Design of a Transceiver for 3G DECT Physical Layer

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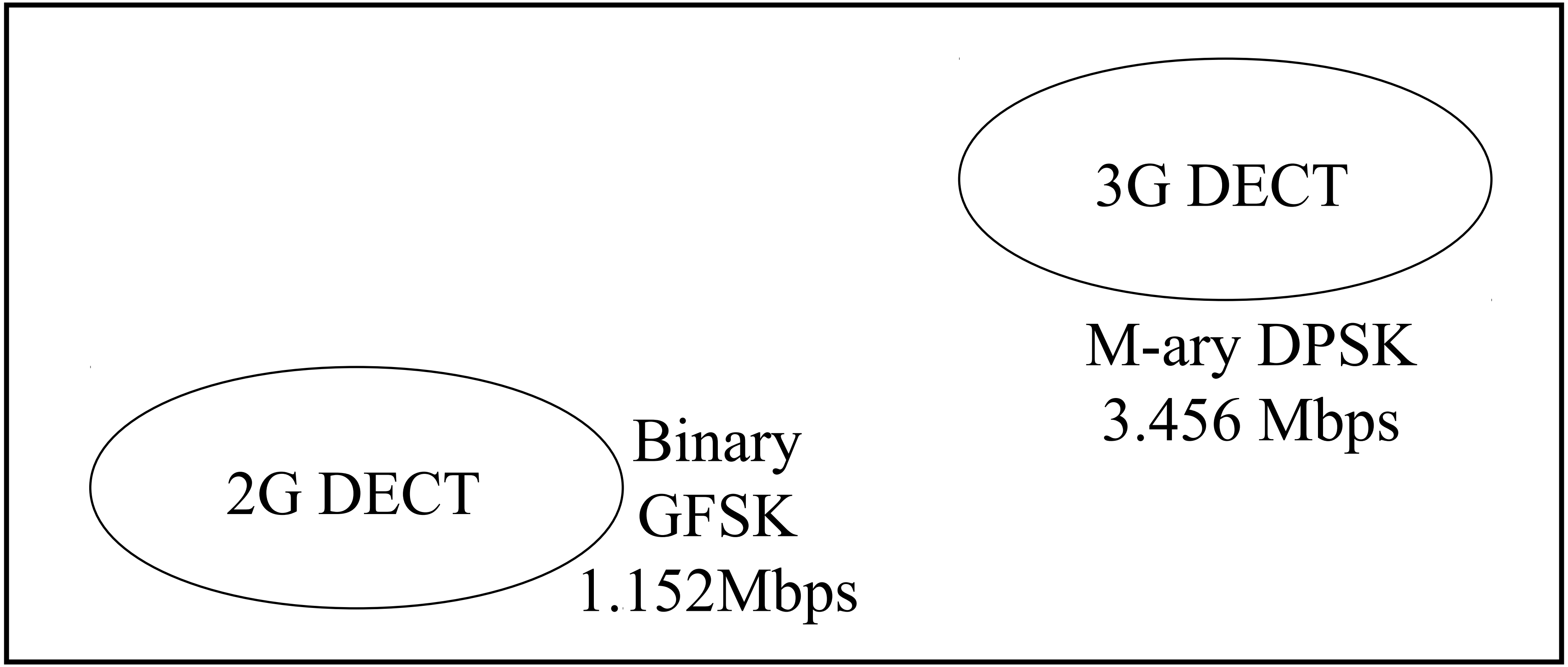
The Big Picture



DECT - Digital Enhanced Cordless Telecommunications

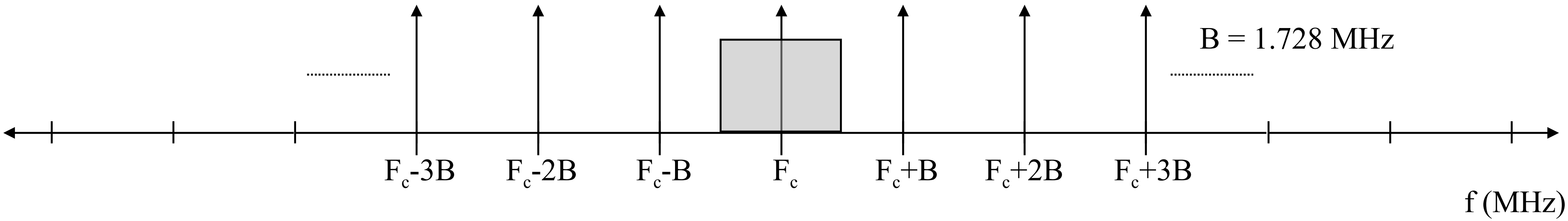
Overview

- 2G DECT specifications and 2G transceiver
- 3G DECT specifications
- Issues in receiver design
- Digital FM demodulator
- Coherent detector for DPSK symbols
- Results and Conclusion

2G DECT Specifications

- Multi-Carrier TDMA TDD system

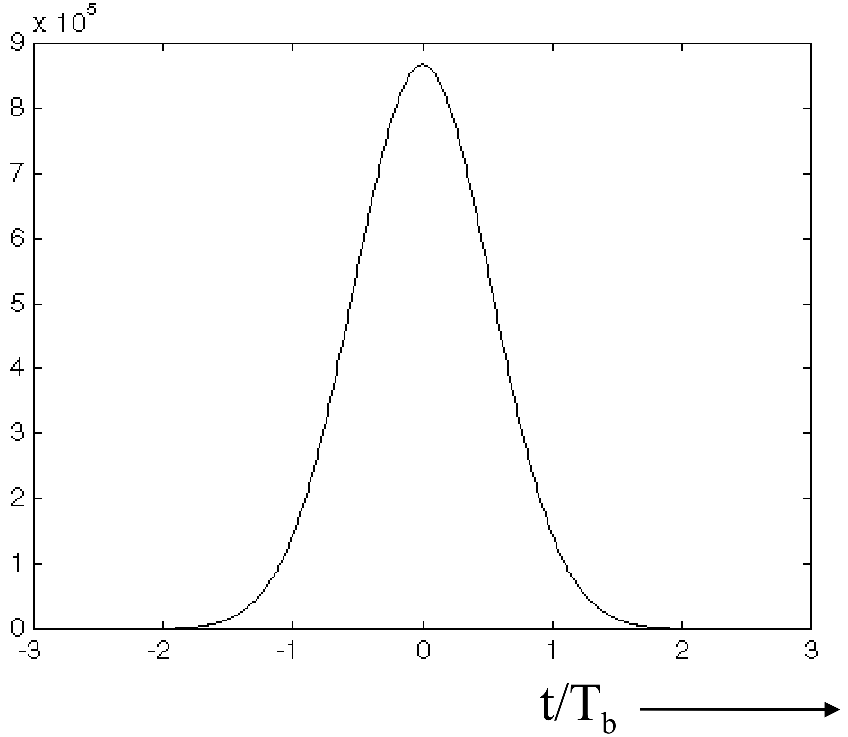
- RF carriers separated by 1.728 MHz (=B) each in 1880 MHz to 1938 MHz band



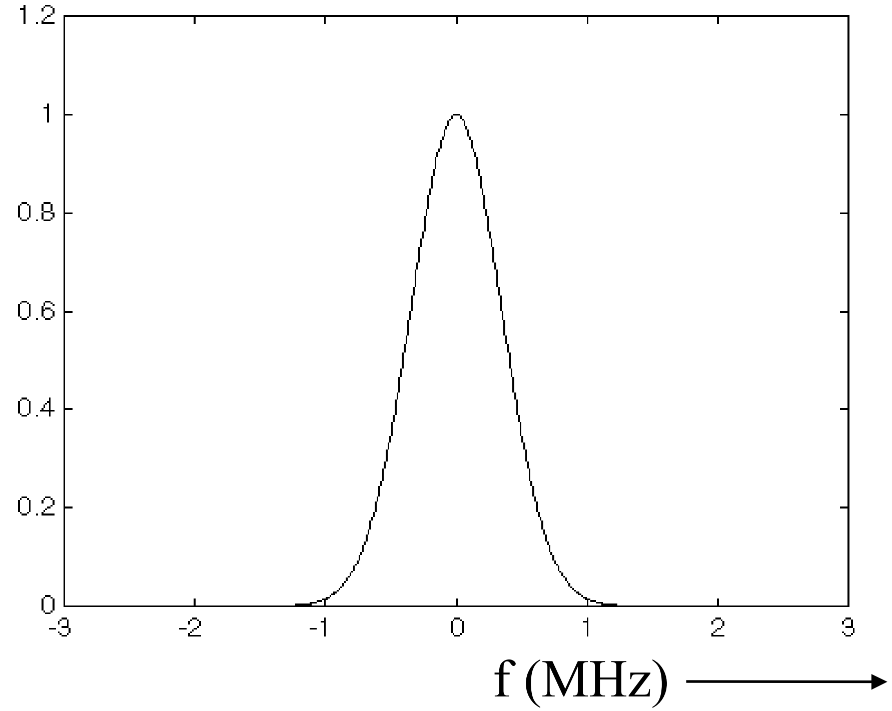
- Bit rate, $R_b = 1/T_b = 1.152$ Mbps

- GFSK modulation with BT_b=0.5

2G DECT Specifications (contd.)



