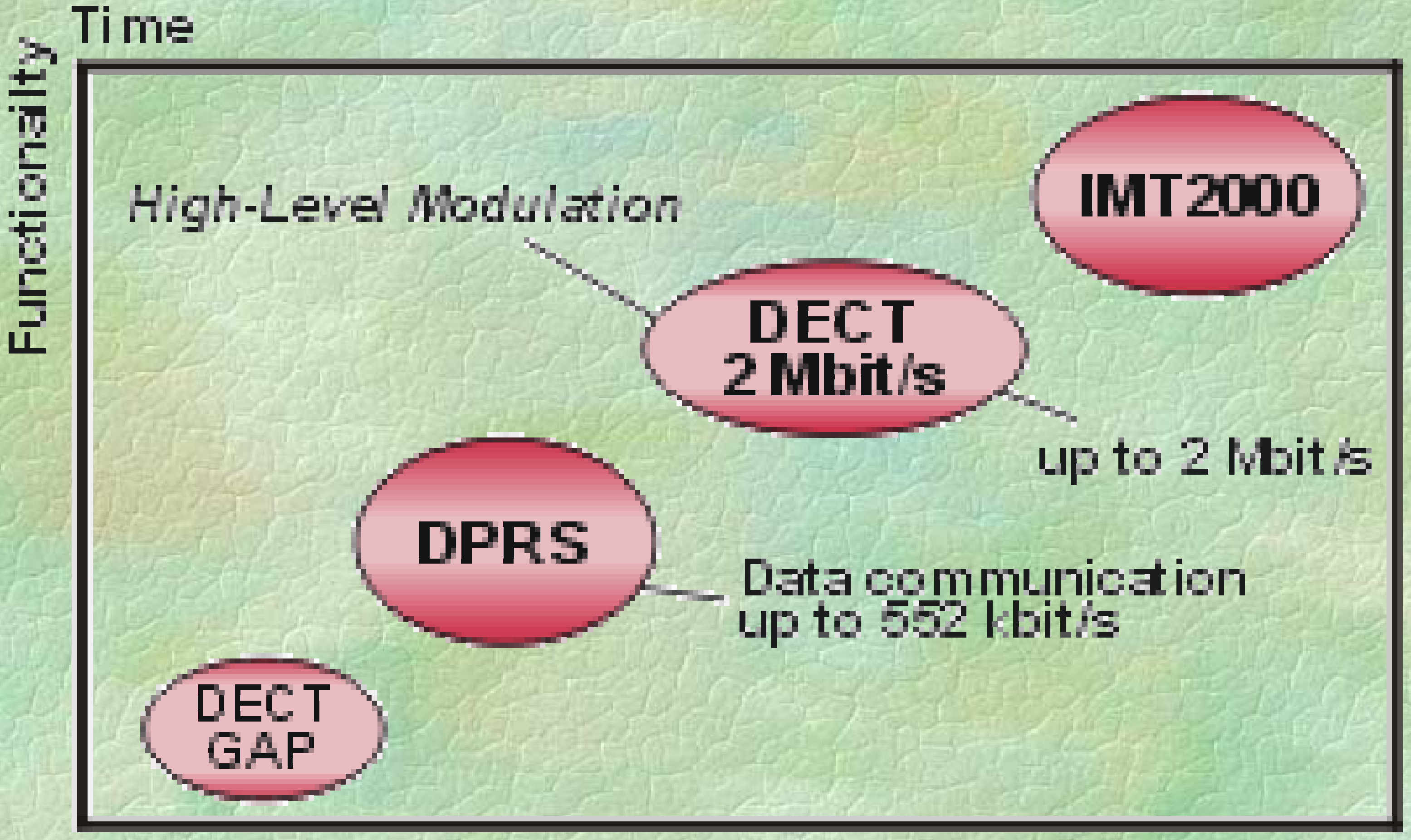
Receiver for 3G DECT Physical Layer

DECT Road Map



DECT - Digital Enhanced Cordless Telecommunications

Overview

- Old DECT specifications
- Transceiver based on old specifications
- New physical layer specifications
- New transceiver implementation
- Issues related to Coherent detection of data

Old DECT Specifications

- Multi-Carrier TDMA TDD system
- Ten RF carriers with centre frequencies given by:

