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Fast acquisition GPS receivers

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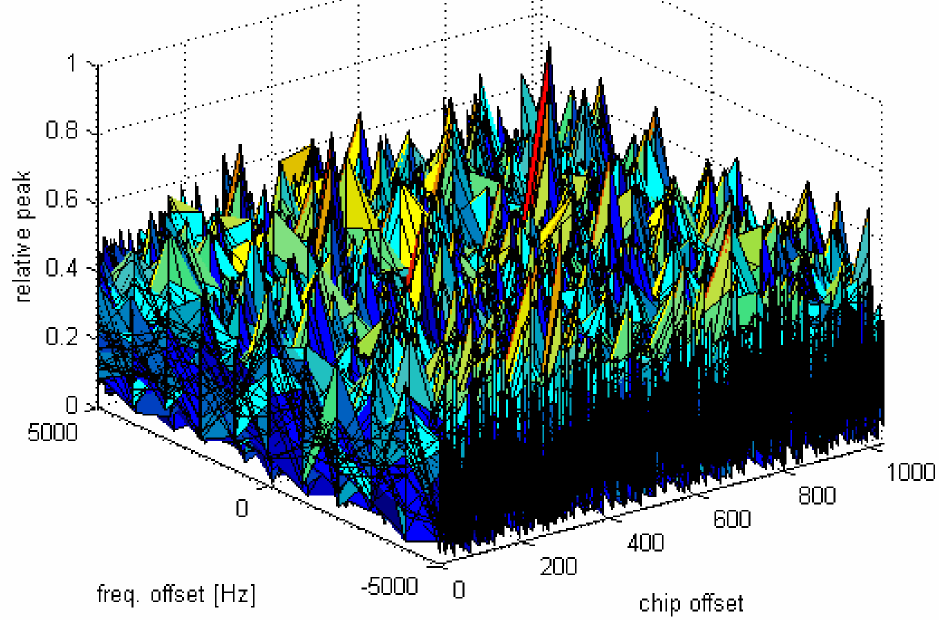
Preview

- Motivation for fast acquisition schemes
- first new receiver: post-correlation FFT
- second new receiver: AFSR
- Conclusions

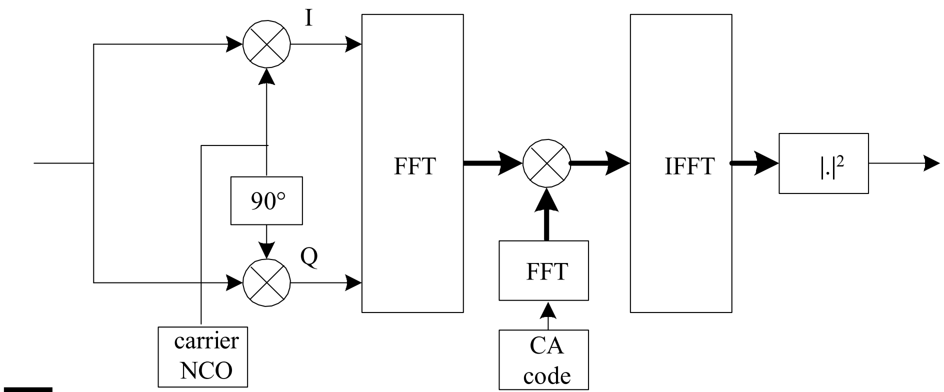
Motivation

- search space of acquisition task is huge
- example: 2046 code positions (half-chip)
  ±5kHz Doppler uncertainty
  ±30kHz frequency offset (20ppm)
- resolution better than 250Hz (for 1ms I&D)

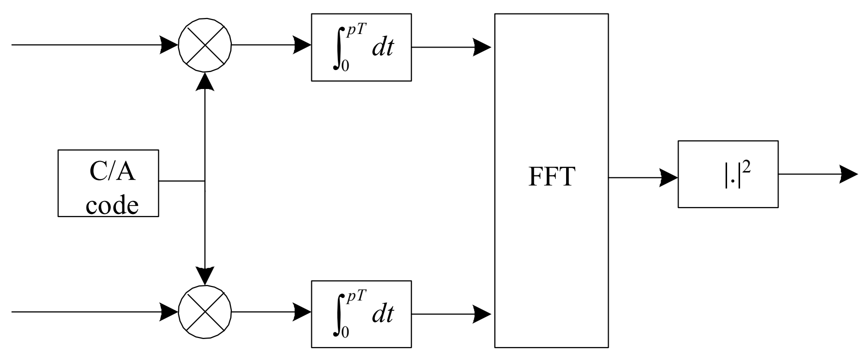


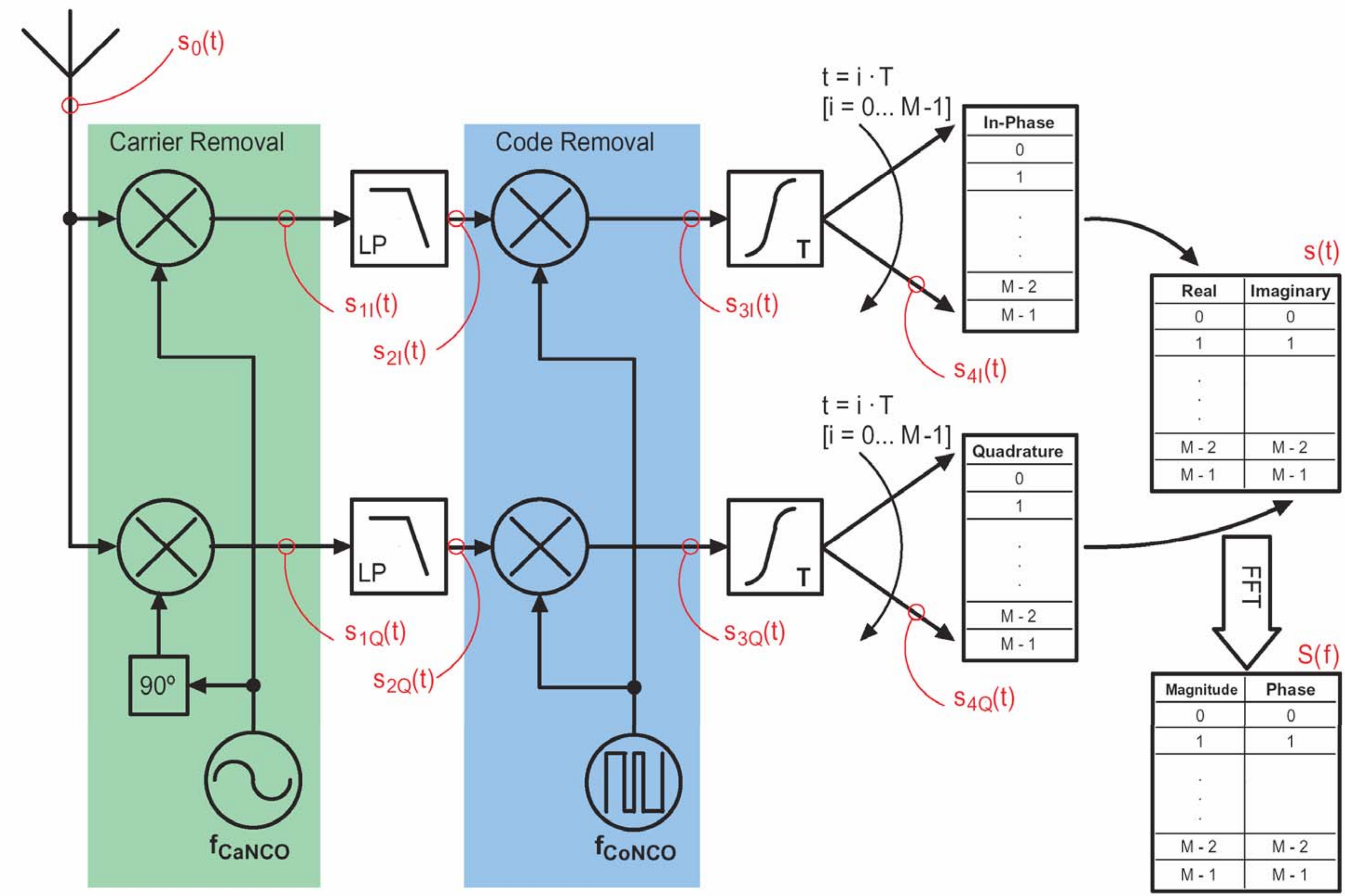
Fast-acquisition algorithms

- massive parallelism
- FFT approach (software receiver)