Time domain waveform

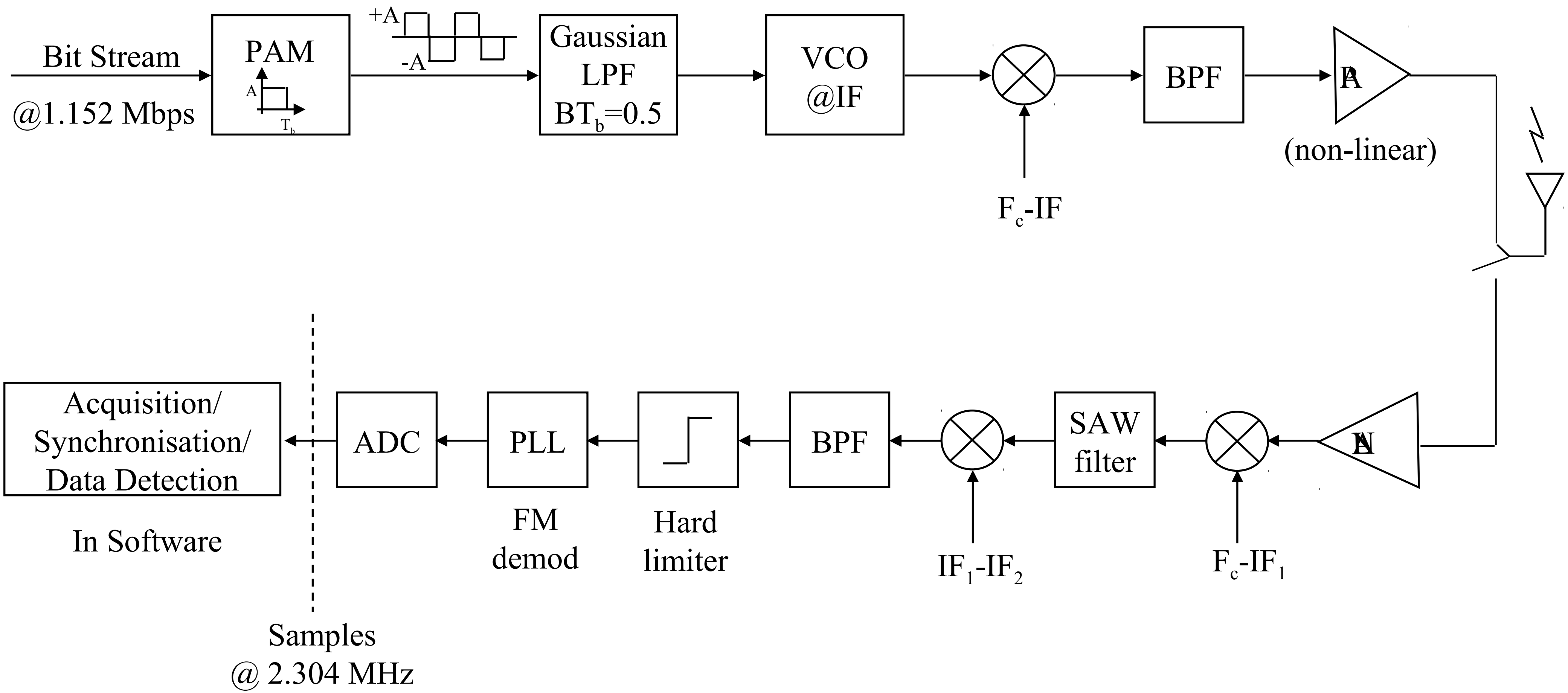


Magnitude spectrum

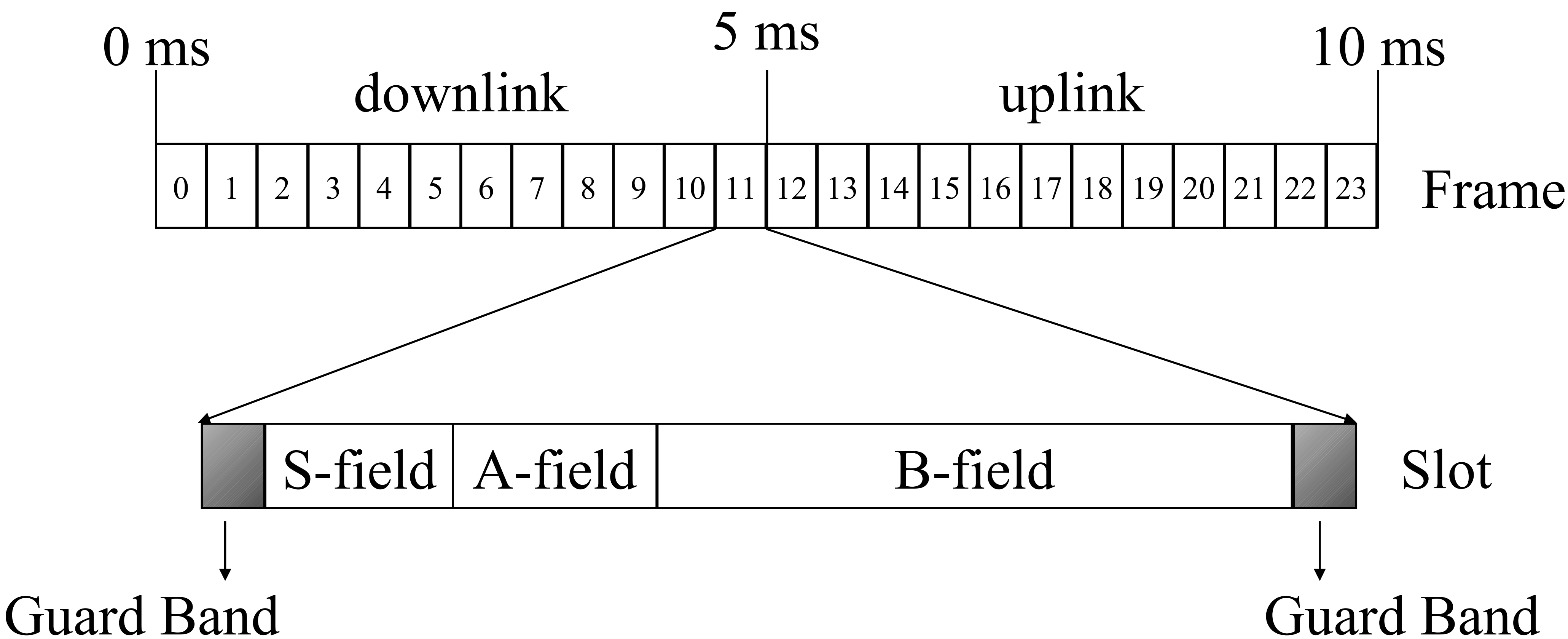
- Nominal frequency deviation of ±288 kHz

Allowed deviation limits: 70% to 140% of nominal

GFSK Transceiver



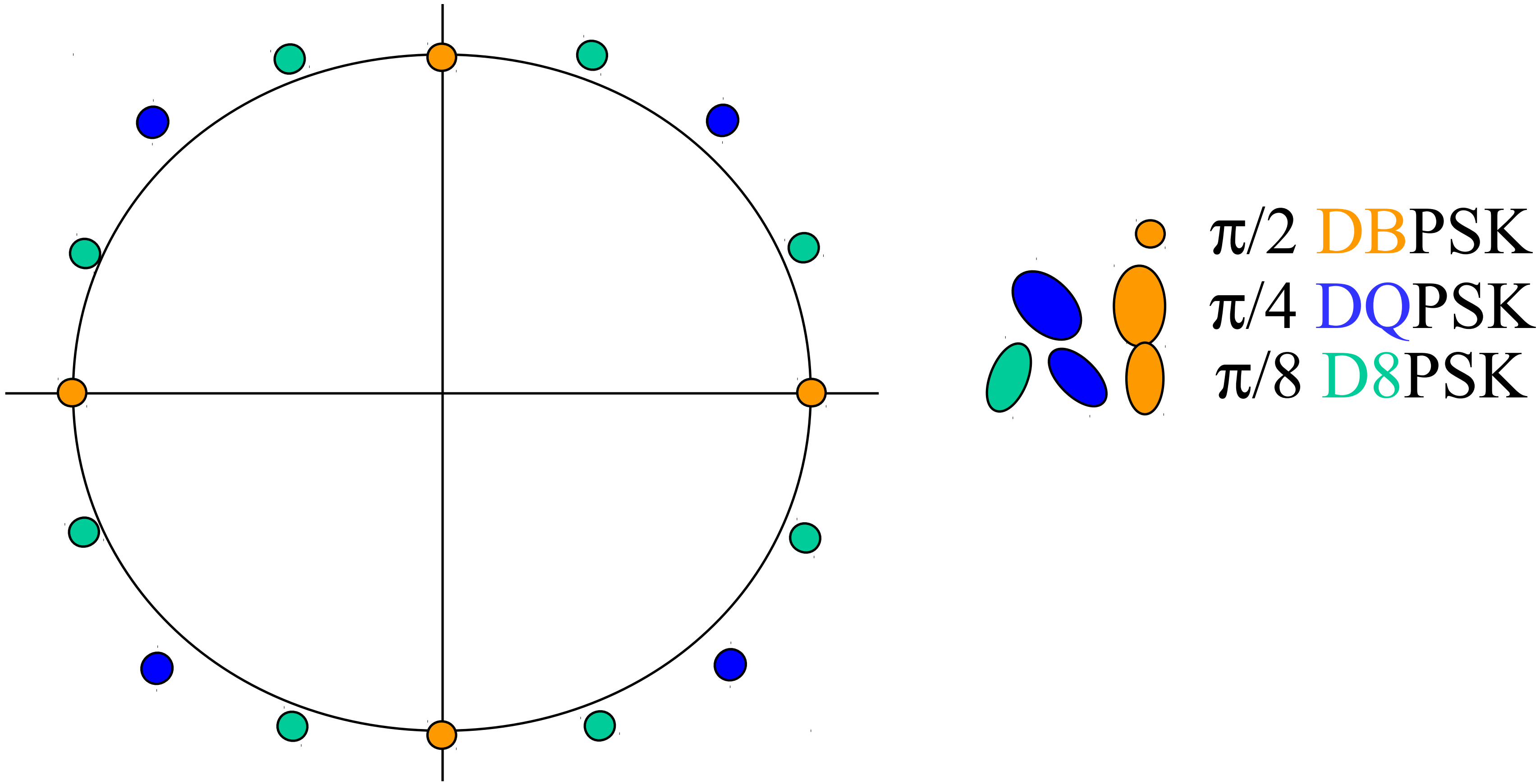
TDMA Frame Structure in DECT



- S-Field: Synchronisation Field
- A-Field: Control Information
- B-Field: Data Packet

