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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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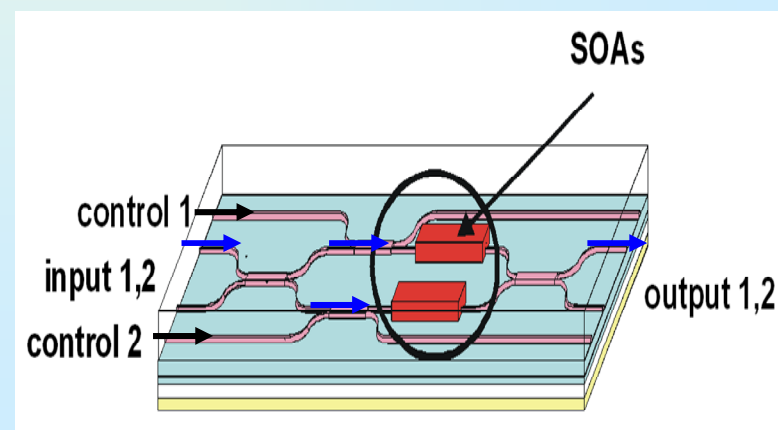
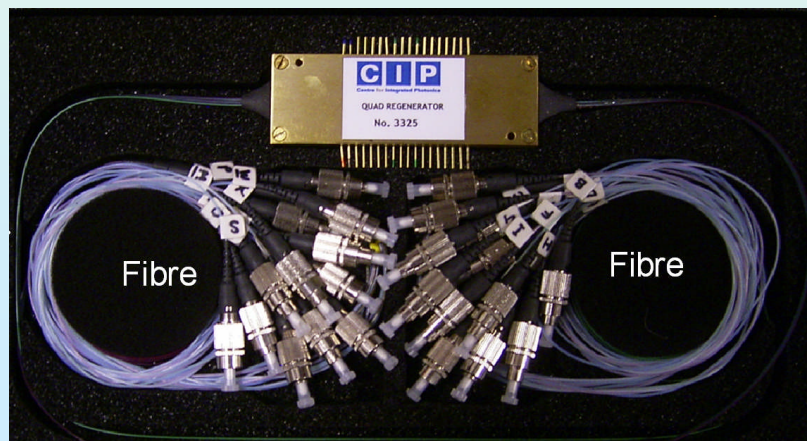
- Introduction
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-

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 \Rightarrow throughput latency

IST-LASAGNE² project - packet label/addressing

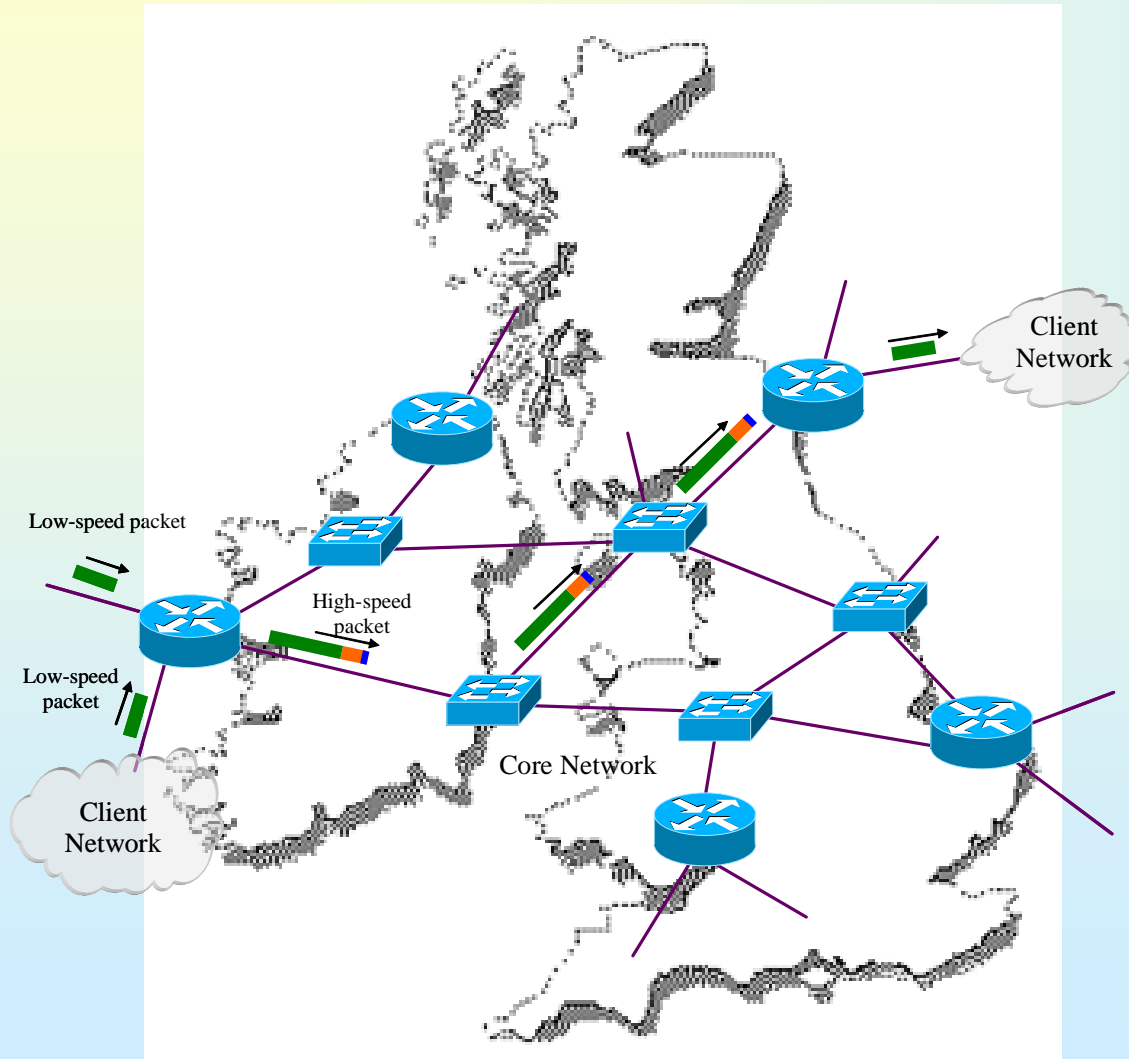
- *all-optical employing a cascade of SOA-MZI structure*
- *requiring large number of SOA-MZI switches are increasing as the numbers of the address bit increase.*


