Increasing Spectral Efficiency by Multilevel Optical Modulation

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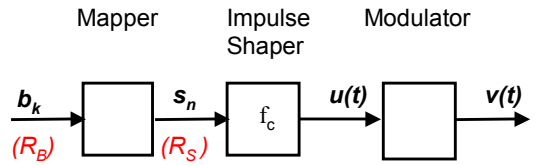
Overview

- **Introduction**
- **Multilevel Optical Modulation**
  - 4-Amplitude-Phase Shift Keying (4-ASK/PSK)
  - 4-Differential PSK (4-DPSK)
  - 8-DPSK
  - Minimum Shift Keying (MSK)
  - Non-coherent threshold detection
- **Impulse Shaping: Non Return (NRZ) and Return to Zero (RZ)**
- **Performance** (bandwidth, EOP, dispersion tolerance, fiber non-linearities)
- **Conclusion**

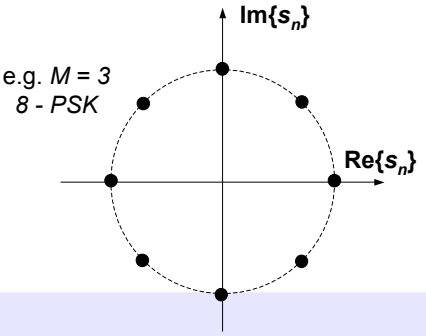
Principle of Multilevel Modulation



M bits → *1* symbol

$R_S = R_B / M$

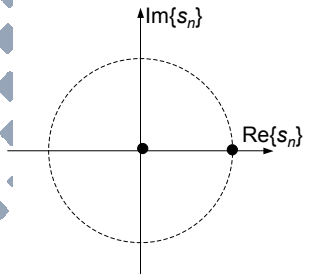
$L = 2^M$ number of levels

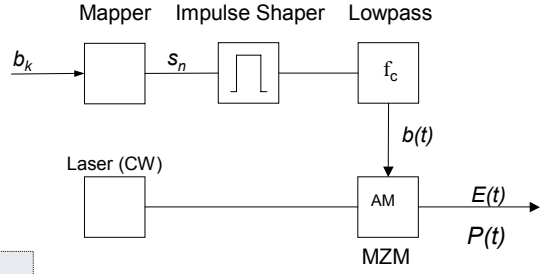


spectral efficiency:
M bit/symbol

symbol/Hz → (bit/s)/Hz

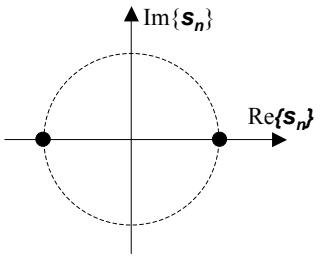
2-ASK (intensity modulation)



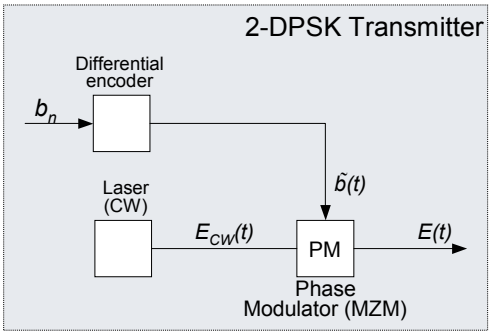


spectral efficiency:
1 bit/symbol

2-DPSK (DBPSK)

