An Ultrafast 1x*M* All-optical WDM Packet-Switched Router based on the PPM Header Address

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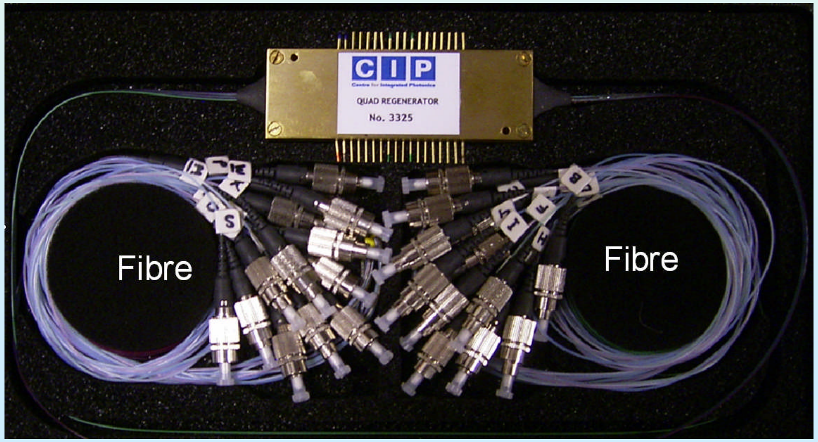
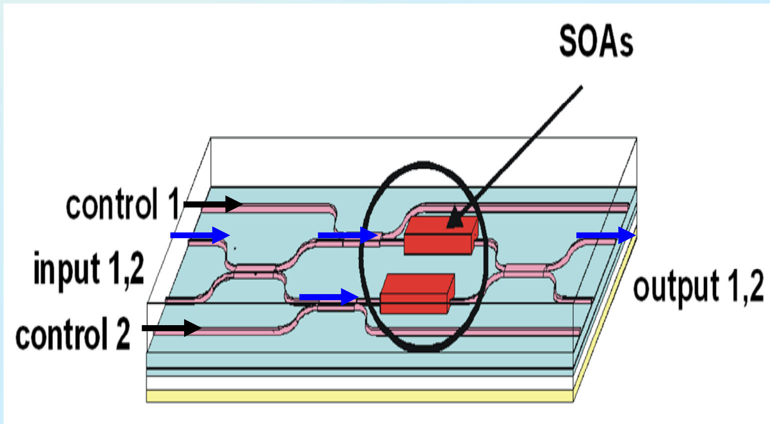
Introduction- Research Aim (1)

▪ 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 KEOPS[1] (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).