➤ 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.

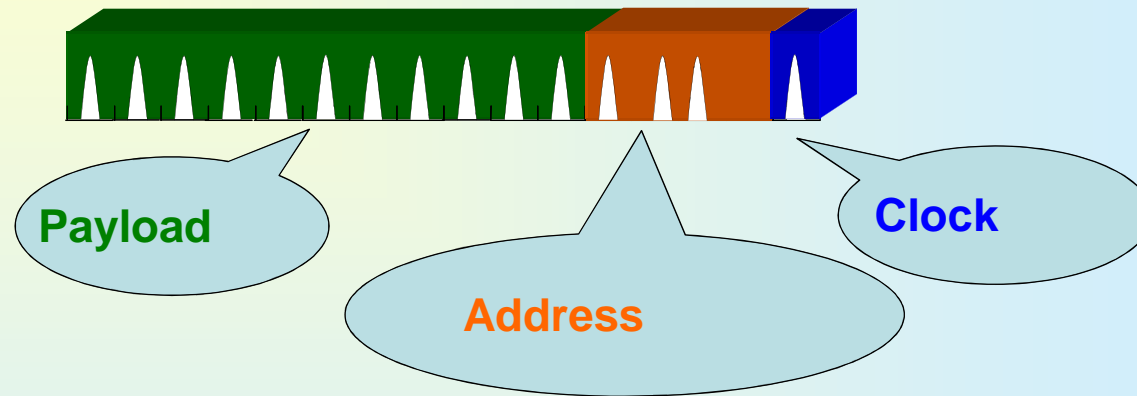
Introduction- Optical Networks




Proposed core optical router


Source / target node

Introduction- Optical Packets

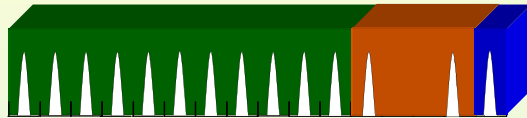


An optical packet is composed of three parts:

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

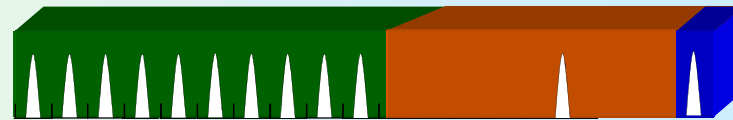
Packets with PPM Address

Packet with binary
address bits



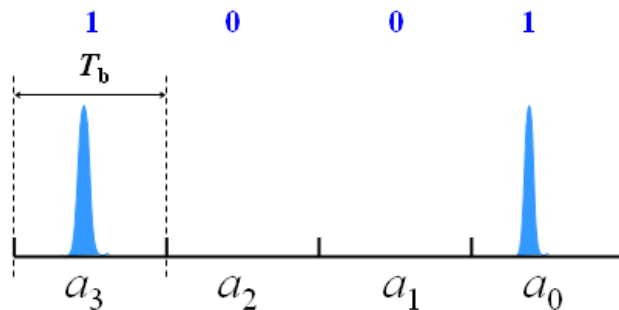
Binary Address

Packet with PPM address bits



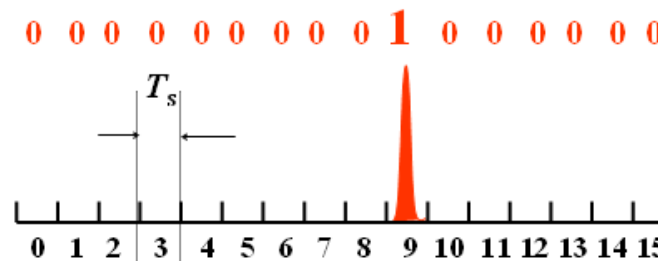
PPM Address

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

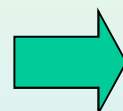


T_b – bit duration, T_s – slot duration

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

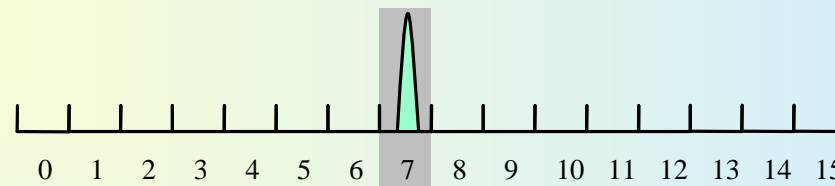


PPRT

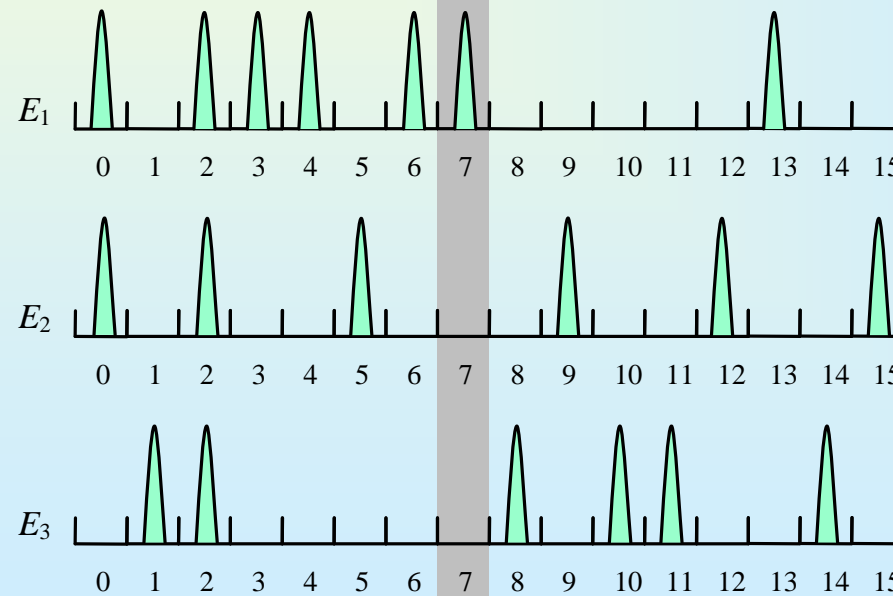
Address patterns (grouped)	PPRT entries
0000 0010 0011 0100 0110 0111 1101	E_1 $\{0, 2, 3, 4, 6, 7, 13\}$
0000 0010 0101 1001 1100 1111	E_2 $\{0, 2, 5, 9, 12, 15\}$
0001 0010 1000 1010 1011 1110	E_3 $\{1, 2, 8, 10, 11, 14\}$

