# FPGA Implementation of Gaussian Multicarrier Receiver with Iterative Interference Canceller

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# Outline

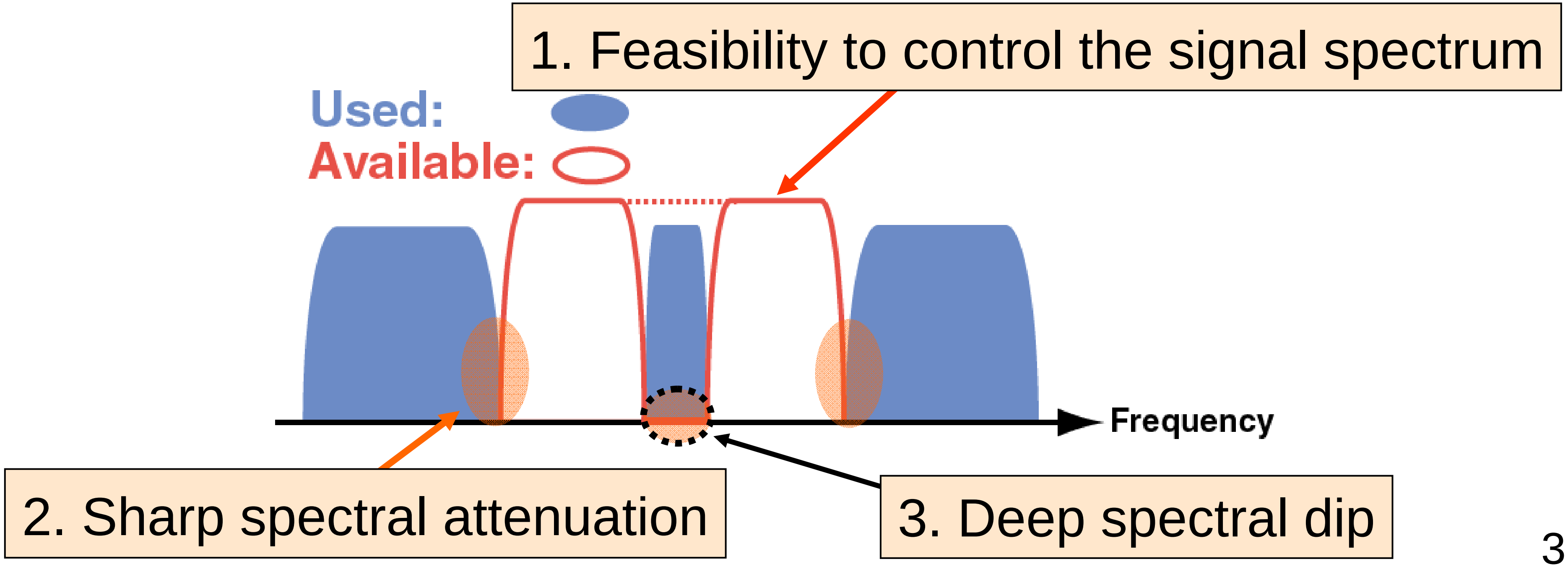
- Background
- Design of Gaussian Multicarrier (GMC)
- GMC receiver with
  iterative interference canceller
- FPGA implementation
- Performance evaluation
- Conclusion

# Background

## Future wireless communication

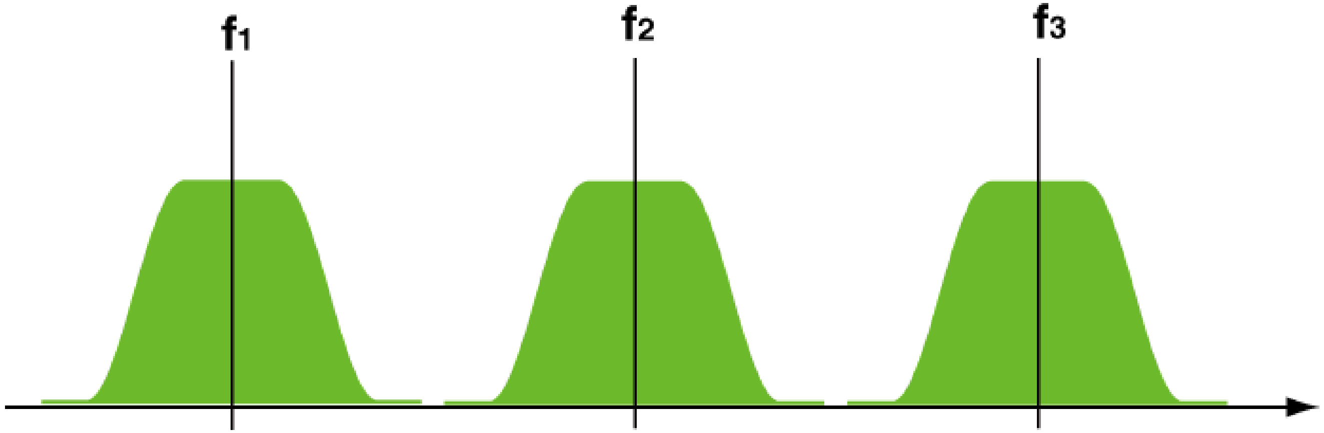
More sophisticated spectrum management by multicarrier transmission is one of the most promising techniques (Example : Cognitive radio)

Multicarrier transmission scheme should satisfy the following items;