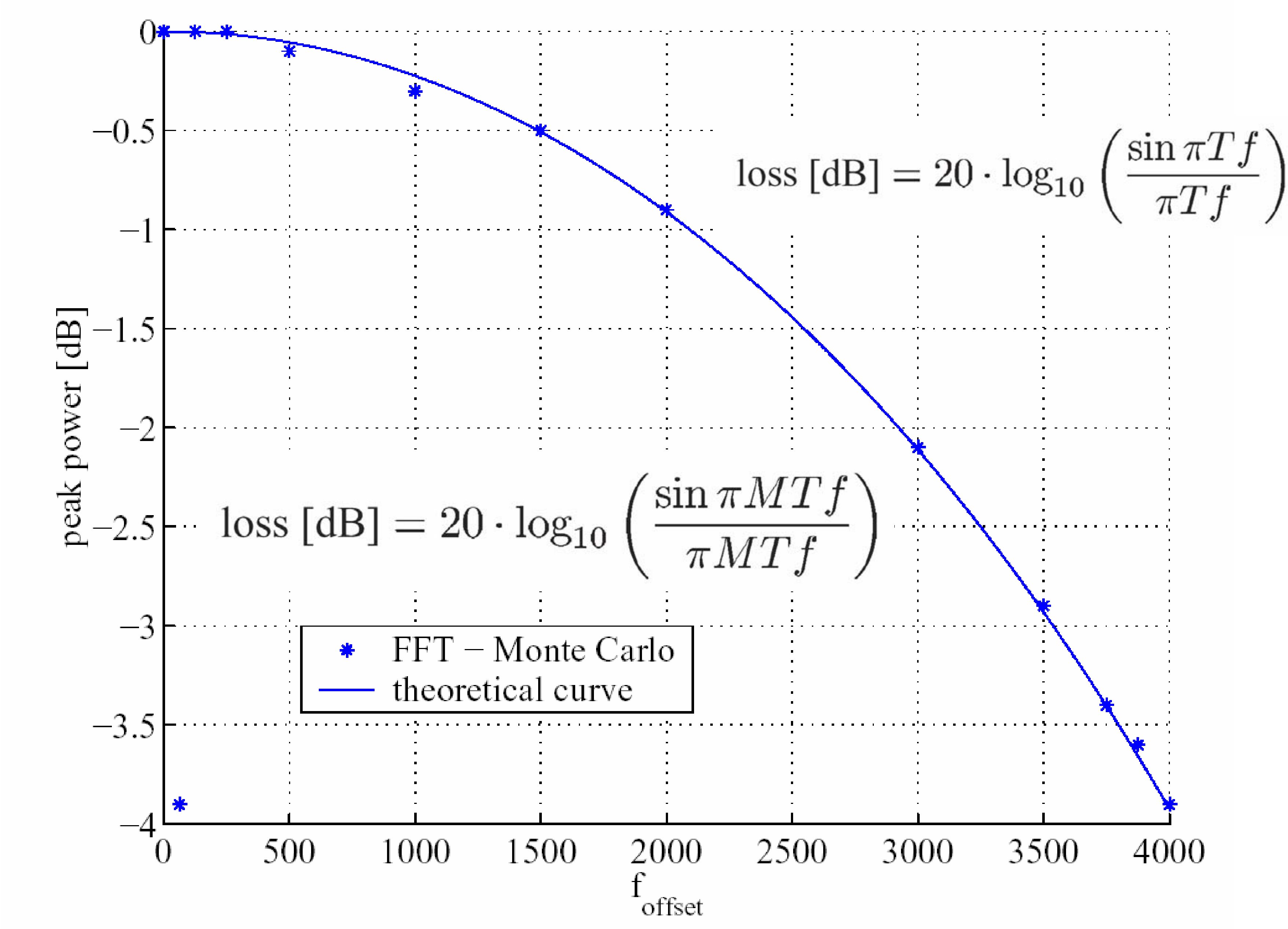
- post-correlation FFT

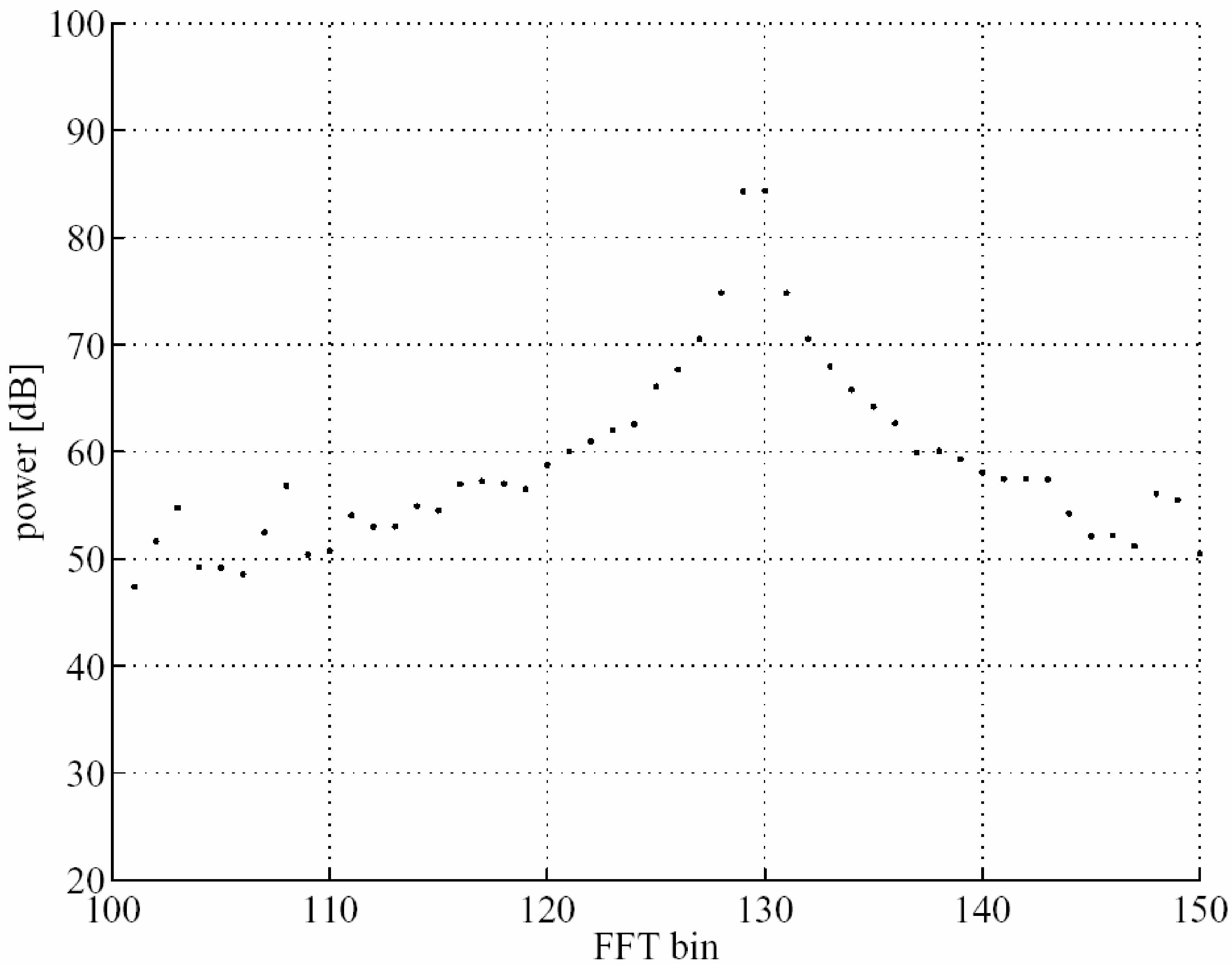


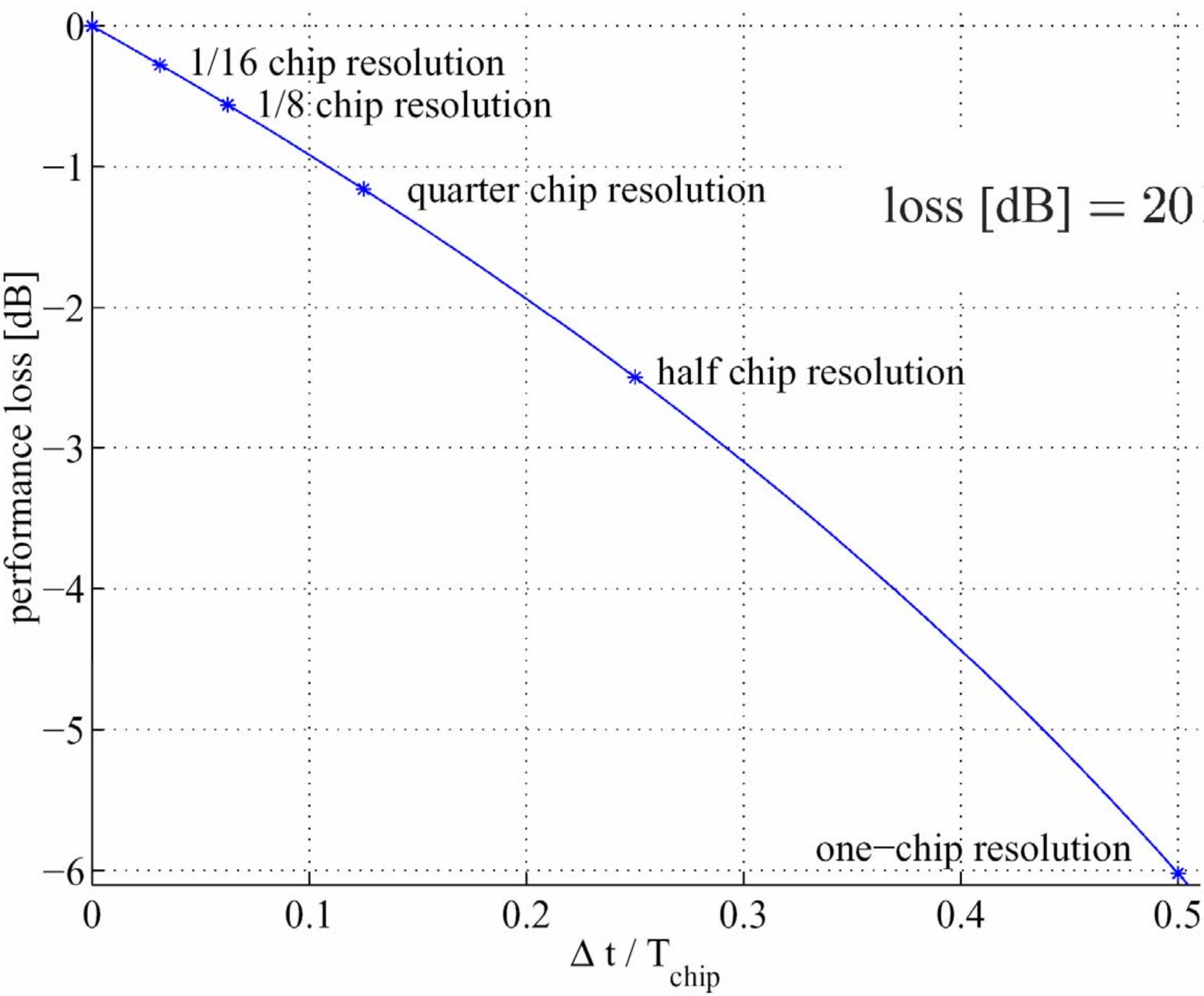

$s_0(t)$
Carrier Removal
Code Removal
LP
LP
T
T
90°
f_{CaNCO}
f_{CoNCO}
$s_{1I}(t)$
$s_{2I}(t)$
$s_{3I}(t)$
$s_{4I}(t)$
$s_{1Q}(t)$
$s_{2Q}(t)$
$s_{3Q}(t)$
$s_{4Q}(t)$
$t = i \cdot T$
$[i = 0 \ldots M-1]$
$t = i \cdot T$
$[i = 0 \ldots M-1]$
In-Phase
0
1
M - 2
M - 1
Quadrature
0
1
M - 2
M - 1
s(t)
Real
Imaginary
0
0
1
1
M - 2
M - 2
M - 1
M - 1
FFT
S(f)
Magnitude
Phase
0
0
1
1
M - 2
M - 2
M - 1
M - 1