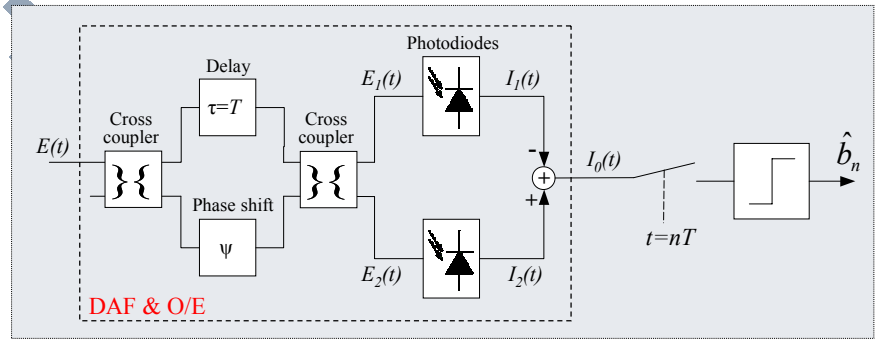


spectral efficiency:
1 bit/symbol

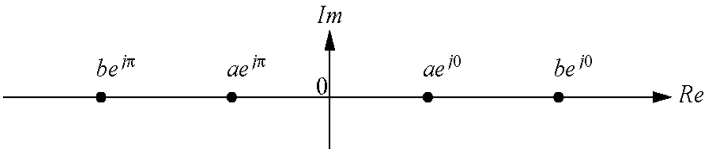


2-DPSK Receiver

$$I_0(t) = RP\cos[\Delta\varphi(t)]$$

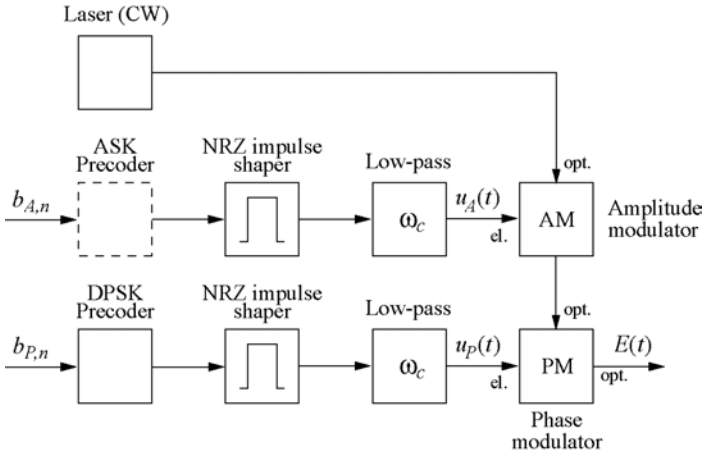


4-ASK/DPSK



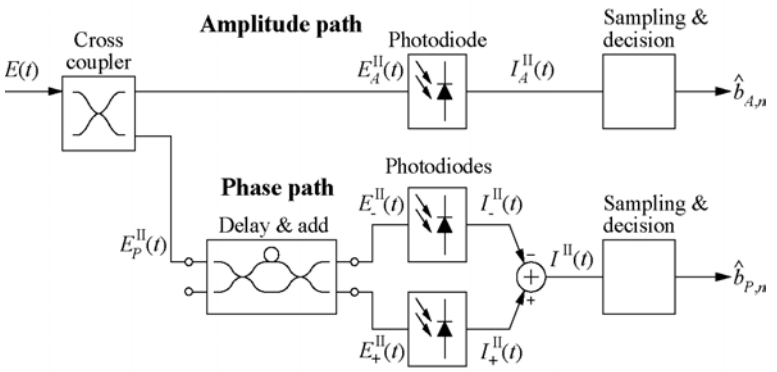
spectral efficiency:
2 bit/symbol

4-ASK/DPSK Modulator



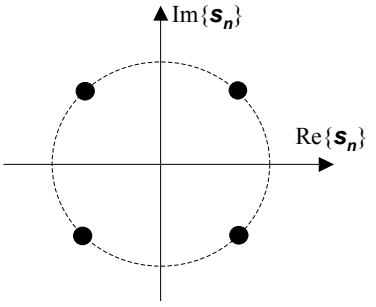
$$E(t) = \sqrt{P}A(t)e^{j(\omega_0 t+\phi(t))}$$

4-ASK/DPSK Demodulator



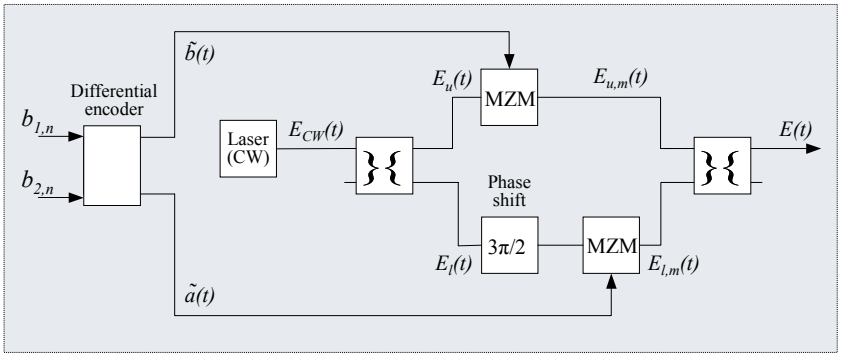
We have found various alternative receiver structures