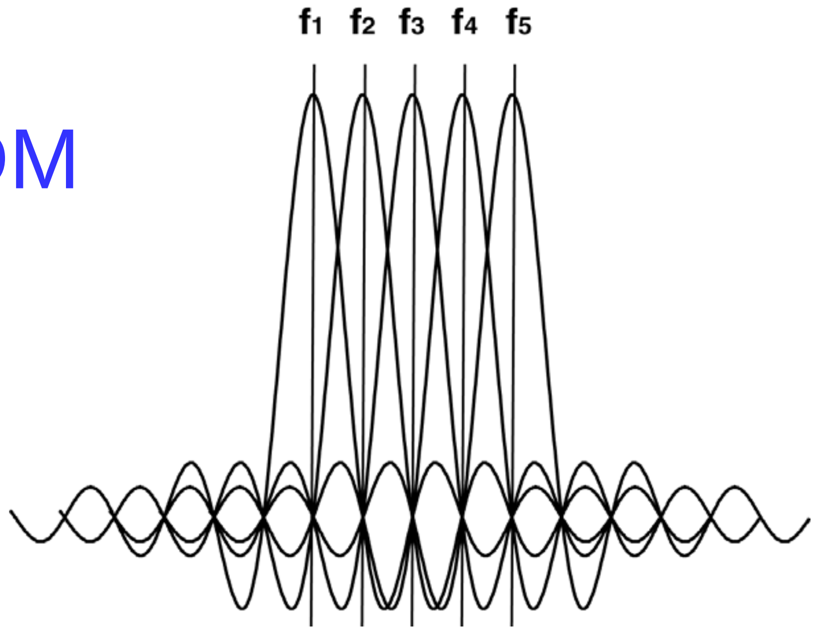


# Multicarrier (MC) Transmission

Single-carriers with spectrum shaping



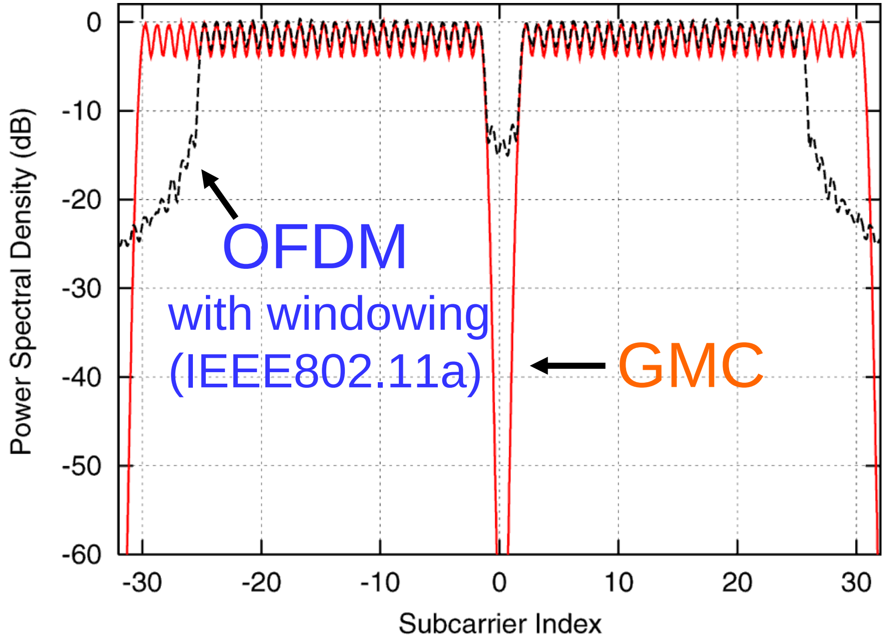

OFDM



# OFDM vs GS-OFDM

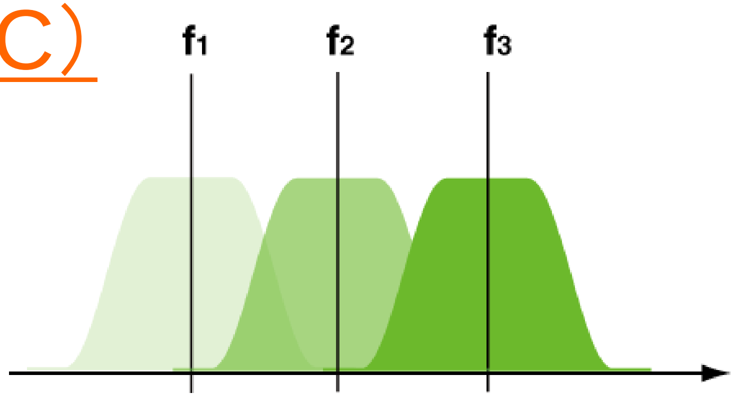
## OFDM

- Considerable amount of sidelobes
- Large guard band
- Orthogonality

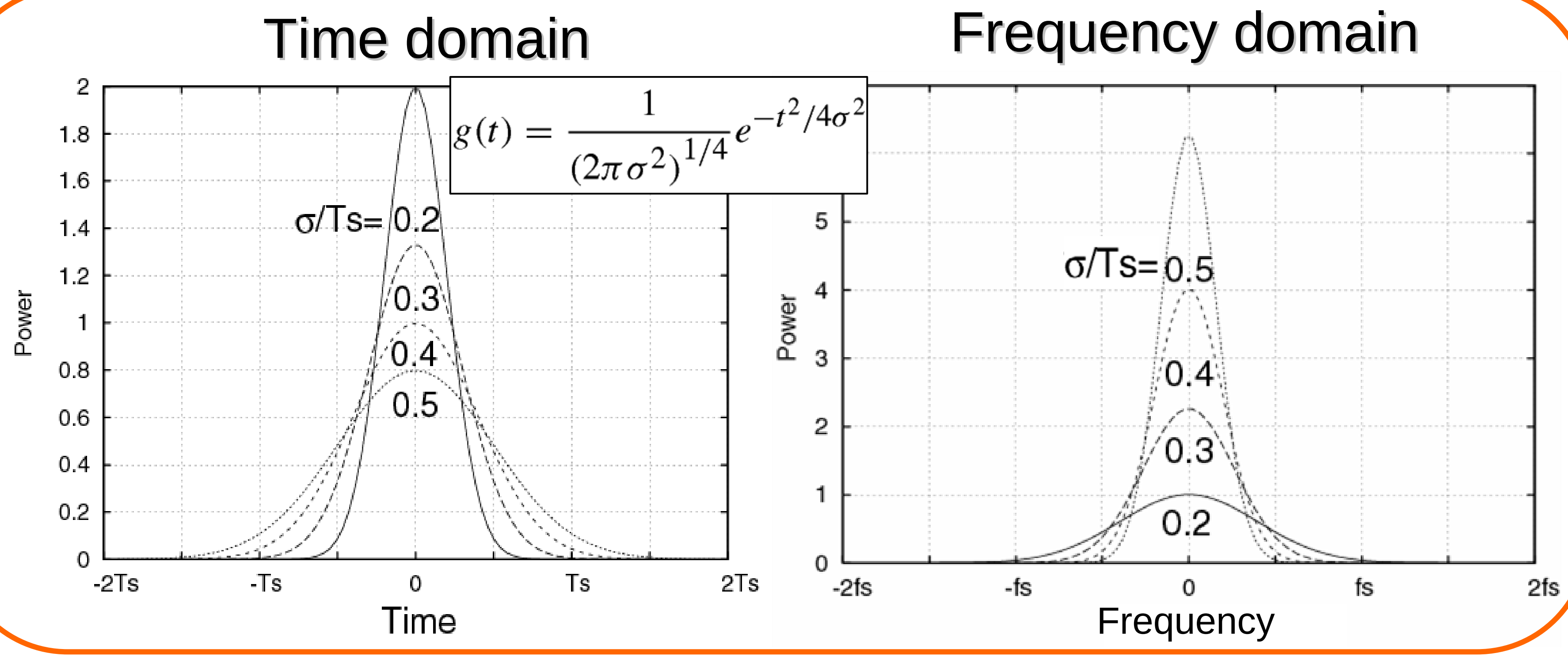



## Gaussian multicarrier（GMC）

- Sharp spectral attenuation
- High spectral efficiency
