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An Ultrafast $1 \times M$ All-optical WDM Packet-Switched Router based on the PPM Header Address

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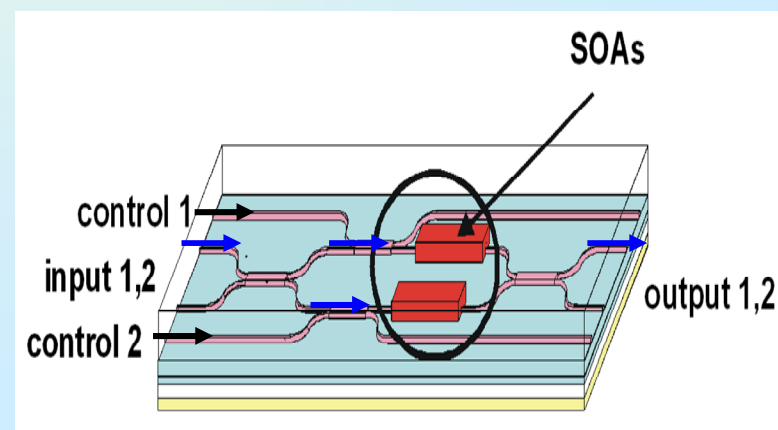
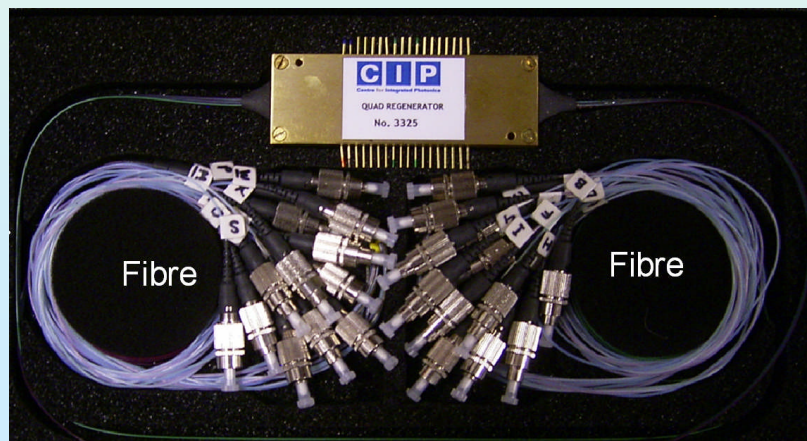
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-

Introduction- Research Aim (1)

- There is a growing demand for all optical switches and routers at very high speed, to **avoid the bottleneck imposed by the electronic switches**.

*In KEOPS¹ (keys to optical packet switching) a EU project, the packet payload are maintained, **But** the packet header addresses are transmitted at low bit-rate and processed in electrical domain.*

- We present a router architecture employing **all-optical switches**, such as *symmetric Mach-Zehnder (SMZ)*.



¹C. Guillemot, etc., "Transparent Optical Packet Switching: The European ACTS KEOPS Project Approach," *IEEE Light. Tech.*, vol. 16, pp. 2117-2134, 1998.

Introduction- Research Aim (2)

- In large dimension networks (routing table with hundreds or thousands of entries) packet processing \rightsquigarrow **throughput latency**

IST-LASAGNE² project - packet label/addressing

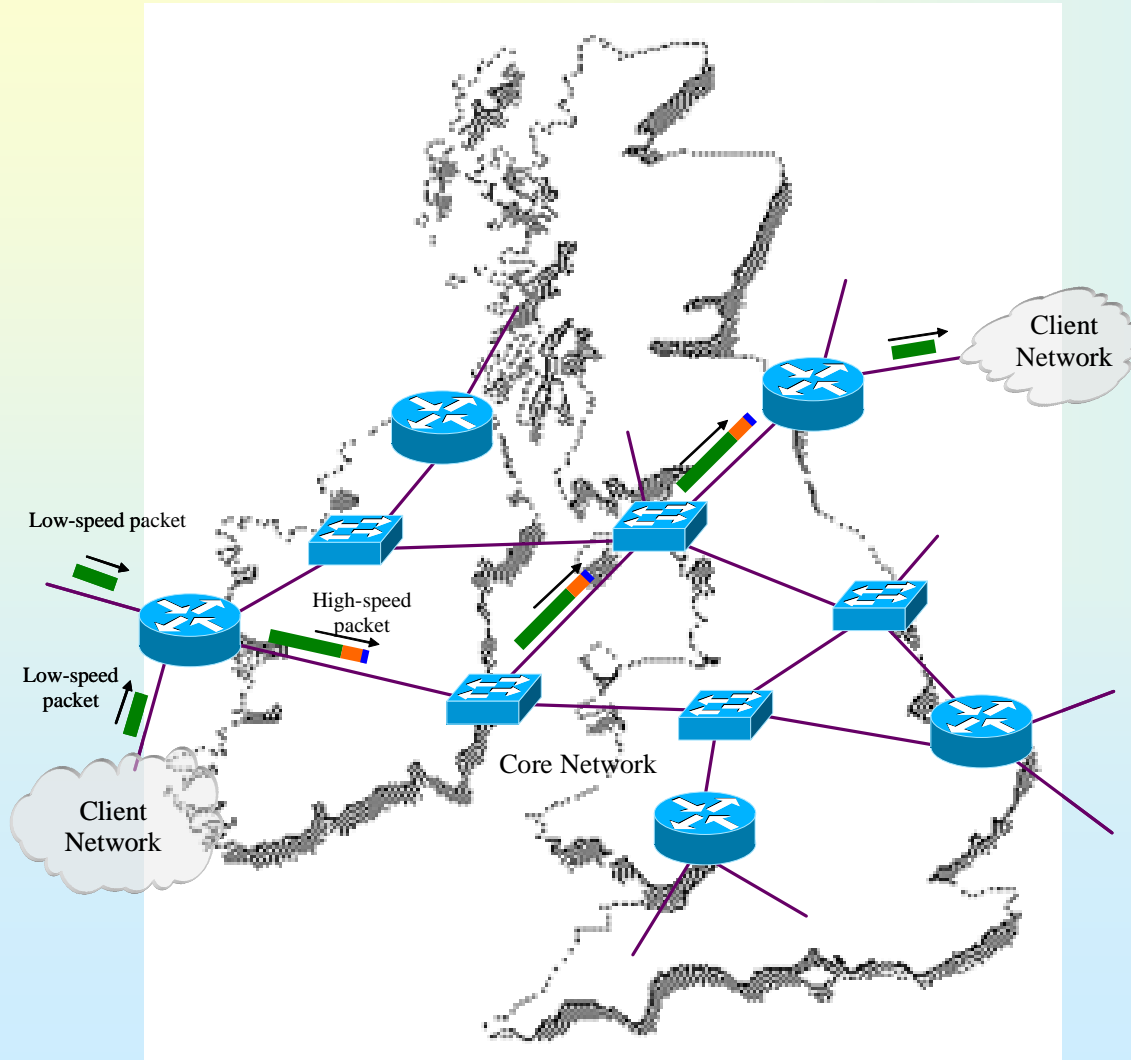
- *all-optical employing a cascade of SOA-MZI structure*
- *requiring large number of SOA-MZI switches are increasing as the numbers of the address bit increase.*