Address Correlation

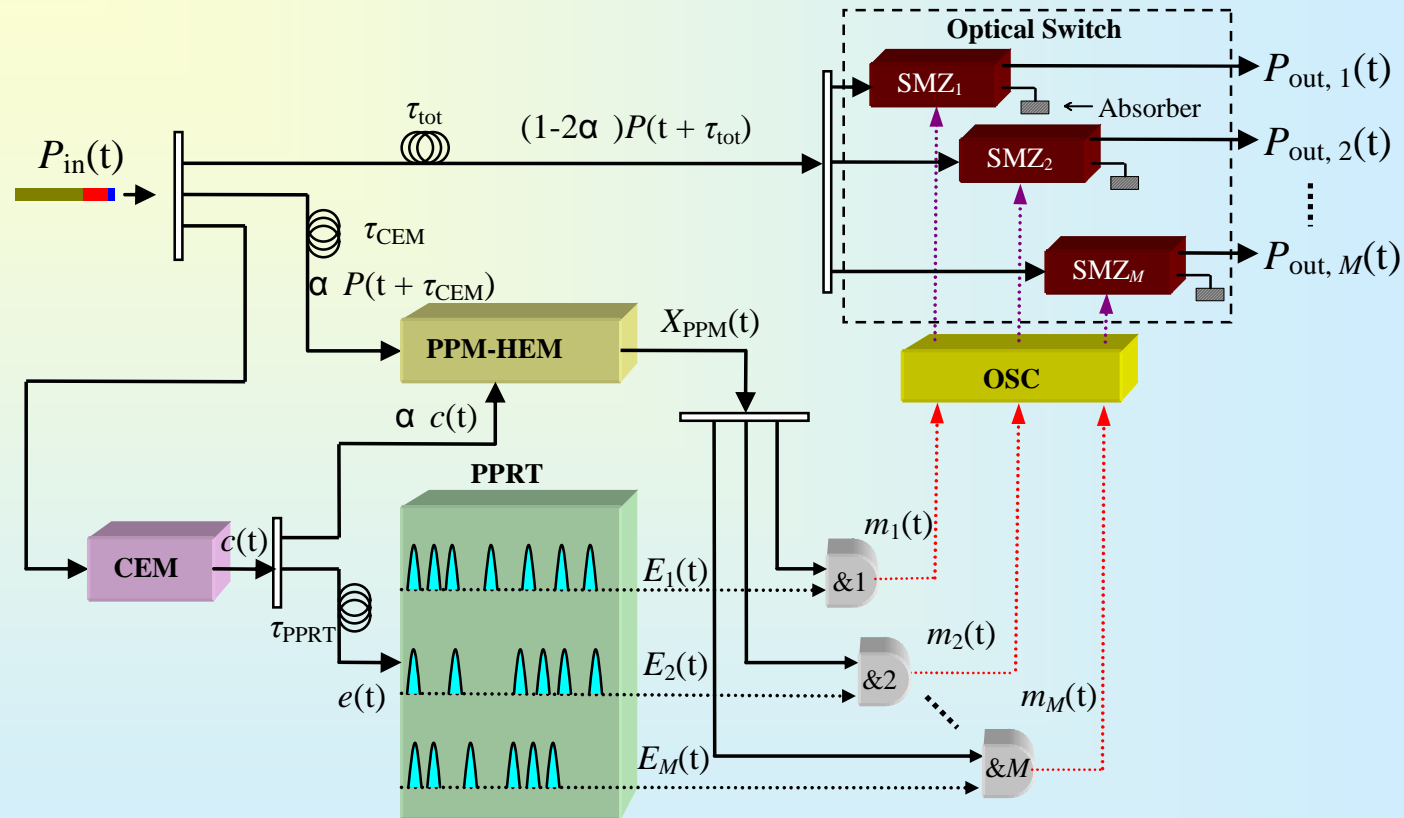
PPM Address



PPM Routing Table in Node A



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



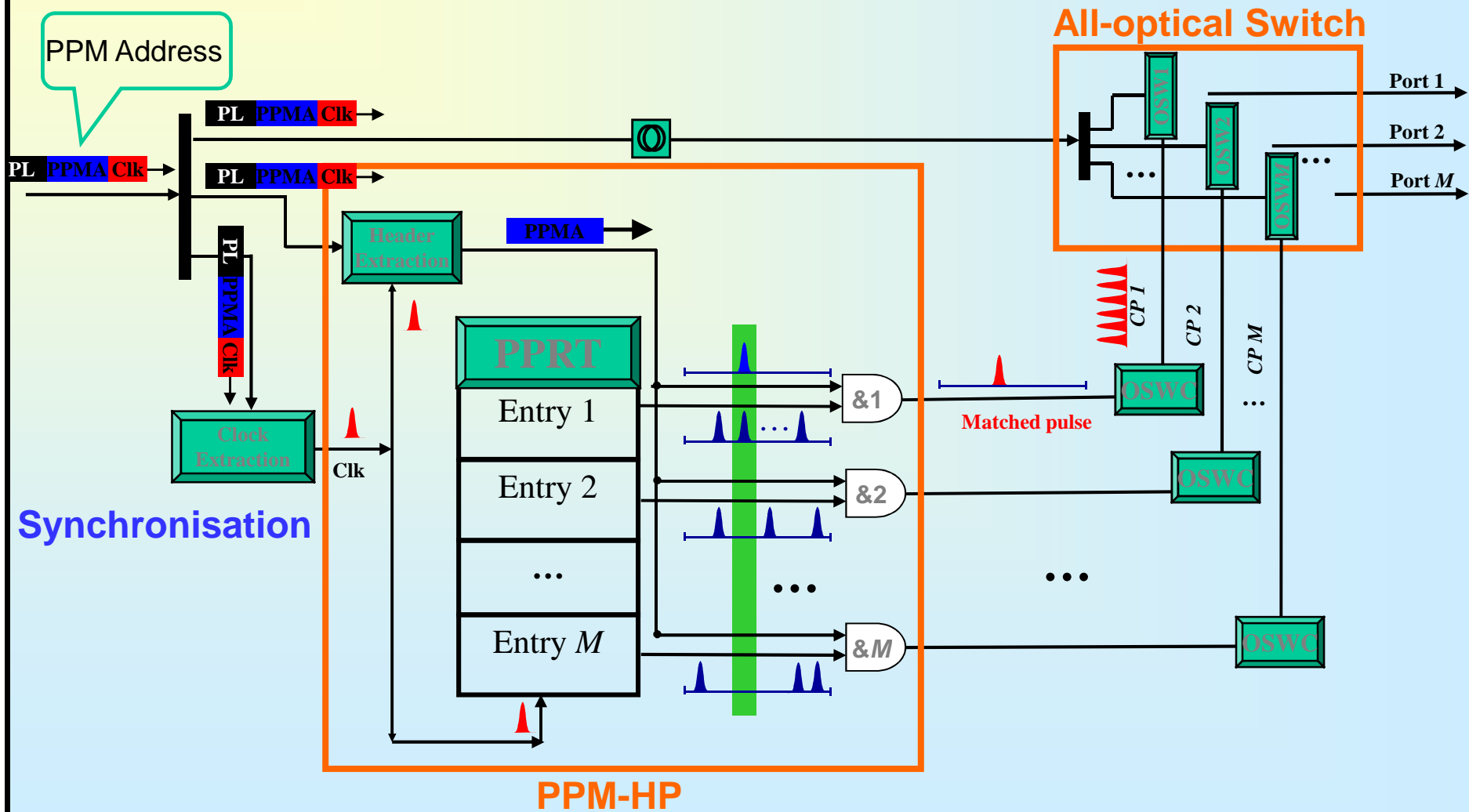
CEM: clock extraction module