- Non-orthogonality



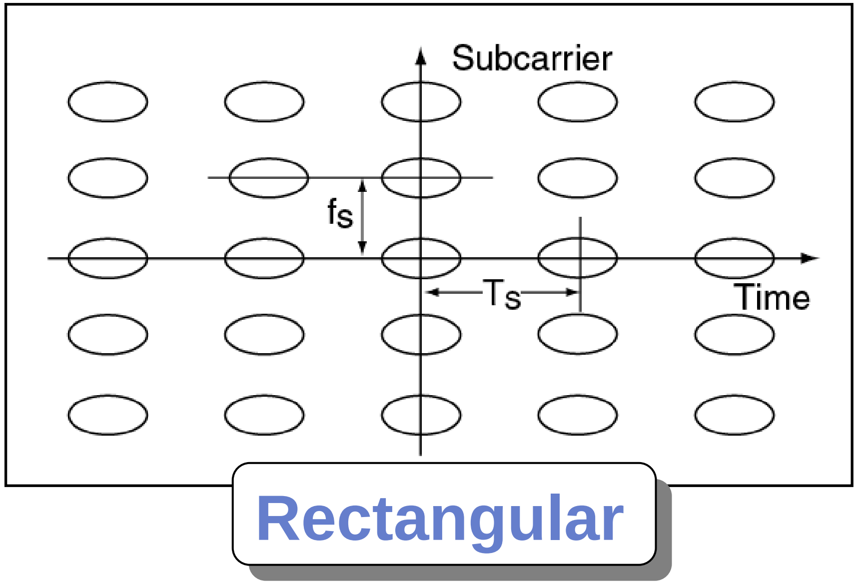
# Gaussian Pulse

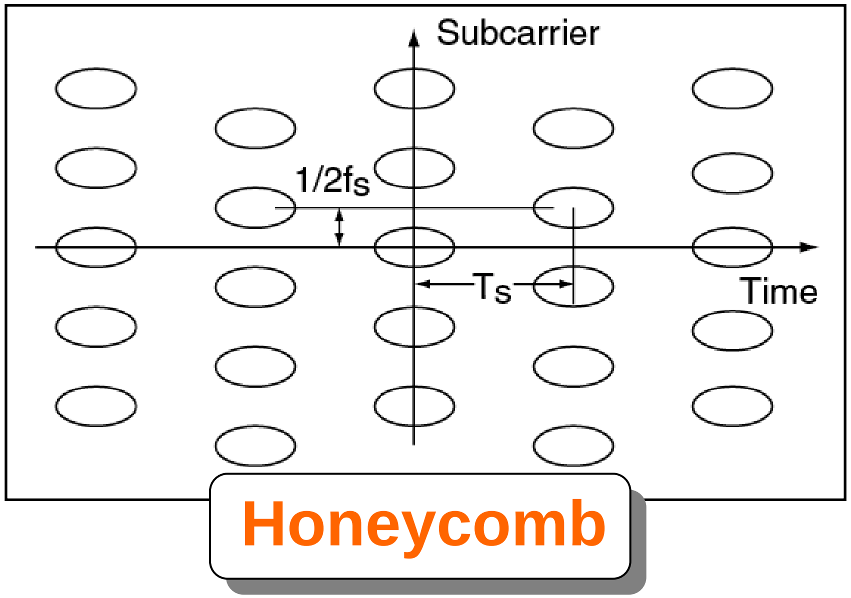


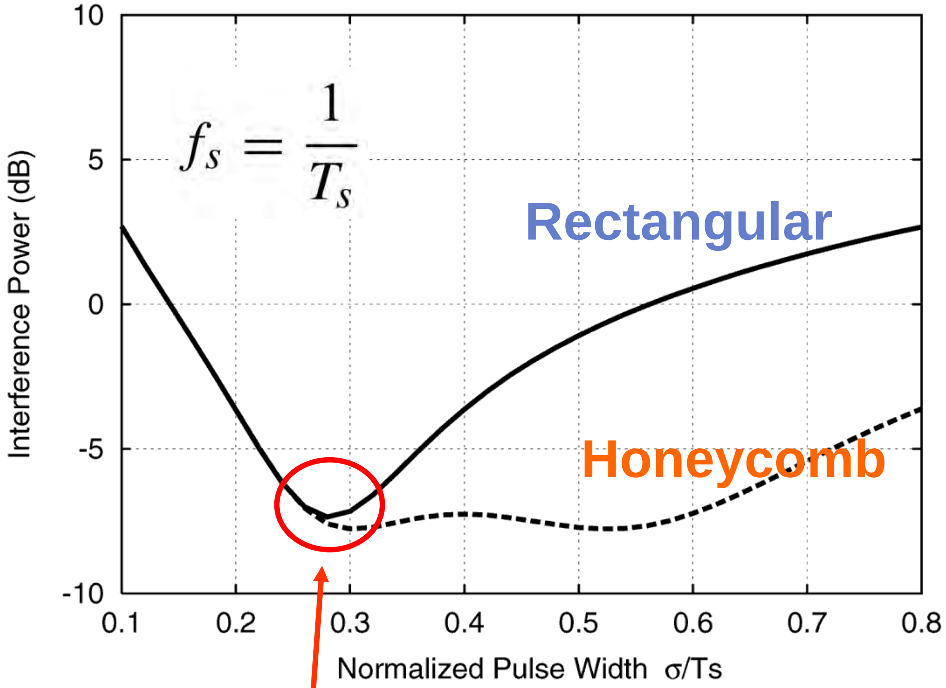

$$g(t) = \frac{1}{(2\pi\sigma^2)^{1/4}} e^{-t^2/4\sigma^2}$$

| | Interference in time domain | Interference in frequency domain |
|---|---|---|
| **$\sigma$ is large** | **Large** | **Small** |
| **$\sigma$ is small** | **Small** | **Large** |