➤ We present an optical router,

- where **packet header** and the **routing table entries** are converted from a binary RZ into a **pulse position modulation (PPM)** format.
 - uses only **a single AND operation** for address correlation.
 - offers reduced packet processing time - size of the PPM routing table is **significantly reduced**.
- Base on the PPM header address processing, we propose an all-optical **1xM WDM router** architecture for packet routing at multiple wavelengths simultaneously, **with no wavelength conversion modules**.

²F. Ramos, etc., "IST-LASAGNE: Towards All-Optical Label Swapping Employing Optical Logic Gates and Optical Flip-Flops," *IEEE Light. Tech.*, vol. 23, pp. 2993-3011, 2005.

Introduction- Optical Networks

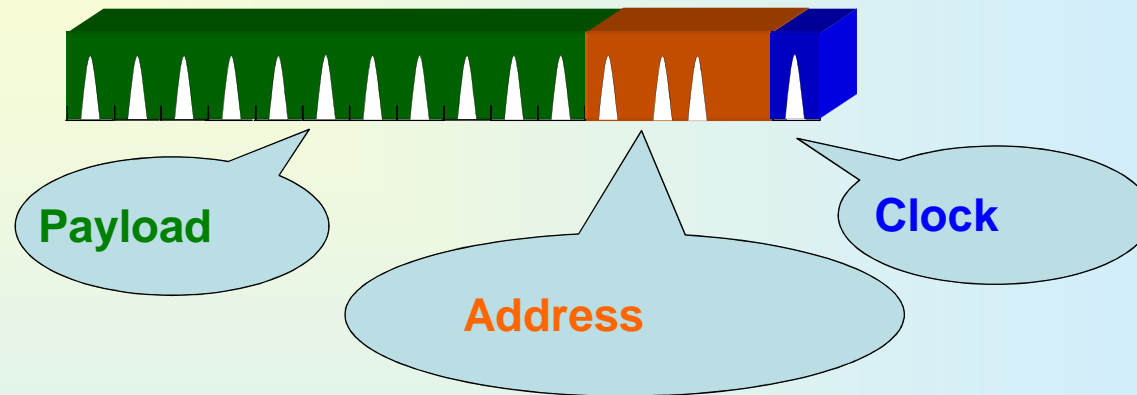


Proposed core optical router



Source / target node

Introduction- Optical Packets

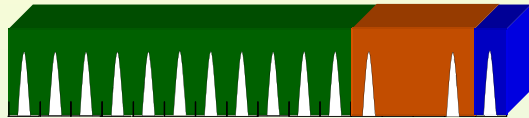


An optical packet is composed of three parts:

- **Clock bit:** For synchronisation purpose
- **Address bits:** Destination of the packet
- **Payload bits:** The really information desired to be transmitted

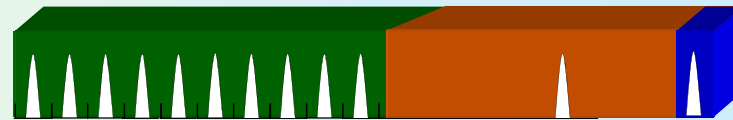
Packets with PPM Address

Packet with binary address bits



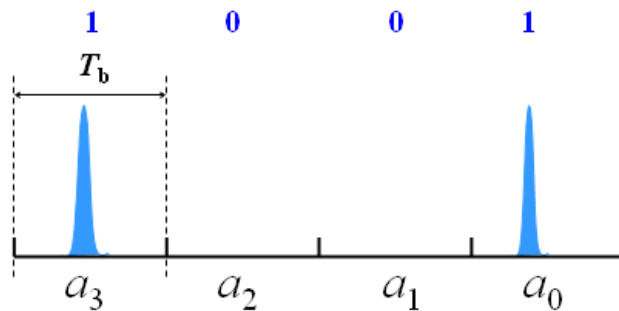
Binary Address

Packet with PPM address bits



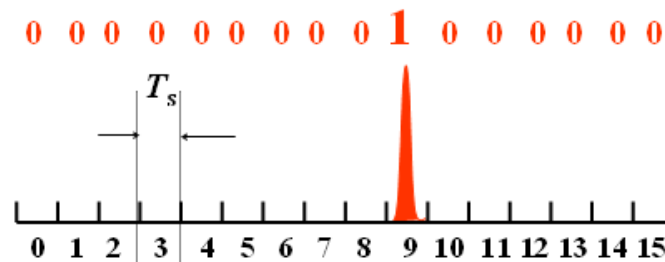
PPM Address

4-bit binary packet address ($N=4$)



