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Abstract: [Intermediate status of 2.4GHz Chirp-Radio activity]

Purpose: [This document is for discussion on the Modulation and Detection of 2.4GHz Chirp-Radio]

CSS Modulation & Detection

by

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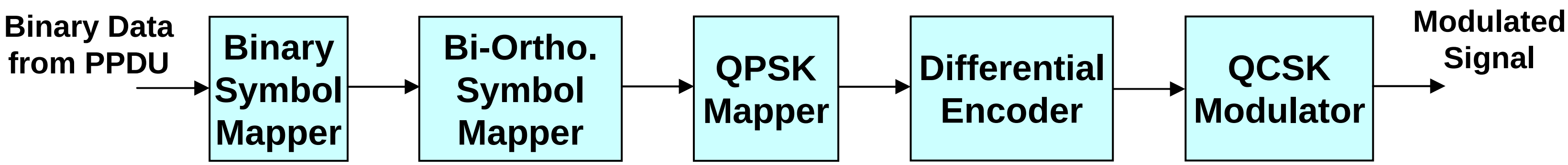
Modulation & Coding



- **Bit to Binary Symbol mapper:**
  Group every 3-bits (or 6-bits) into a Symbol for 1Mbps (or 250Kbps)
- **Binary Symbol to Bi-Orthogonal Symbol mapper:**
  Each 3-bits (or 6-bits) symbol is mapped to one of 4-chip (or 32-chip) Bi-Orthogonal Symbol Sequence for 1Mbps (or 250Kbps)
- **QPSK Mapper:**
  Group every alternative 4-chips into I and Q for Group of 4 QPSK
- **Differential Encoder: QPSK → D-QPSK**
  Symbol-by-Symbol Differential Encoding between Group of 4 QPSK
- **QCSK Modulator:**
  Phase Modulation of 4 sub-chirps with Group of 4 D-QPSK Symbols

Modulation & Coding

Bi-Orthogonal Mapping Table

H_8 =

1	1	1	1	-1	-1	-1	-1
1	-1	1	-1	-1	1	-1	1
1	1	-1	-1	-1	-1	1	1
1	-1	-1	1	-1	1	1	-1

H_{64} =

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1
1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1
1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1
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1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1
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Decimal: 0 1 2 3 4 5 6 7 -- 63

QCSK Signal Generation

Sub-chirp Formula

QCSK:

$$\tilde{s}^m(t) = \sum_{n=0}^{\infty} \tilde{s}^m_{chirp}(t,n)$$

$$= \sum_{n=0}^{\infty}\sum_{k=0}^{3} \tilde{c}_{n,k} \exp\left[j\left(\omega_{k,m} + \frac{\mu}{2}\xi_{k,m}\left(t - T_{n,k,m}\right)\right)\left(t - T_{n,k,m}\right)\right] \times p_{RC}\left(t - T_{n,k,m}\right)$$

$$\text{where} \begin{cases} m = 1, \cdots, 4 \ (piconet) \\ \tilde{c}_{n,k} = e^{j\pi/4},\ e^{-j\pi/4},\ e^{j3\pi/4},\ or\ e^{-j3\pi/4}\ (QCSK) \\ T_{n,k,m} = (k+0.5)T_{sub} + nT_{chirp} - \left(1-(-1)^n\right)\tau_m \\ T_{sub} = 1.2\times10^{-6}\ \text{sec}, \quad T_{chirp} = 6.0\times10^{-6}\ \text{sec} \\ \mu = \omega_{BW}/T_{sub}, \quad \omega_{BW} = 2\pi\times7\times10^6\times(1+\alpha), \quad \alpha = 0.25 \\ \tau_1 = 4.5\times10^{-7}\ \text{sec},\ \tau_2 = 3\times10^{-7}\ \text{sec},\ \tau_3 = 1.5\times10^{-7}\ \text{sec},\ \tau_4 = 0\ \text{sec} \\ \omega_{k,m} = 2\pi\times f_{k,m} \end{cases}$$