[1]C. 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 ➠ throughput latency

IST-LASAGNE[2] project - packet label/addressing

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

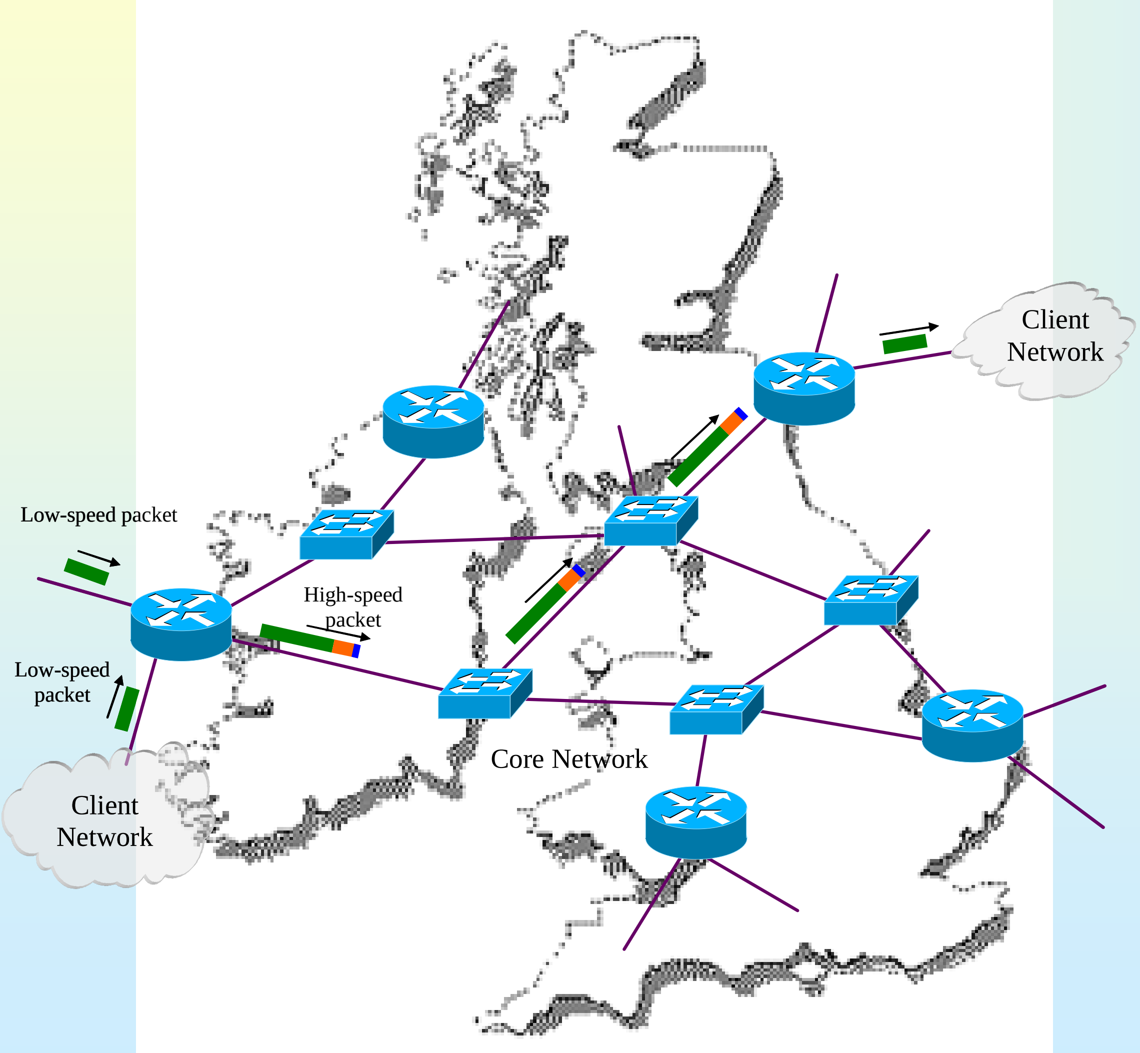
➢ We present an optical router,

- 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 1x*M* WDM router architecture for packet routing at multiple wavelengths simultaneously, with no wavelength conversion modules.

[2] F. 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.

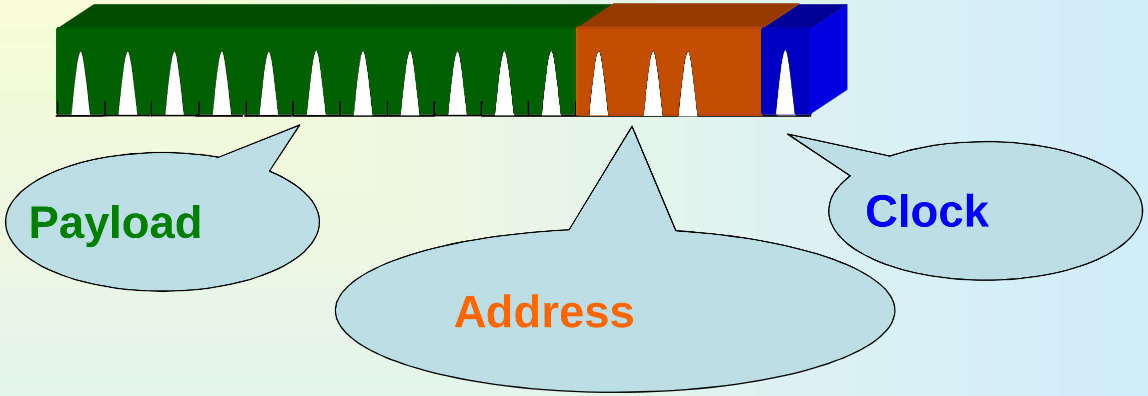
Introduction- Optical Networks



Proposed core optical router

Source / target node

Introduction- Optical Packets



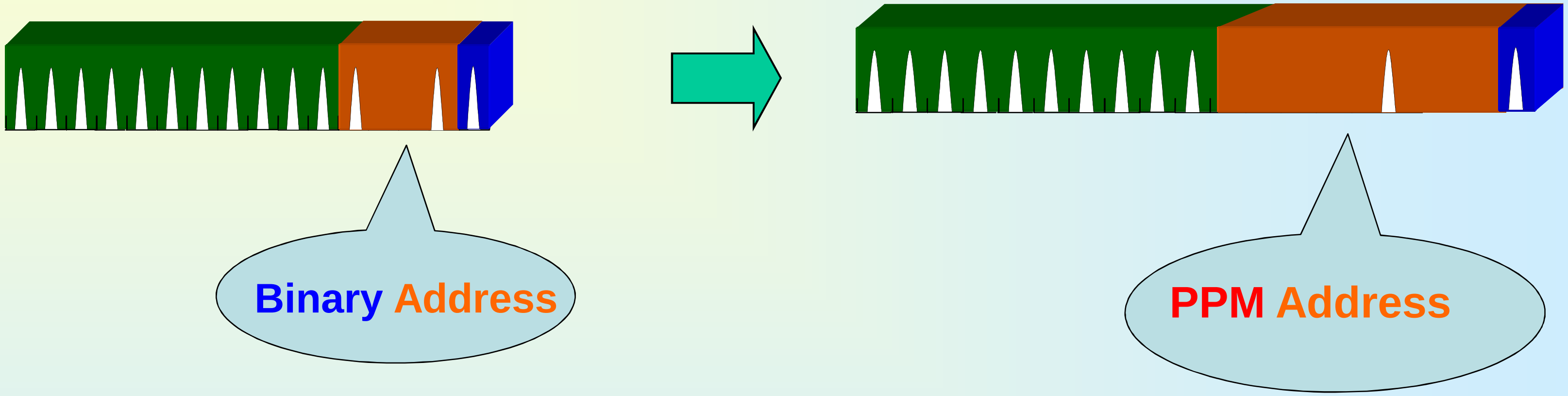
An optical packet is composed of three parts:

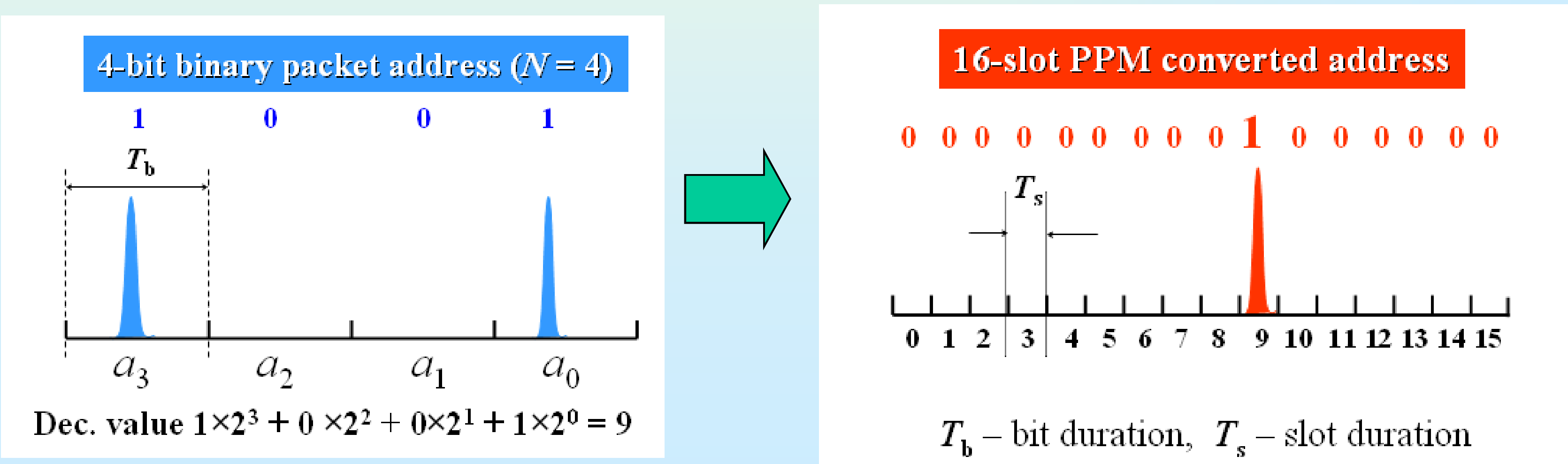
- Clock bit: For synchronisation purpose
- Address bits: Destination of the packet
- Payload bits: The really information desired to be transmitted