4-DPSK

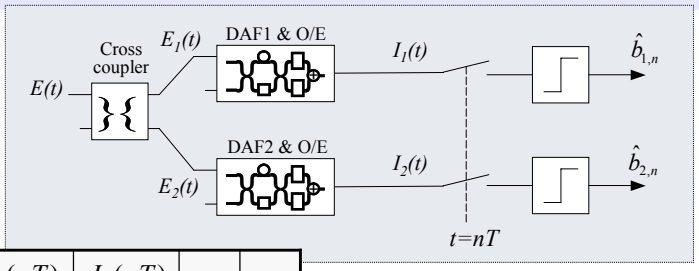


Spectral efficiency
2 bit/symbol

4-DPSK Transmitter



4-DPSK Receiver

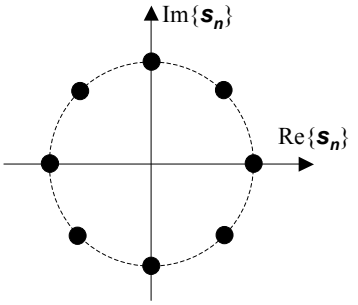


$\Delta\varphi(nT)$	$\frac{I_1(nT)}{4\sqrt{2}/RP}$	$\frac{I_2(nT)}{4\sqrt{2}/RP}$	$\hat{b}_{1,n}$	$\hat{b}_{2,n}$
0	1	1	1	1
π/2	-1	1	0	1
π	-1	-1	0	0
3π/2	1	-1	1	0

$$I_1(t) = \frac{RP}{4\sqrt{2}}[\cos\Delta\varphi(t) - \sin\Delta\varphi(t)]$$

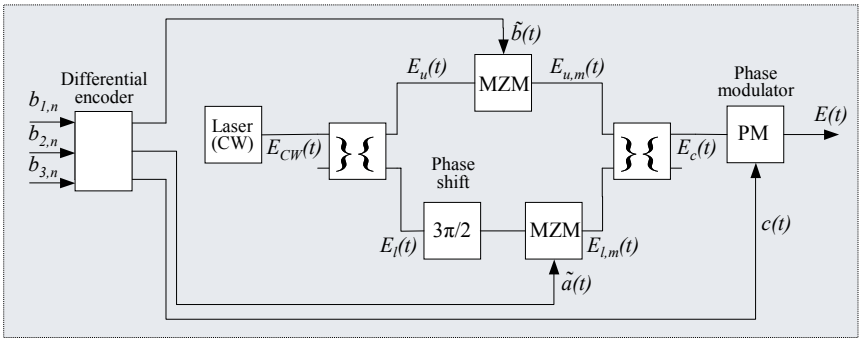
$$I_2(t) = \frac{RP}{4\sqrt{2}}[\cos\Delta\varphi(t) + \sin\Delta\varphi(t)]$$