$$p_{RC}(t) = \begin{cases} 1 & |t| \le \frac{(1-\alpha)}{(1+\alpha)}\frac{T_{sub}}{2} \\ \frac{1}{2}\left[1+\cos\left(\frac{(1+\alpha)\pi}{\alpha T_{sub}}\left(|t| - \frac{(1-\alpha)}{(1+\alpha)}\frac{T_{sub}}{2}\right)\right)\right] & \frac{(1-\alpha)}{(1+\alpha)}\frac{T_{sub}}{2} < |t| \le \frac{T_{sub}}{2} \\ 0 & |t| > \frac{T_{sub}}{2} \end{cases}$$

m \ k	1	2	3	4
1	+1	+1	-1	-1
2	+1	-1	+1	-1
3	-1	-1	+1	+1
4	-1	+1	-1	+1

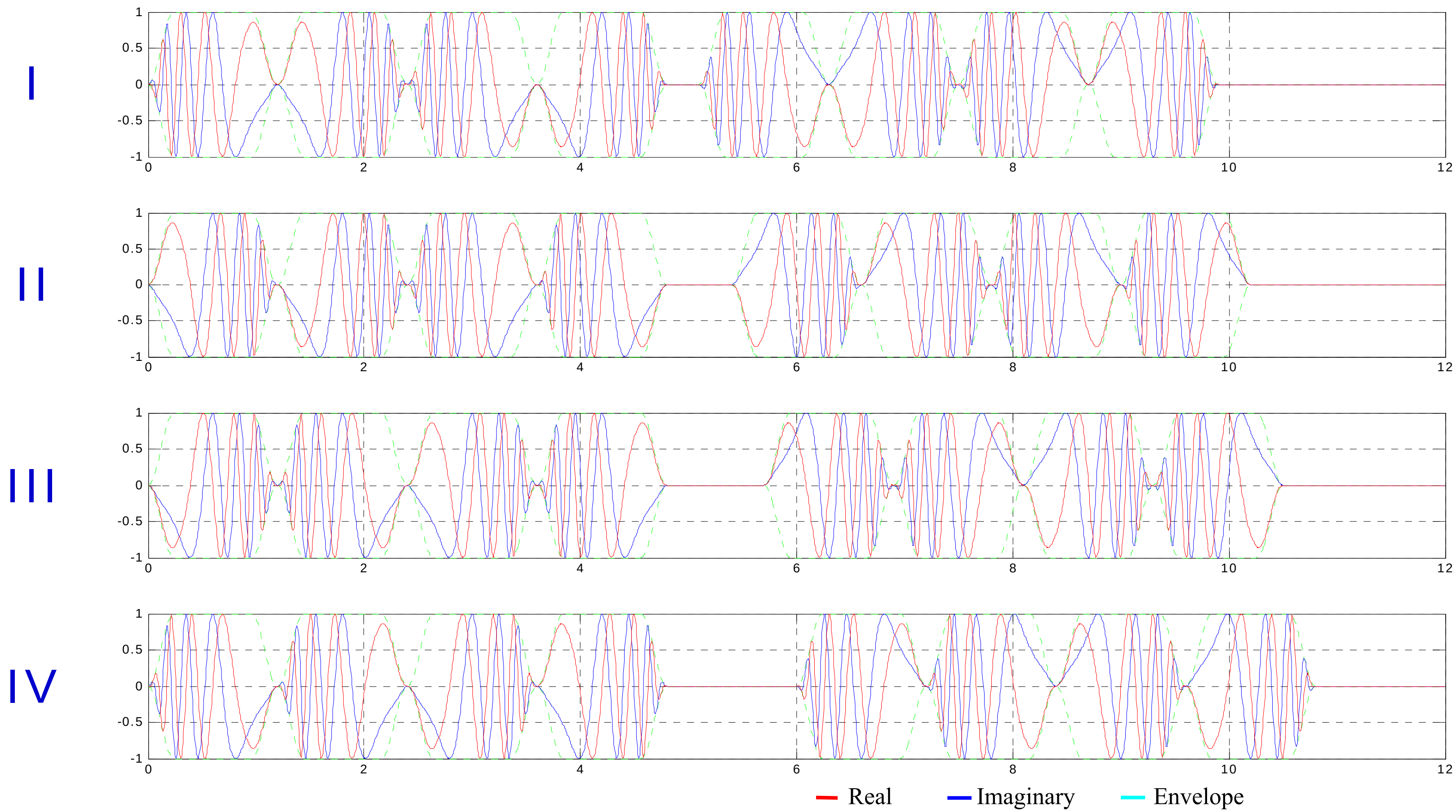
Table 1. $\xi_{k,m}$

m \ k	1	2	3	4
1	f_C-3.15	f_C+3.15	f_C+3.15	f_C-3.15
2	f_C+3.15	f_C-3.15	f_C-3.15	f_C+3.15
3	f_C-3.15	f_C+3.15	f_C+3.15	f_C-3.15
4	f_C+3.15	f_C-3.15	f_C-3.15	f_C+3.15