Packets with PPM Address

Packet with binary address bits

Packet with PPM address bits





PPM Routing Table

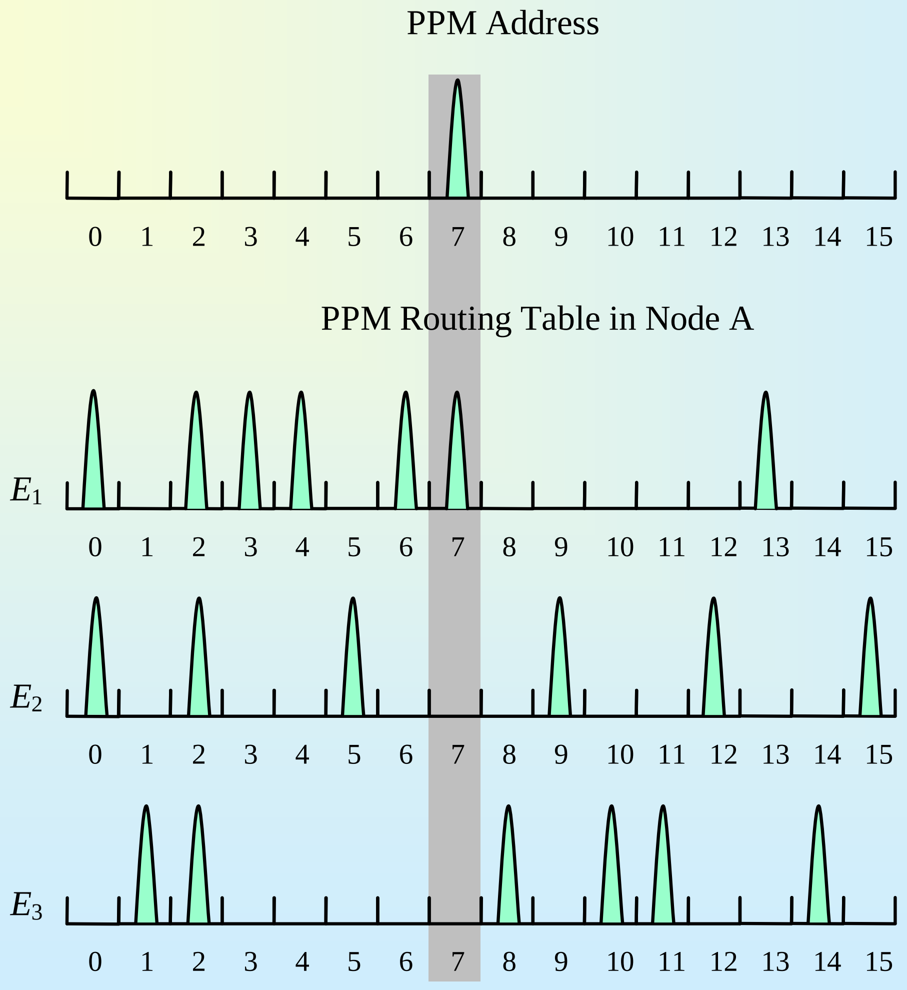
Binary RT

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

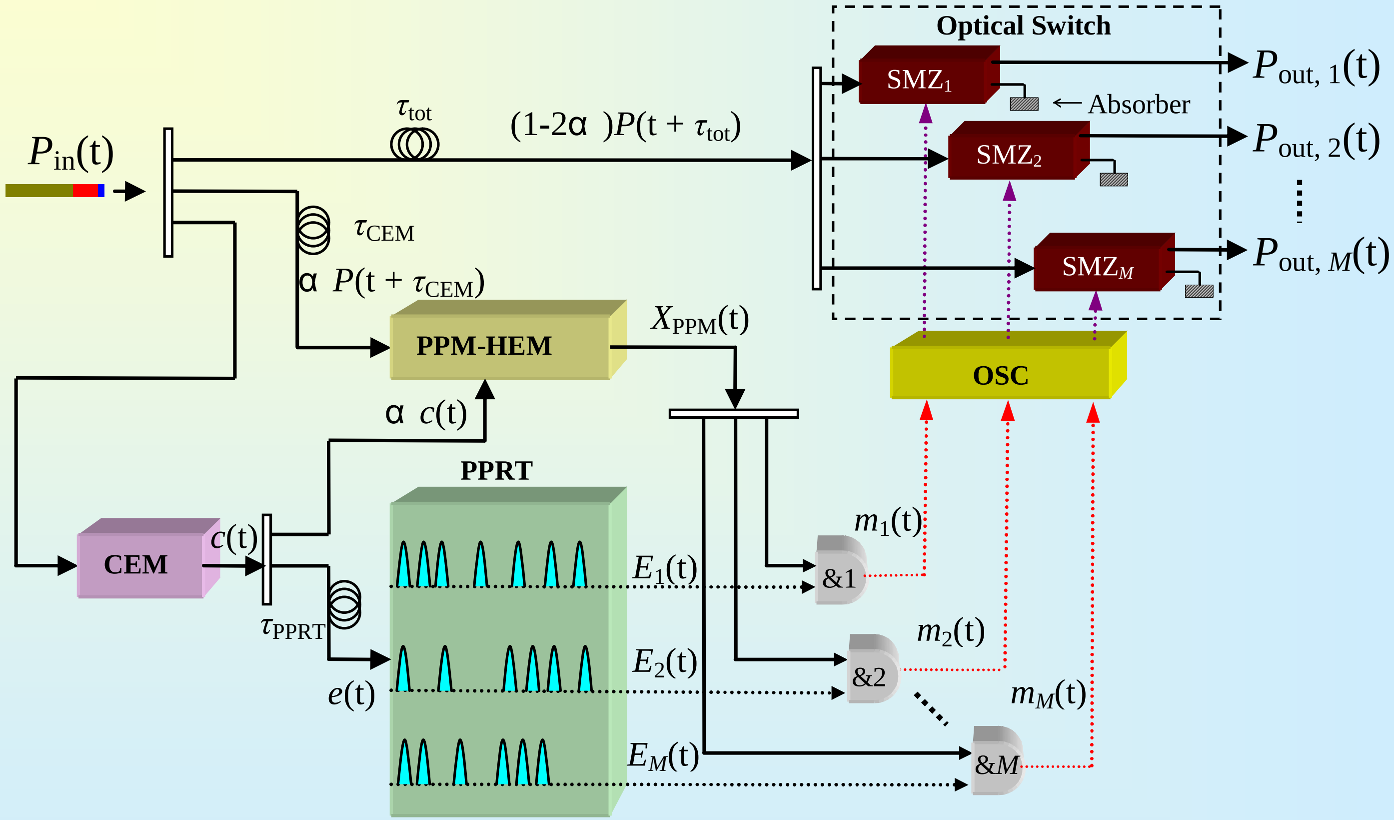
PPRT

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)