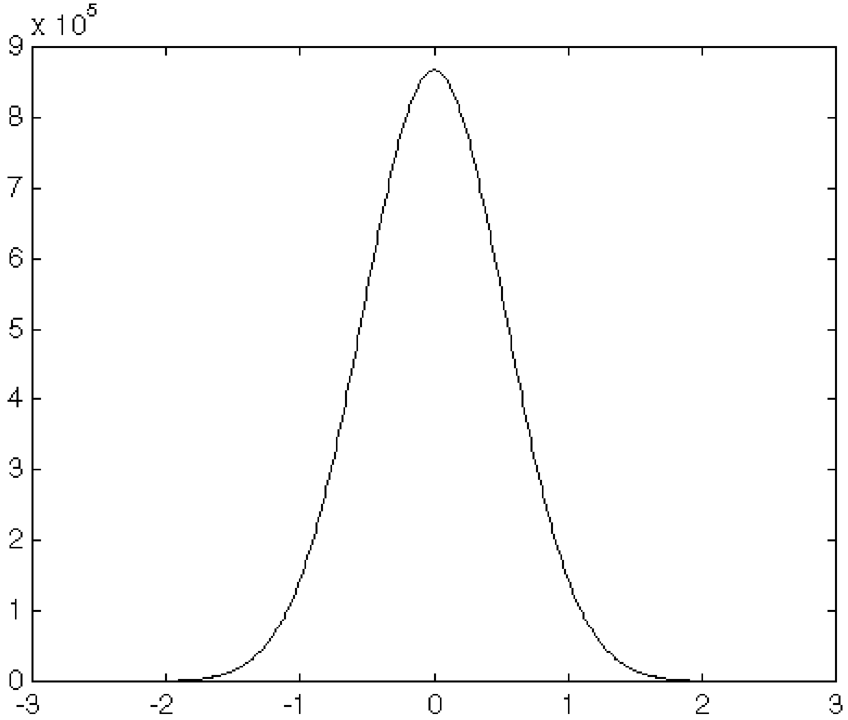
  $F_c = F_0 - c*1.728$ MHz,

where: F_0=1897.344 MHz and $c = 0,1, \ldots, 9$

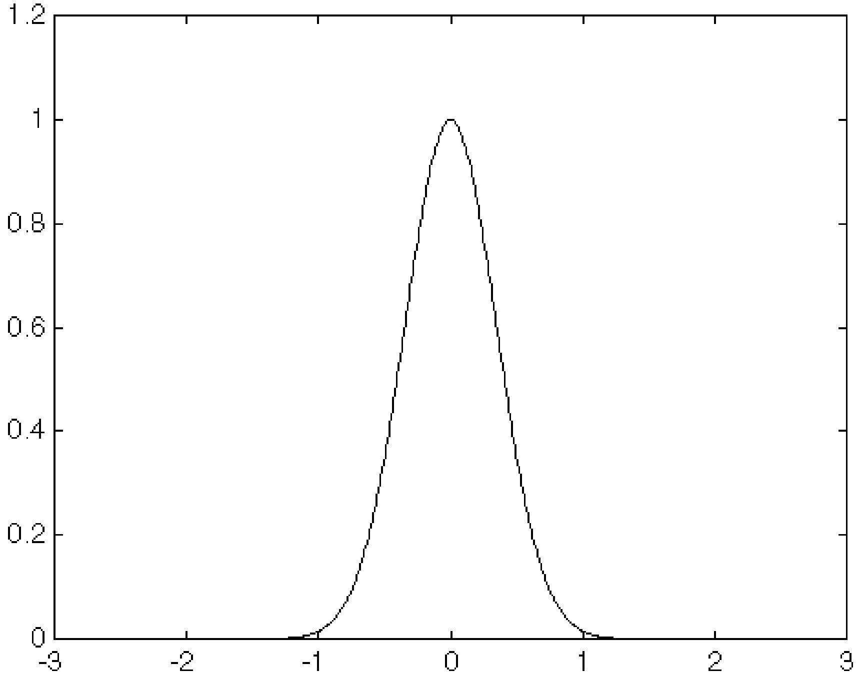
- Bit rate, $R_b = 1/T_b = 1.152$ Mbps
- GFSK modulation with BT_b=0.5
- Binary ‘1’ is encoded as f_1= Fc + 288 kHz and Binary ‘0’ is encoded as f_0= Fc - 288 kHz, nominally.

Note: GFSK and not GMSK because frequency deviation can vary up to 403 kHz or down to 202 kHz

Gaussian pulse with BT_b=0.5



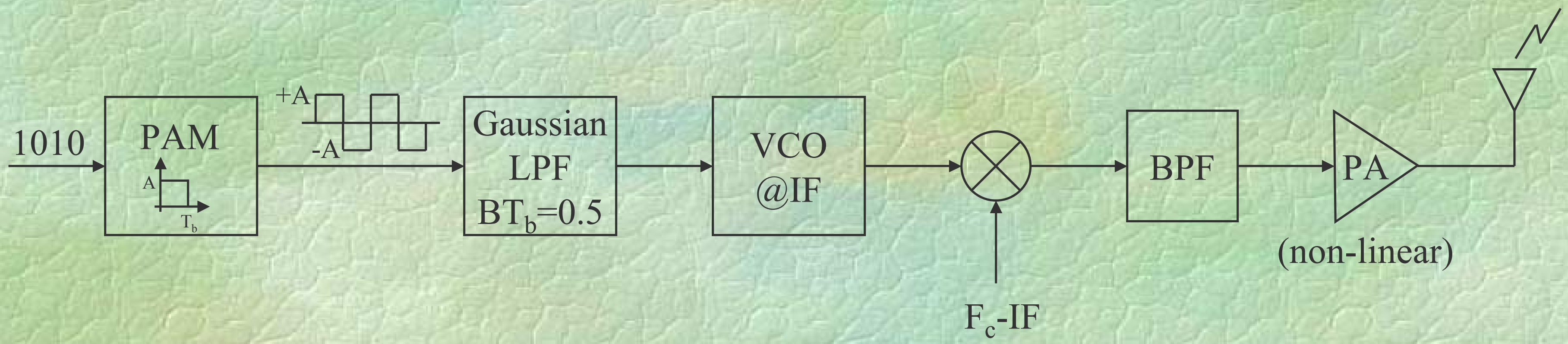
Time domain waveform
(plotted versus t/T_b)



Magnitude spectrum
(with frequency in MHz)

- With 1.152Mbps bit rate, 3dB BW, $B = 0.5/T_b = 576$ kHz
- Non-zero ISI, though not considerable

GFSK modulator

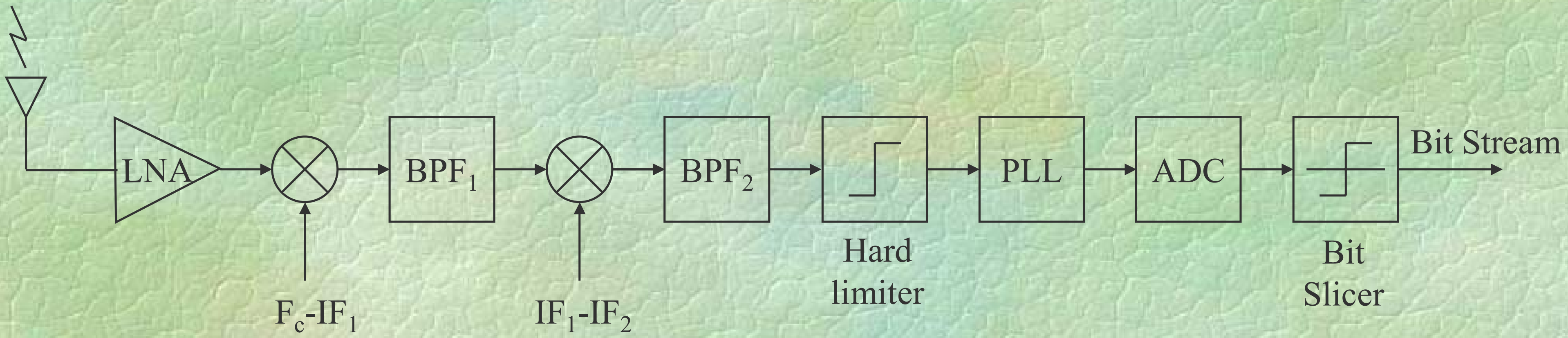


- Implemented as a simple VCO-based FM modulator
- Transmit Power spectrum:

  With frequency deviation, $\Delta f = 288$ kHz and
  max. modulating frequency, $f_m \approx 288$ kHz