Table 2. $f_{k,m}$ [MHz]

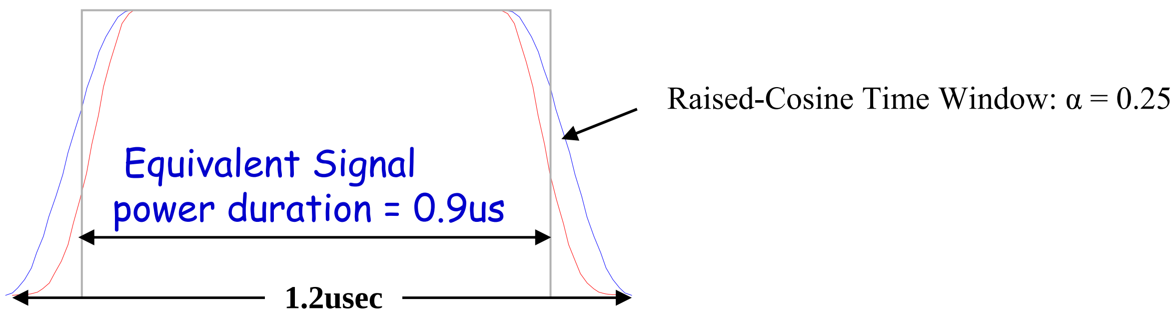
QCSK Signal Waveform

Multiple piconet

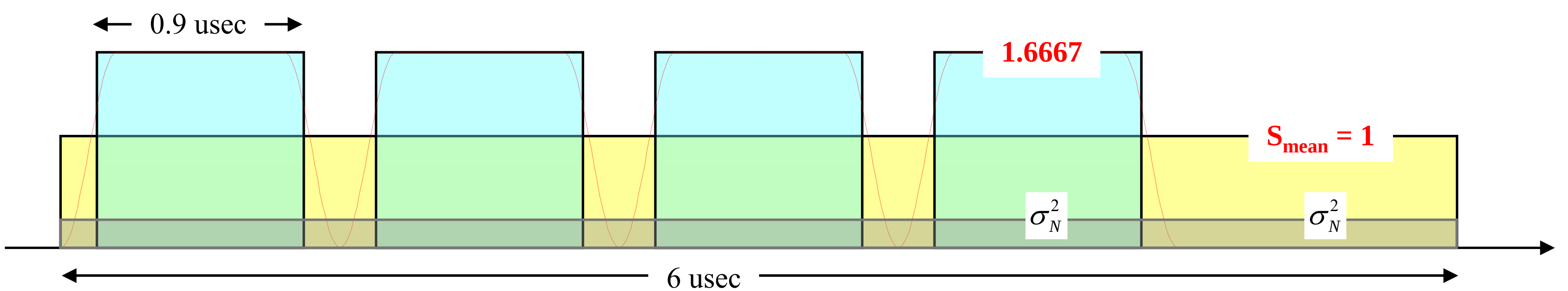


Power Factor of QCSK Symbol

- Signal Power Factor: $PF \triangleq \frac{\text{Symbol Duration}}{\text{Effective Signal Duration}}$



$$\therefore \quad PF = \frac{6\times10^{-6}}{0.9\times10^{-6}\times 4} = 1.6667 = 2.2\ [dB]$$