3G Physical Layer Specifications

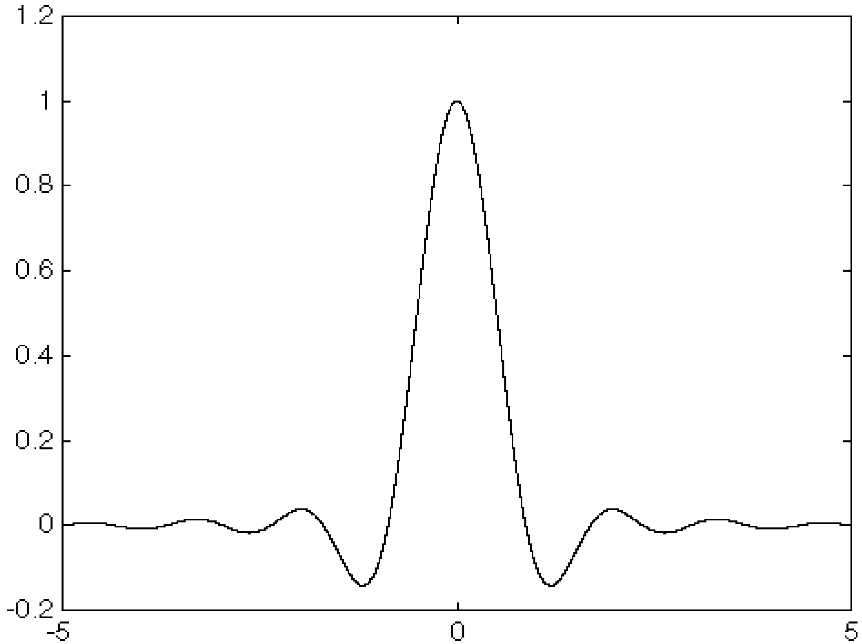
- Modulation Schemes : π/2 DBPSK, π/4 DQPSK, π/8 D8PSK



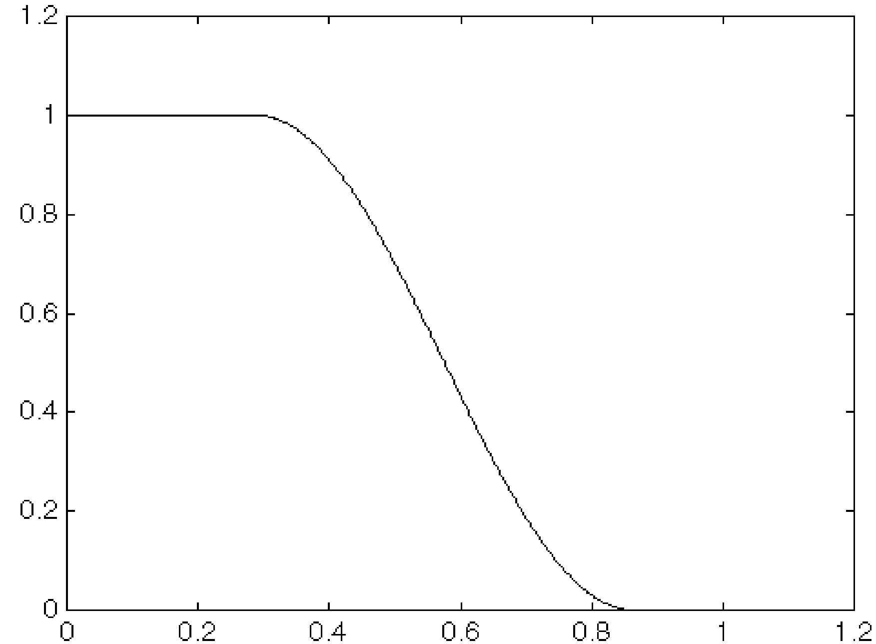
Constellation for differential PSK modulation

3G Physical Layer Specifications (contd.)

- Root-Raised Cosine with 50% excess bandwidth
- Symbol rate is 1.152 Msps
- Zero ISI at the output of the matched filter in the receiver



Normalized time-domain waveform



Power spectrum (frequency in MHz)

3G Physical Layer Specifications (contd.)

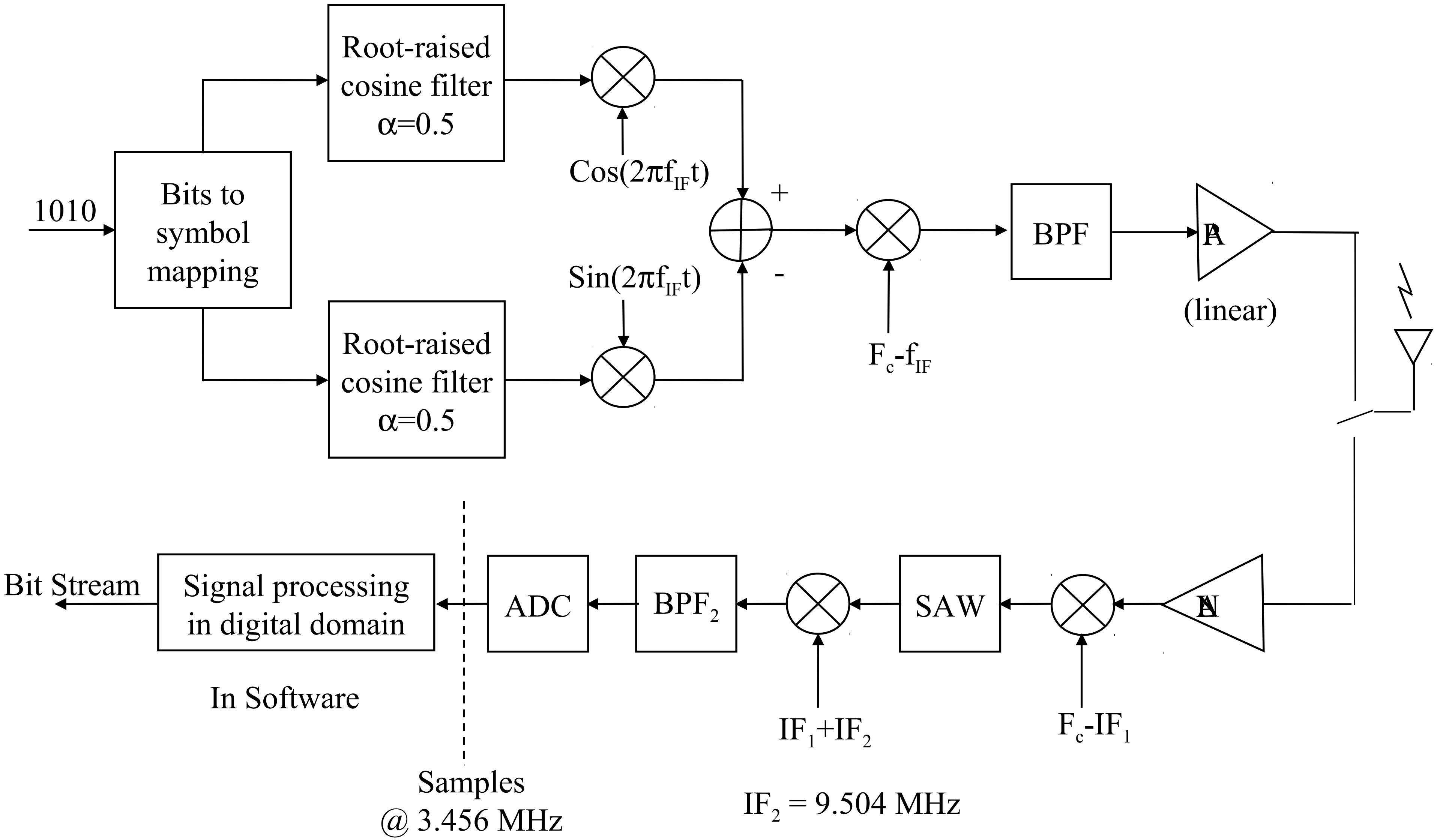
- Allowed combination of modulation schemes

Configuration	S-field	A-field	B-field
1a	GFSK	GFSK	GFSK
1b	π/2-DB	π/2-DB	π/2-DB
2	π/2-DB	π/2-DB	π/4-DQ
3	π/2-DB	π/2-DB	π/8-D8

- S and A fields always employ π/2-DBPSK

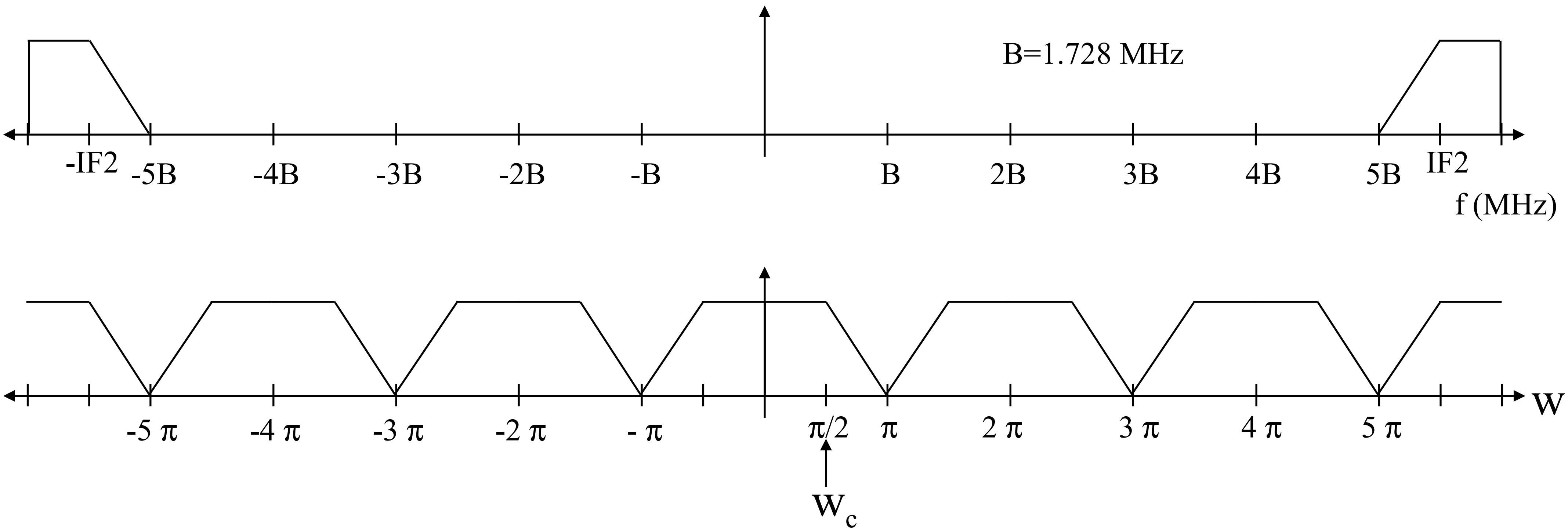
  ⇒ can be detected in a non-coherent GFSK receiver