8-DPSK

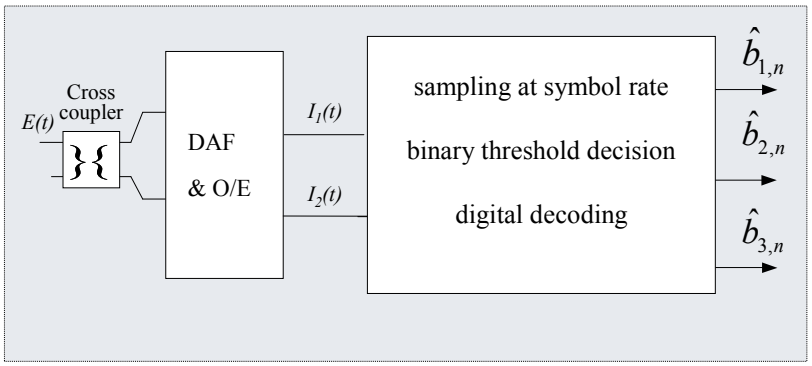


Spectral efficiency
3 bit/symbol

8-DPSK Transmitter



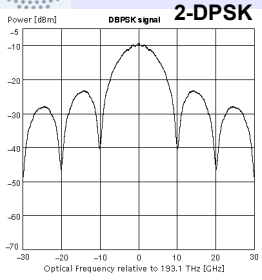
8-DPSK Receiver



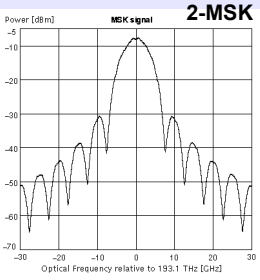
We have found various alternative receiver structures

Spectra of multilevel optical signals

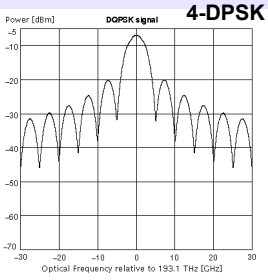
2-DPSK



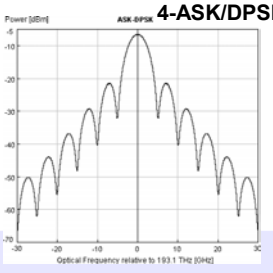
2-MSK



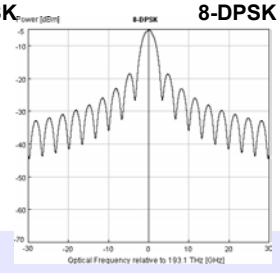
4-DPSK



4-ASK/DPSK



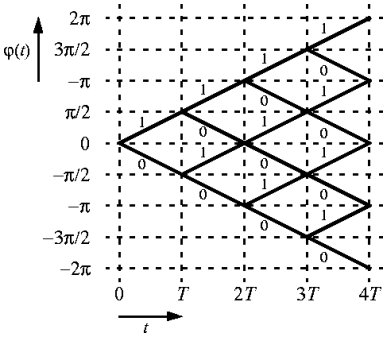
8-DPSK



R_b = 10 Gbit/s
P_{signal} = 0 dBm

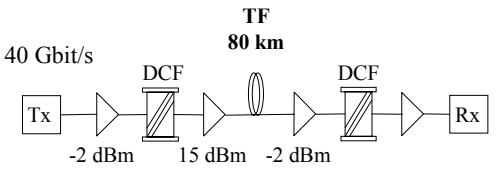
2-level MSK

- MSK signal: $e_{\mathrm{MSK}}(t) = A \cdot \sqrt{P} \cdot \mathrm{e}^{\mathrm{j}[\omega_0 t + \varphi(t)]}$
- Phase $\varphi(t)$ continuous, linear time function
- Constant power
- MZM drive signal is saw tooth