Sensitivity losses

- windowing effect (affects larger freq.)
- bin spreading (affects off-grid freq.)
- code phase uncertainty


0
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
−4
peak power [dB]
0
500
1000
1500
2000
2500
3000
3500
4000
f offset
loss [dB] = 20 · log10 (sin πTf / πTf)
loss [dB] = 20 · log10 (sin πMTf / πMTf)
FFT − Monte Carlo
theoretical curve

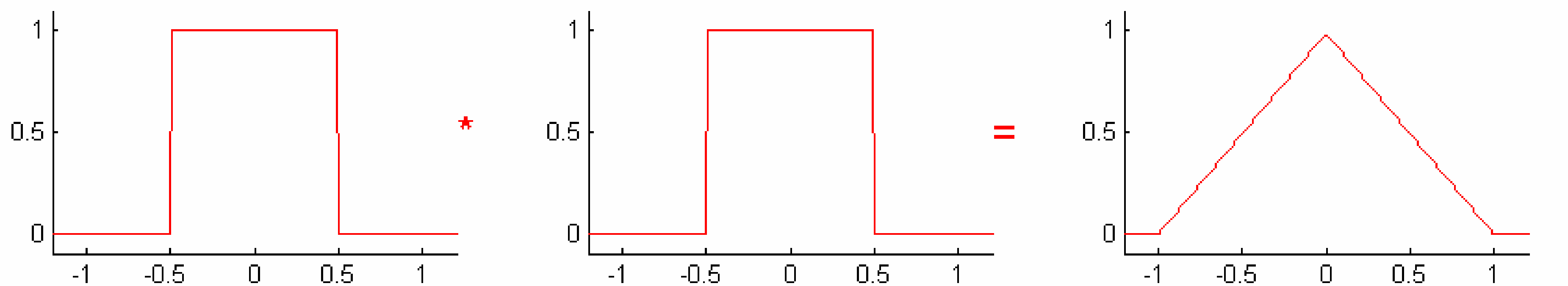

power [dB]
100
90
80
70
60
50
40
30
20
100
110
120
130
140
150
FFT bin



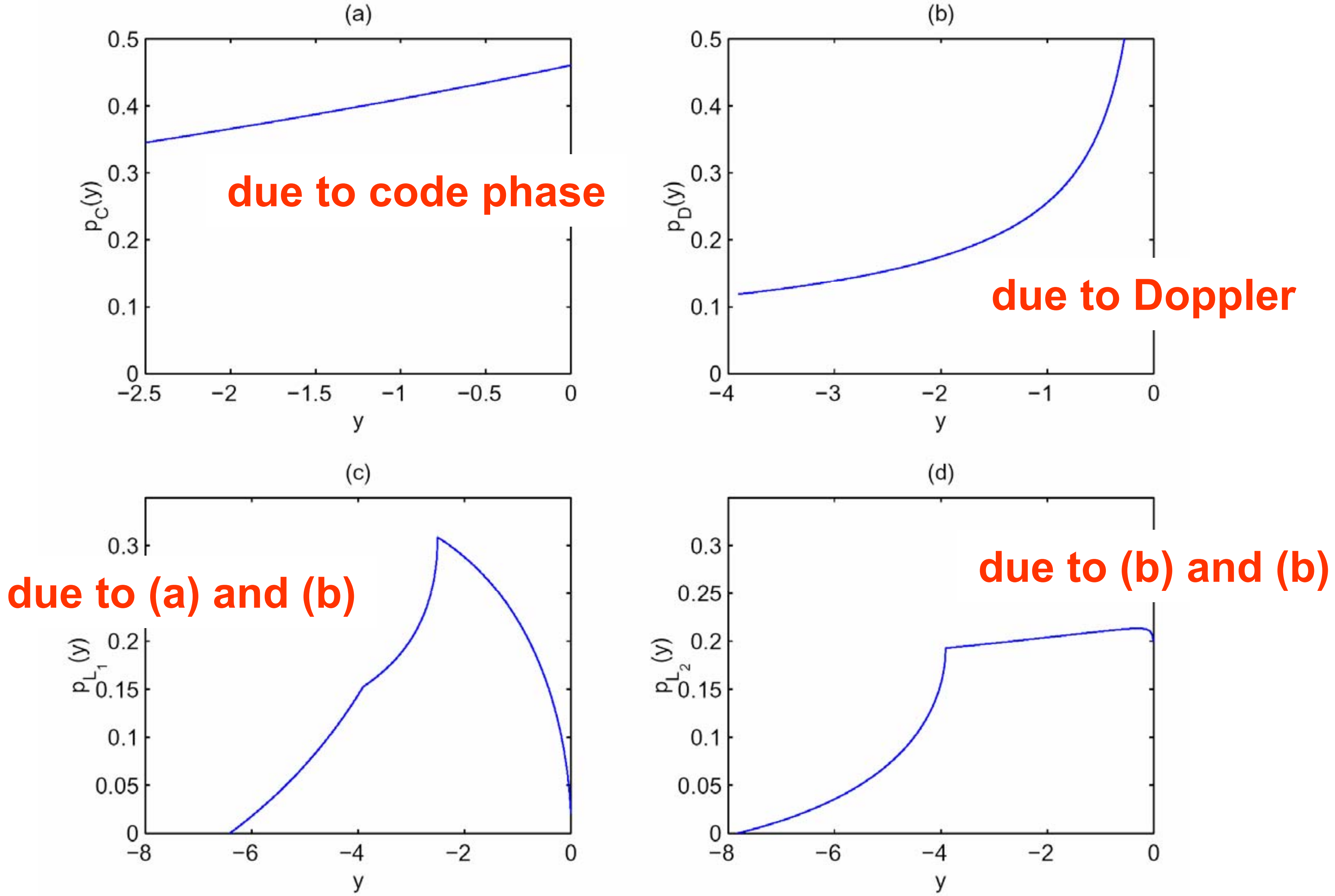
$$\text{loss [dB]} = 20\log_{10}\left(1 - \frac{|\Delta t|}{T_{\text{chip}}}\right)$$

Loss combining

- loss expressed in dB ➔ additive effect
- independent stochastic effects ➔ convolution of pdfs



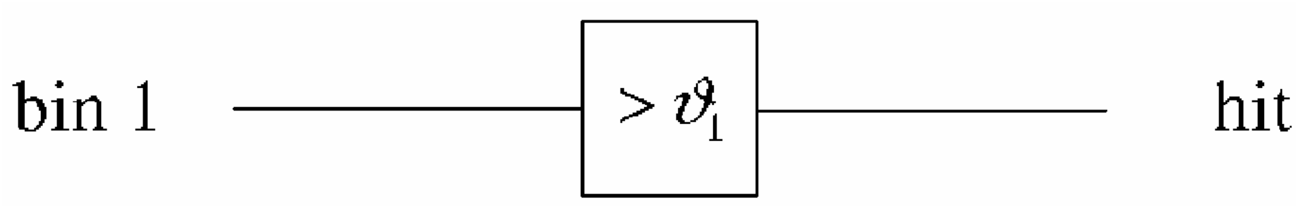
Loss distributions (dB)



Detection task

- **Neyman-Pearson Test:**
  maximize p_d , given p_{FA}
- **p_{FA} is tail of Rayleigh distribution**
- **p_d is tail of Rice distribution**
  approximated by Gaussian distributio

simple detector



probability of detection

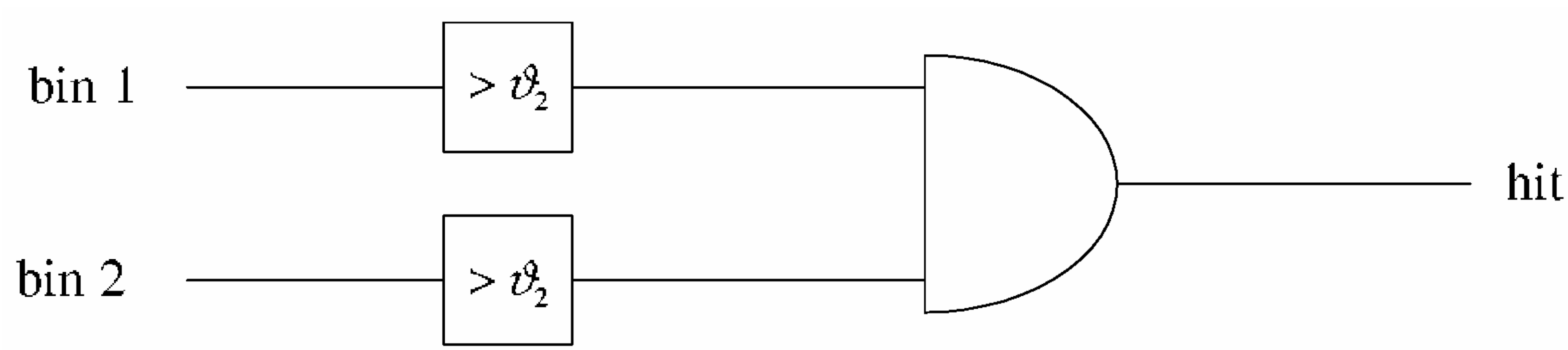
$$p_{d,1} = \int_{-\infty}^{\infty} p_L(l) Q\left(\frac{\vartheta_1 - 10^{(r+l)/20}}{\sigma}\right) dl$$