Chirp Spreading Gain

$$\frac{E_b}{N_0} = \frac{S_{mean}/R_b}{N/BW} = SG \cdot \frac{S_{mean}}{N}$$

- Spreading Gain @ 1Mbps: $SG_{1Mbps} = \frac{BW}{R_b} = \frac{14\ [MHz]}{1\ [\text{Mbps}]} = 14 = 11.5\ [dB]$
- Spreading Gain @ 250Kbps: $SG_{250Kbps} = \frac{BW}{R_b} = \frac{14\ [MHz]}{0.25\ [\text{Mbps}]} = 56 = 17.5\ [dB]$

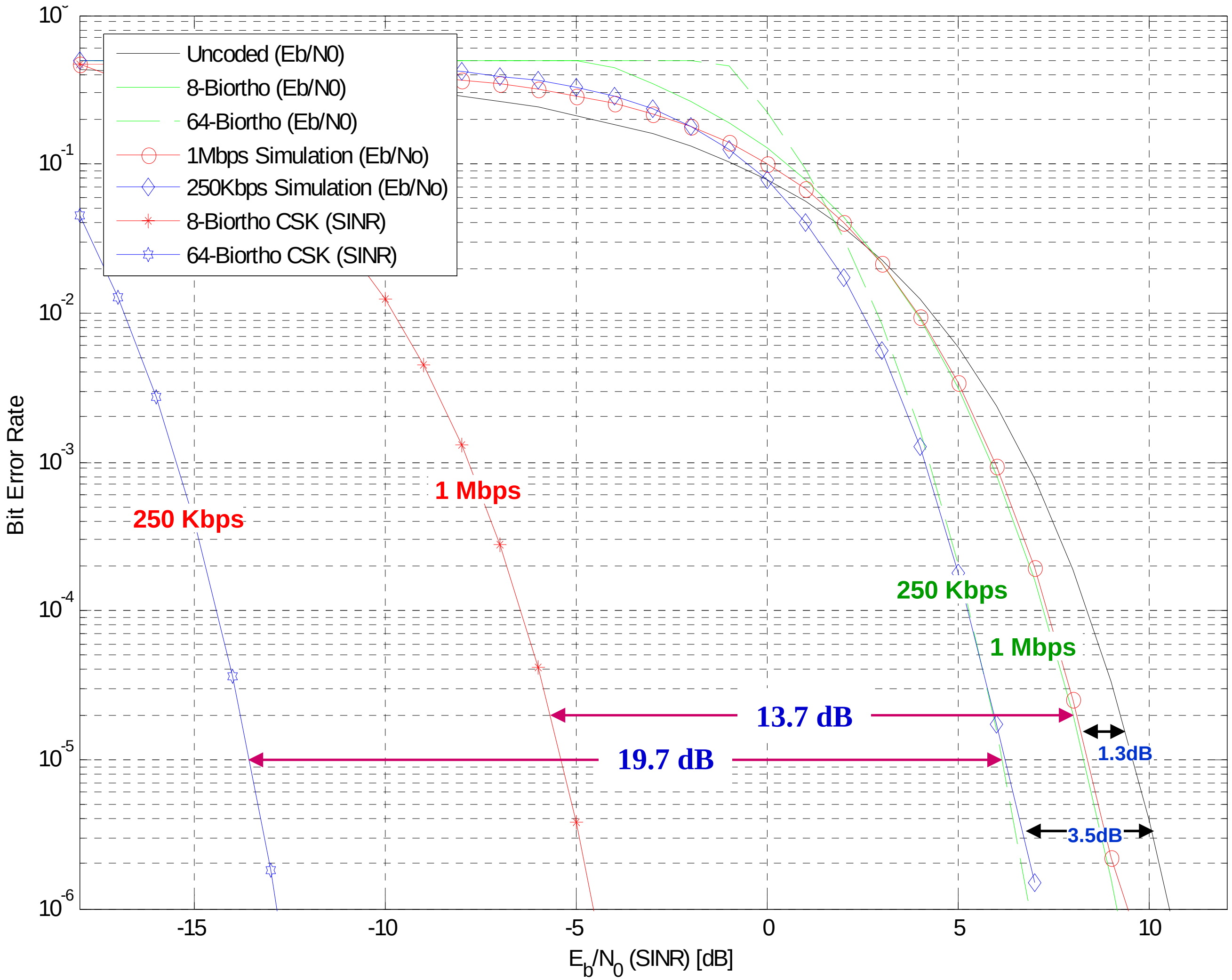
* Equivalent Noise Bandwidth of CSS: BW_{noise} = 14MHz