# Subcarrier Arrangement

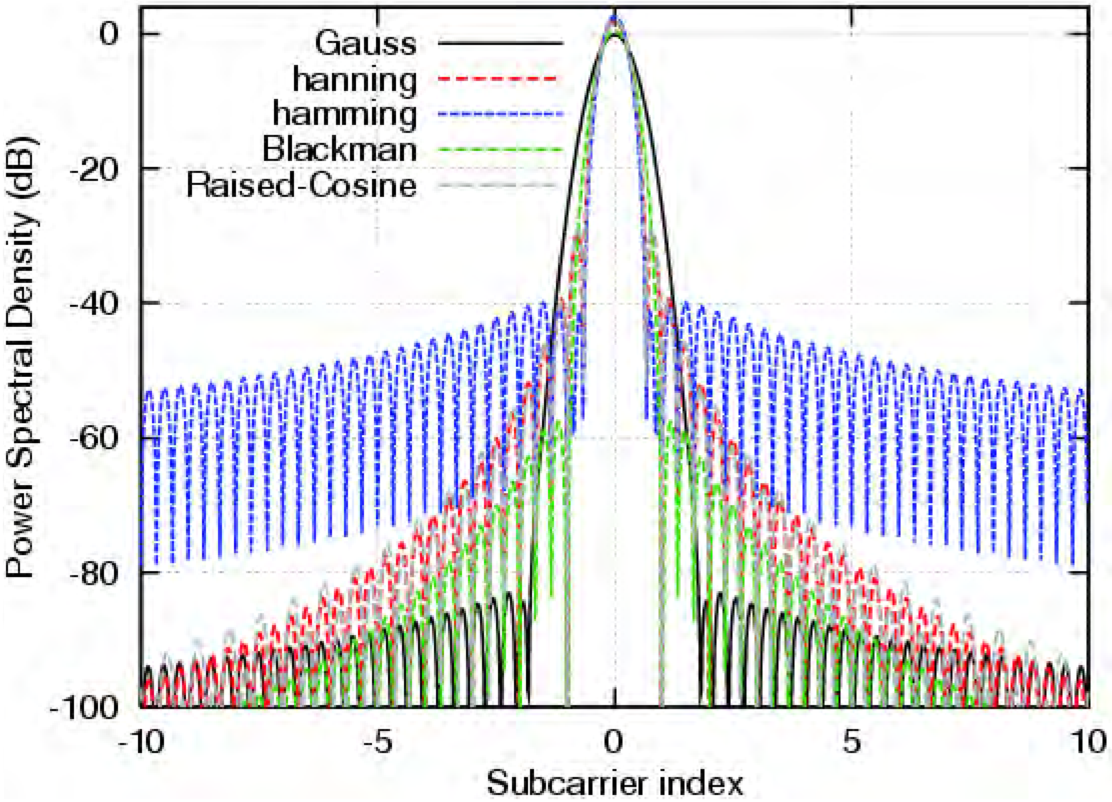


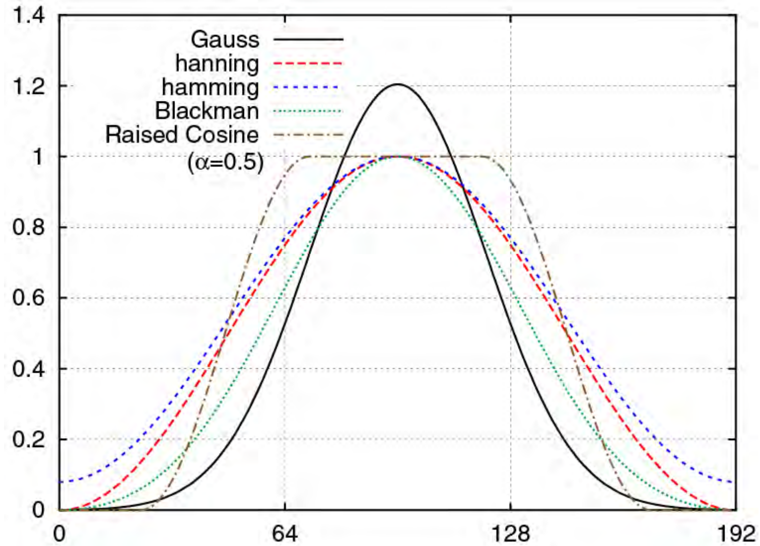




$\sigma = 0.275T_s$ minimizes interference power

# Which is Best Pulse Shaping Waveform?




Pulse Waveform

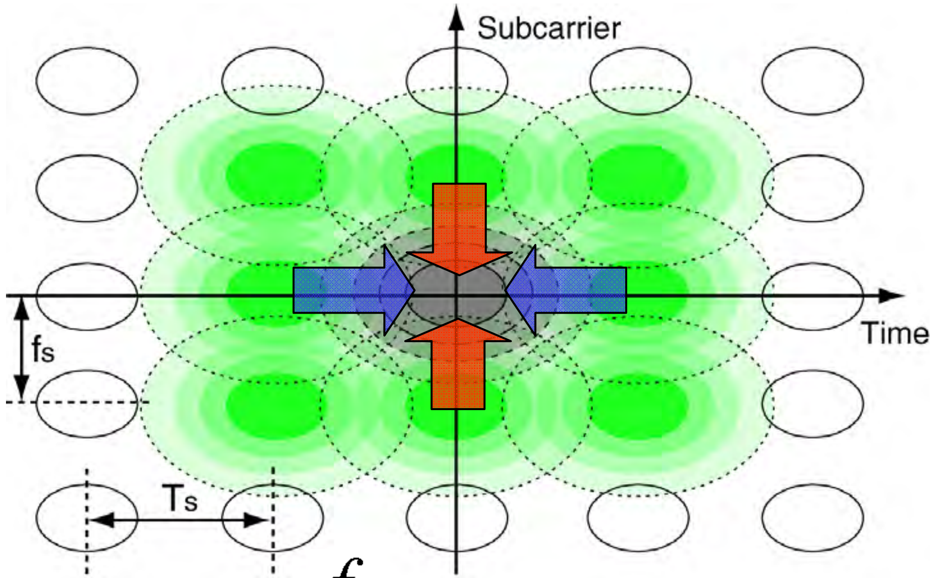



| パルス | 総干渉量 (dB) |
|---|---|
| ガウス ($\sigma = 0.275T_s$) | -7.35 |
| ハニング | -2.64 |
| ハミング | -0.97 |
| ブラックマン | -6.59 |
| レイズドコサイン (ロールオフ率 0.8) | -2.65 |

# Interference in GMC

GMC cannot maintain complete orthogonality among symbols and subcarriers :

- **Inter-symbol Interference**
- **Inter-carrier Interference**




$f_s$ : **Subcarrier spacing**

$T_s$ : **Symbol duration**

GMC receiver requires interference canceller.