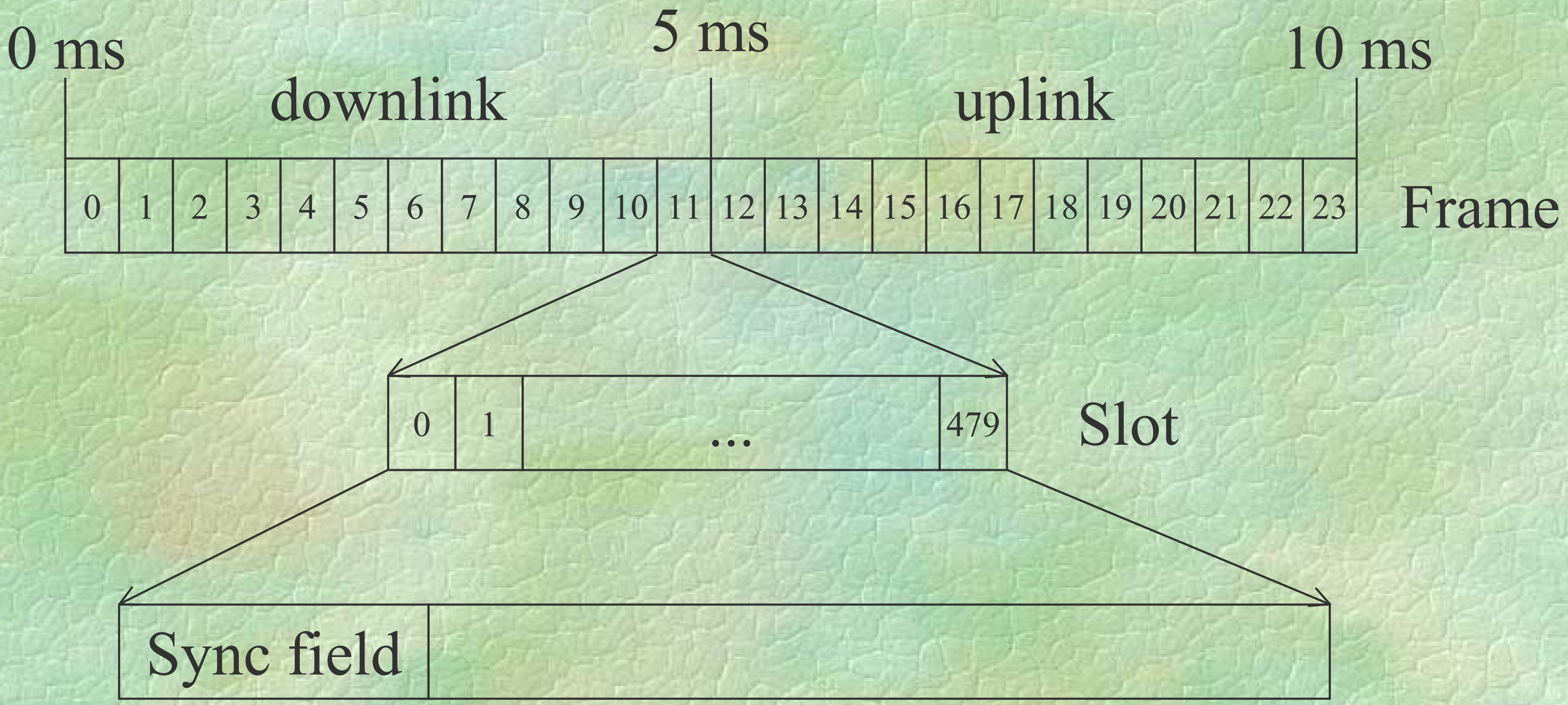
  - Carson’s rule: $2(\Delta f + f_m) = 1.152$ MHz
  - 99% BW rule: $\beta = \Delta f / f_m = 1$, BW $= 6 x f_m = 1.728$ MHz

GFSK Demodulator



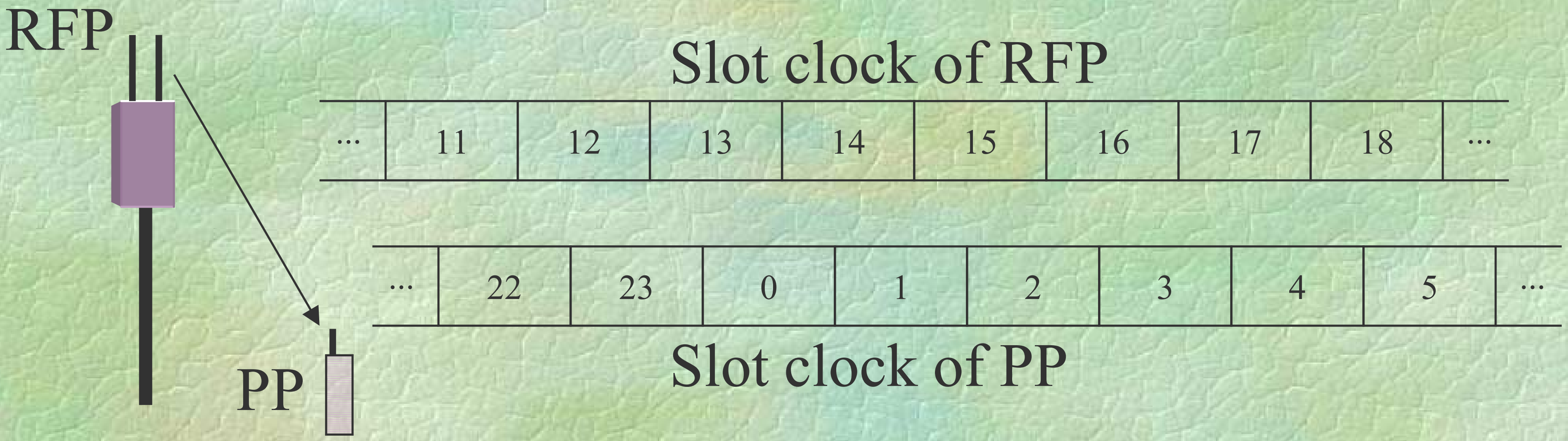
- PLL-based FM demodulator
- Sub-optimal because noise at the output of the PLL does not have Gaussian statistics

TDMA Frame Structure



- Synchronization field: 32 bits wide
  first 16 bits: alternating 1,0 pattern - sync word
  last 16 bits: fixed bit pattern - preamble