Processing Gain

$$\frac{E_b}{N_0} = SG \cdot \frac{S_{mean}}{N} = \left(SG \cdot PF\right) \cdot \frac{S_{effective}}{N} = PG \cdot \frac{S_{effective}}{N}$$

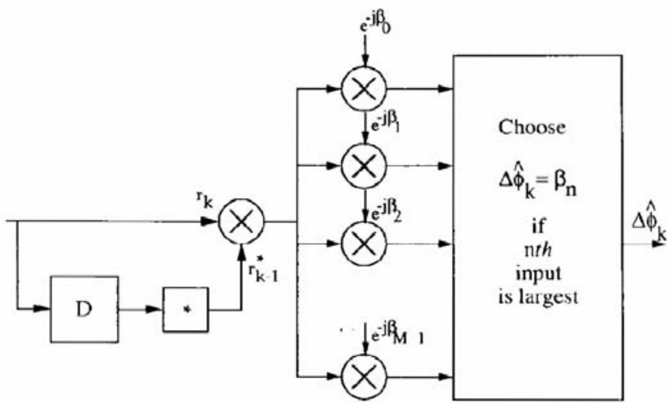
- 1 Mbps: $PG_{1Mbps} = 11.5 + 2.2 = 13.7\ [dB]$
- 250 Kbps: $PG_{250Kbps} = 17.5 + 2.2 = 19.7\ [dB]$

BER – over - Eb/No (SINR)

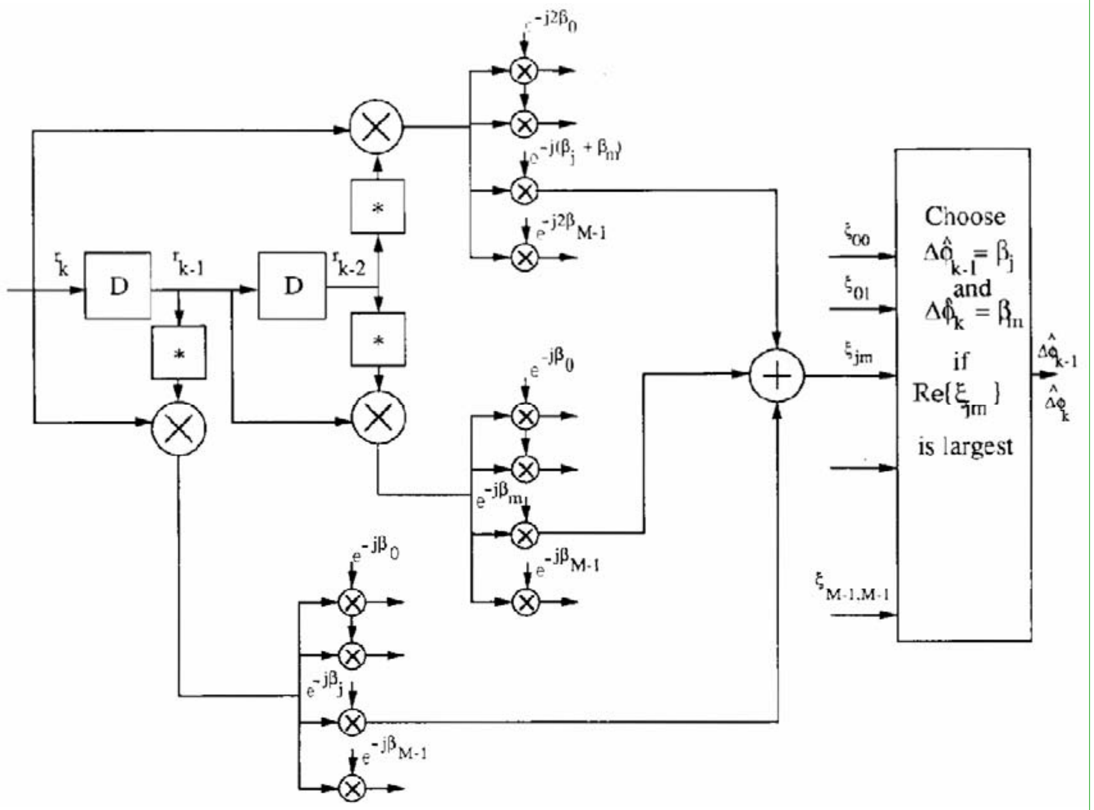


Reference: Bernard Sklar, "Digital Communications: Fundamentals and Applications", 2nd Edition $P_b = \left[(M-2) * Q\left(\sqrt{3 * Eb/N0}\right) + Q\left(\sqrt{6 * Eb/N0}\right) \right] / 2$