Dec. value $1 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 = 9$

16-slot PPM converted address

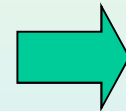


T_b – bit duration, T_s – slot duration

PPM Routing Table

Binary RT

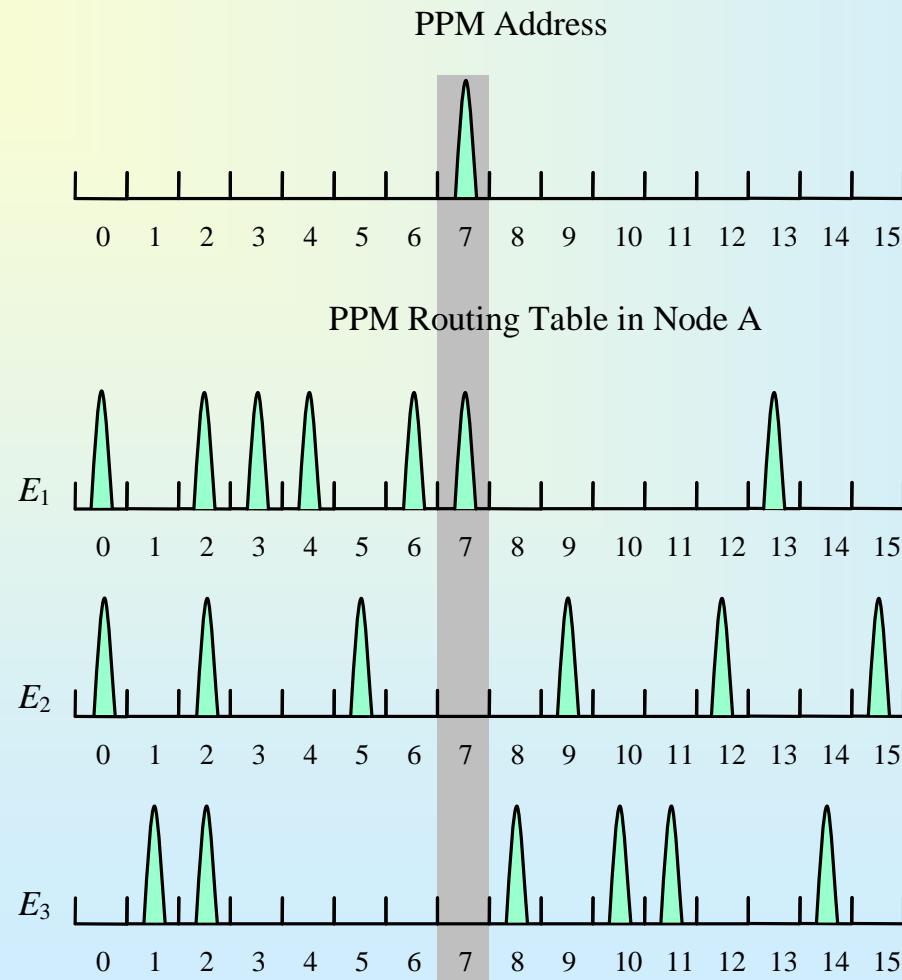
| Address patterns | Decimal value | Output ports |
|------------------|---------------|---------------------------|
| 0000 | 0 | Port 1,2 (multicast) |
| 0001 | 1 | Port 3 |
| 0010 | 2 | Port 1,2,3 (broadcast) |
| 0011 | 3 | Port 1 |
| 0100 | 4 | Port 1 |
| 0101 | 5 | Port 2 |
| 0110 | 6 | Port 1 |
| 0111 | 7 | Port 1 |
| 1000 | 8 | Port 3 |
| 1001 | 9 | Port 2 |
| 1010 | 10 | Port 3 |
| 1011 | 11 | Port 3 |
| 1100 | 12 | Port 2 |
| 1101 | 13 | Port 1 |
| 1110 | 14 | Port 3 |
| 1111 | 15 | Port 2 |