false-alarm probability

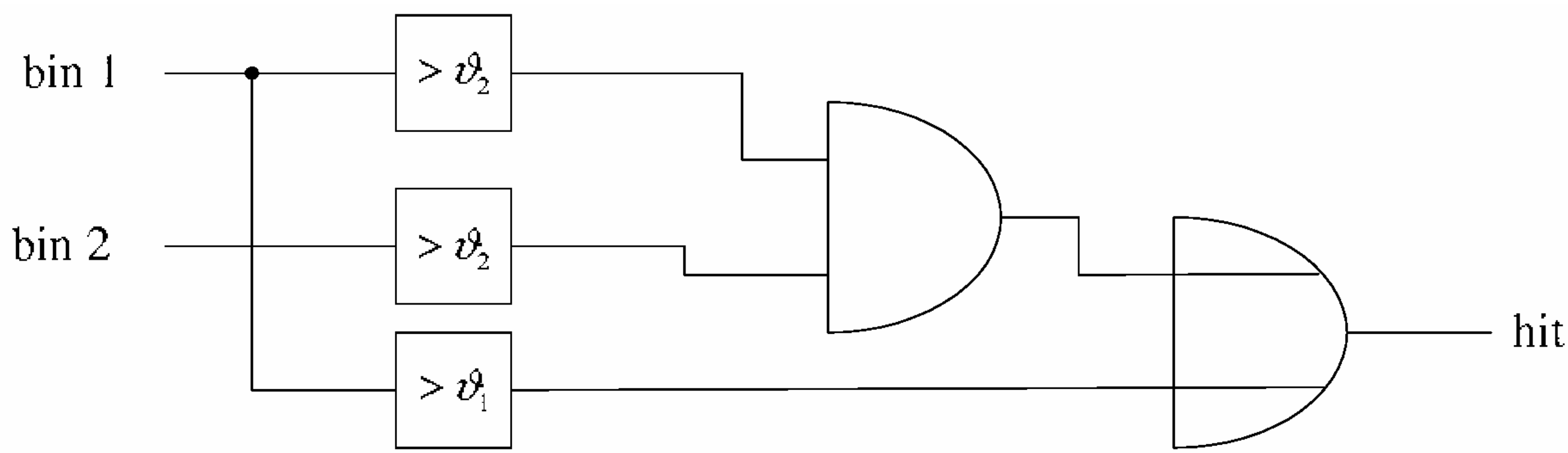
$$p_{\mathrm{FA},1} = \int_{\vartheta_1}^{\infty} p_r(x) dx = \exp\left(-\frac{\vartheta_1^2}{2\sigma^2}\right)$$