PP-RFP Synchronization on power-up



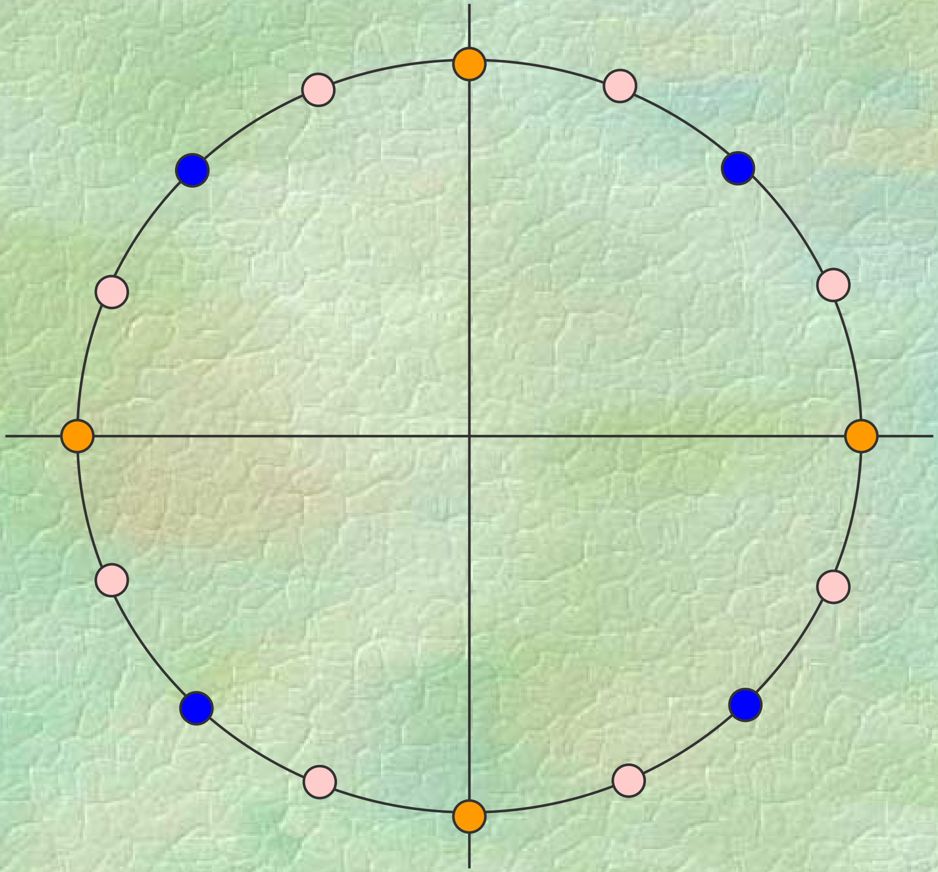
RFP - Radio Fixed Part; PP - Portable Part

When the PP is powered on, initially

- Detect RFP activity from RSSI measurements
- Detect synchronization pattern in the received data
- Align local clocks based on control information from the RFP

New Physical Layer Specifications

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



● π/2 DBPSK

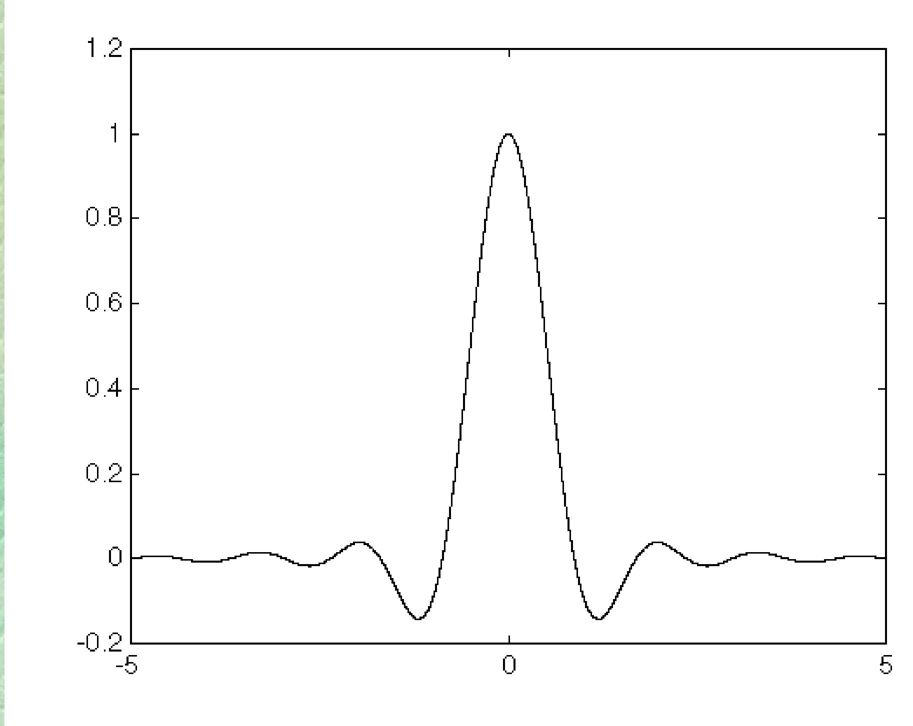
● ● π/4 DQPSK

● ● ● π/8 D8PSK

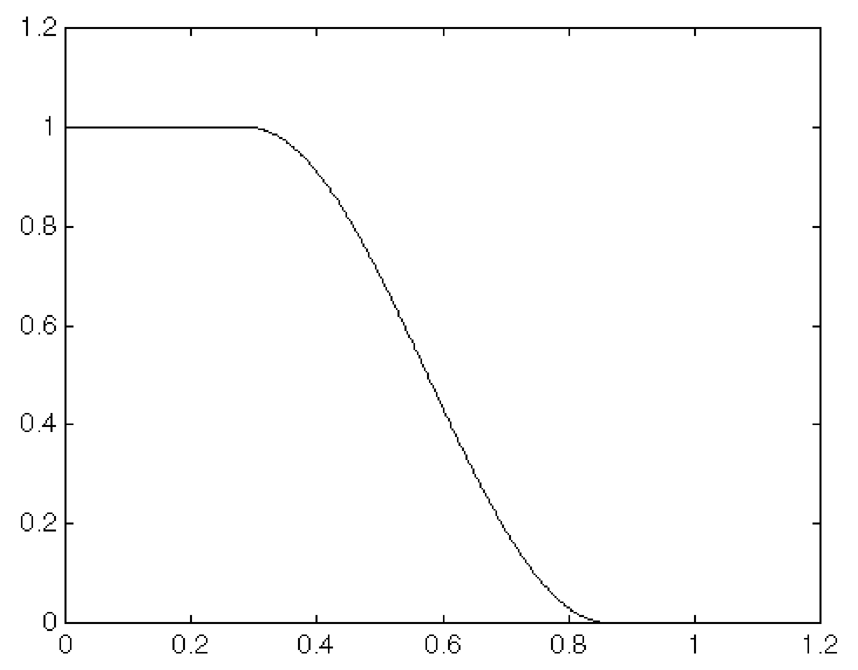
Constellation for differential PSK modulation

New Physical Layer Specifications (contd.)