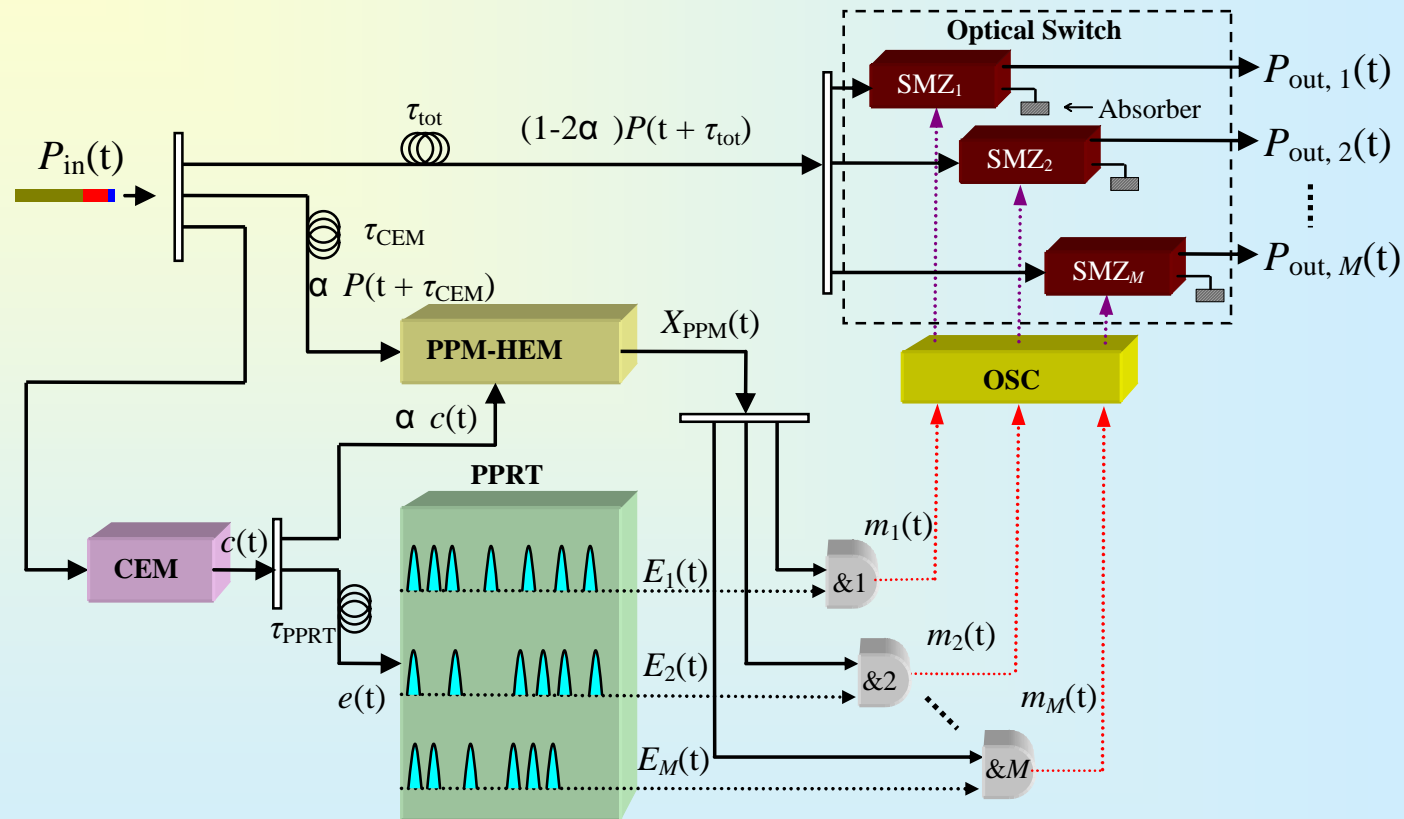
PPRT

| Address patterns (grouped) | PPRT entries |
|--|-------------------------------------|
| 0000 0010 0011 0100 0110 0111 1101 | E_1 $\{0, 2, 3, 4, 6, 7, 13\}$ |
| 0000 0010 0101 1001 1100 1111 | E_2 $\{0, 2, 5, 9, 12, 15\}$ |
| 0001 0010 1000 1010 1011 1110 | E_3 $\{1, 2, 8, 10, 11, 14\}$ |

Address Correlation



The Architecture of a PPM Header Processing Node (PPM-HP)