PPM-HEM: PPM header address extraction module

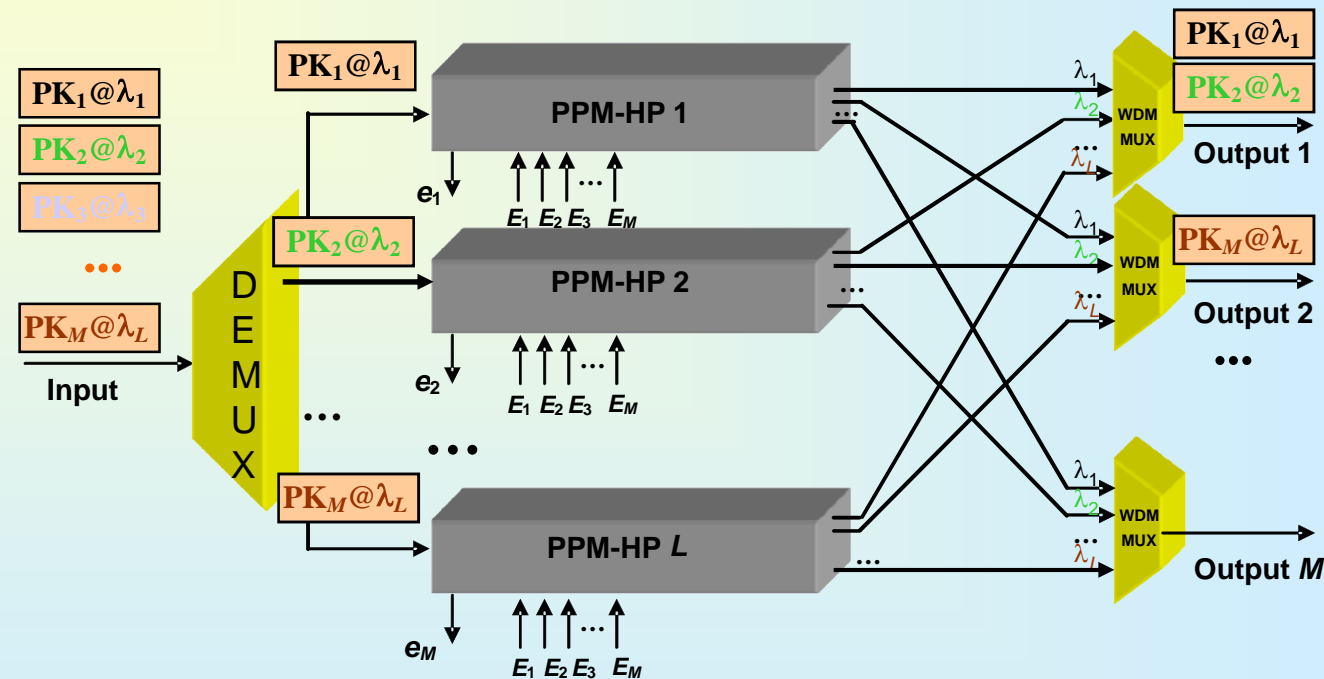
PPRT: PPM Routing Table

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

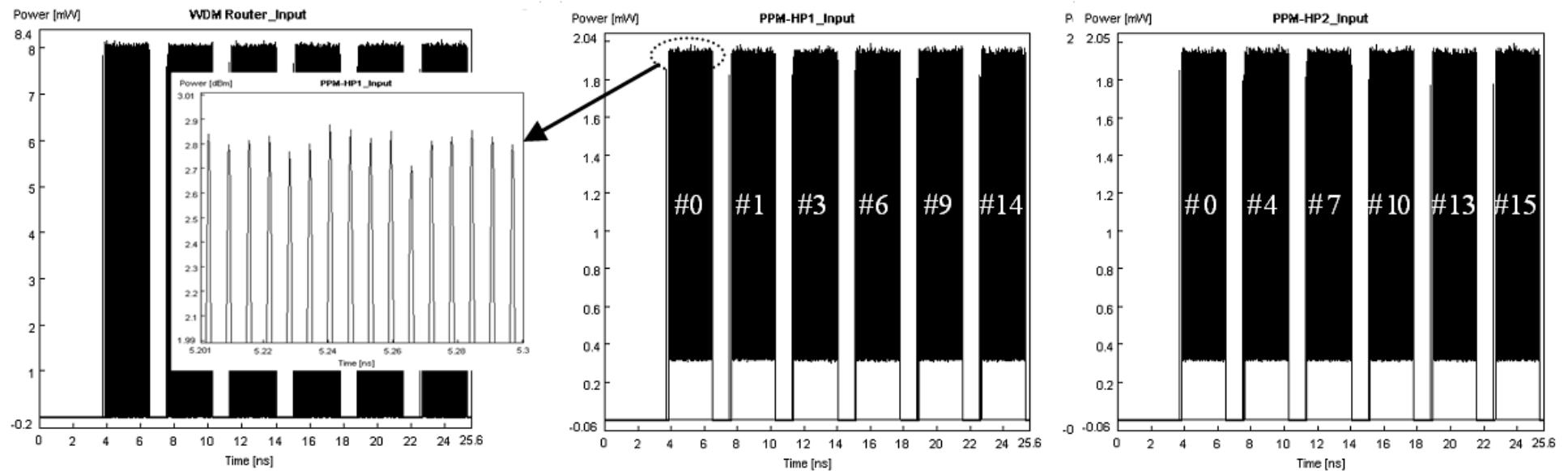
(In this simulation $L = 2$ and $M = 3$)

