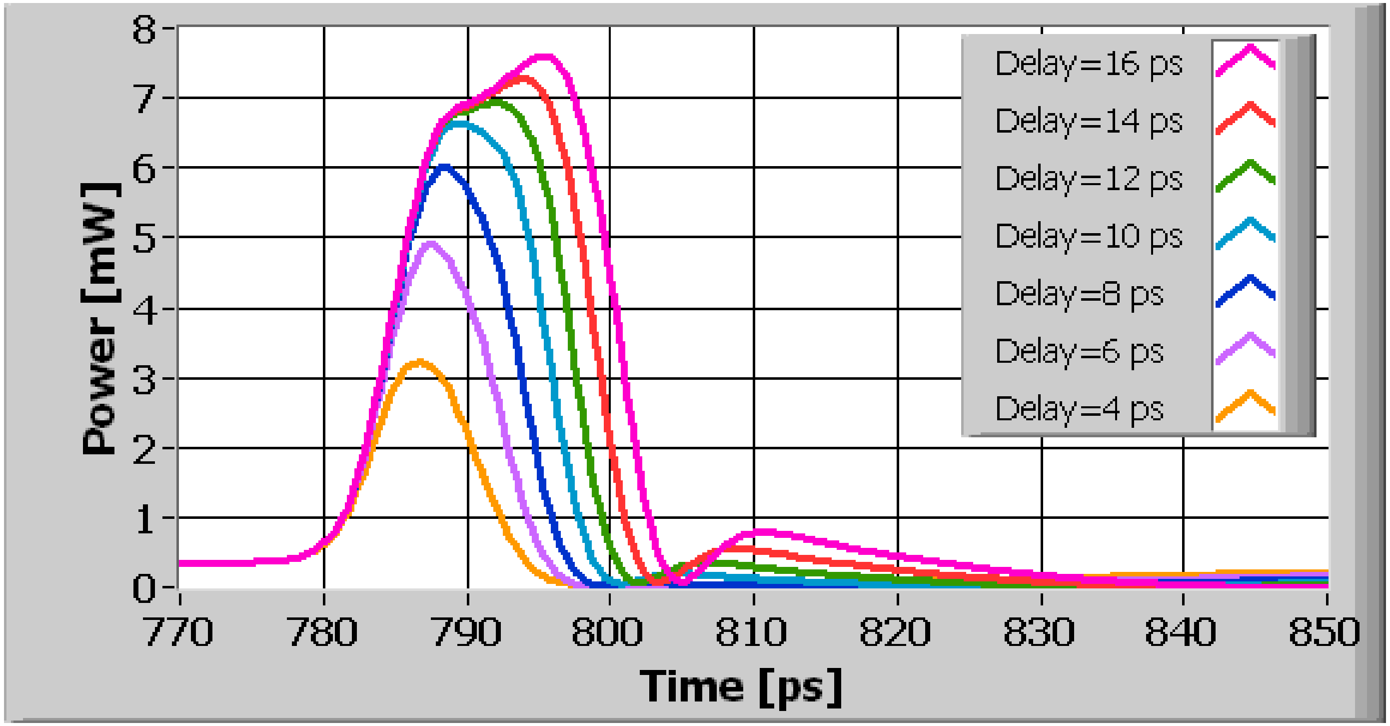
- Upper port: PRBS @ λ_{sig} = 1565.5 nm (~191.5 THz), 40 Gb/s, RZ-Gaussian puses, 8.25 ps FWHM.
- Lower port: CW signal @ λ_{target} = 1554.1 nm (~192.9 THz).
- Identical 1 mm long SOAs with 400 mA of injected current.

Single Gaussian pulse: transmission window



- Short delays: short and narrow AMZI transmission window.
- Long delays: flat-top or even double peaked windows.