- Pulse shaping filter: Root-Raised Cosine with $T_s = (1/1.152)\ \mu s$, where T_s is the symbol duration, and roll-off factor, $\alpha = 0.5$;
- Zero ISI at the output of the receiver match filter



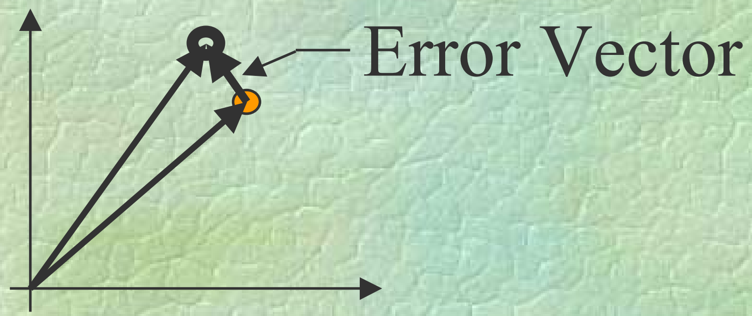
Normalized time domain waveform (plotted versus t/T_b)



Power spectrum (frequency in MHz)

New Physical Layer Specifications (contd.)

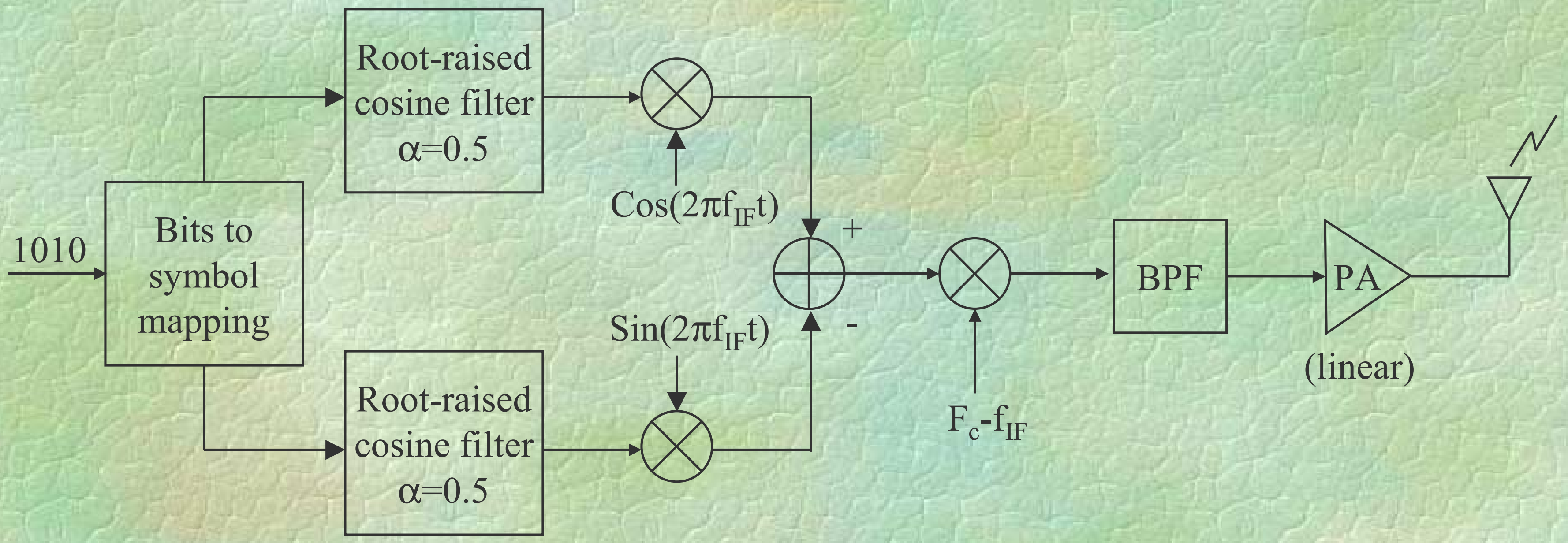
- Modulation accuracy defined in terms of vector error magnitude (VEM).



- VEM < 0.125 in a slot for DBPSK and DQPSK
- VEM < 0.06 in a slot for D8PSK

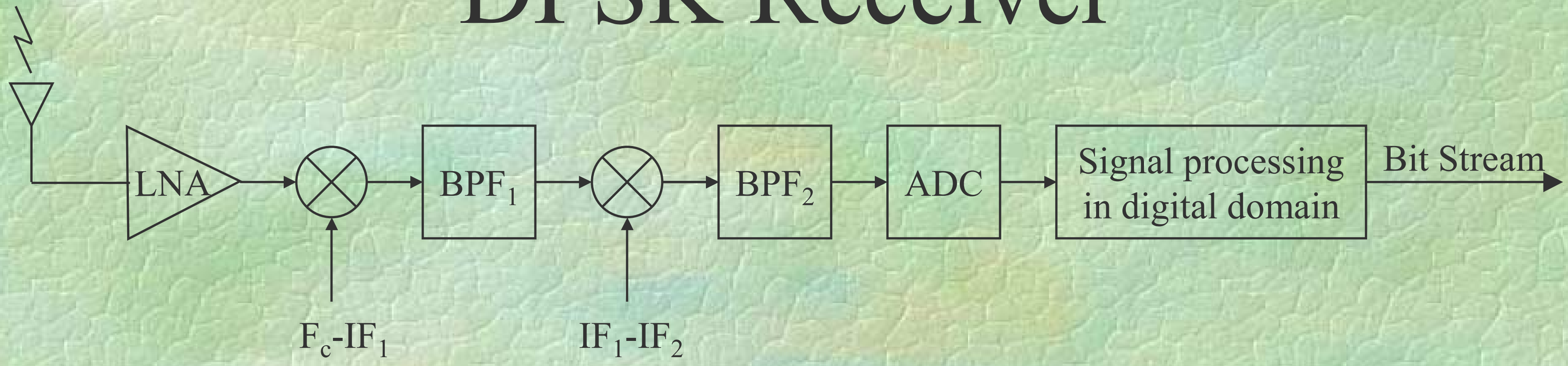
- Modulation accuracy requirements allow coherent detection