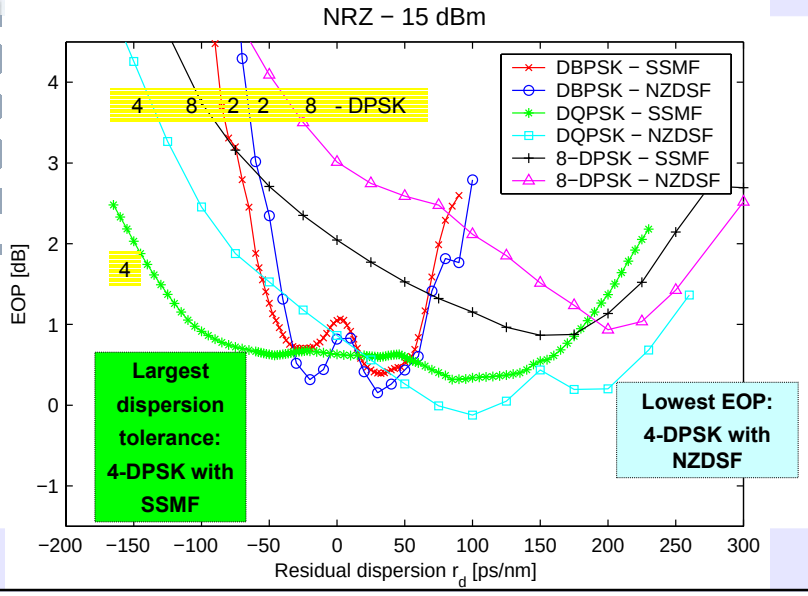
spectral efficiency:
1 bit/symbol

Performance for Single Span Transmission

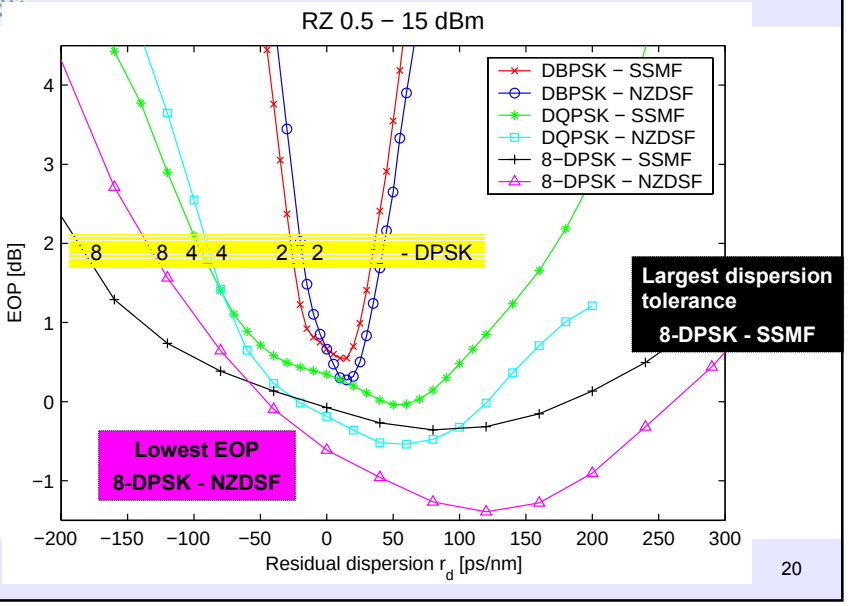


Transmission Fiber TF:
Standard Single-Mode Fiber -SSMF
Nonzero Dispersion-Shifted Fiber -NZDSF

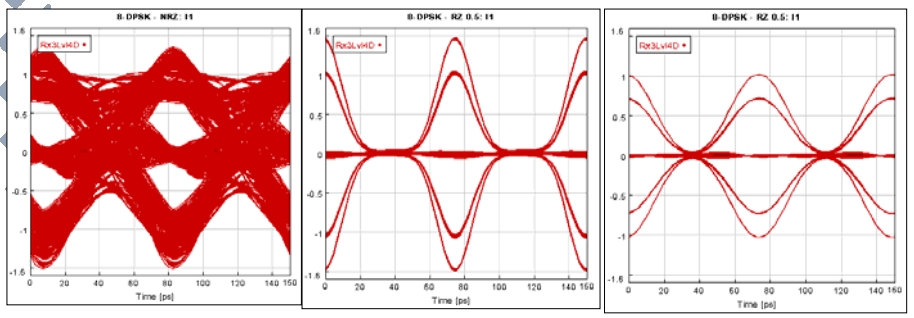
Single Span Transmission - Non Return to Zero (NRZ)



Single Span Transmission – Return to Zero (RZ)



Eye Diagram 8-DPSK



NRZ RZ RZ (back to back)

Conclusion

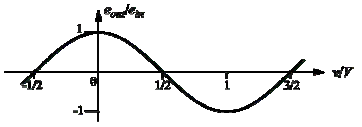
- 2-DPSK, 4-ASK/PSK, 4-DPSK, 8-DPSK, MSK
- L-level modulation (L>2) and MSK increased spectral efficiency, reduced speed
- 8-DPSK-RZ: High dispersion tolerance, low EOP
- Hardware complexity increasing with L
- Future work
  - BER simulation
  - Implementation constraints (hardware)
  - DWDM
  - Higher modulation levels L