DPSK Transceiver

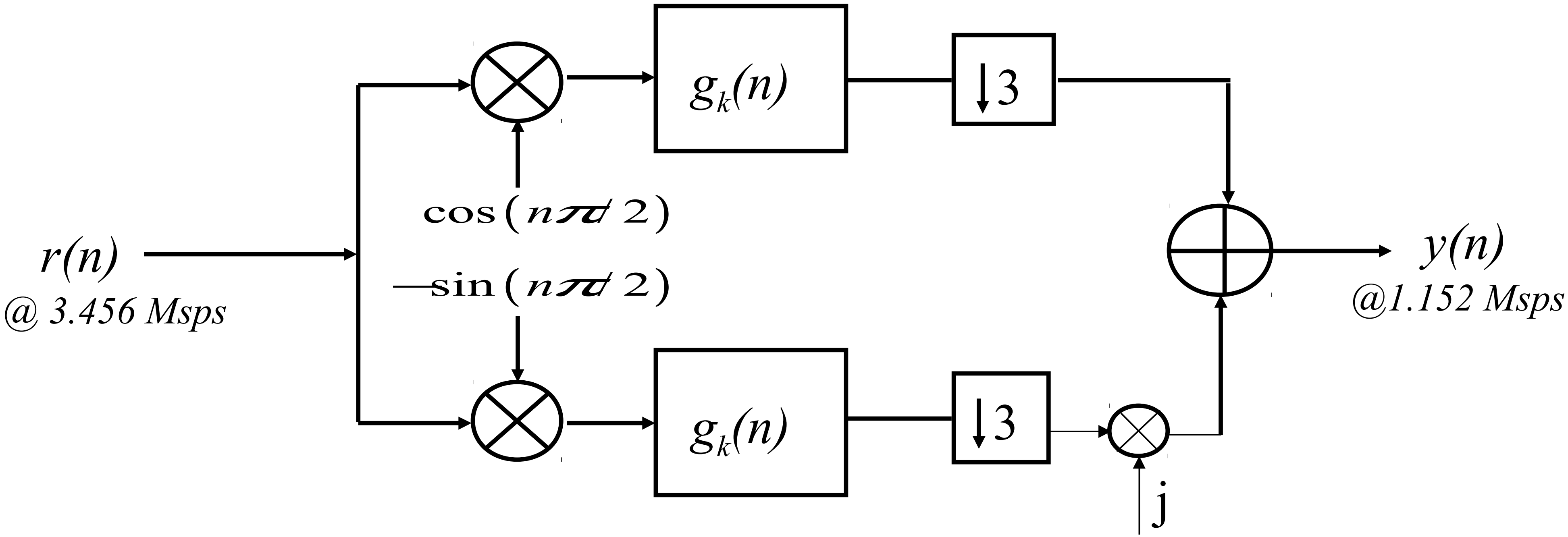


Bandpass Sampling - choice of IF2

- IF2 = 9.504 MHz = (5+0.5)*B; B = 1.728 MHz
  ⇒ minimum sampling rate, F_s = 2B = 3.456 MHz



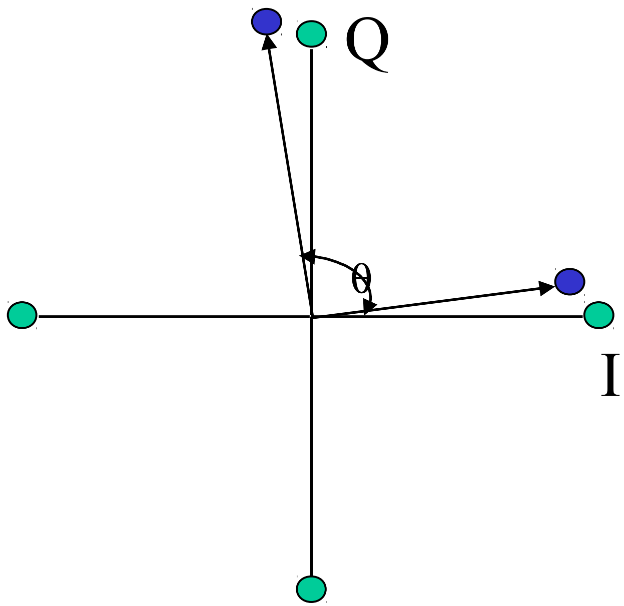
I-Q Demodulation



- Carrier Frequency and Carrier Phase synchronization
- Clock Frequency and Clock Phase synchronization

Data Detection in the receiver

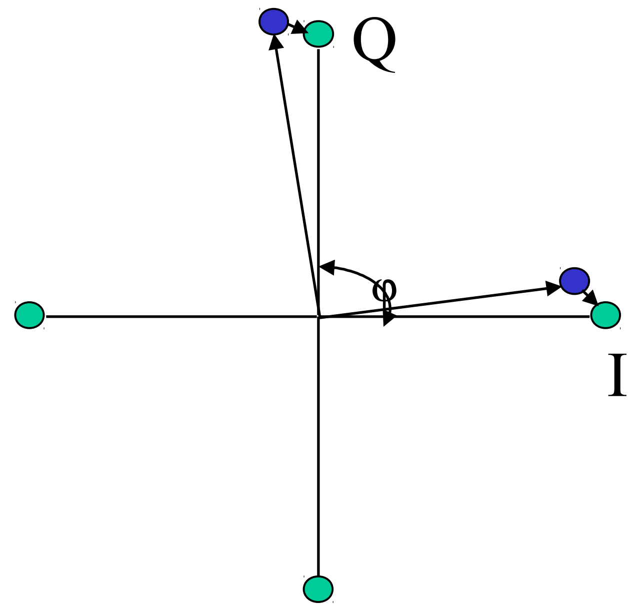
a) non-coherent differential



$\theta > 0 \Rightarrow$ bit 1

$\theta < 0 \Rightarrow$ bit 0

b) coherent differential



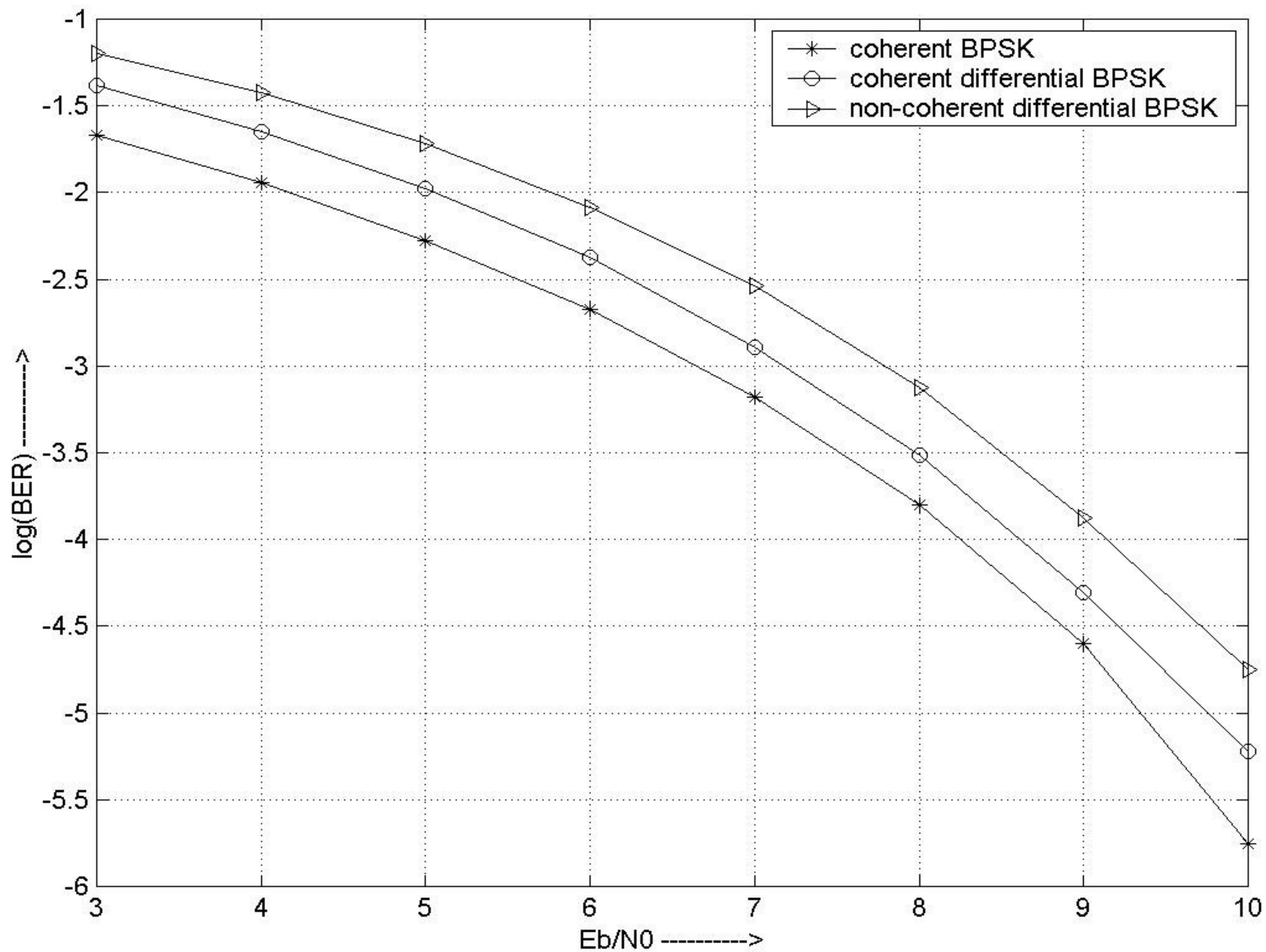
$\varphi = +90$ degrees => bit 1

$\varphi = -90$ degrees => bit 0

- Transmitted constellation points

- Received constellation points (in noise), y(n)