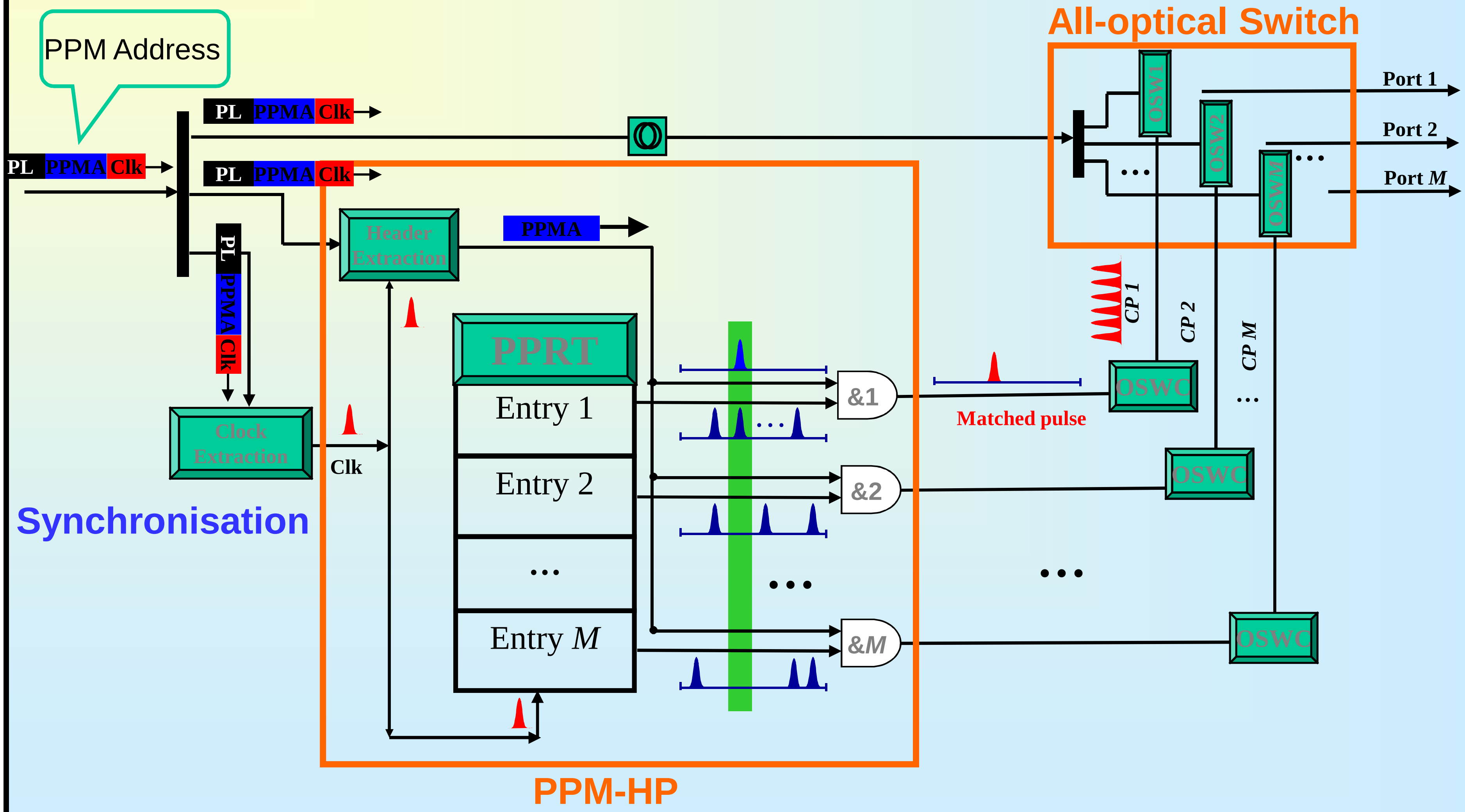
CEM: clock extraction module

PPM-HEM: PPM header address extraction module

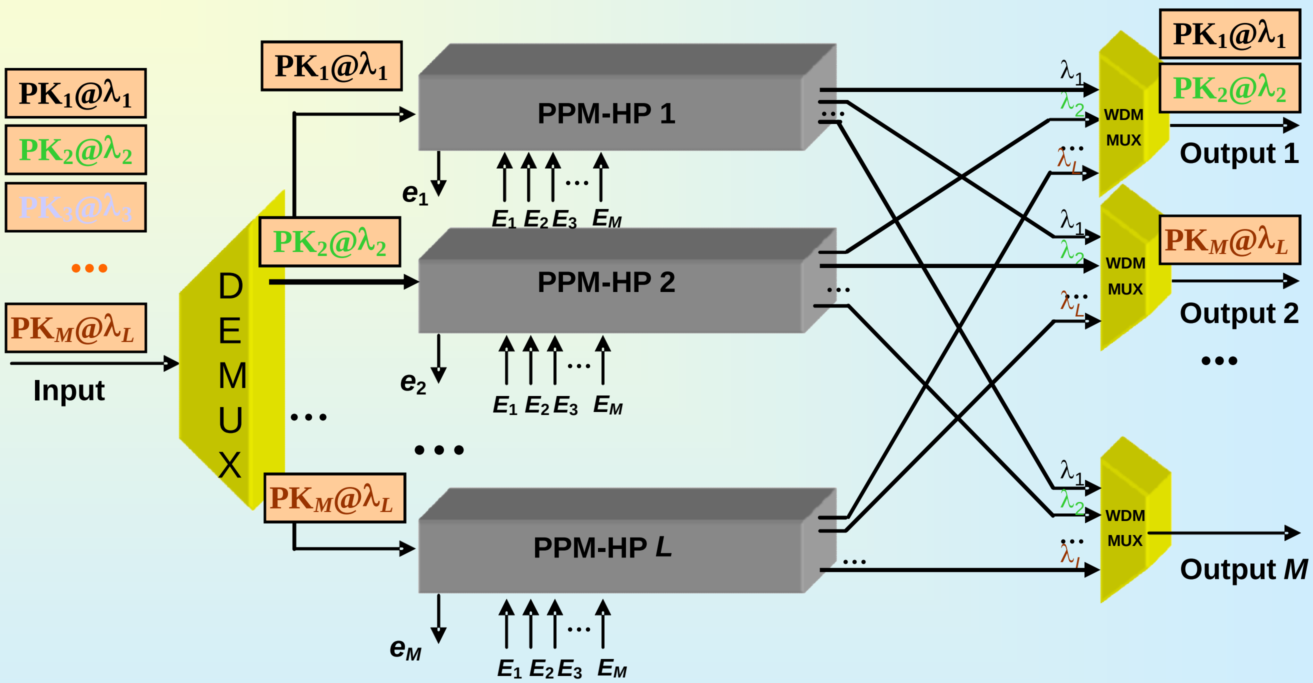
PPRT: PPM Routing Table

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)

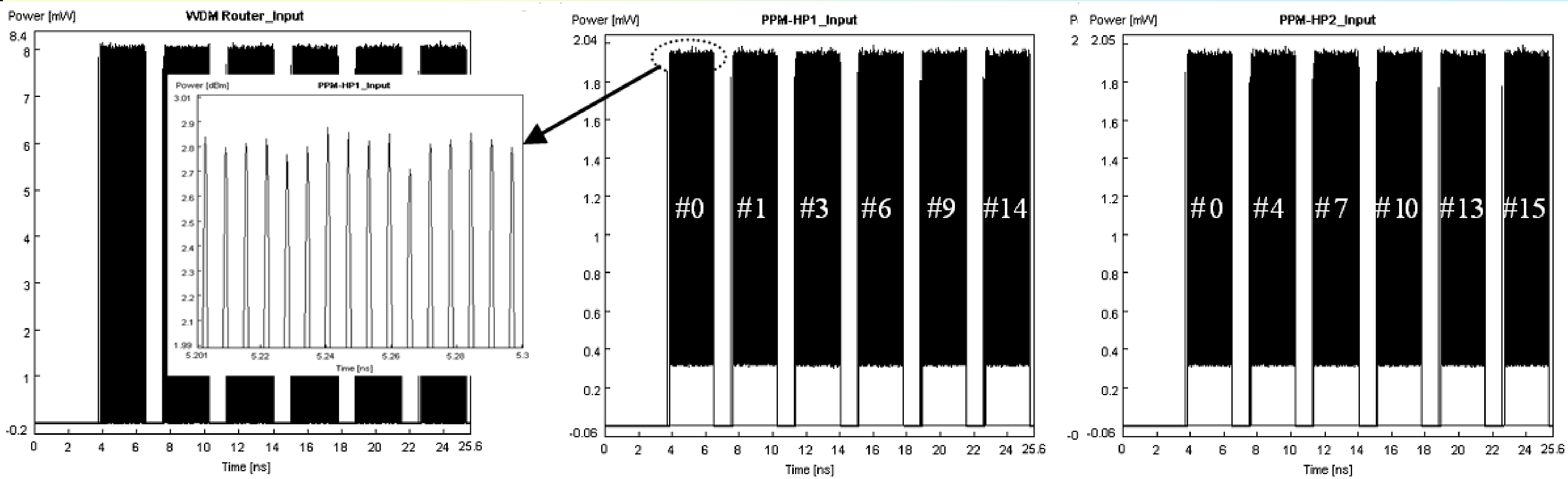
Simulation Results- Simulation Parameters

Simulation Tool: Virtual Photonic Inc. (VPI)

Parameter and description	Value
Data packet bit rate – $1/T_b$	160 Gb/s
Packet payload length	53 bytes (424 bits)
Wavelength 1 (f_1)	1552.52 nm (193.1 THz)
Wavelength 2 (f_2)	1544.52 nm (194.1 THz)
Data pulse width – FWHM	2 ps
PPM slot duration T_s ($=T_b$)	6.25 ps
Average transmitted power P_{in}	2 mW
Optical bandwidth	500 GHz
Splitting factor α	0.25
Number of control pulses	60
Average control pulse power	10 mW