Detection strategies

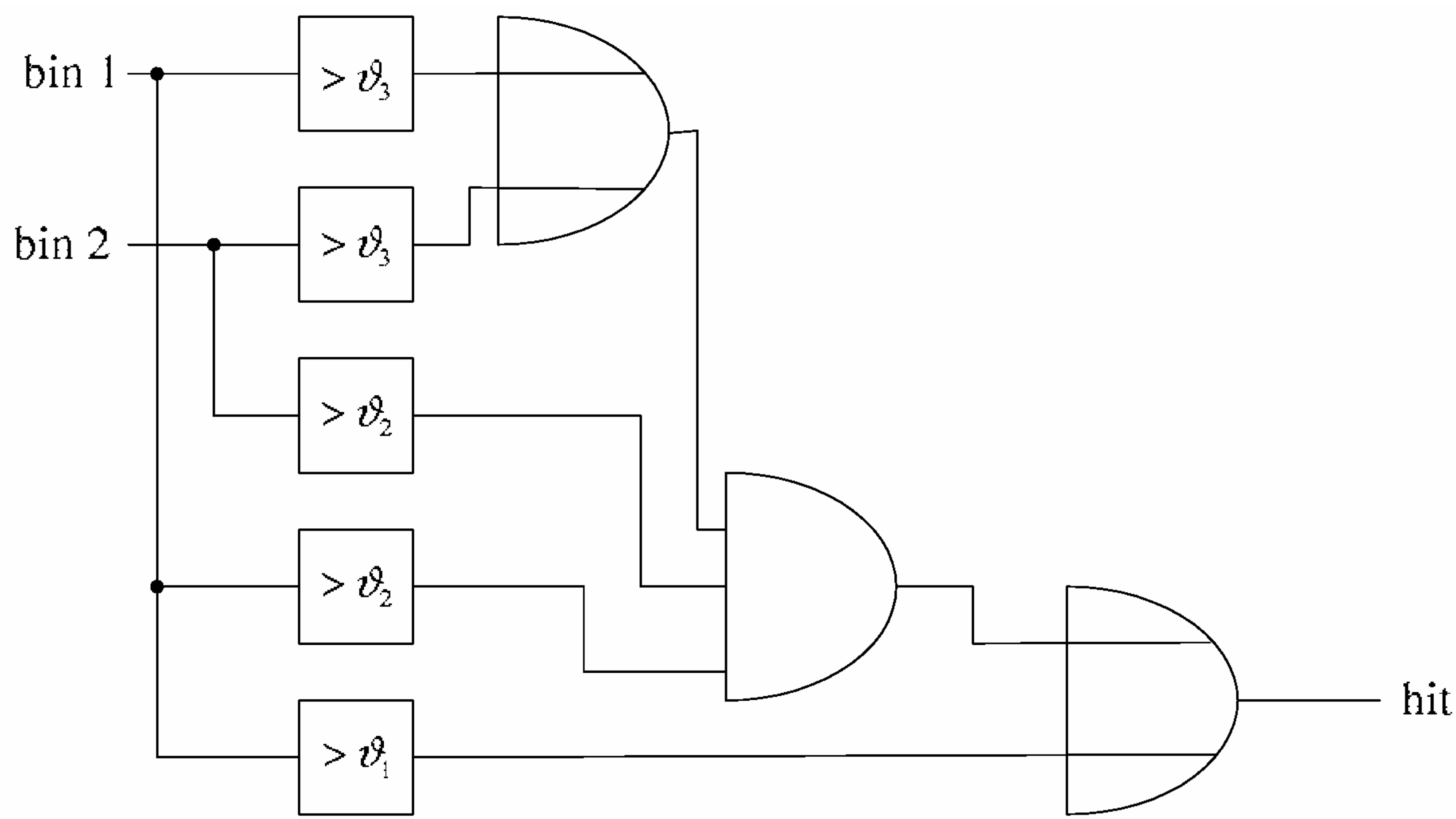
➢One-level strategy



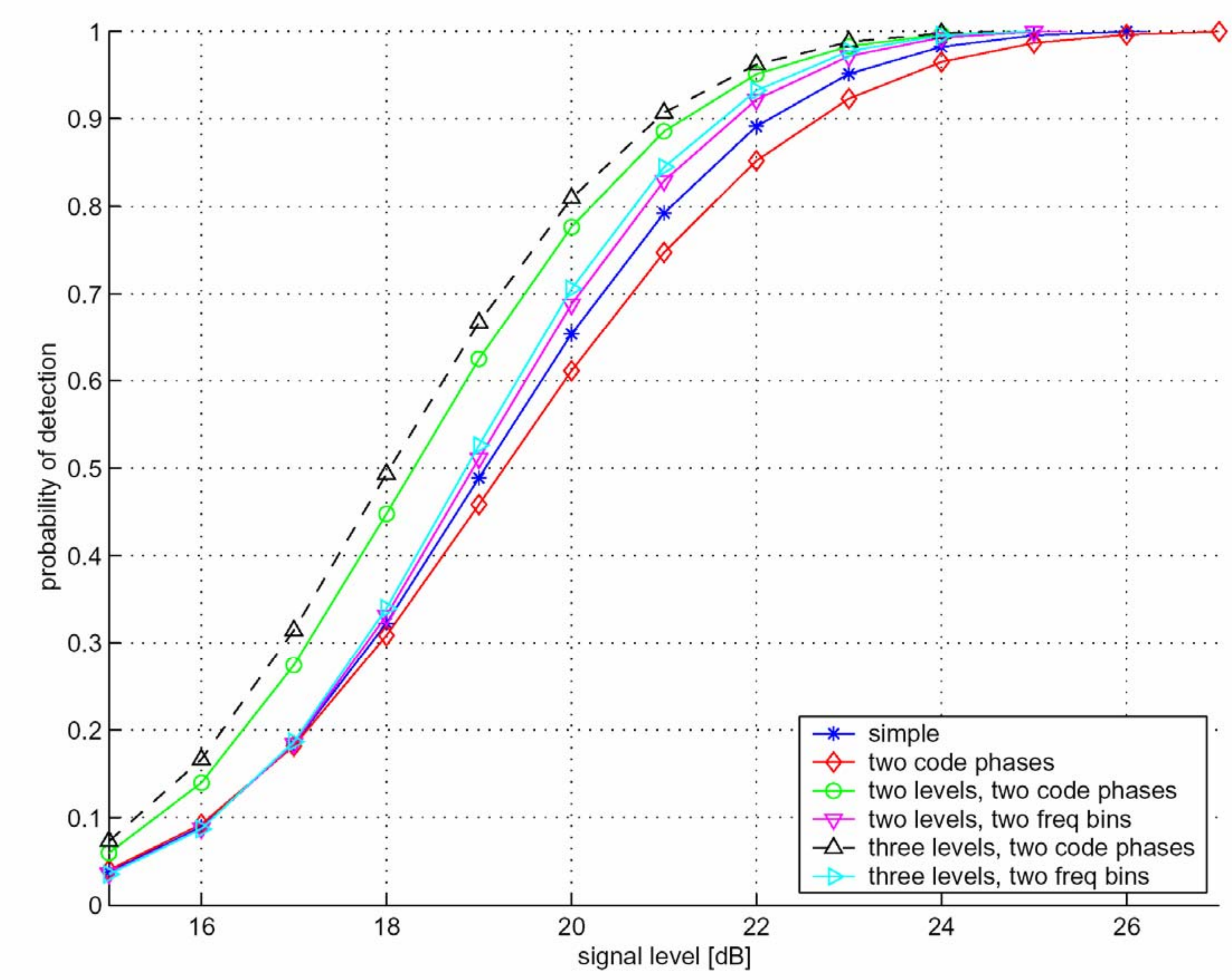
➢Two-level strategy

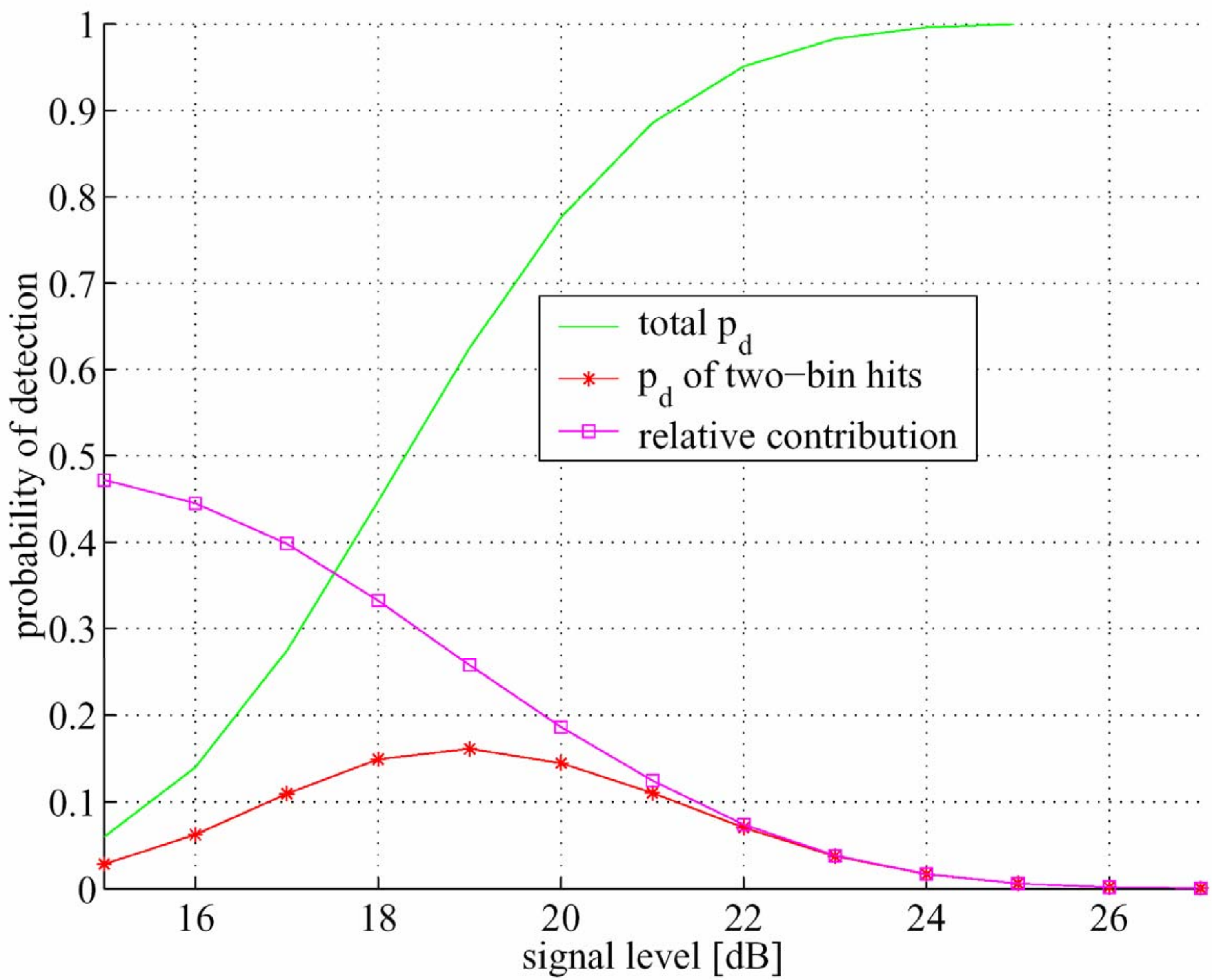


➢Three-level strategy

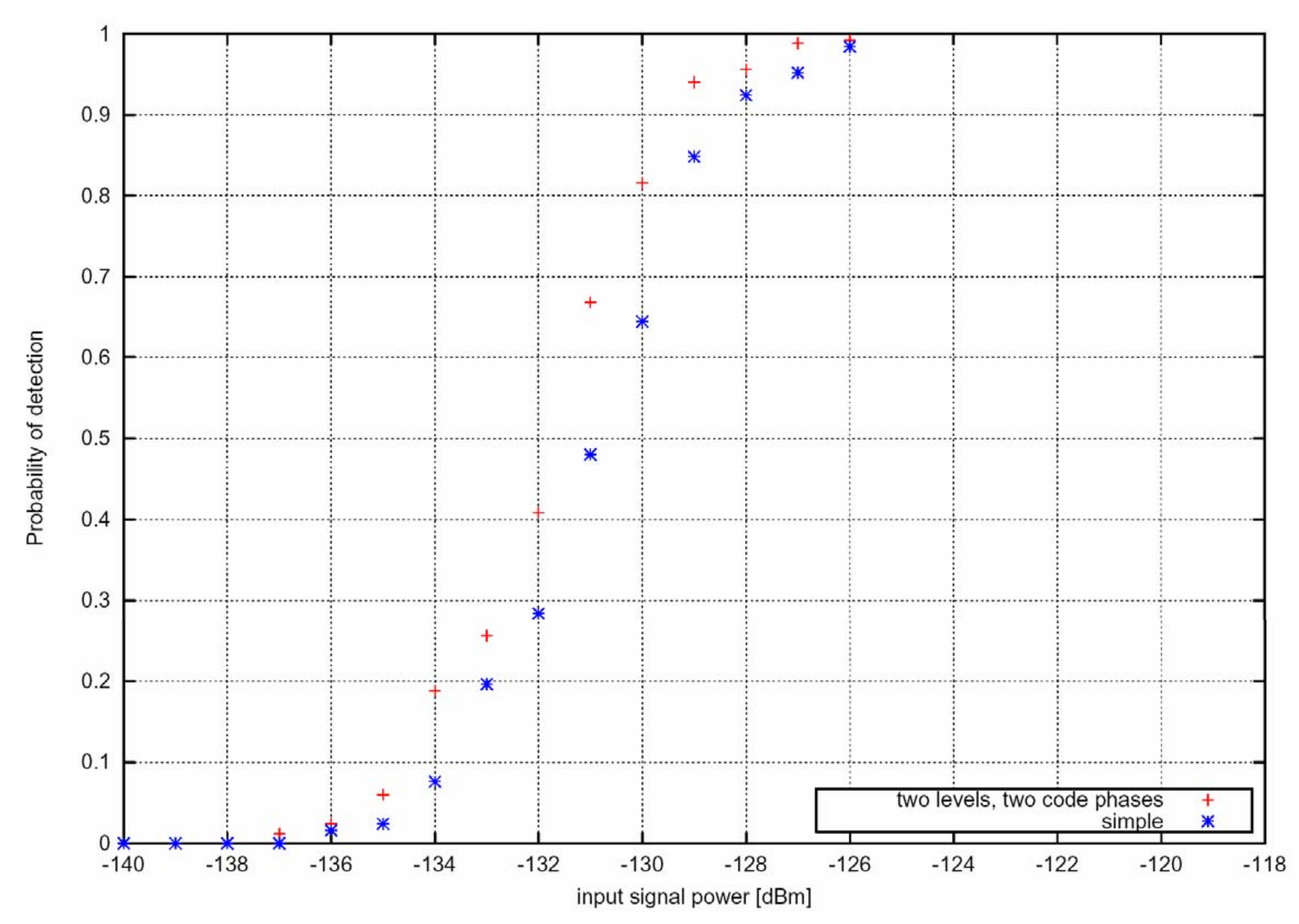


Simulation results




total p_d
p_d of two−bin hits
relative contribution
probability of detection
signal level [dB]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
16
18
20
22
24
26