DPSK Transmitter

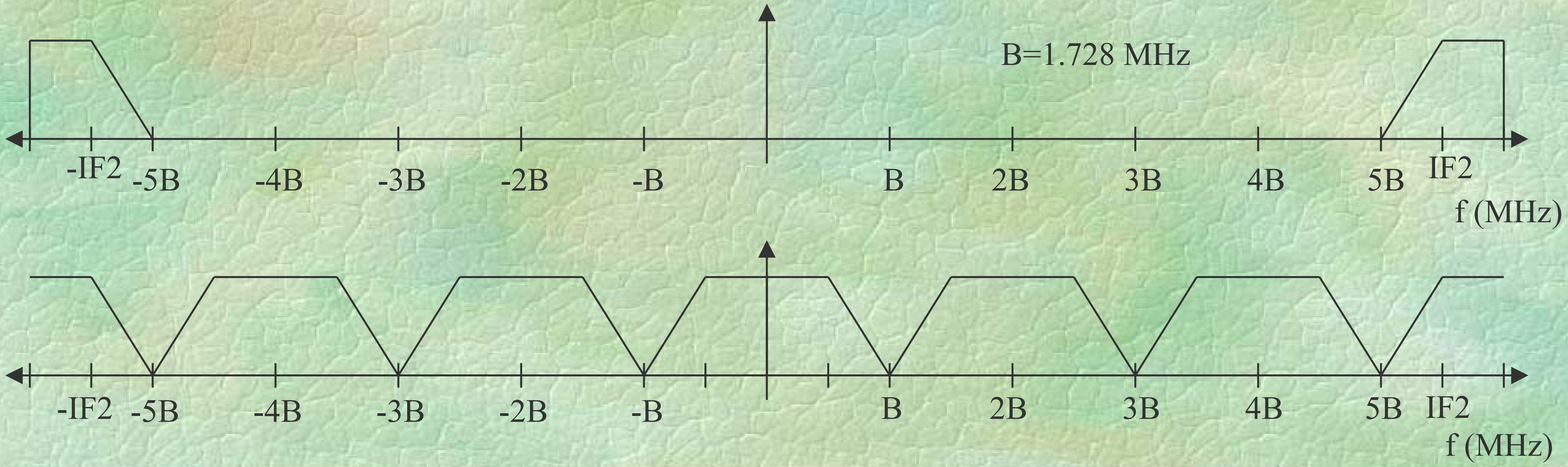


- I/Q modulator at IF and then up-converted to F_c
- Transmit Power spectrum: Passband BW = 2x(baseband BW) = 2x(1+0.5)x(576kHz) = 1.728 MHz

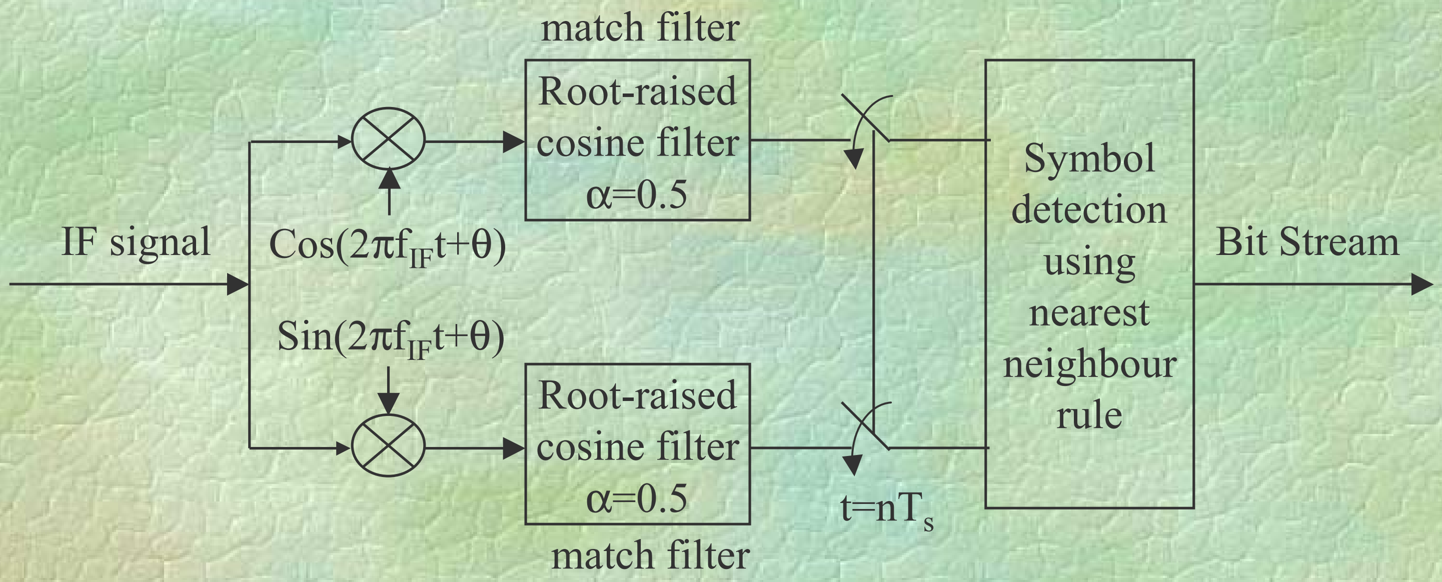
DPSK Receiver



- IF2 = (5+0.5)x1.728 = 9.504 MHz
- Perform bandpass sampling @ 3.456 MHz



Issues in Coherent Detection



match filter

Root-raised cosine filter $\alpha=0.5$

IF signal

$\mathrm{Cos}(2\pi f_{IF}t+\theta)$

$\mathrm{Sin}(2\pi f_{IF}t+\theta)$

Root-raised cosine filter $\alpha=0.5$

match filter

$t=nT_s$

Symbol detection using nearest neighbour rule

Bit Stream

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

Issues in Coherent Detection (contd.)

- +/-50 kHz - allowed carrier frequency offset at RFP and PP

$$\Delta\Phi = 2\pi * 100 * 10^3 * \left(1 / 1.152 * 10^6 \right) = 0.1736 * \pi \text{ rad/symbol}$$

- Estimate frequency offset with sufficient accuracy, so that residual frequency offset contributes nearly constant phase offset over each symbol.

- Phase offset is tracked and corrected at the end of each symbol

Issues in Coherent Detection (contd.)