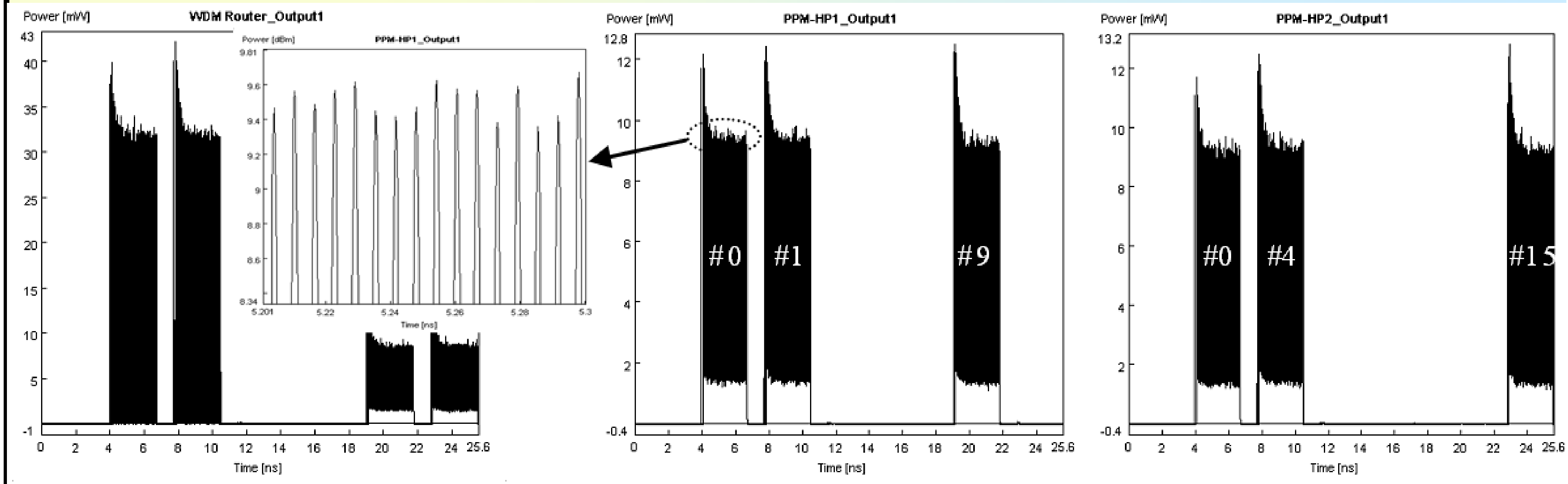
Parameter and description	Value
Inject current to SOA	150 mA
SOA length	500 μm
SOA width	3×10^{-6} m
SOA height	80×10^{-9} m
SOA n_{sp}	2
Confinement factor	0.15
Enhancement factor	5
Differential gain	2.78×10^{-20} m^2
Internal loss	40×10^2 m^{-1}
Recombination constant A	1.43×10^8 s^{-1}
Recombination 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



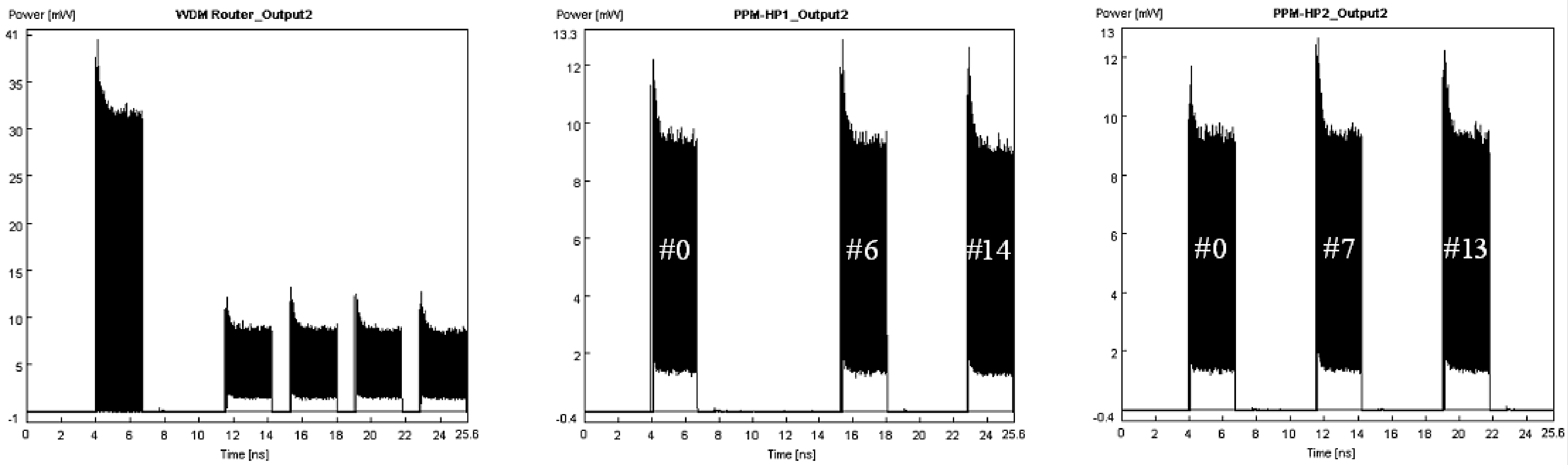
(a) Packets at the inputs of the WDM router and PPM-HP1&2