Supplementary Material

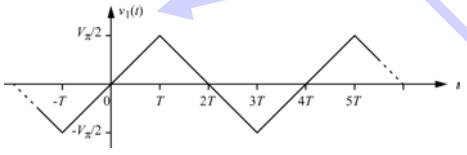
Optical MSK transmitter (2)

Offset-QPSK with cosine-impulse shaping

MZM transfer characteristic



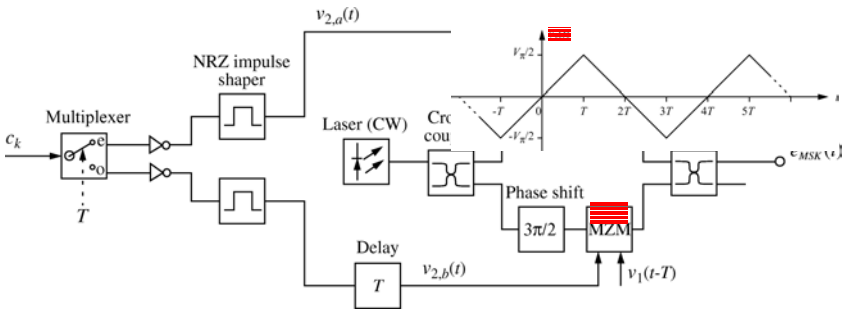
MZM drive signal: $v(t) = v_1(t) + v_2(t)$



Time interval $mT \le t < (m+2)T$

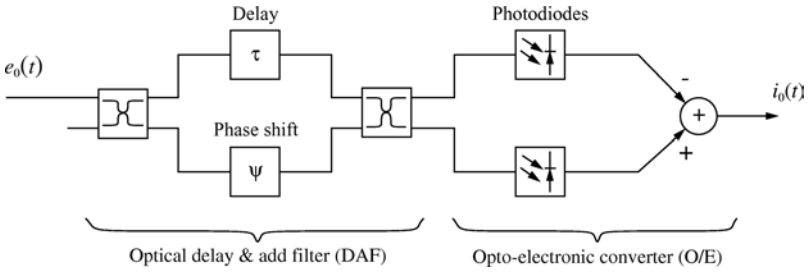
$$v_2(t) = \begin{cases} V_\pi & \text{for } q_m = +1 \\ 0 & \text{for } q_m = -1 \end{cases}$$

Optical MSK transmitter (3)



Basic structure similar to DQPSK

Optical MSK receiver

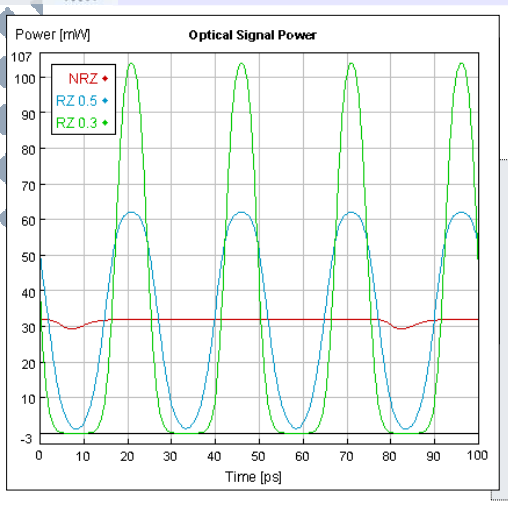


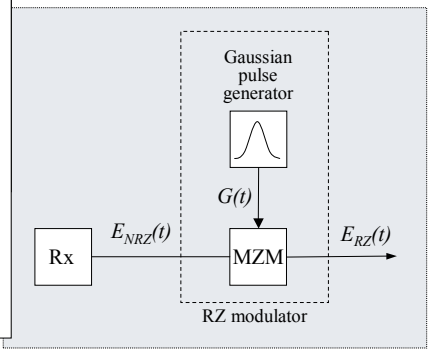
Delay: $\tau = T$
Phase shift: $\psi = 3\pi/2$

$$i_0(nT) = \pm C$$

Receiver similar to DBPSK.

Impulse Shaping: NRZ vs. RZ





Eye Diagram 4-DPSK NRZ