- Symbol clock accuracy specifications:
  < 25 ppm at PP and < 10 ppm at RFP

- Net drift in one slot using a 27.648 MHz oscillator

$$\Delta T / T_s = \left(35 / 10^6 \right) * 480 * \left(27.648 * 10^6 / 1.152 * 10^6 \right) * \left(1.152 * 10^6 / 27.648 * 10^6 \right) = 0.0168$$

- Recover symbol clock phase at the beginning of each slot - no need for tracking.

Tasks in the receiver

- Slot acquisition on power-up, or when frame/slot synchronization is lost
- Coarse frequency estimation every frame, or once every N frames, and on connection handover
- Clock phase recovery in every slot
- Refined frequency and phase estimation in every slot
- Data detection and frequency offset tracking and correction every symbol

FM Demodulator in Software

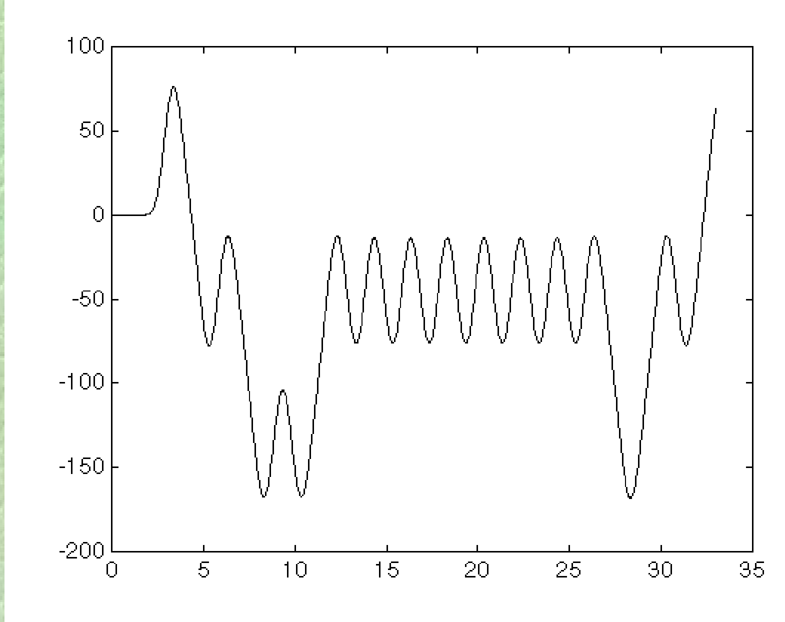
- Sync pattern always employs $\pi/2$ DBPSK which can be detected in a non-coherent GFSK receiver too.

- New receiver has a software-based FM demodulator to be able to demodulate GFSK modulated signals.

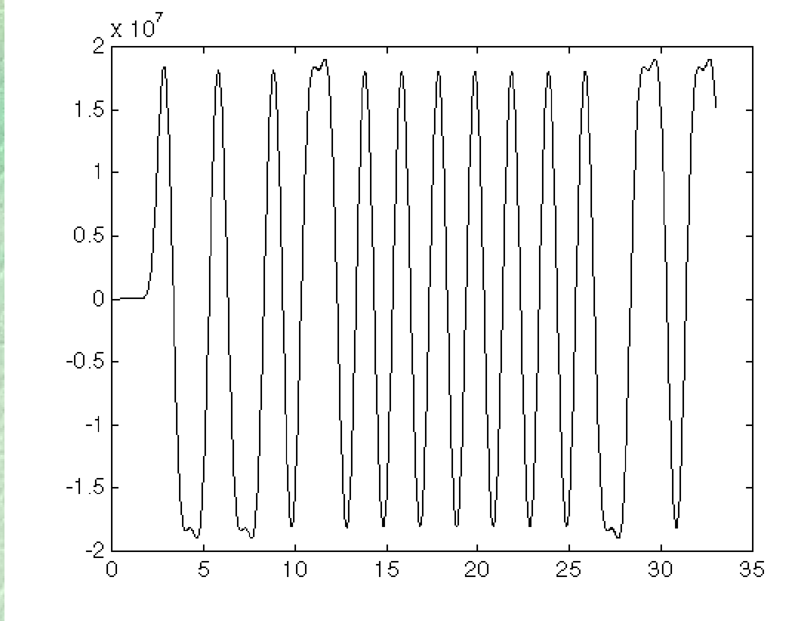
- FM demodulator is used in coherent detector too - for slot acquisition, clock phase recovery and coarse frequency estimation.

- Carrier frequency estimate is then refined in baseband, after I/Q demodulation.