Detection of D-QPSK



Conventional Differential Detector of MDPSK



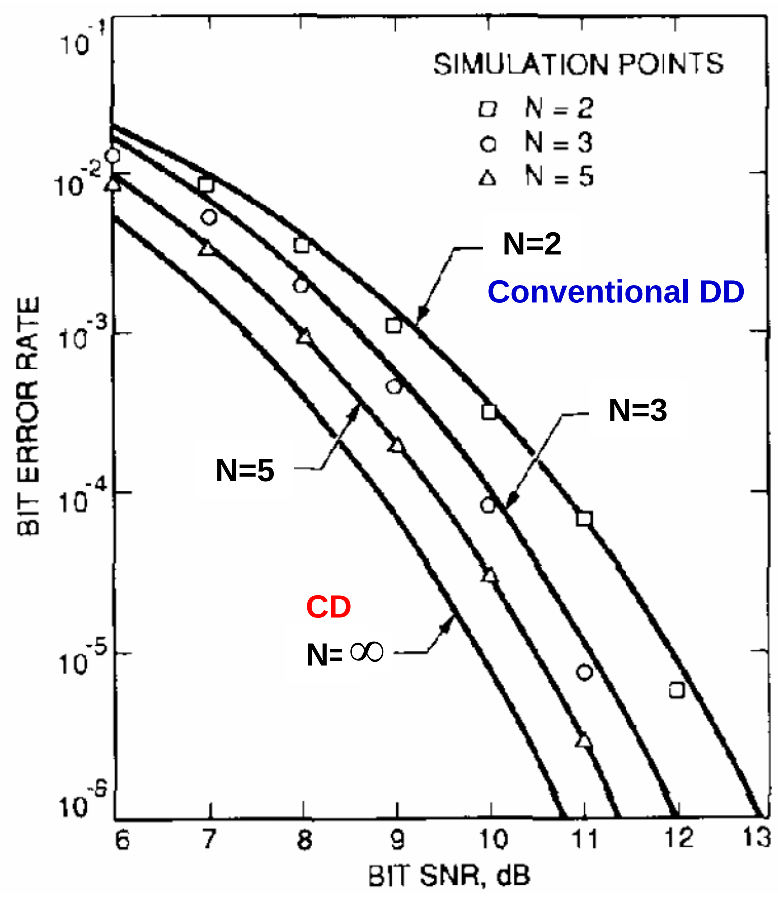
Multiple-bit Differential Detector of MDPSK (N=3)

Reference: M. K. Simon, S. M. Hinedi, andW. C. Lindsey, "*Digital Communication Techniques*", Englewood Cliffs, NJ: Prentice-Hall, 1995.