Objective

- Feasibility study of Iterative Interference Canceller (IIC)
- FPGA implementation of GMC transceiver, and evaluation of its performance and circuit size

# Configuration of GMC Transmitter

**Transmitted Signal**

$$s(t) = \sum_{n=-\frac{N}{2}}^{\frac{N}{2}-1} \sum_{i=-\infty}^{\infty} d_n(i)\, g(t - iT_s)\, e^{j2\pi n f_s t}$$

$$= \sum_{i=-\infty}^{\infty} g(t - iT_s) \sum_{n=-\frac{N}{2}}^{\frac{N}{2}-1} d_n(i) e^{j2\pi n f_s t}$$

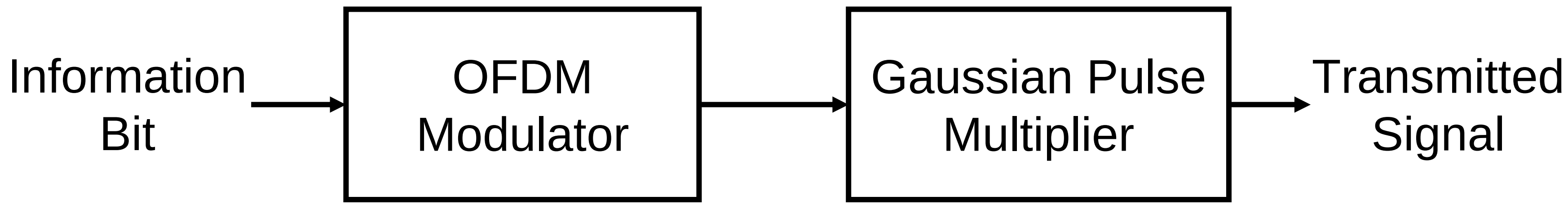
IFFT

Gaussian pulse

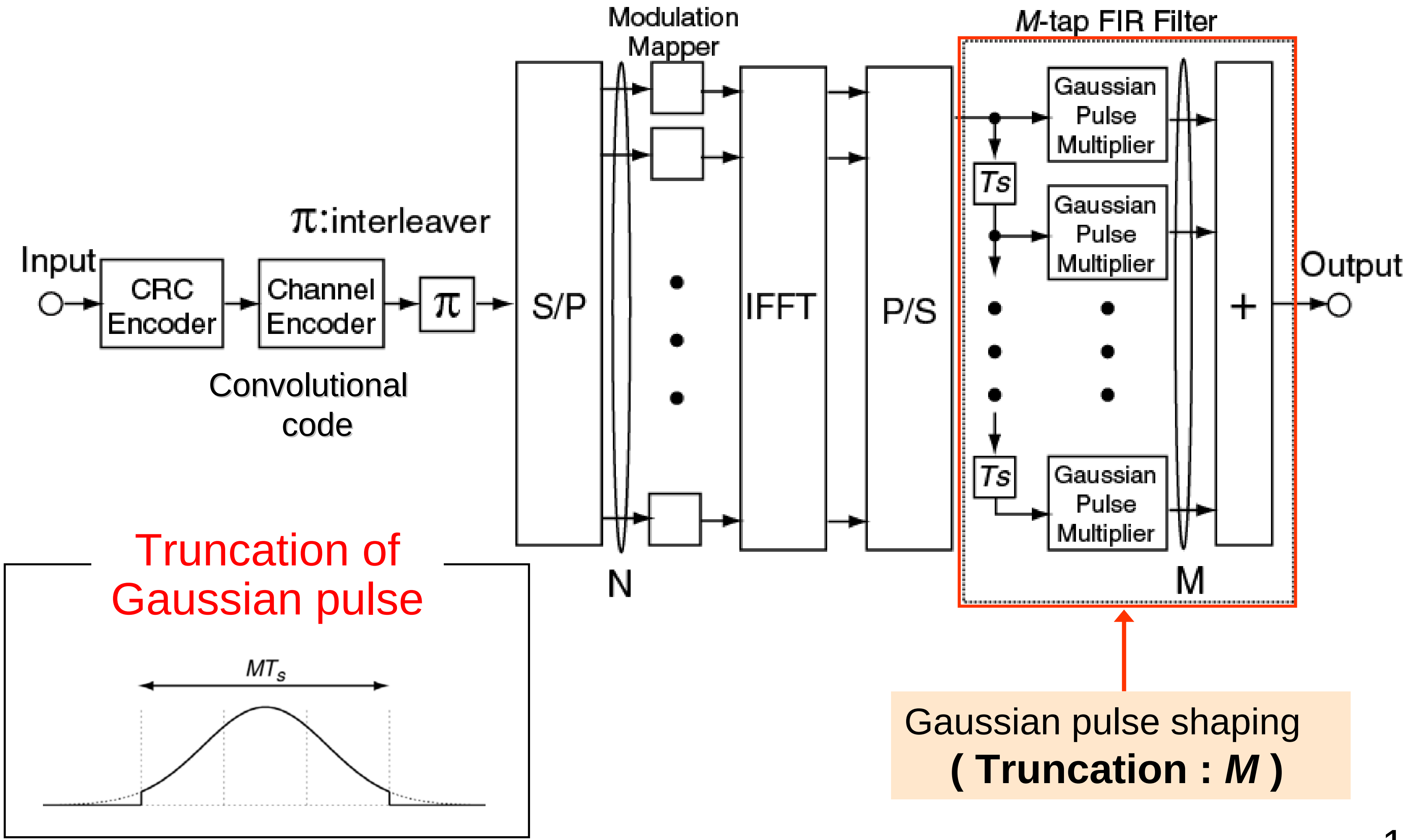
$$g(t) = \frac{1}{(2\pi\sigma^2)^{1/4}} e^{-t^2/4\sigma^2}$$