Simulation Results- Simulation Parameters

Simulation Tool: Virtual Photonic Inc. (VPI)

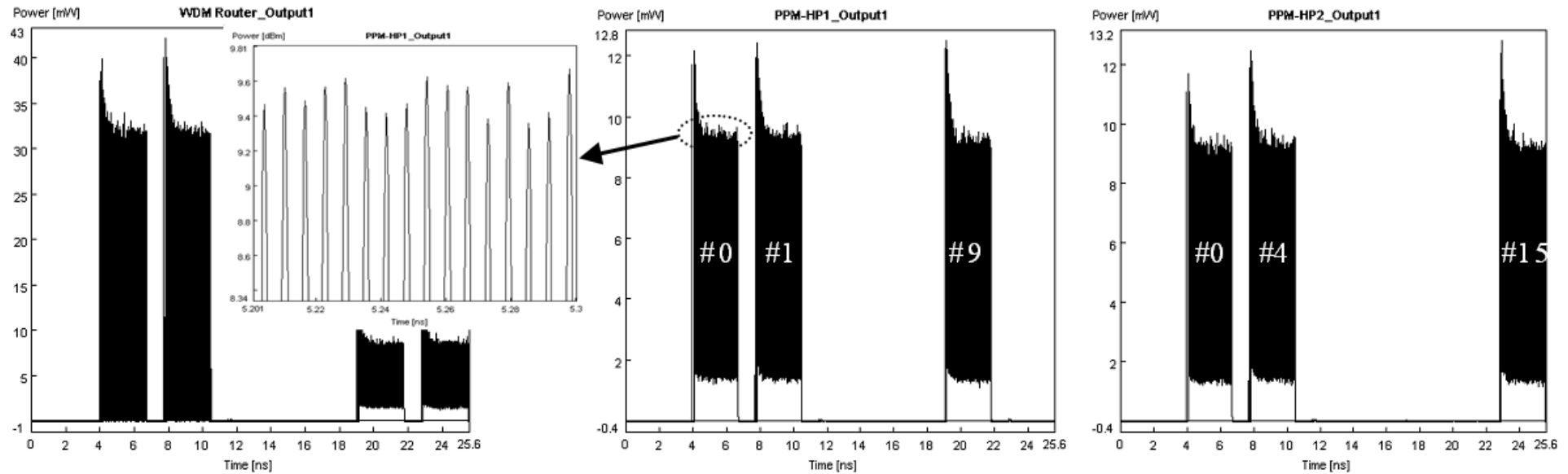
Parameter and description	Value	Parameter and description	Value
Data packet bit rate – $1/T_b$	160 Gb/s	Inject current to SOA	150 mA
Packet payload length	53 bytes (424 bits)	SOA length	500 μm
Wavelength 1 (f_1)	1552.52 nm (193.1 THz)	SOA width	$3 \times 10^{-6} \text{ m}$
Wavelength 2 (f_2)	1544.52 nm (194.1 THz)	SOA height	$80 \times 10^{-9} \text{ m}$
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	$2.78 \times 10^{-20} \text{ m}^2$
Splitting factor α	0.25	Internal loss	$40 \times 10^2 \text{ m}^{-1}$
Number of control pulses	60	Recombination constant A	$1.43 \times 10^8 \text{ s}^{-1}$
Average control pulse power	10 mW	Recombination constant B	$1.0 \times 10^{-16} \text{ m}^3 \text{ s}^{-1}$
		Recombination constant C	$3.0 \times 10^{-41} \text{ m}^6 \text{ s}^{-1}$
		Carrier density transparency	$1.4 \times 10^{24} \text{ m}^{-3}$
		Initial carrier density	$3 \times 10^{24} \text{ m}^{-3}$