Detection of D-QPSK

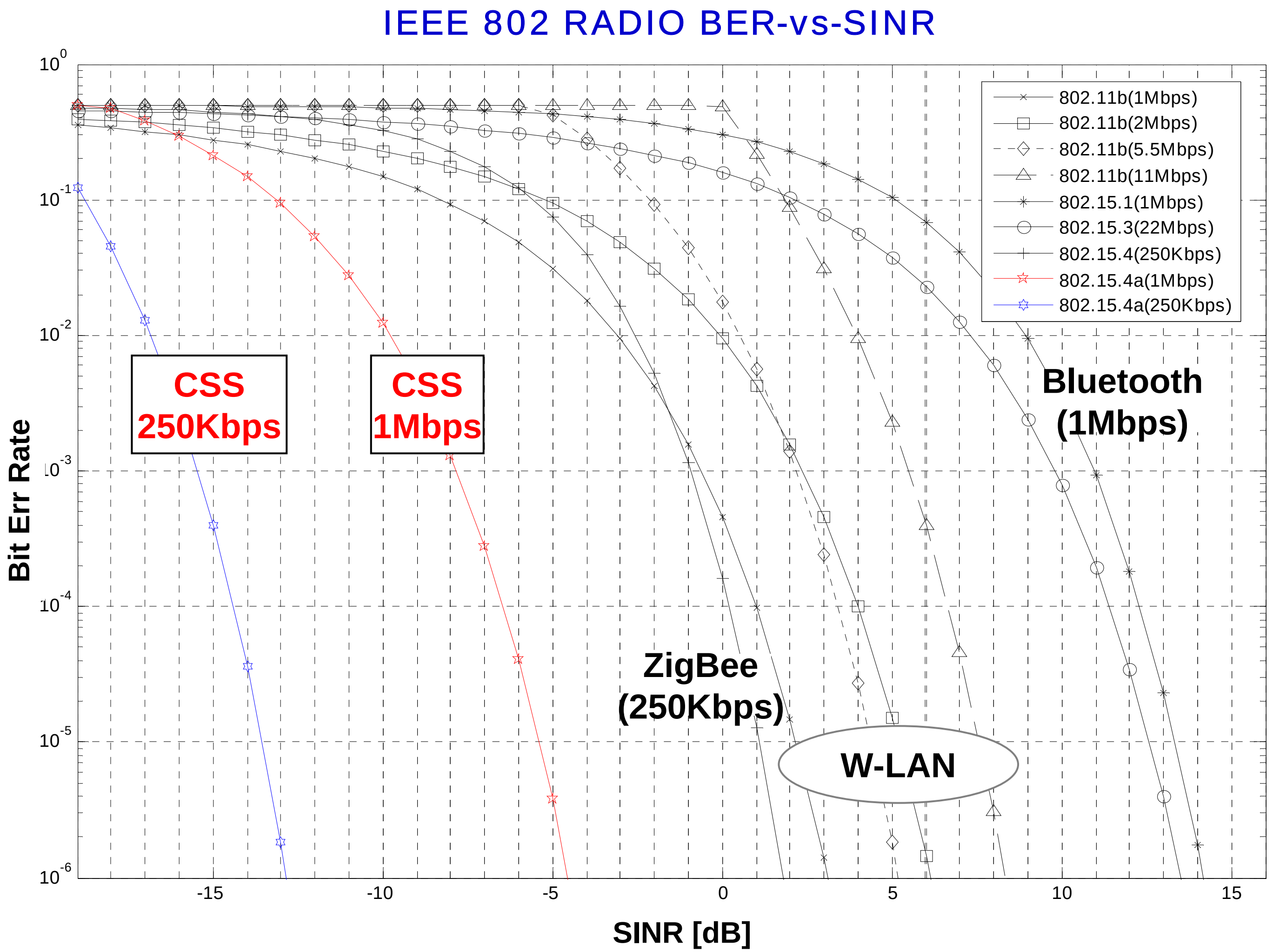
- Maximum lkelihood sequence estimation rather than symbol-by-symbol detection
- Performance of this scheme fills the gap between differentially-CD and ideal CD
- The amount of improvement gained over conventional C-DD depends on M (ary) and N (Symbol intervals)
- Substantial performance improvement can be obtained for some additional symbol intervals of observation.

Detection of D-QPSK



BER-over-Eb/No for Multiple-Differential Detection of D-QPSK

Comparison of IEEE 802 Radios



Concluding Remarks

- **Modulation:**
  - 8ary Bi-Orthogonal D-QCSK for 1Mbps
  - 64ary Bi-Orthogonal D-QCSK for 250Kbps
- **Bi-Orthogonal Coding Gain:**
  - Coding Gain = 1.3dB @ 1Mbps
  - Coding Gain = 3.5dB @ 250Kbps
- **Significant Processing Gain: Chirp-SG + PF**
  - PG = 13.7dB @ 1Mbps
  - PG = 19.7dG @ 250Kbps
- **Recommended Maximum-Likelyhood Differential Detection**
  - Substantial performance improvement over conventional DD
  - Easy to implement nearly Ideal CD performance
- **Coexistence & Robustness**
  - Low Interference Level to the other Radios
  - Robustness for interference and multi-path