$d_n(i)$ : Modulation signal at $n$-th subcarrier

GMC transmission can be realized by adding the Gaussian pulse shaping to IFFT



# GMC Transmitter with Truncated Gaussian Pulse



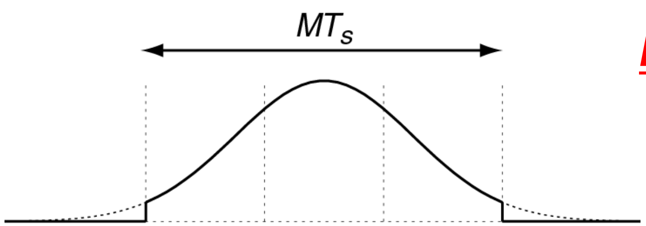
# Principle of GMC Modulation Using IFFT

**Transmitted Signal**

$$s(t) = \sum_{i=-\infty}^{\infty} g(t - iT_s)\,\boxed{s_i'(t)}$$

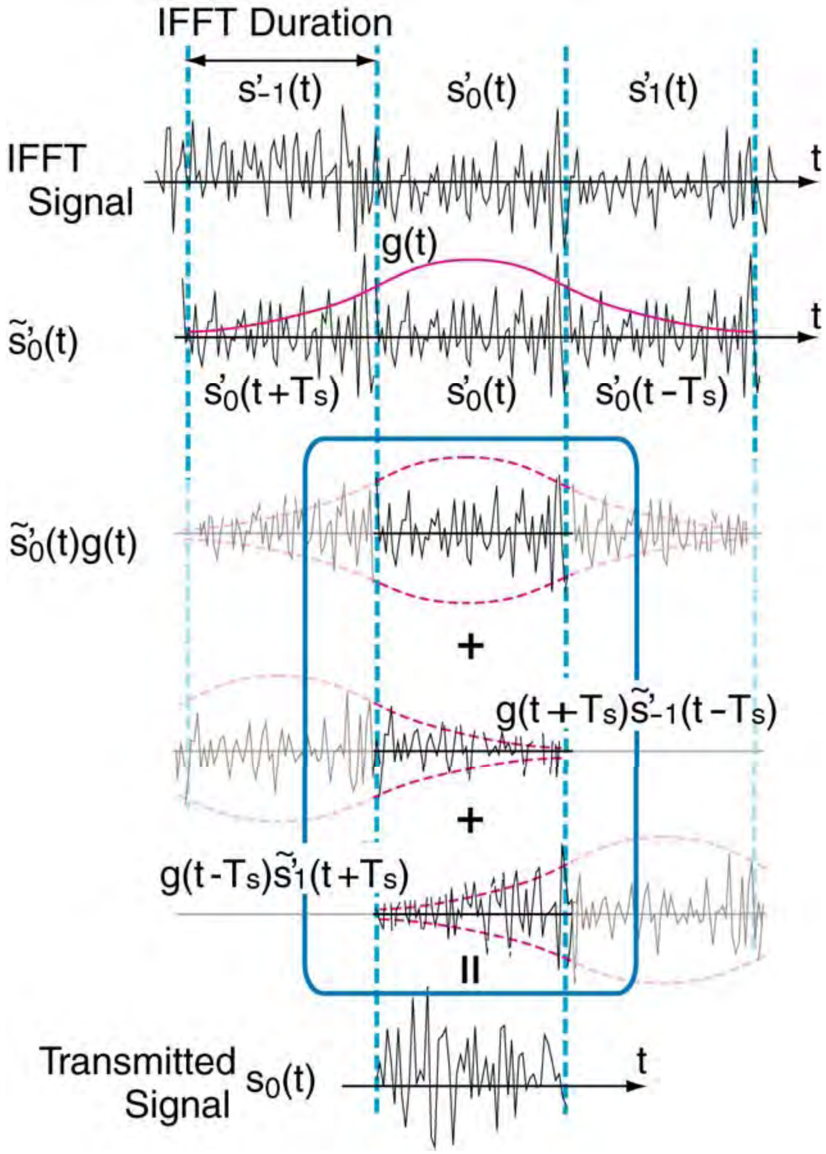
IFFT output

**Truncation of Gaussian pulse**

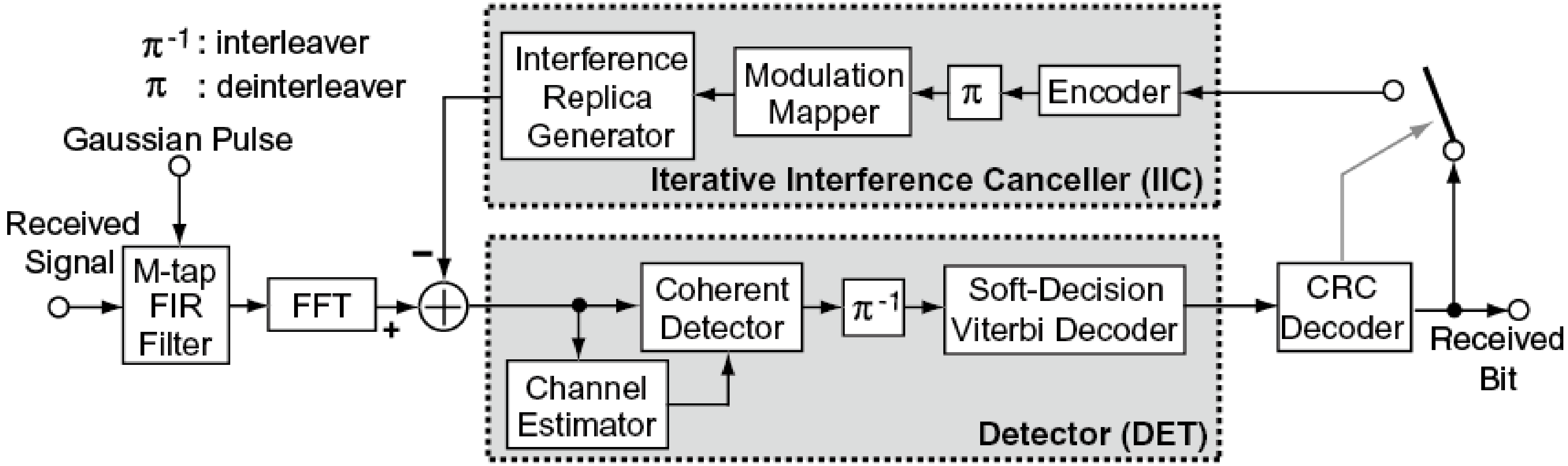



***M* = 3**

In case of *M* = 3



# Block Diagram of GMC Receiver




<u>FFT output</u>

$$r_n(iT_s) = c_n(0,0)\, d_n(i) + \sum_{i' \neq i} \sum_{n' \neq n} c_n(\tilde{n}, \tilde{i})\, d_{n'}(i') + n_n(iT_s)$$