Simulation Results- Time Waveforms



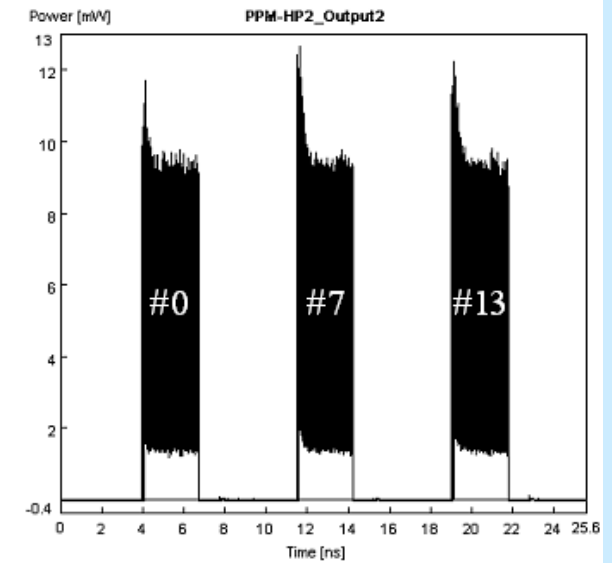
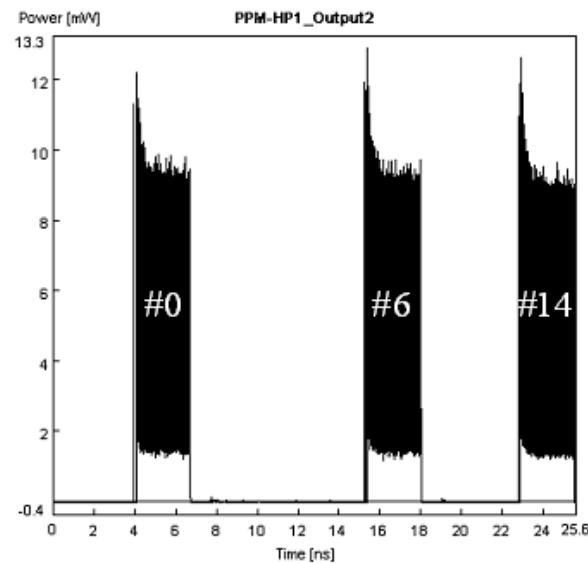
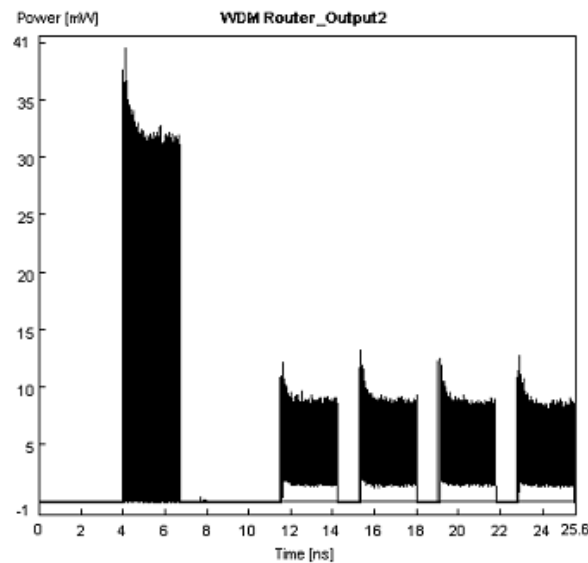
(a) Packets at the inputs of the WDM router and PPM-HP1&2