Carrier frequency and phase plots

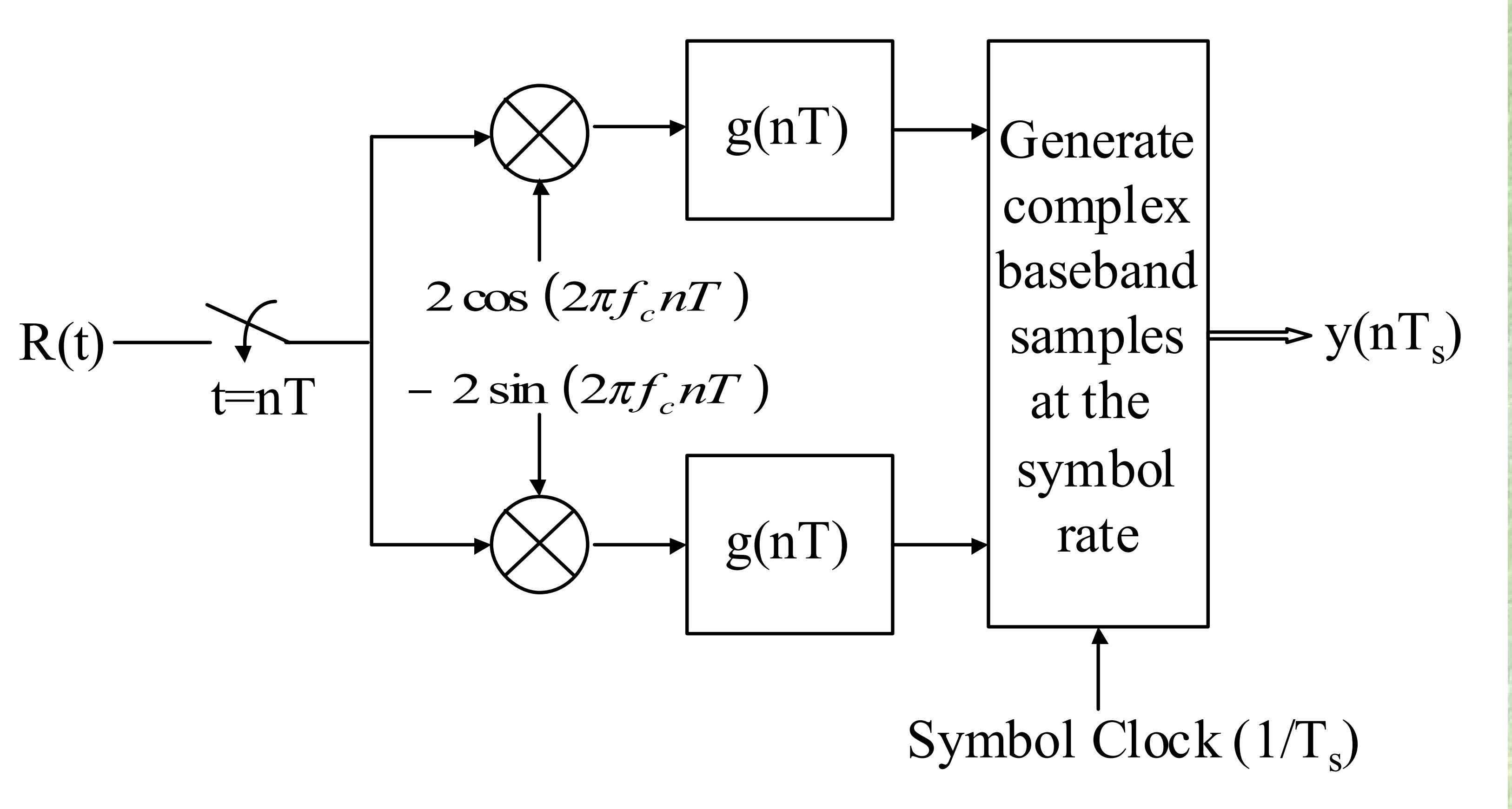


Carrier phase plot for sync word buried in random data



Instantaneous carrier frequency for sync word buried in random data

Software I/Q demodulator



- R(t) - Received IF signal
- g(nT) - root-raised cosine match filter
- Sampling rate, 1/T = 3.456 MHz = 3/Ts, where T_s is the symbol clock @ 1.152 MHz

Refined Carrier Frequency Estimation

$$R(nT) = \sum_m \{I_m \cos(2\pi(f_c + \delta f)nT + \theta) - Q_m \sin(2\pi(f_c + \delta f)nT + \theta)\} \cdot g(nT - mT_s) + w(nT)$$

I-phase arm: $[R(nT) * 2\cos(2\pi \cdot f_c \cdot nT)] \otimes g(nT)$

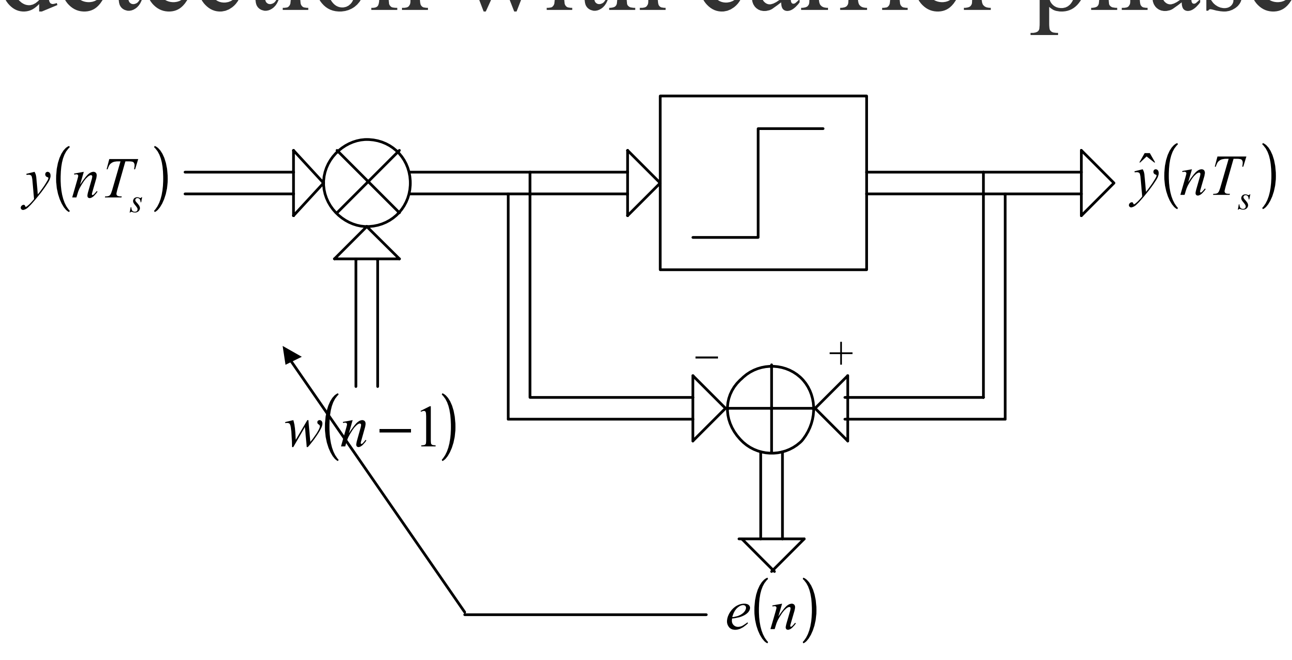
Q-phase arm: $[R(nT) * -2\sin(2\pi \cdot f_c \cdot nT)] \otimes g(nT)$

$y(nT_s) = (I_m + jQ_m) * K_m$, where $K_m = \exp\{j(2\pi \cdot \delta f \cdot nT_s + \theta)\}$.

- $I_m + jQ_m$ alternate between 1+j0 and 0+j1 in the sync word
- Estimate δf differentially after undoing the above modulation
- Estimate θ after estimating δf

Note: Estimates of δf and θ have to made by averaging over many symbol durations.

Data detection with carrier phase tracking



$$e(n) = \hat{y}(nT_s) - [w(n-1) \cdot y(nT_s)];$$

The update $w(n)$ is computed as follows,

$$w(n) = w(n-1) + \mu \cdot e^*(n) \cdot y(nT_s)$$ where, μ is a real constant.

$$w(n) = \frac{w(n)}{\|w(n)\|}$$ (for ensuring that the phase de-rotator has unit gain)