Desired Signal

Interference

Leakage Coefficient

Interference cancellation by generating the interference replicas from decoded bits

# Specification of GS-OFDM Transceiver

| | |
|---|---|
| Sampling frequency | 20 MHz |
| Gaussian pulse width $\sigma$ | $0.275T_s$ ($T_s = 3.2\ \mu$s) |
| Packet length | 11 symbols (preamble:1, data:10) |
| FFT Points | 64 |
| Active subcarriers | 48 |
| Modulation | QPSK, 16QAM |
| Channel coding | convolutional code ($R = 1/2$, $K = 7$) |
| Bit rate | 30 Mbps (16QAM, $R = 1/2$) |
| Bit width of fixed-point | 16 bit |
| Truncation duration $M$ | 3 symbols |
| Max. number of iterations | 3 |
| Channel model | AWGN, 6-path exponential decay |
| Channel estimation | detector : estimation with pilot signals |
| | IIC : ideal estimation |

**Max. 90 MHz**

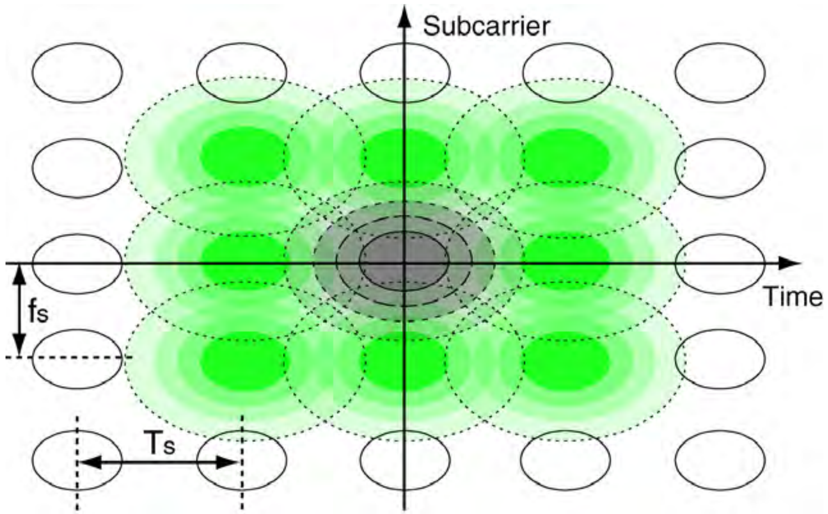
**Max. 135 Mbps**

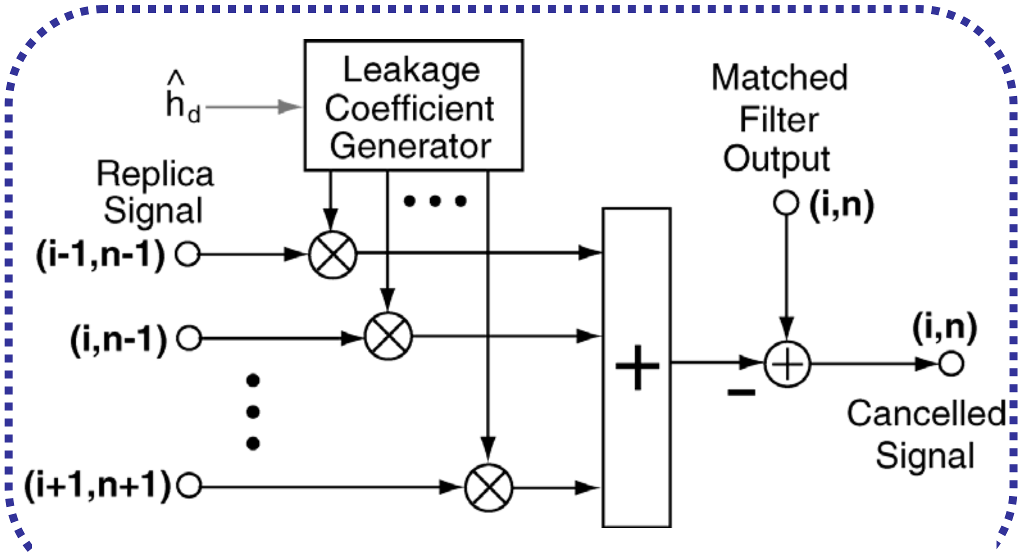
**OFDM x 5/4**
**(24 Mbps)**

# Implementation of IIC

$$r_n(iT_s) = \underbrace{c_n(0,0)\, d_n(i)}_{\text{Signal}} + \underbrace{\sum_{i' \neq i} \sum_{n' \neq n} c_n(\tilde{n}, \tilde{i})\, d_{n'}(i')}_{\text{Interference}} + n_n(iT_s)$$