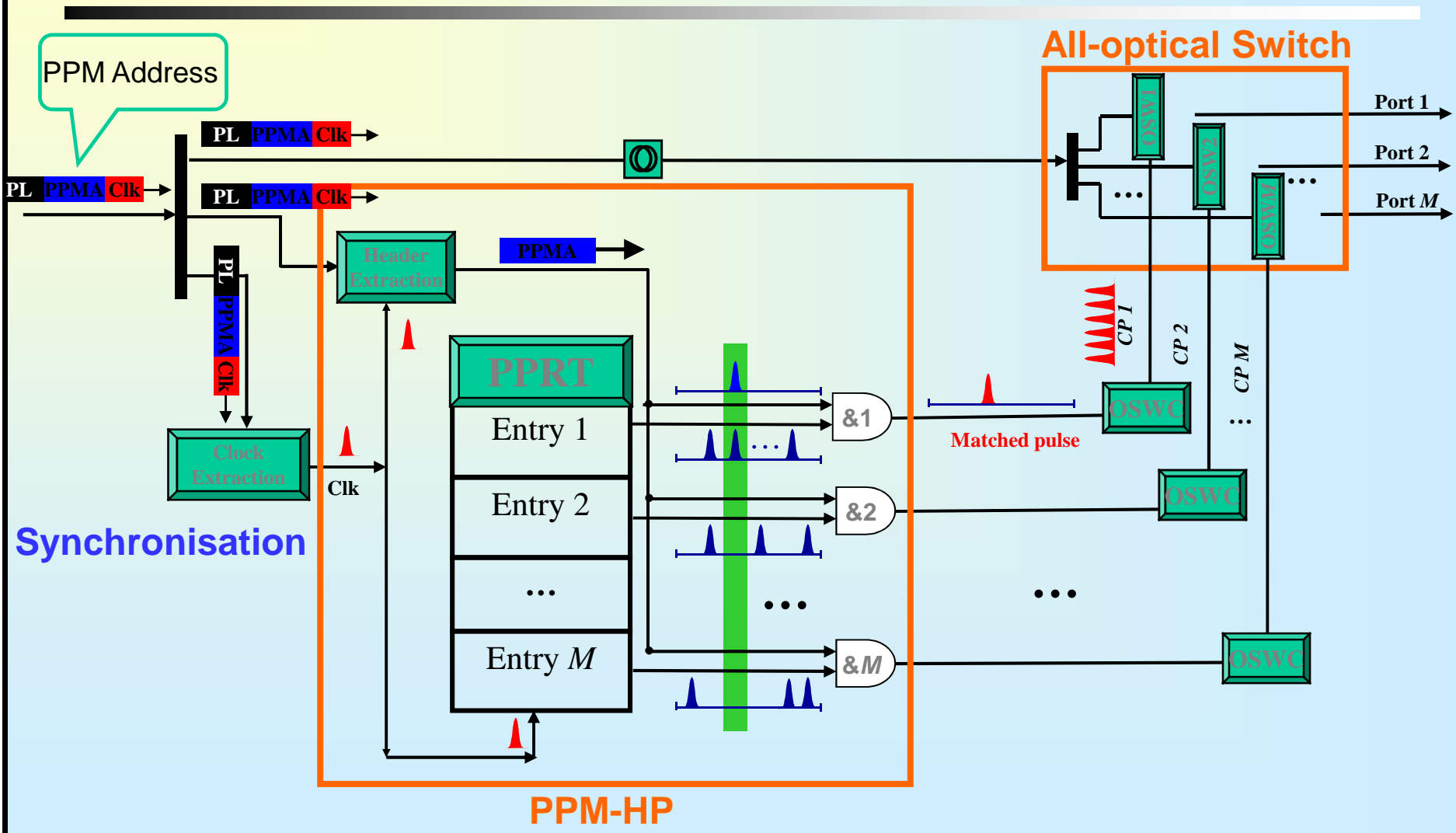
CEM: clock extraction module

PPM-HEM: PPM header address extraction module

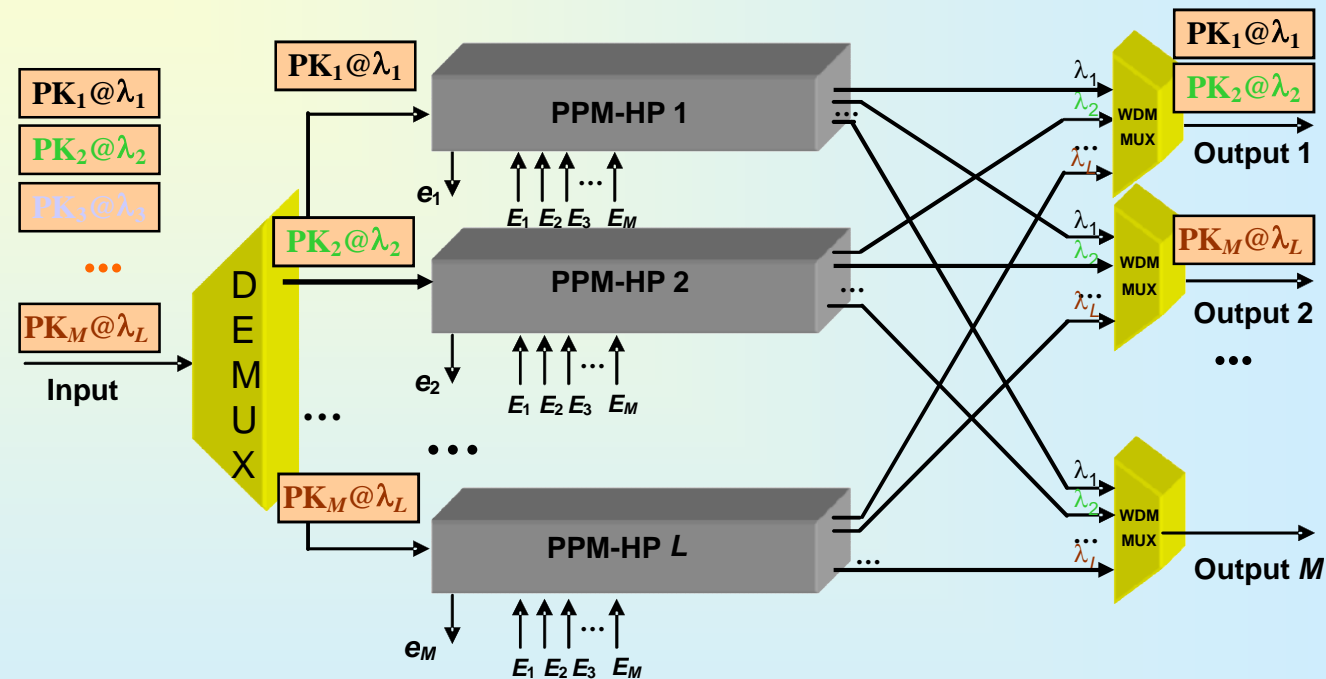
PPRT: PPM Routing Table

OS: All-optical switches, **OSC:** OS control module

Operation of PPM-HP



1xM All-optical Packet-switched WDM Router



L : The numbers of input wavelengths

M : The numbers of the output ports

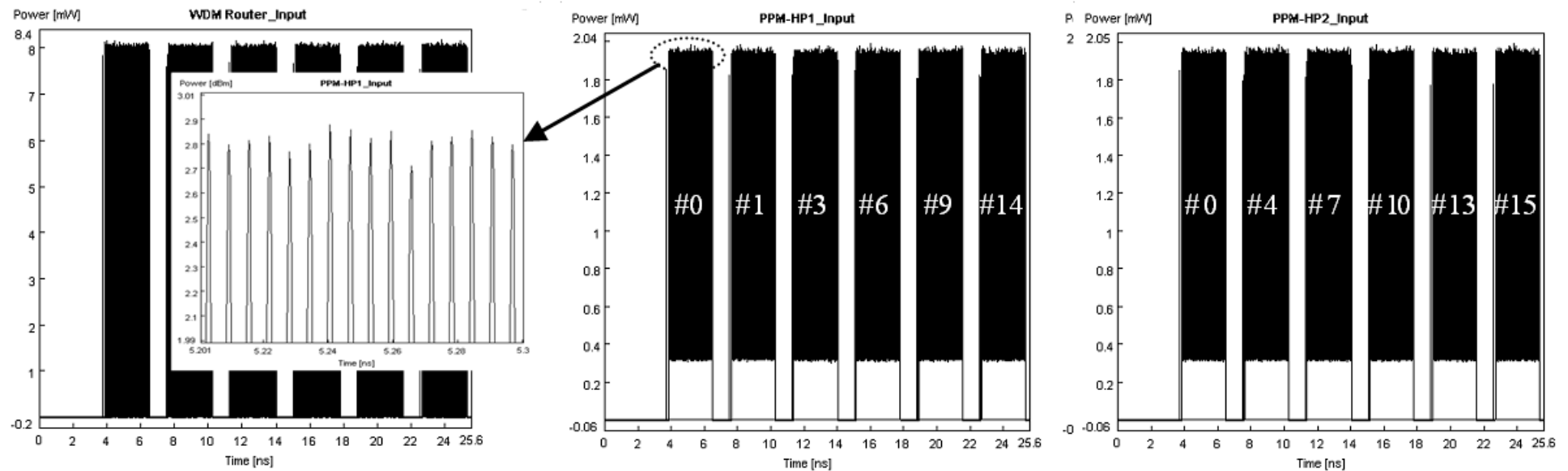
(In this simulation $L = 2$ and $M = 3$)

Simulation Results- Simulation Parameters

Simulation Tool: Virtual Photonic Inc. (VPI)

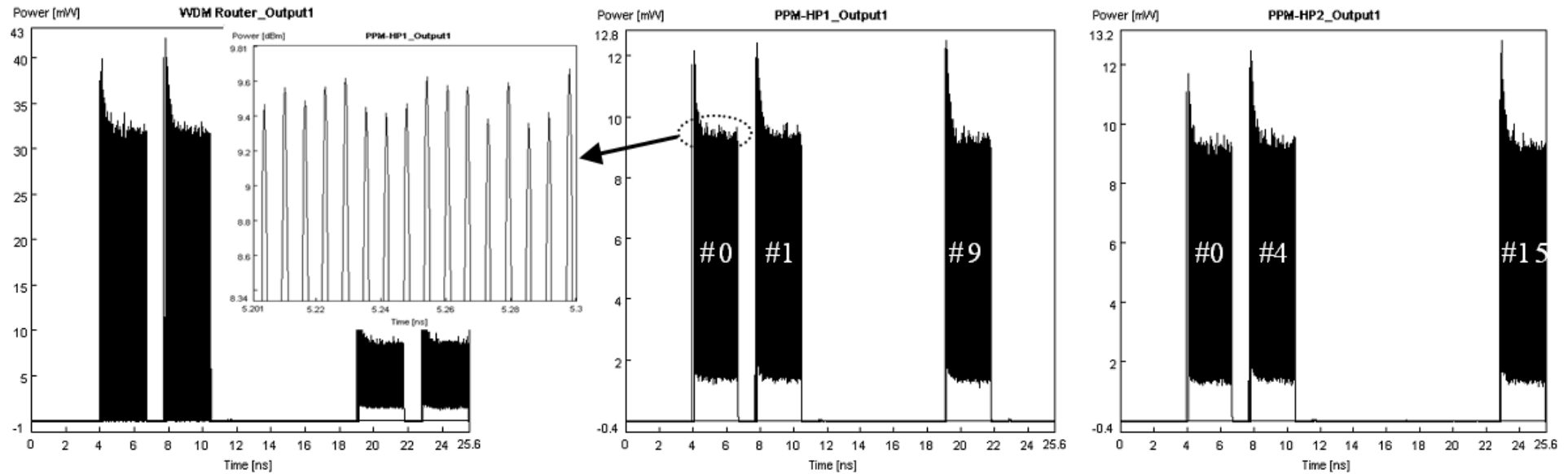
| Parameter and description | Value | Parameter and description | Value |
|------------------------------------|------------------------|------------------------------|--|
| Data packet bit rate – $1/T_b$ | 160 Gb/s | Inject current to SOA | 150 mA |
| Packet payload length | 53 bytes (424 bits) | SOA length | 500 μm |
| Wavelength 1 (f_1) | 1552.52 nm (193.1 THz) | SOA width | 3×10^{-6} m |
| Wavelength 2 (f_2) | 1544.52 nm (194.1 THz) | SOA height | 80×10^{-9} m |
| Data pulse width – FWHM | 2 ps | SOA n_{sp} | 2 |
| PPM slot duration T_s ($=T_b$) | 6.25 ps | Confinement factor | 0.15 |
| Average transmitted power P_{in} | 2 mW | Enhancement factor | 5 |
| Optical bandwidth | 500 GHz | Differential gain | 2.78×10^{-20} m ² |
| Splitting factor α | 0.25 | Internal loss | 40×10^2 m ⁻¹ |
| Number of control pulses | 60 | Recombination constant A | 1.43×10^8 s ⁻¹ |
| Average control pulse power | 10 mW | Recombination constant B | 1.0×10^{-16} m ³ s ⁻¹ |
| | | Recombination constant C | 3.0×10^{-41} m ⁶ s ⁻¹ |
| | | Carrier density transparency | 1.4×10^{24} m ⁻³ |
| | | Initial carrier density | 3×10^{24} m ⁻³ |