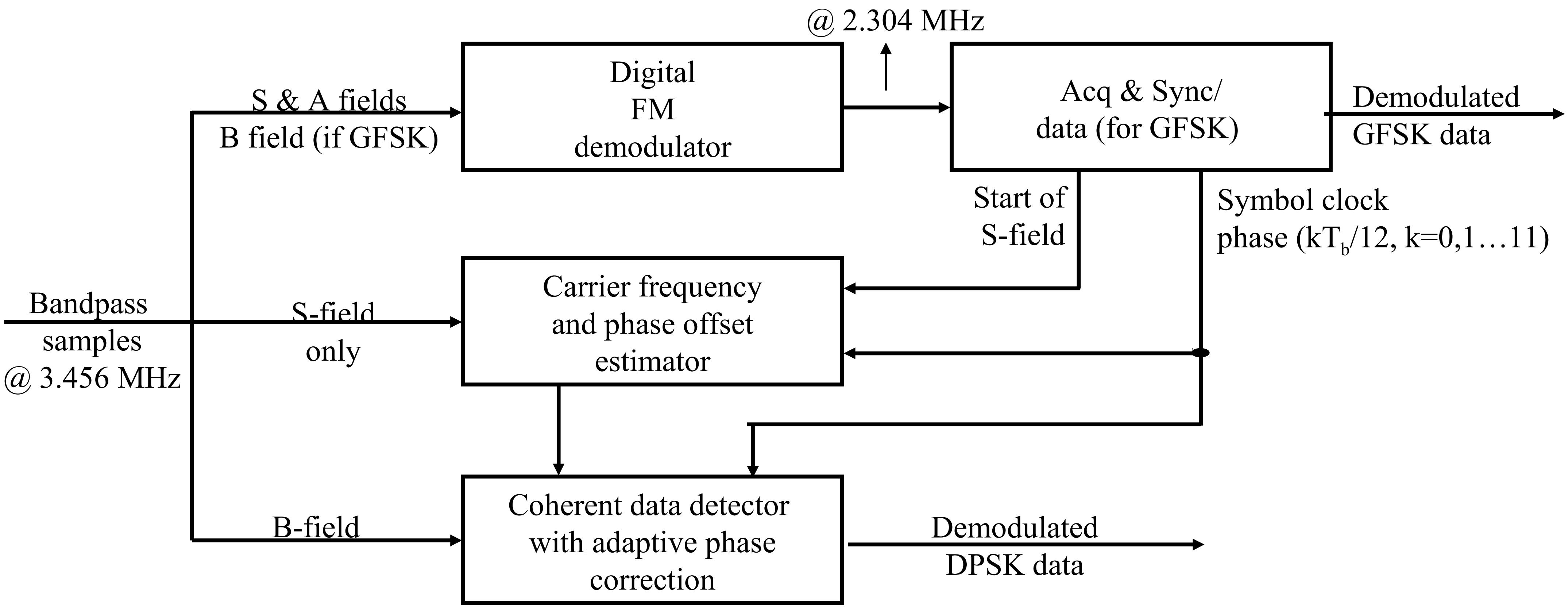
Performance of Different Demodulation Schemes



Tasks in the receiver

- Slot boundary acquisition on power-up/sync loss
- Clock recovery in every slot
- Frequency and phase offset estimation
- Data detection with adaptive carrier phase tracking

Signal Processing in Digital Domain



FM Demodulation

- **An FM signal**

$$r(t) = A\cos(2\pi f_c t + \phi(t))\ ; \qquad \phi(t) = 2\pi k_f \int m(\tau)d\tau + 2\pi \Delta f\, t$$

$$= A\cos(\phi(t))\cos(2\pi f_c t) - A\sin(\phi(t))\sin(2\pi f_c t)$$

$A\cos(\phi(t))$ ↑ $x_c(t)$ $\qquad$ $A\sin(\phi(t))$ ↑ $x_s(t)$

- **Instantaneous phase**

$$\phi(t) = \tan^{-1}(x_s(t)/x_c(t))$$

- **Instantaneous frequency**

$$\frac{d\phi(t)}{dt} = 2\pi k_f m(t) + 2\pi \Delta f$$

Digital FM Demodulator

- r(t) sampled @ 3.456MHz

  $\Rightarrow$ ***$r(n) = x_c(n)\cos(n\pi/2) - x_s(n)\sin(n\pi/2)$***

- $x_c(n) = r(2n+1)(-1)^n$

  $x_s(n) = r(2n)(-1)^n$

  $\Rightarrow$ **$x_c(n)$ and $x_s(n)$ are not samples at same time instant.**

Implementations constraints

- Output of Demodulator should be @ 2.304MHz.

  $\Rightarrow$ **Interpolate $x_c(t)$ and $x_s(t)$ by 4 and then decimate by 3**

ALSO

- For $\tan^{-1}(\ )$ samples of $x_c(t)$ and $x_s(t)$ should be at same time instant

  $\Rightarrow$ **Decimate with different phases**

Digital FM Demodulator (contd.)