Single Gaussian pulse: output power

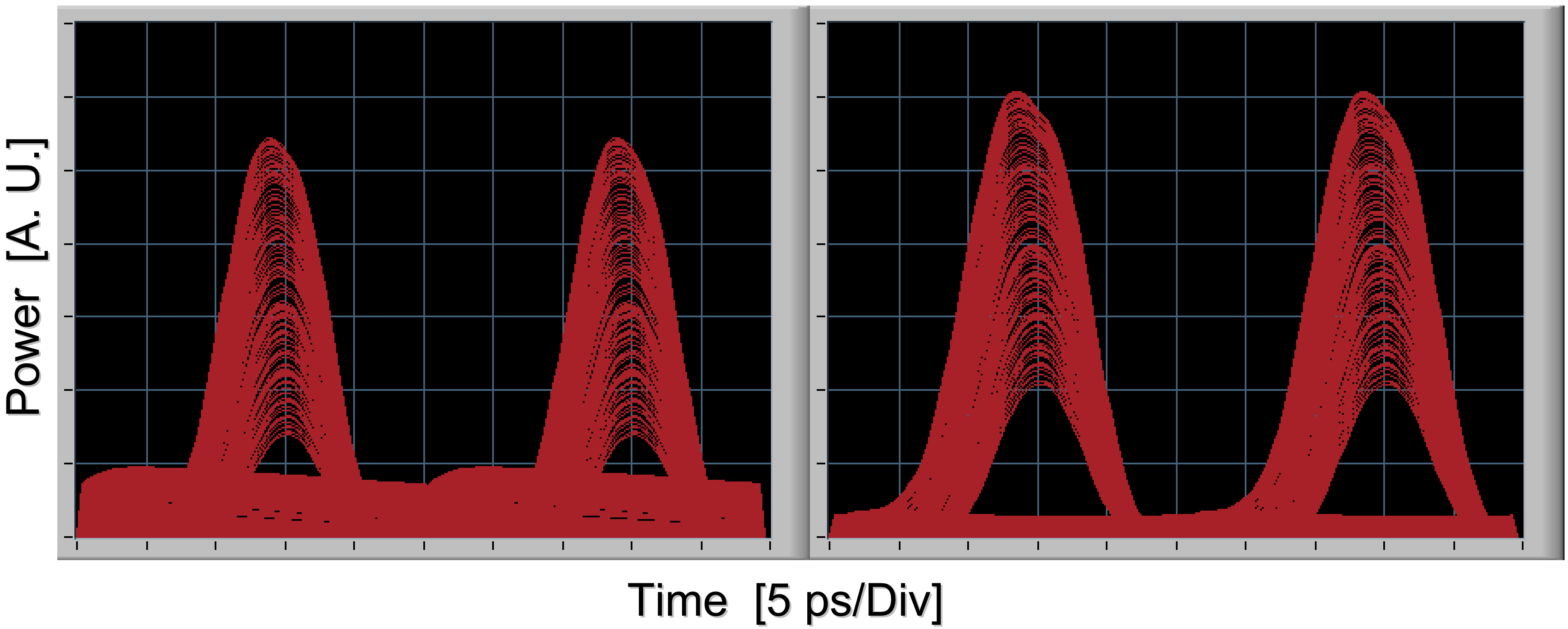


- Best results when delay equals input pulse width: 8.25 ps.
- For this delay the pulse width is preserved