Simulation Results- Time Waveforms



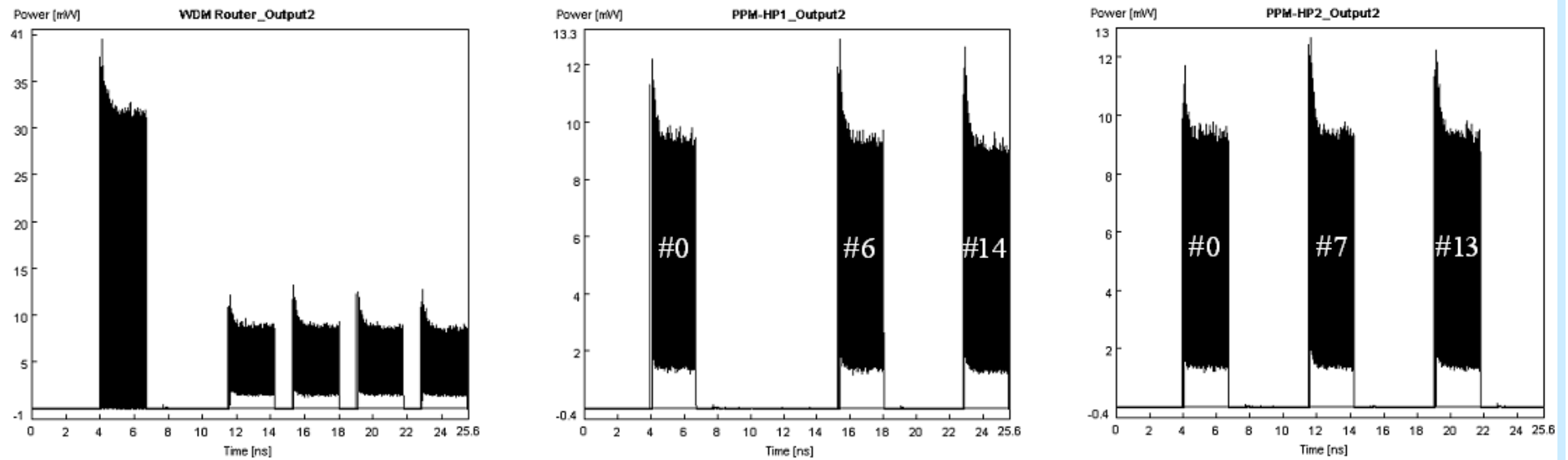
(a) Packets at the inputs of the WDM router and PPM-HP1&2

Simulation Results- Time Waveforms



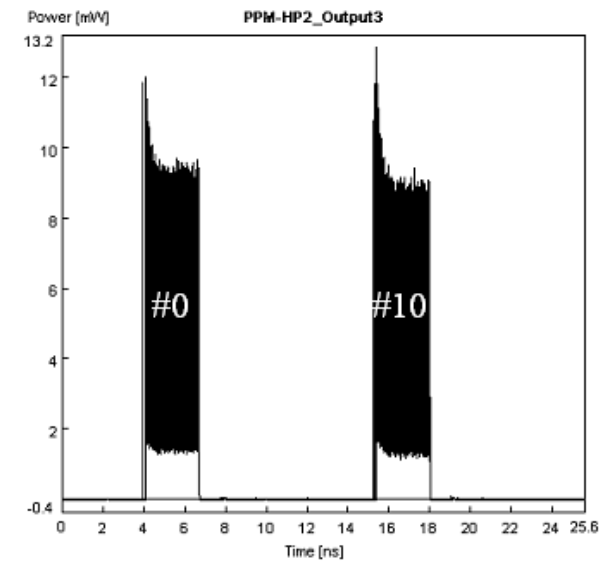
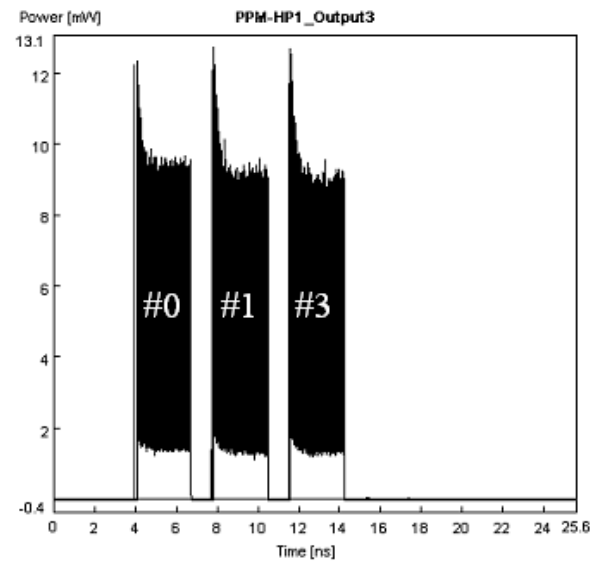
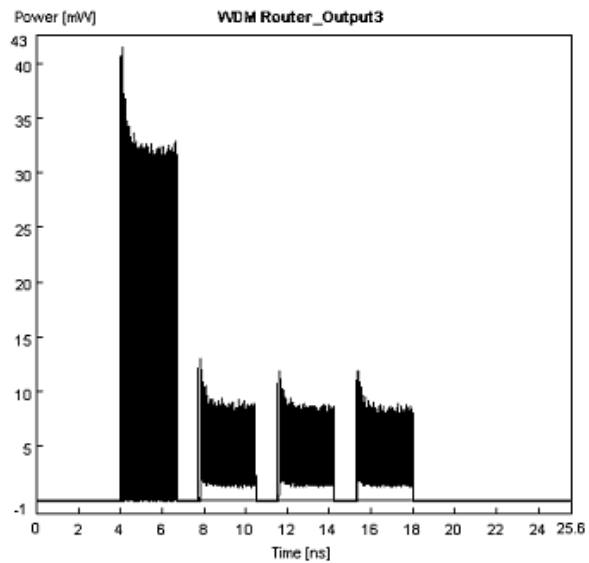
(b) Packets observed at the output 1 of the WDM router and PPM-HP1&2 (the inset shows the power fluctuation observed at the output 1 of PPM-HP1)