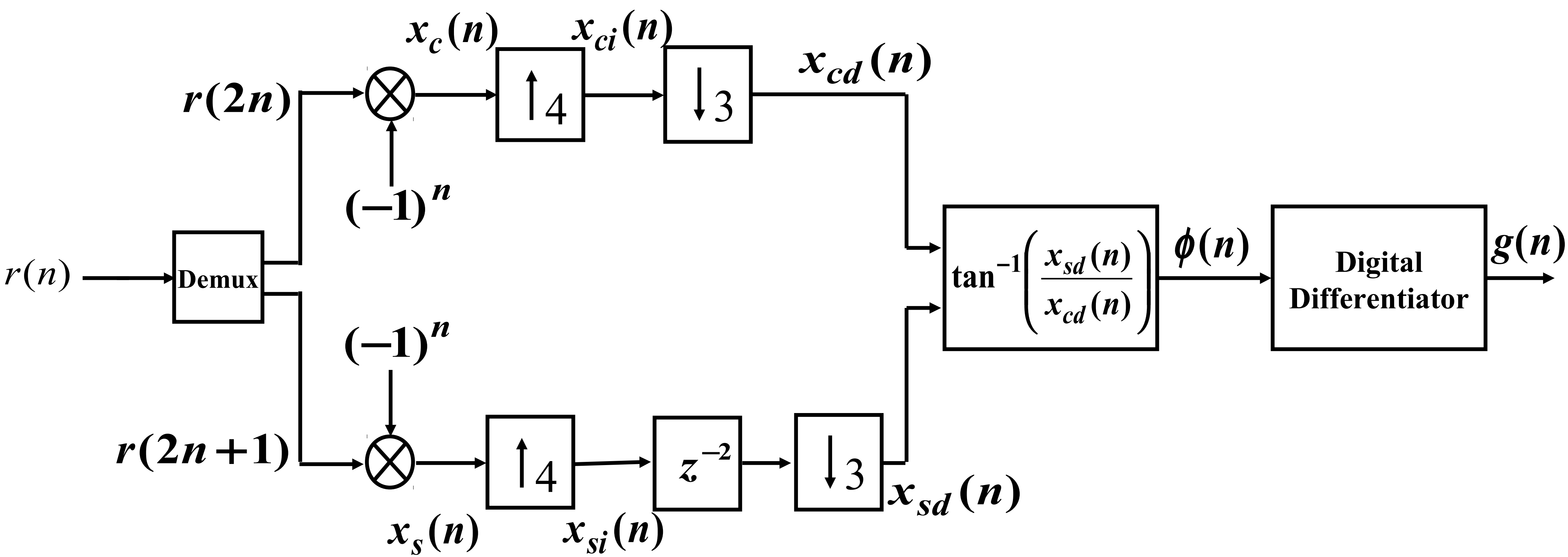
$\text{Tan}^{-1}(\ )$ calculation

- Calculation of $\phi(n) = tan^{-1}(x_s(n)/x_c(n))$ is computation intensive

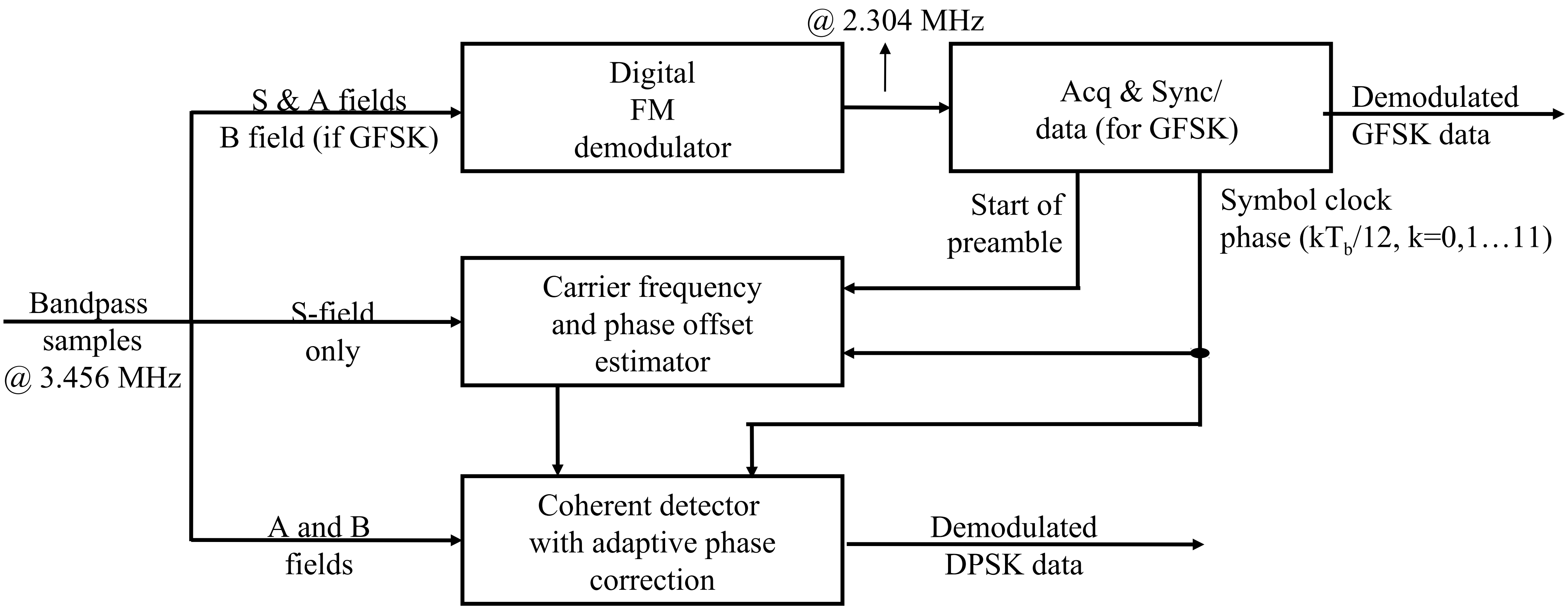
  ⇒ **Table Look-up method**

  Trade-off between computational complexity and memory requirement

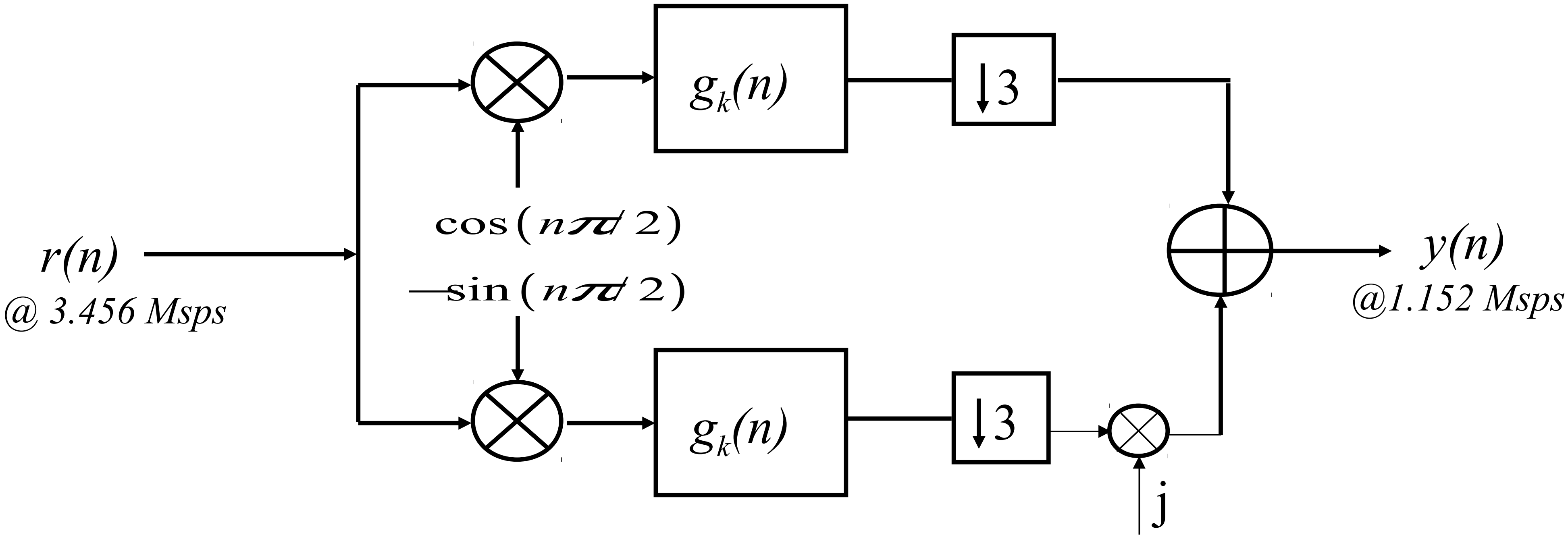
Soft FM demodulator block diagram



Signal Processing in Digital Domain



Soft I/Q Demodulator

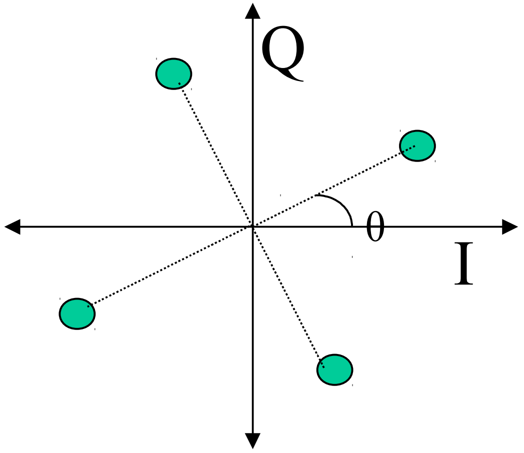


- $g_k(n)$ - root-raised cosine matched filter
  $\Rightarrow g_k(n) = g(nT - kT_b/12), k = 0,1,2.....11$, from clock recovery

Symbols in S-field

- $y(n) = (I_n + jQ_n)\, e^{j(n\alpha + \theta)}$, where $\alpha = 2\pi.\delta f.T_s$
  - S-field (1-0 pattern) always DBPSK

$\Rightarrow y(n) = [I_o + jQ_o][e^{j\theta}, e^{j(\pi/2+\theta)}, e^{j\theta)}, \ldots], \delta f = 0, \theta \neq 0$



Estimation of δf

- $y(n) = A.[I_o+jQ_o].[e^{j\theta}, e^{j(\pi/2+\alpha+\theta)}, e^{j(2\alpha+\theta)}, \ldots]$

- $y_1(n) = y(2n) = A.(I_o+jQ_o).e^{j(2n\alpha+\theta)}$

- $y_2(n) = y(2n+1) = A.(I_o+jQ_o).e^{j\pi/2}.e^{j((2n+1)\alpha+\theta))}$

- For i=1,2

  $y_i(n).y_i^*(n-1) = A^2 e^{j2\alpha} = A^2 [\cos(2\alpha)+j\sin(2\alpha)]$

- Average $y_i(n).y_i^*(n-1)$ over the preamble to get an estimate of α, denoted by $\hat{\alpha}$

Estimation of θ

- Compensate for δf

$$y_d(n) = y(n)e^{-jn\hat{\alpha}} = [I_n + jQ_n]e^{j(\alpha-\hat{\alpha})n+\theta} \approx [I_n + jQ_n]e^{j\theta}$$

- Form two sequences $z_e(n)$, $z_o(n)$

$\Rightarrow z_e(n)$

$$z_e(2n) = y_d(2n)e^{-j\pi/2}$$

$$z_e(2n+1) = y_d(2n+1)$$

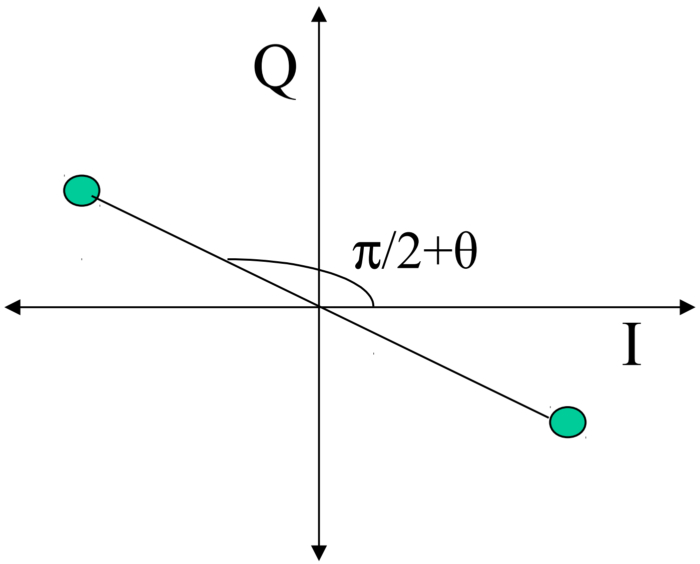
$\Rightarrow z_o(n)$

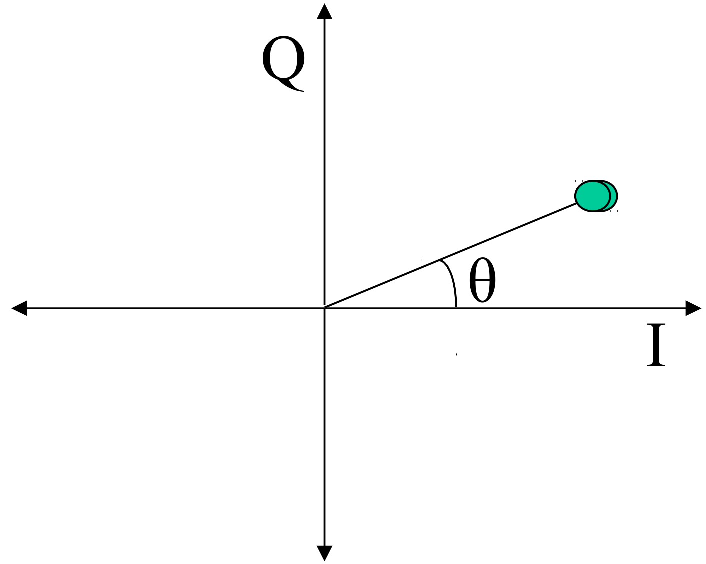
$$z_o(2n) = y_d(2n)$$

$$z_o(2n+1) = y_d(2n+1)e^{-j\pi/2}$$

Estimation of θ (contd.)