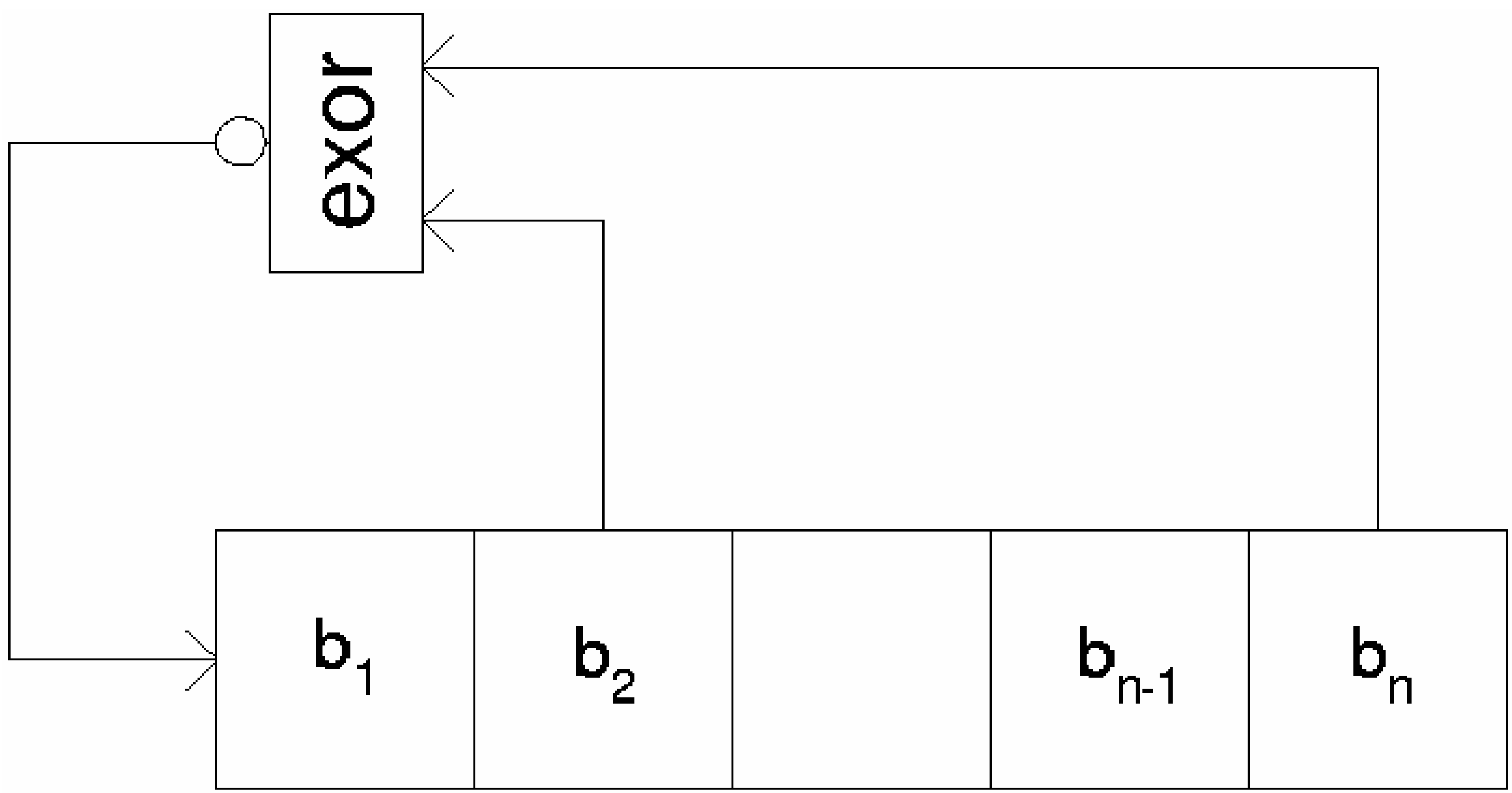
real-time results, FPGA / ARM7



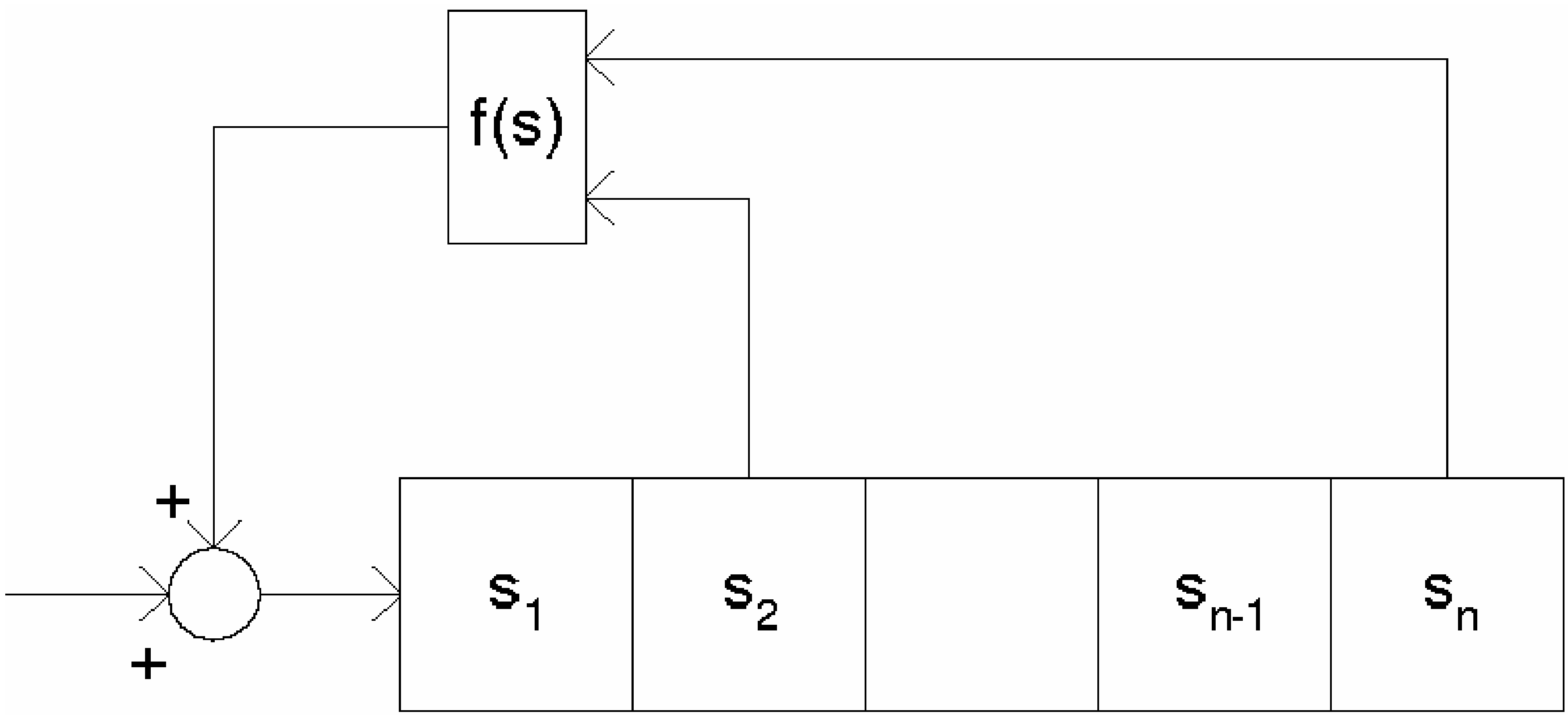
Advantages of AFSR

- A-GPS reduces frequency dimension
  → code dimension remains
- tracking is easier than acquisition at low SNR

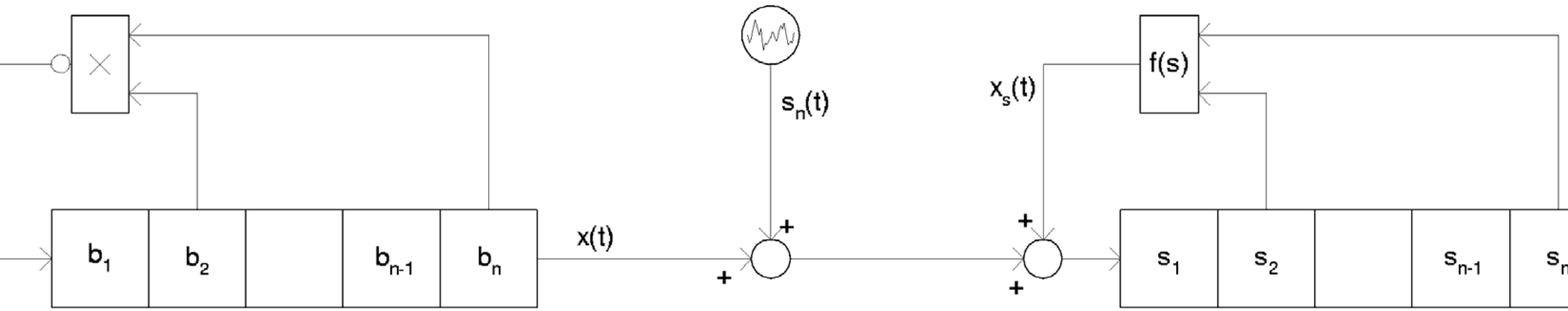
LFSR (linear feedback shift register)



AFSR (analog feedback shift register)