Simulation Results- Time Waveforms



(c) Packets observed at the output 2 of the WDM router, PPM-HP1&2

Simulation Results- Time Waveforms



(d) packets observed at the output 3 of the WDM router and PPM-HP1&2

Simulation Results- Channel Crosstalk (CXT)

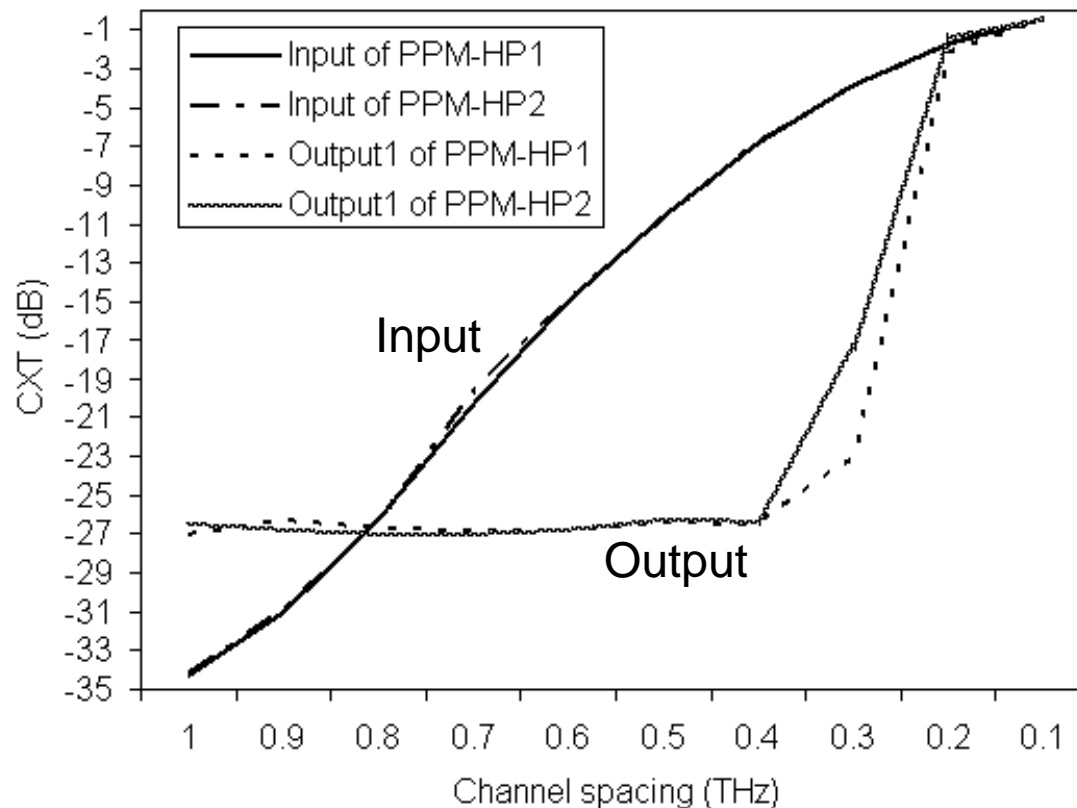
Two packets at λ_1 (packet 1 with address #4) and λ_2 (packet 2 with address #4) are sequentially applied to the input of the WDM router for measuring the channel *CXT*.

$$CXT = 10 \log_{10} \left(P_{nt} / P_t \right)$$

P_{nt} is the peak output signal power of all non-target channels (**undesired wavelength**).

P_t is the average output signal power of the target channel (**desired wavelength**).

Simulation Results- Channel Crosstalk (CXT)



channel spacing $\Delta f = f_2 - f_1$

(the bandwidth of the WDM multiplexers and demultiplexer is 500 GHz)

- $1 \text{ THz} > \Delta f > 0.8 \text{ THz}$

$$CXT_{\text{input}} < CXT_{\text{output}}$$

- CXT_{output} is constant at -27 dB for $1 \text{ THz} > \Delta f > 0.4 \text{ THz}$ and increasing exponentially. (Minimum level of CXT_{output} is limited by the contrast ratio of the extracted clock signals from the CEM.)

- $0.8 \text{ THz} > \Delta f > 0.4 \text{ THz}$,

$$CXT_{\text{output}} < CXT_{\text{input}}$$

Improvement is due to low power levels (<.4 mW) of signals emerging from the demultiplexer at wavelengths other than desired Wavelength. Thus not affecting the CEM, PPM-HEM and AND Gates.

Conclusions

- In this paper, a node architecture, operation principle and performance of the all-optical WDM router based on PPM formatted header address and routing table were presented.
 - It was shown that the proposed router can operate at 160 Gb/s with 0.3 dB of power fluctuations observed at the output ports and a channel *CXT* of ~ -27 dB at a channel spacing of greater than 0.4 THz and a demultiplexer bandwidth of 500 GHz.
 - The proposed WDM router routing with no wavelength conversion modules **offers fast processing time** and **reduced system complexity** and is capable of **operating in the unicast, multicast and broadcast transmission modes**.
-

Thank You !

Question?