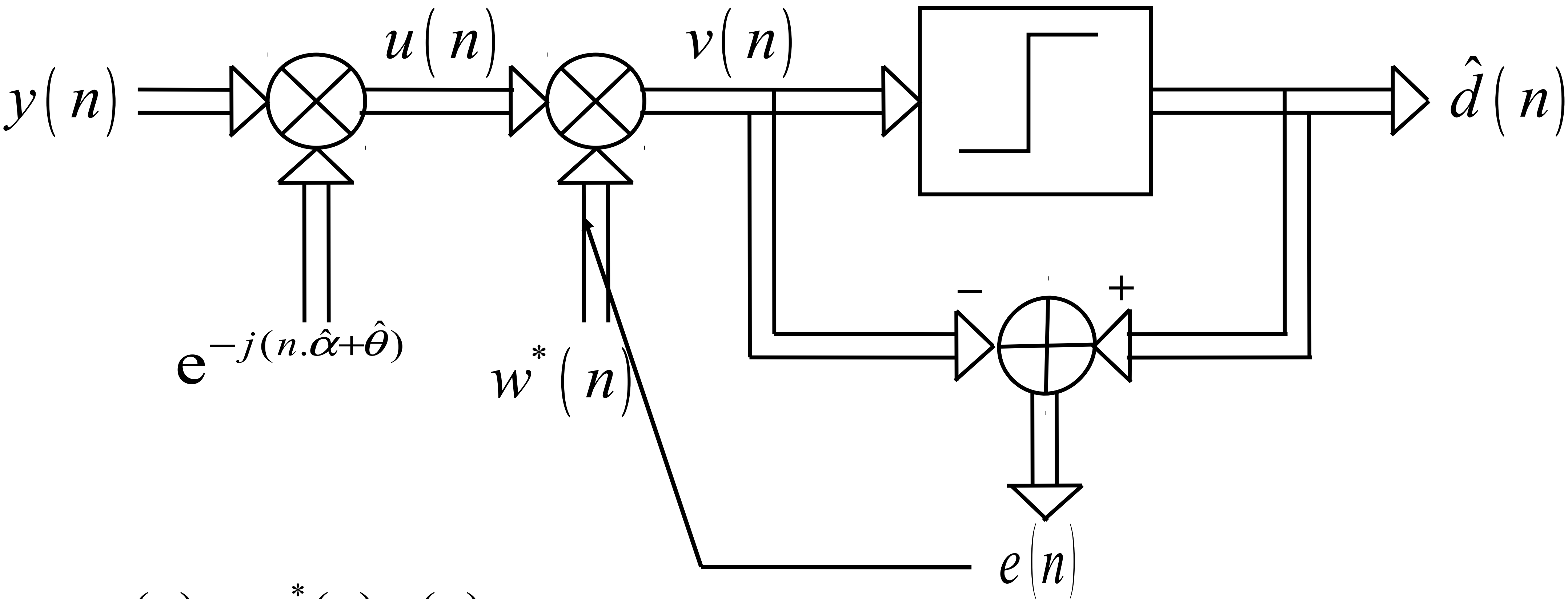
- $z_e(n)$ will be points from one of the following, $z_o(n)$ will be from the other





- The average of $z_e(n)$ or $z_o(n)$ will be small; the other sequence is used to estimate, $\hat{\theta}$