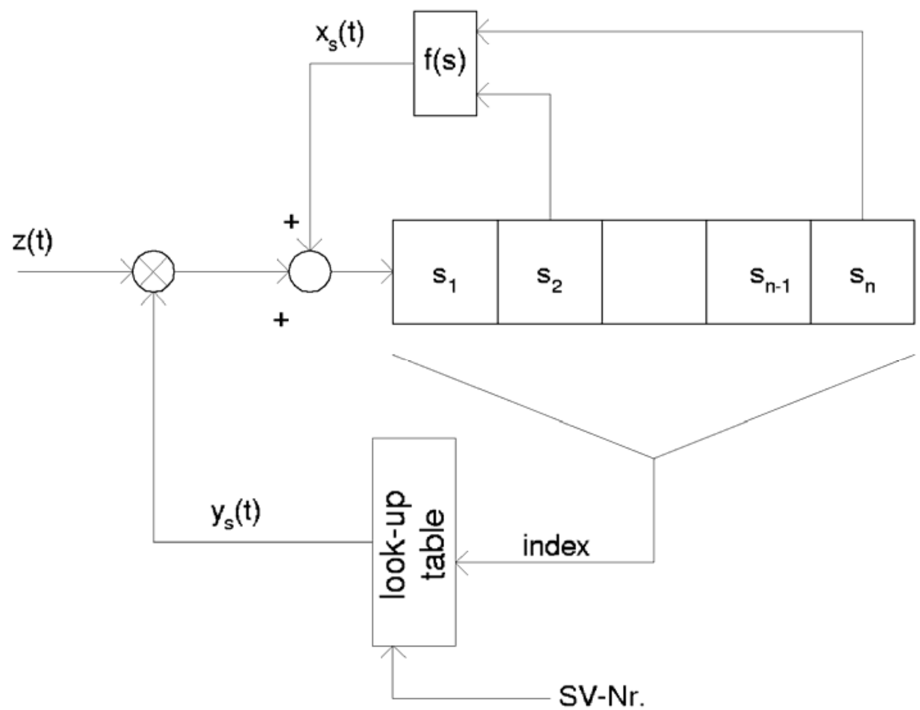
Synchronization using AFSR



Adaptation to GPS

- low SNR of -20dB and below

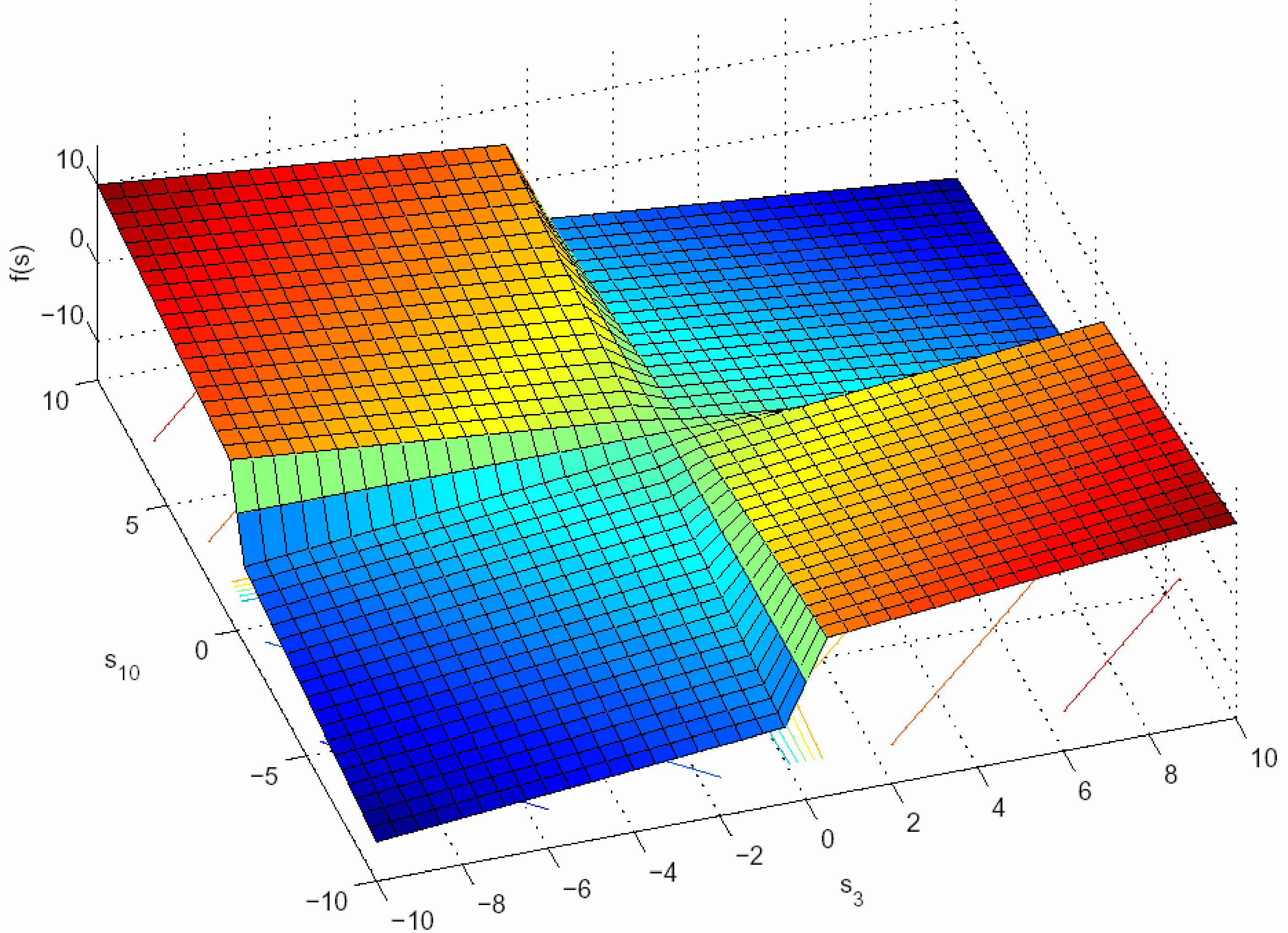
- Gold sequences consist of two m-sequences
  → table-lookup structure



Feedback function (requirements, criteria

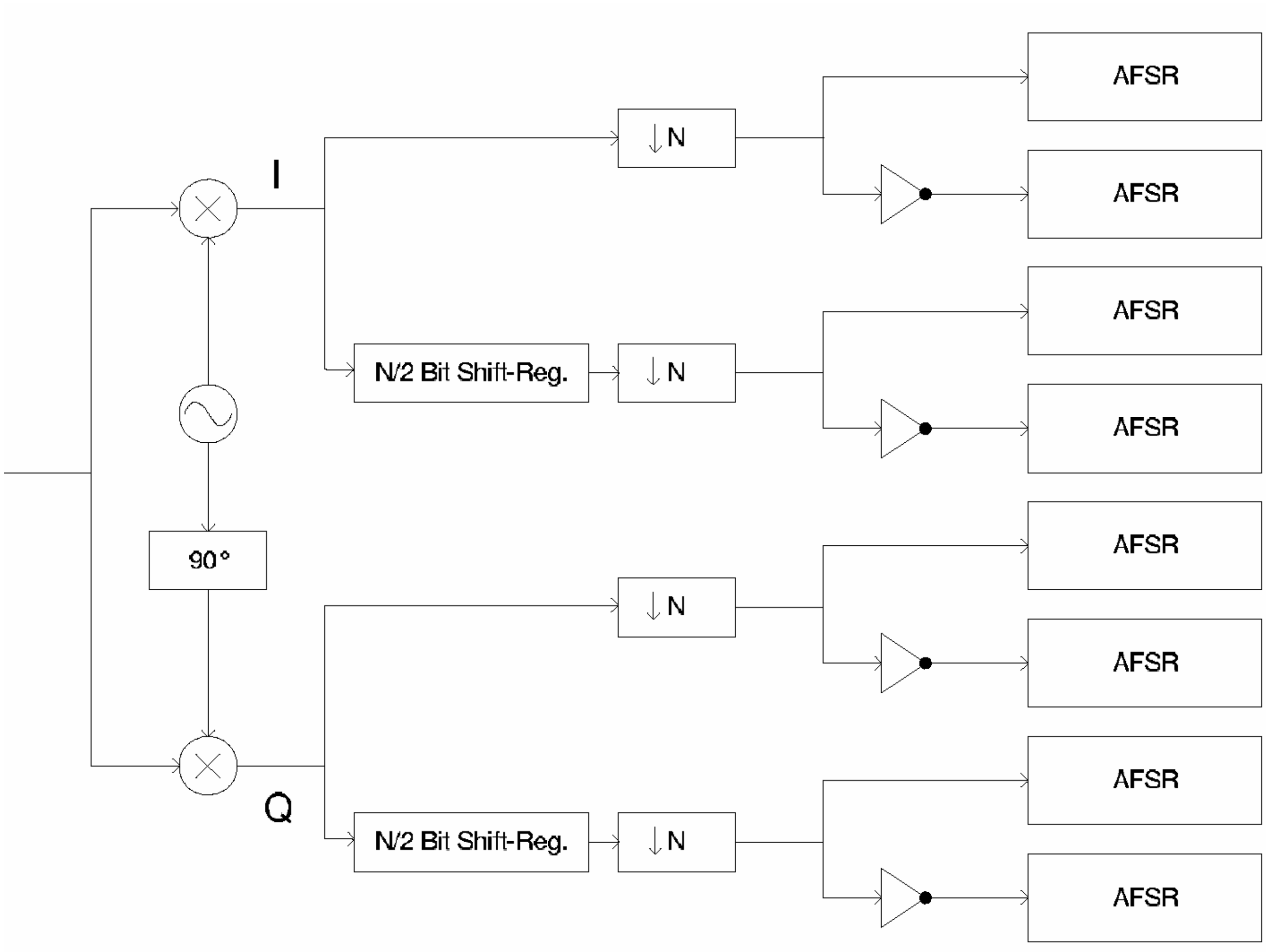
- XOR functions for inputs $\in \{0,1\}$
- synchronization performance
- simple to build
- theoretical justification