Simulation Results- Time Waveforms



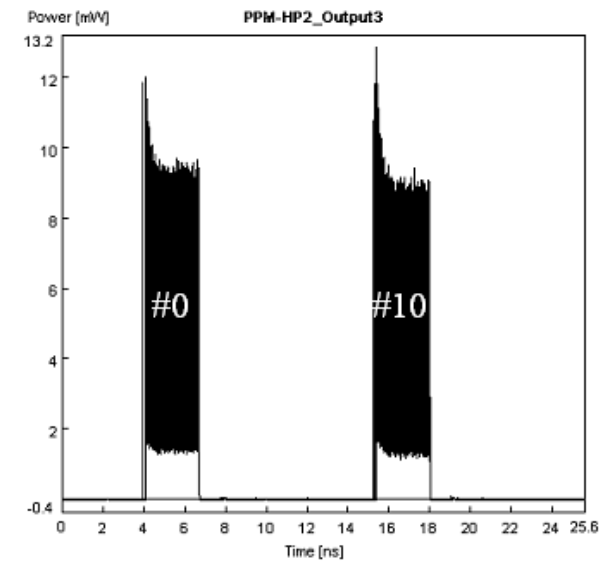
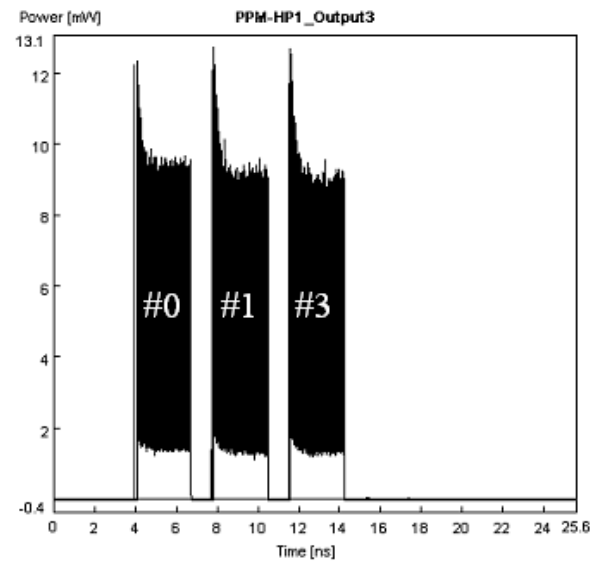
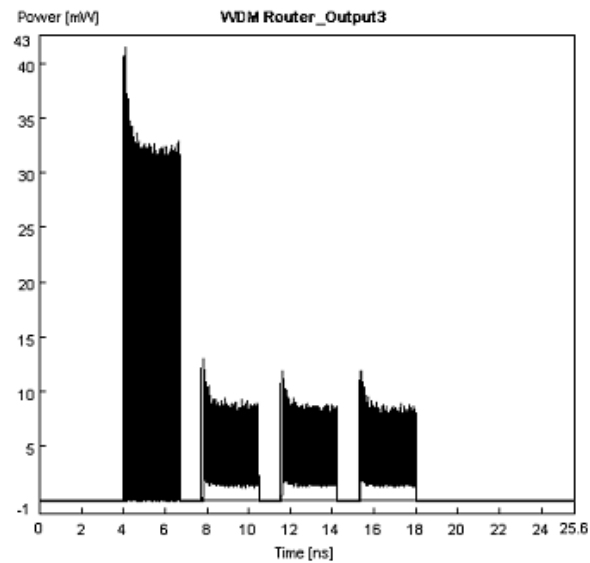
(b) Packets observed at the output 1 of the WDM router and PPM-HP1&2 (the inset shows the power fluctuation observed at the output 1 of PPM-HP1)

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)

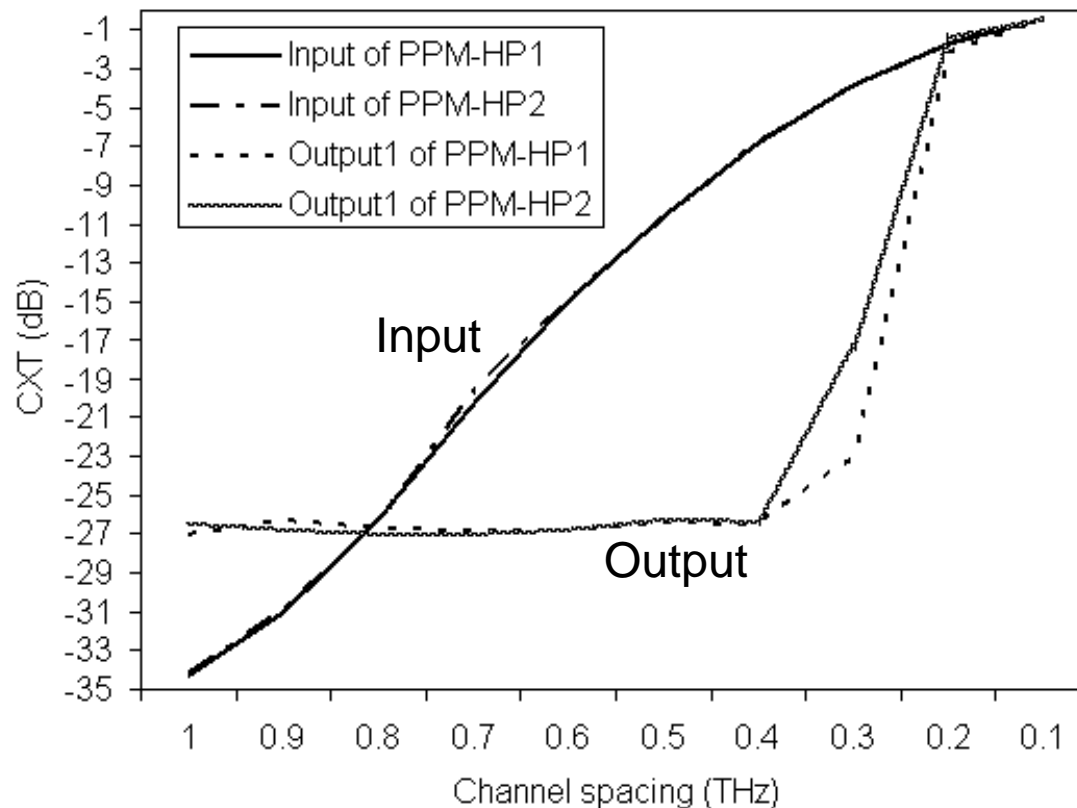
Two packets at λ_1 (packet 1 with address #4) and λ_2 (packet 2 with address #4) are sequentially applied to the input of the WDM router for measuring the channel CXT.

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

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?