Simulated eye diagrams for PRBS 256-bits long

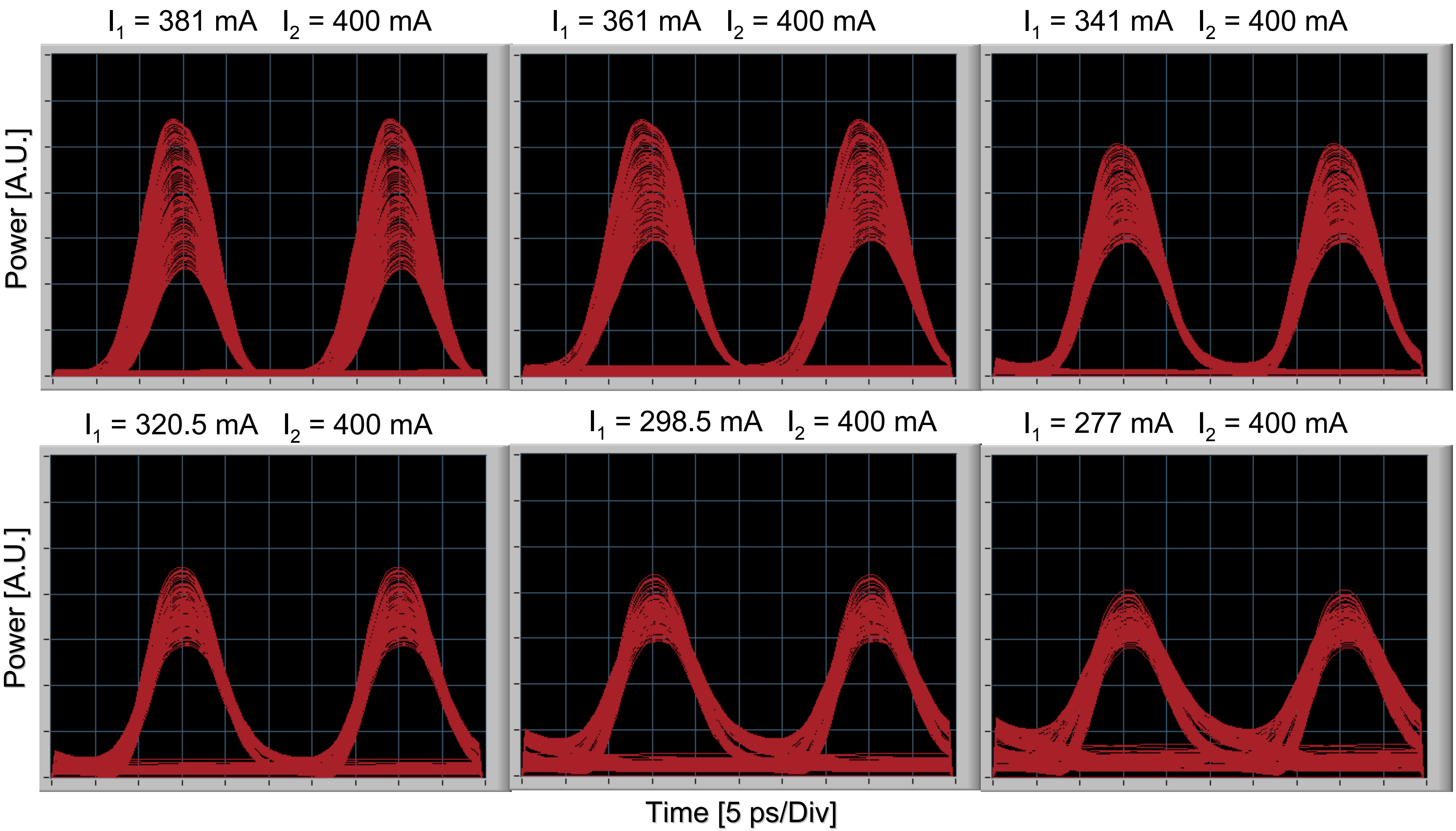
Differential delay = 8.25 ps

I_1 = 400 mA I_2 = 400 mA I_1 = 399 mA I_2 = 400 mA



- Fine-tuning of I_1 reduces noise in marks and spaces.

Tuning of I_1 exhibits quasi-periodic behavior



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Simulation results

- The high execution speed of our simulator allowed several system-level simulations with ΔI_1=0.5 mA.
- Eye diagrams with reduced noise found at: I1= 381, 361, 341, 320.5, 298.5 and 277 mA.
- Apparent quasi-periodic behavior, experimentally confirmed.
- The eyes are not identical: lower values of I_1 produced weaker pulses with lower amplitude jitter (patterning).
- Varying the splitting ratio of the leftmost MMI while keeping I_1=I_2= 400 mA also led to noise reduction.

Conclusion

- We presented a novel graphical simulator for multiple photonic integrated circuits. Attractive alternative.
- Modular I-O approach: circuit elements associated with individual simulation units that are intuitively wired.
- Written in LabVIEW: more than 4 times computational speed outperformance over Matlab (SOA simulator).
- Application example: 40 Gb/s wavelength conversion using an active Mach-Zehnder interferometer.
- Simulator shows that best results are obtained when:
  - Differential delay closely matches the pulse width.
  - Unbalanced operation (quasi-periodicity observed).