Feedback function used

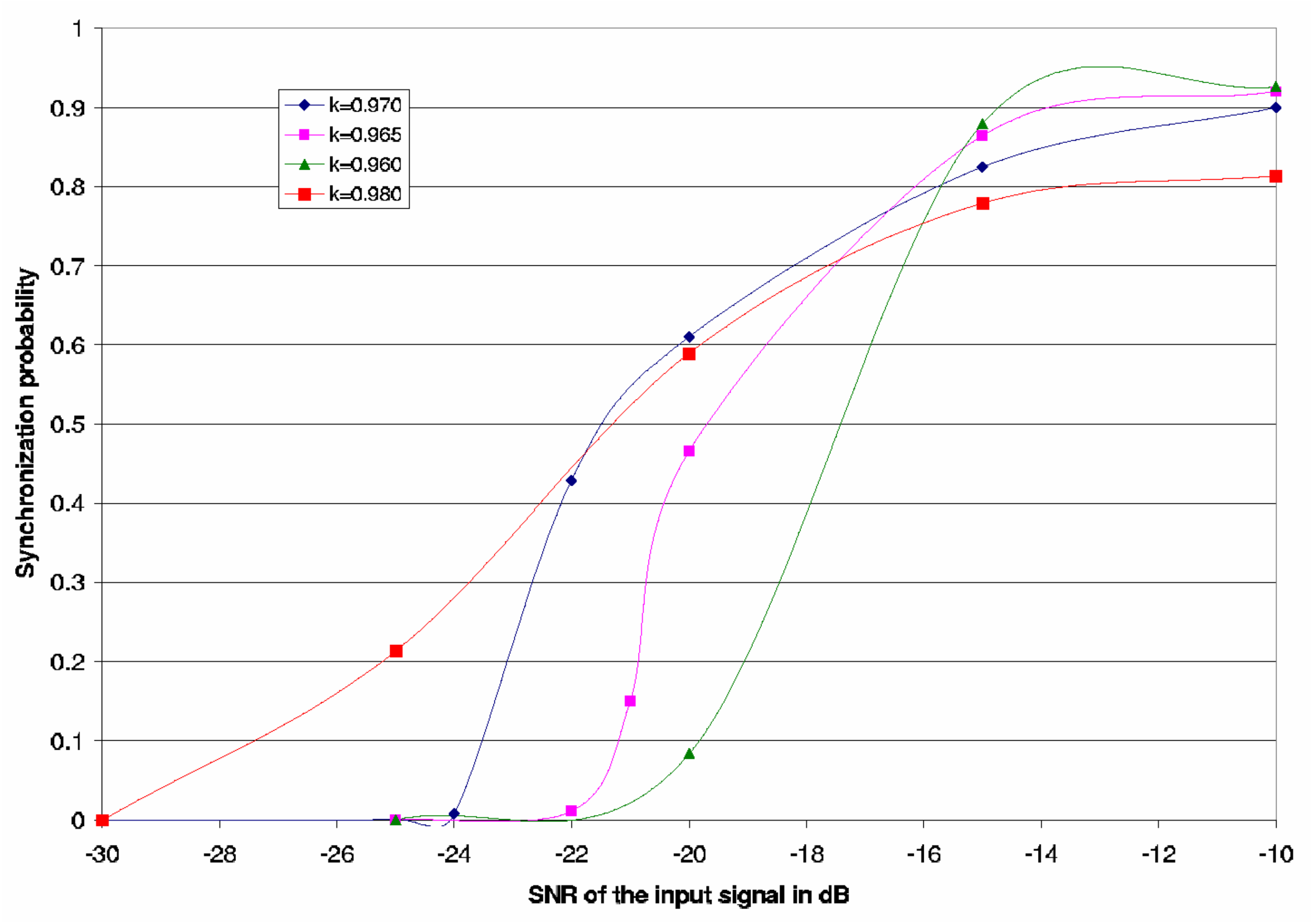


$$x_s(t) = f(\mathbf{s}) = -k \cdot \text{sign}(s_3 s_{10}) \cdot \frac{|s_3| + |s_{10}|}{2}$$

Baseband processing



Simulation results



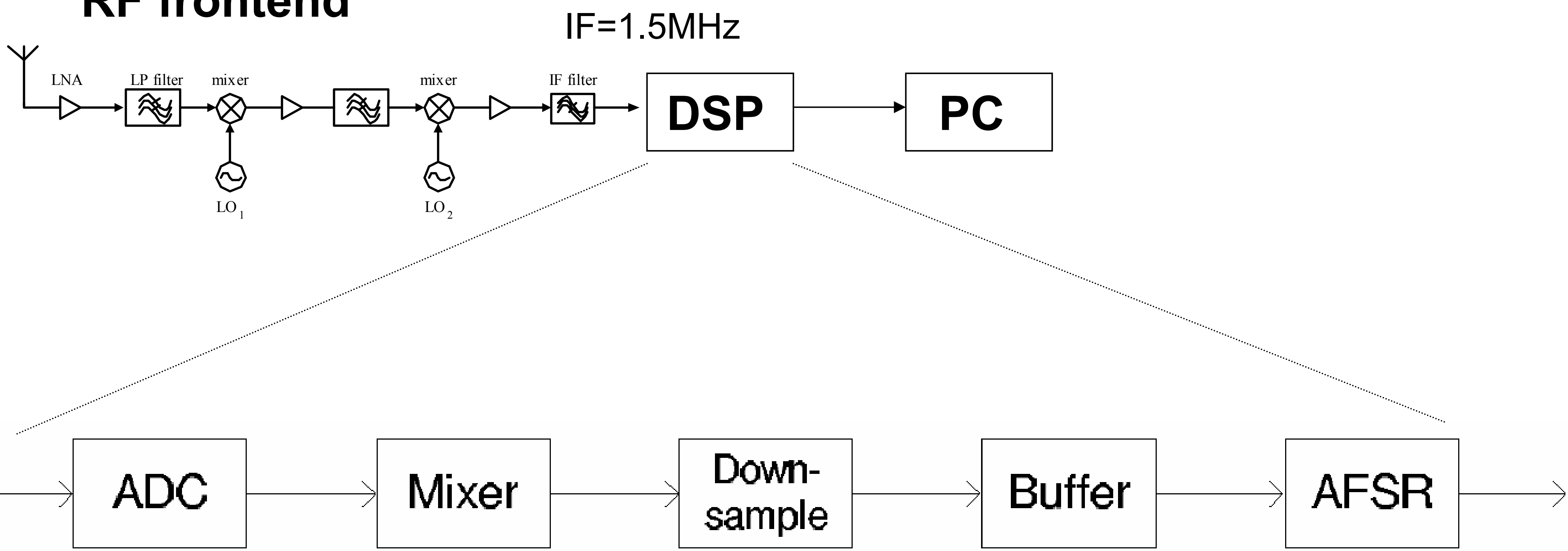
ncreasing the detection probability

- re-run AFSR with same data
- re-run AFSR with new register values
- re-run AFSR with new input data

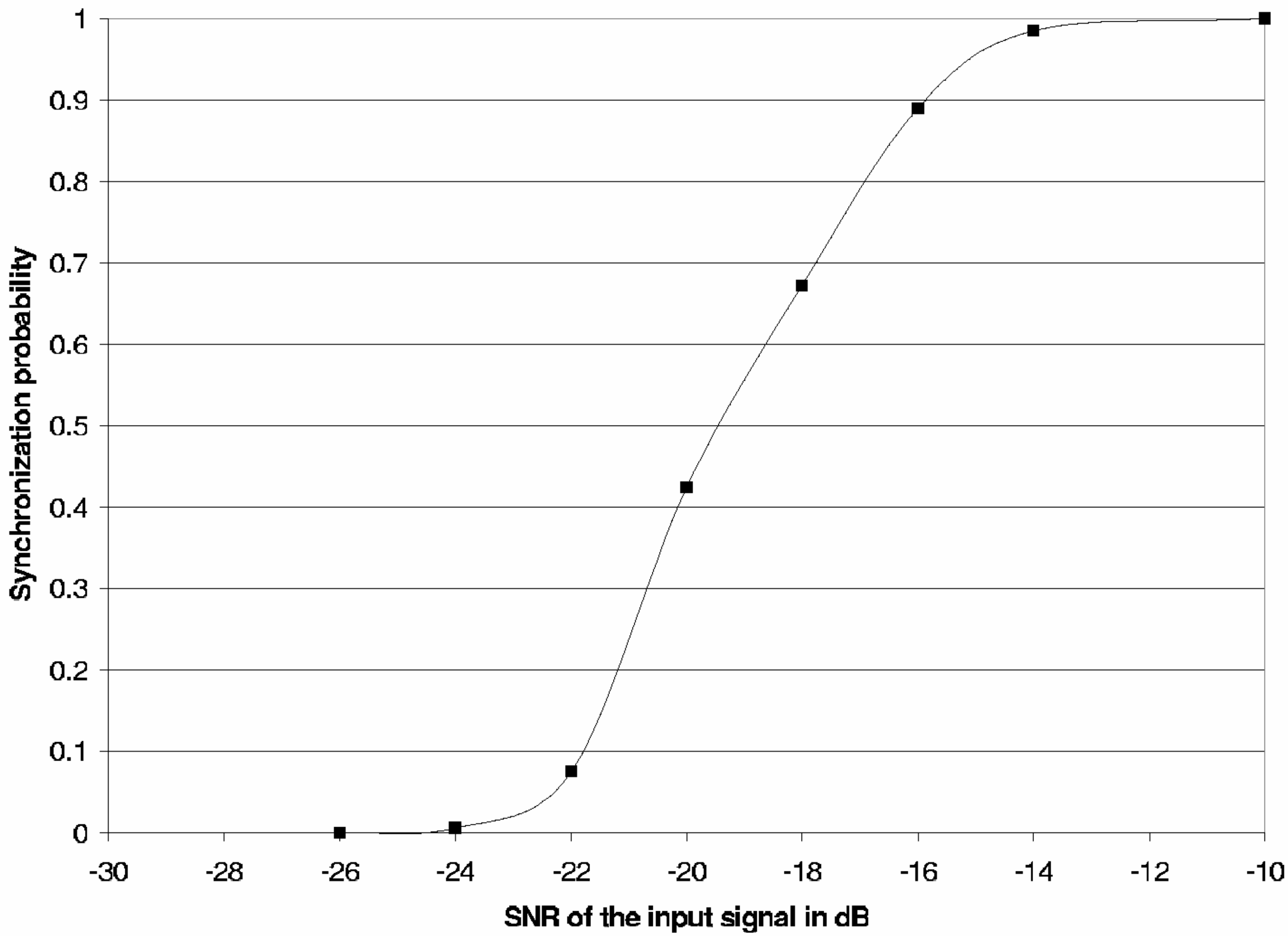
$$P(n) = 1 - (1 - p)^n$$

Hardware demonstrator

RF frontend



Measurement results



Conclusions

Two promising new acquisition GPS receivers have been presented:

- **Post-correlation FFT is computationally efficient**
- **two-level detection strategy is superior to one-level detection (1dB gain)**

- **AFSR is feasible alternative to brute-force correlation and provides very fast acquisition**