Data detection with Phase Tracking

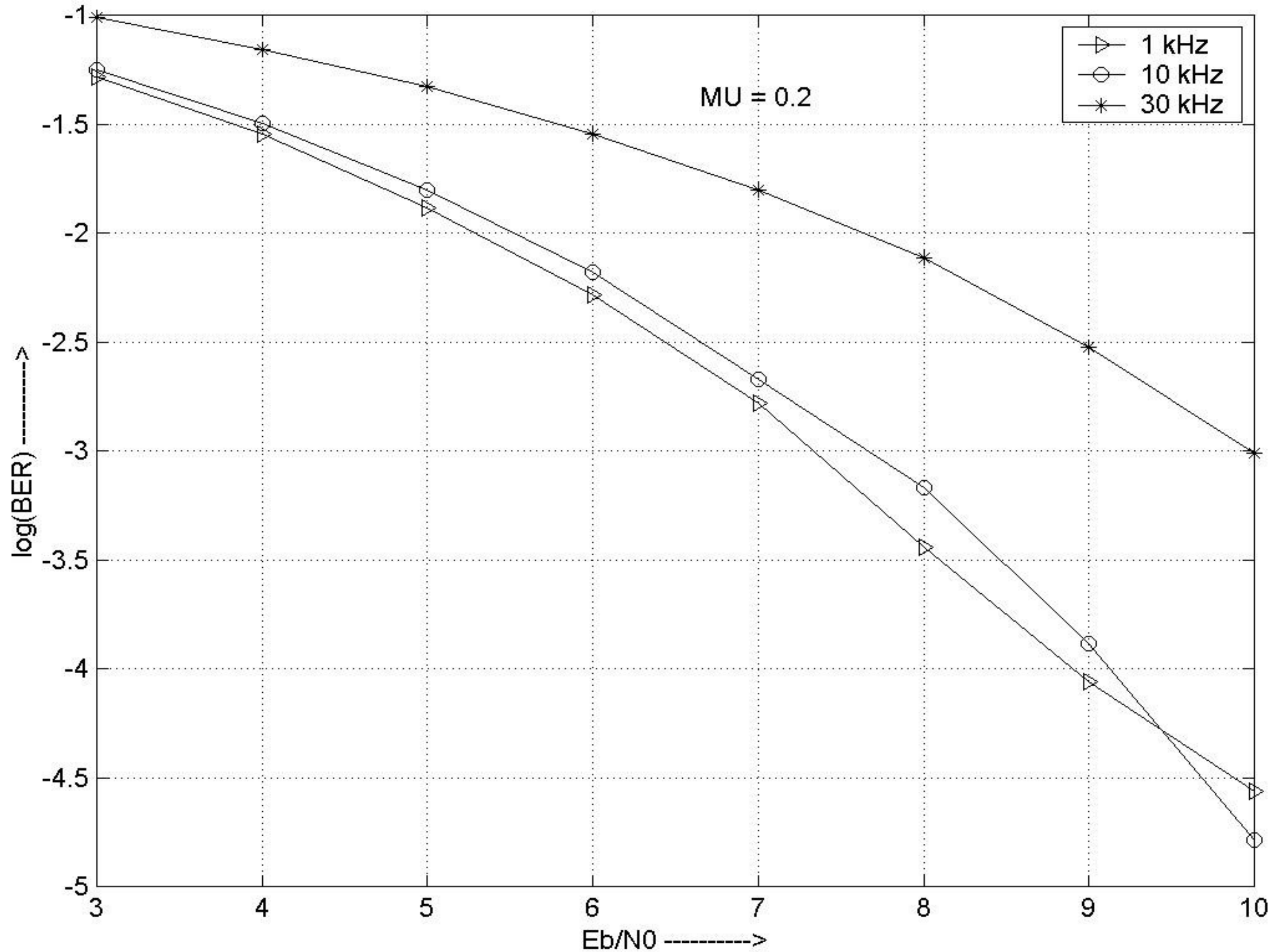


$$v(n) = w^*(n).u(n)$$

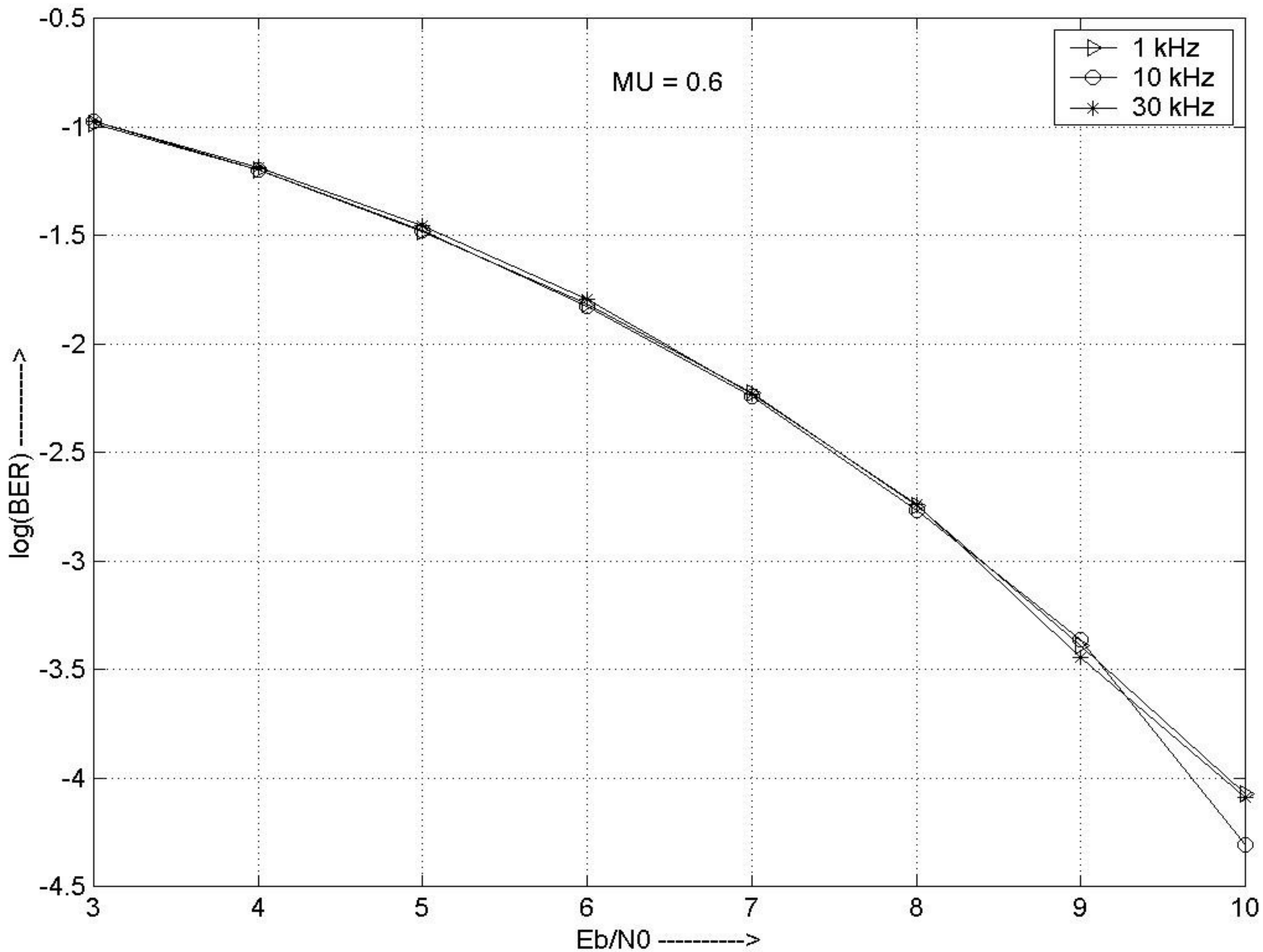
$$e(n) = \hat{d}(n) - v(n)$$

$$w(n) = w(n-1) + \mu.u(n).e^*(n)$$

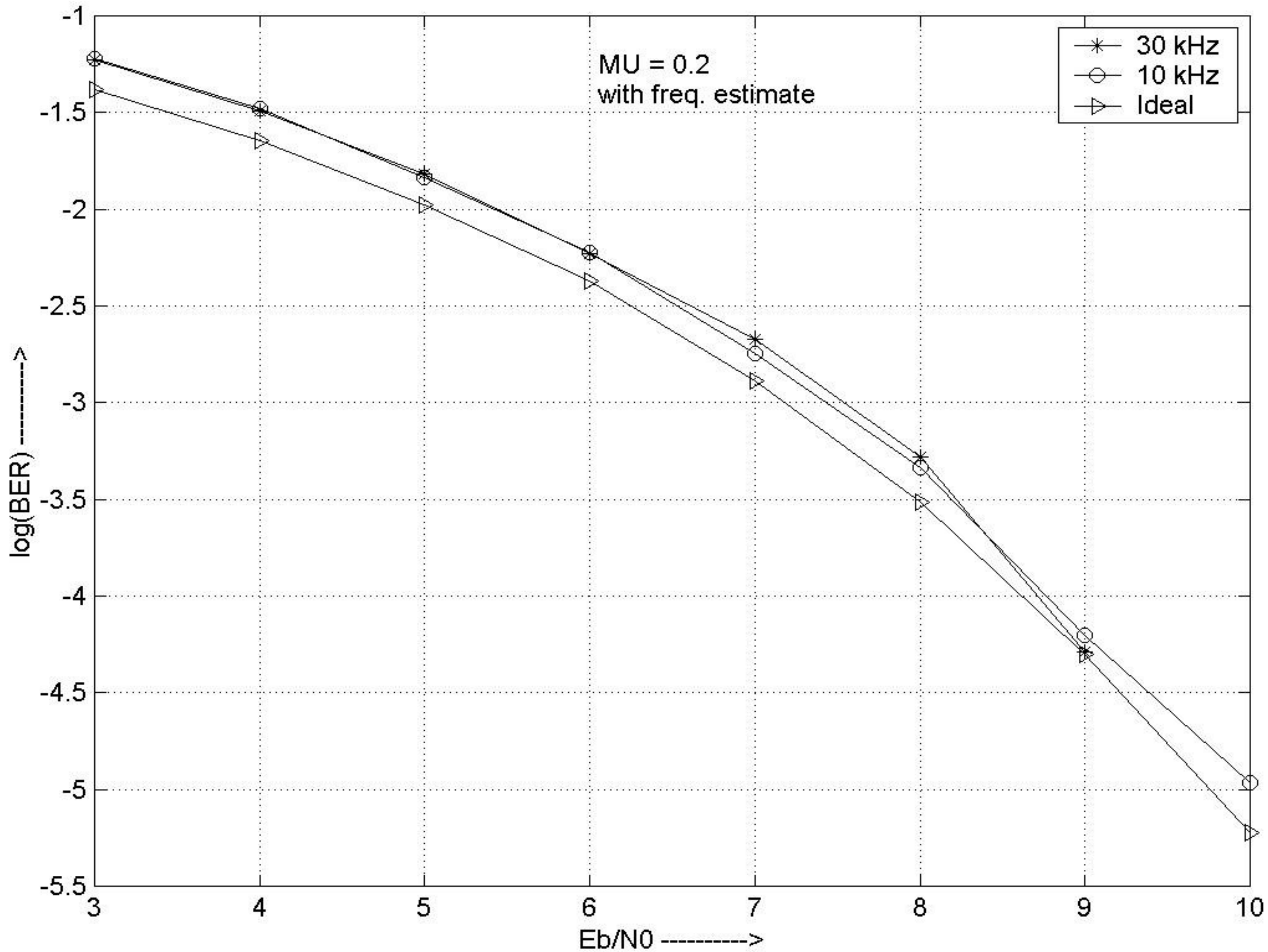
Performance of the LMS Algorithm



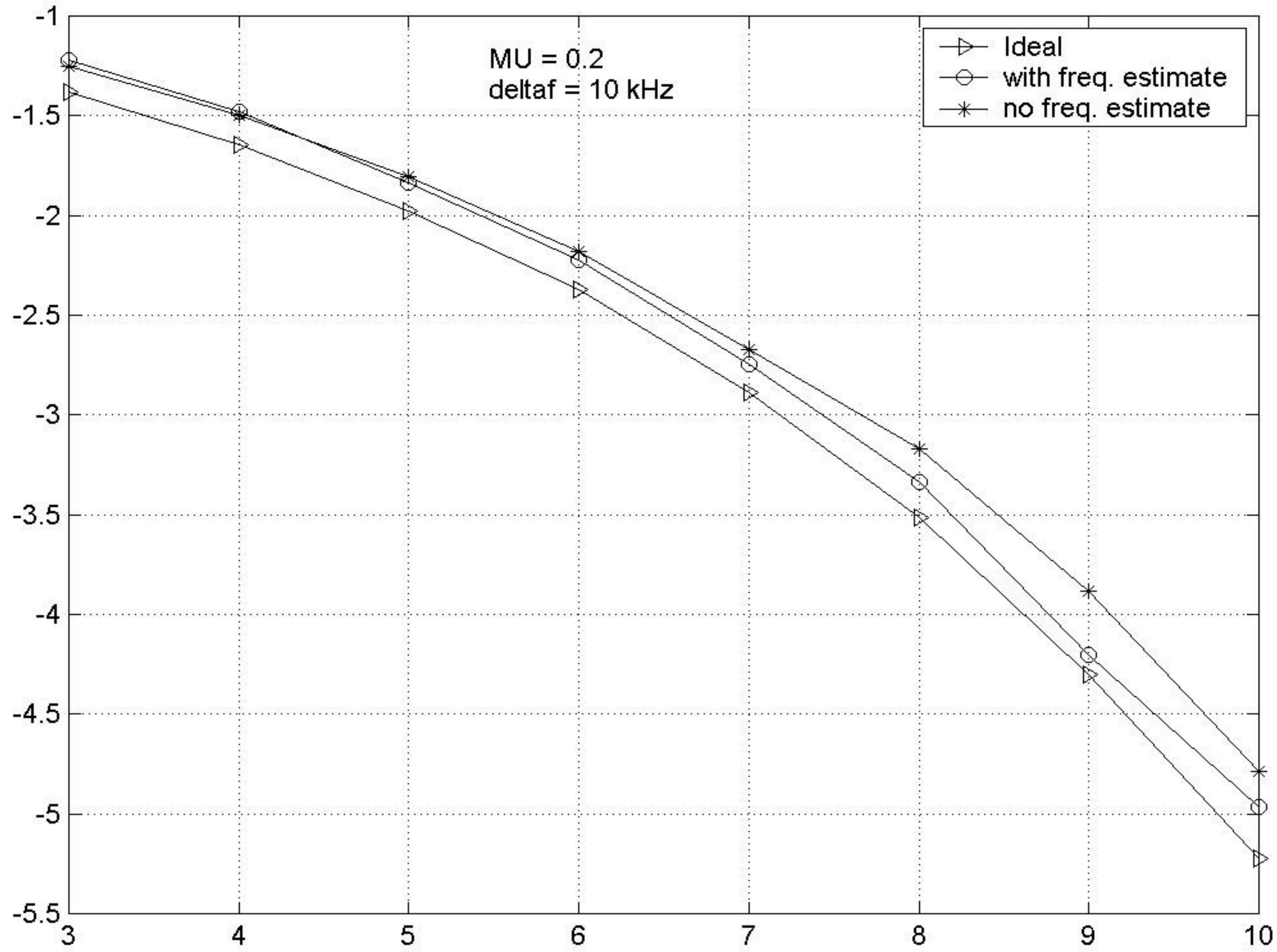
Performance of the LMS Algorithm (contd.)



Performance of the Receiver Algorithm



Performance of the Receiver Algorithm



Conclusions

- Transceiver hardware design for 3G DECT physical layer was presented

- Issues involved in the receiver design were discussed

- Carrier synchronization algorithms were discussed

- Performance results of the receiver were presented