Simulation Results- Time Waveforms



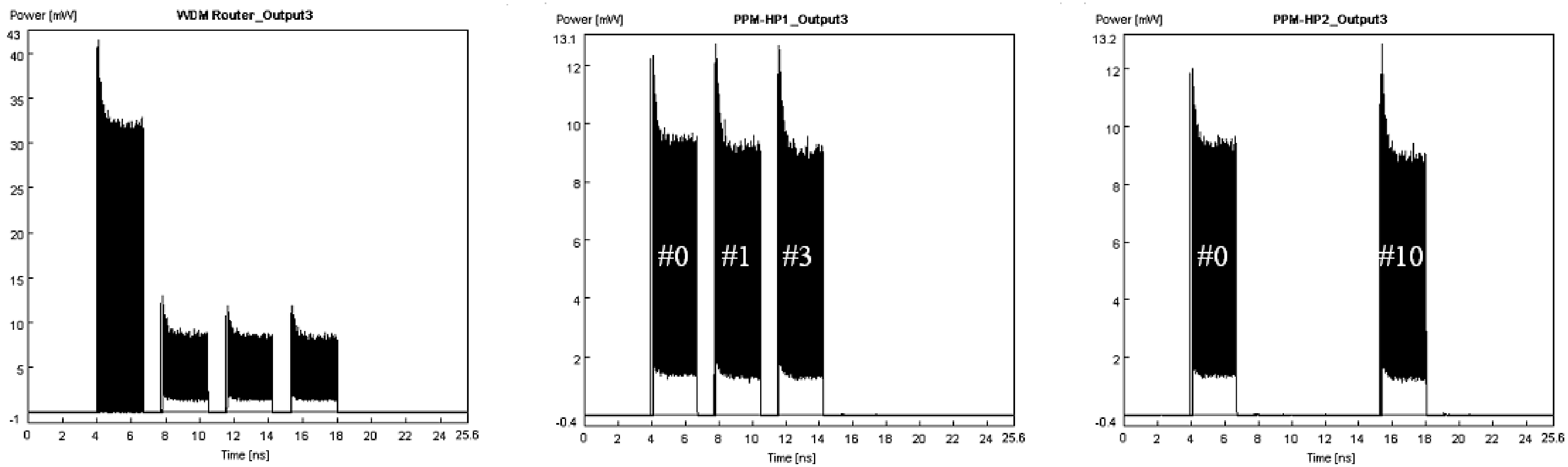
(b) Packets observed at the output 1 of the WDM router and PPM-HP1&2 (the inset shows the power fluctuation observed at the output 1 of PPM-HP1)

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)

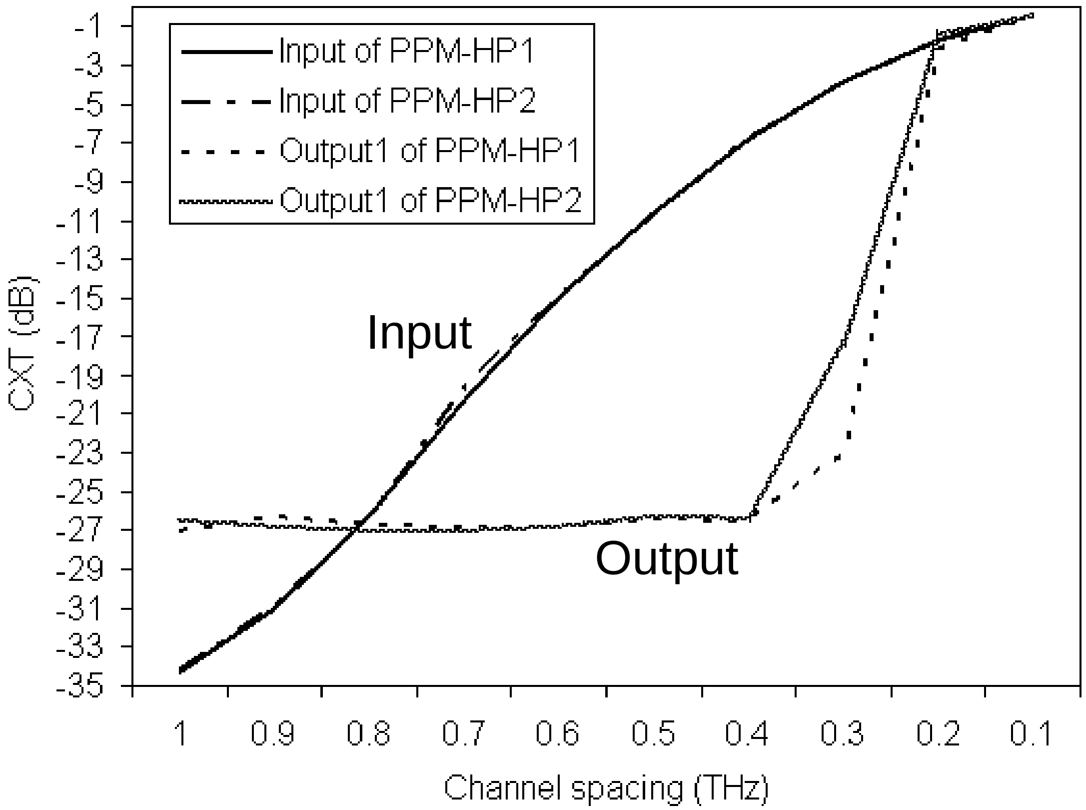
Two packets at λ_1 (packet 1 with address #4) and λ_2 (packet 2 with address #4) are sequentially applied to the input of the WDM router for measuring the channel *CXT.*

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

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 THz > Δf > 0.8 THz

  $CXT_{input} < CXT_{output}$

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

- 0.8THz > Δf > 0.4THz,

  $CXT_{output} < CXT_{input}$

  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?