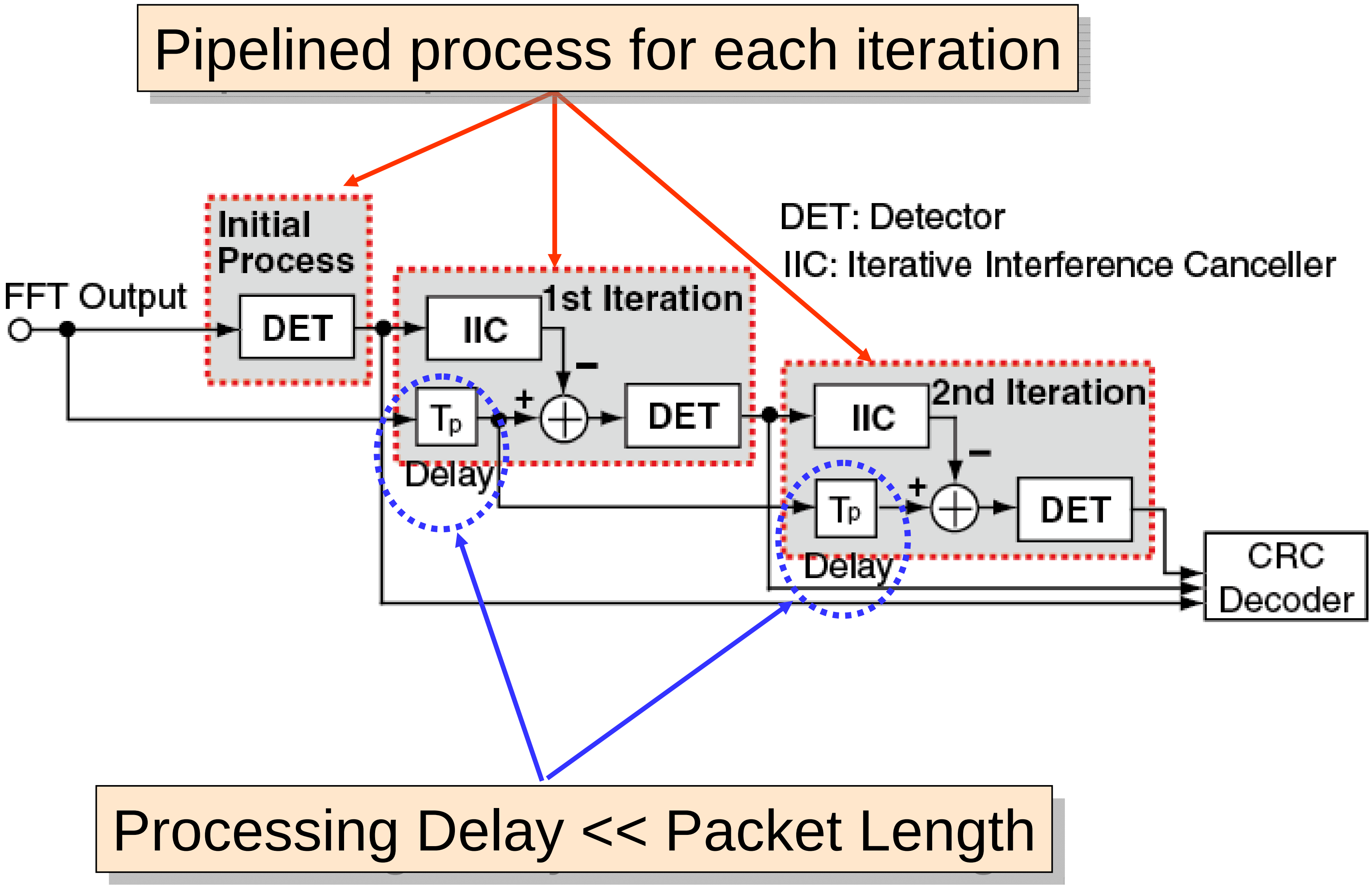
A energy of Gaussian pulse attenuates exponentially → Consider only 8 adjacent subcarriers




Simplified Interference Canceller

# Implementation of GMC Receiver

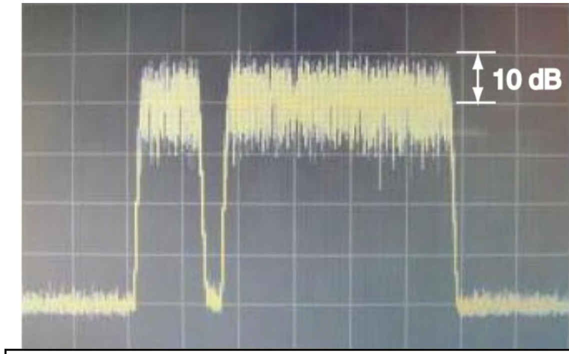


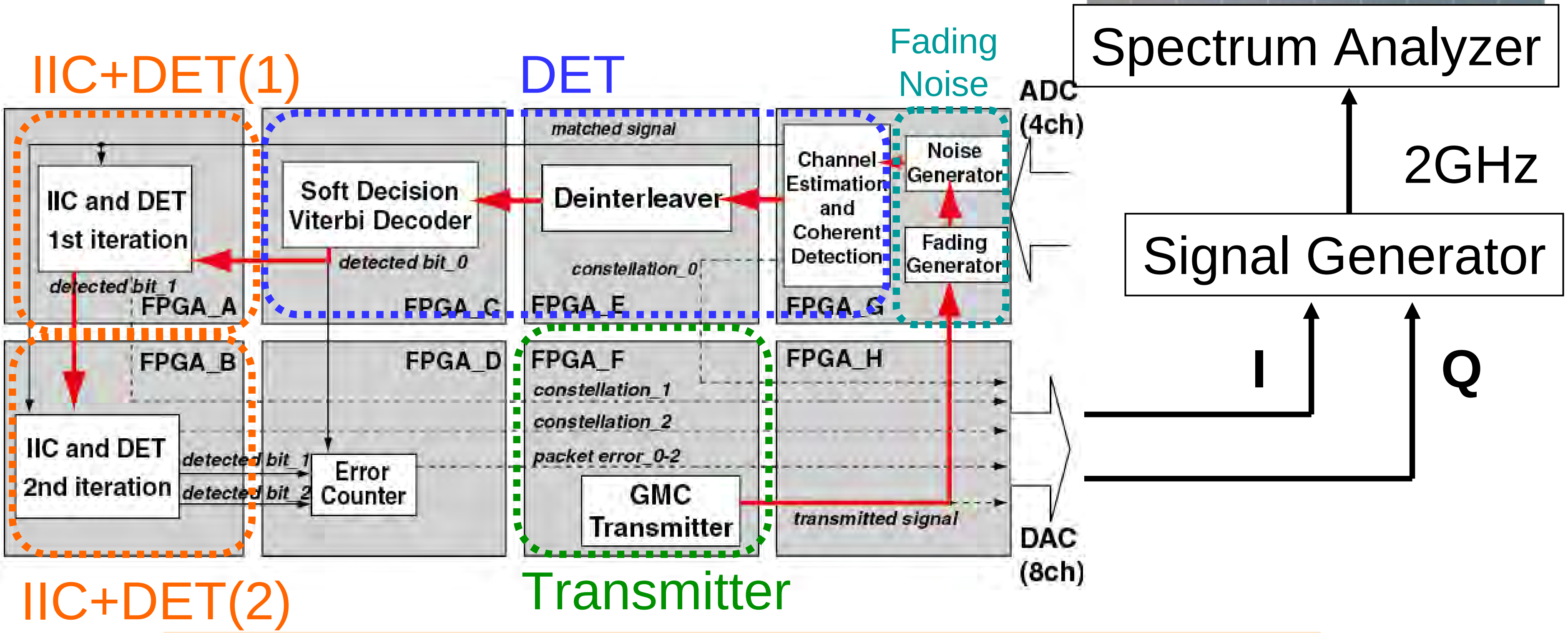
# Implementation

## FPGA Board

Virtex-4 (XC4VLX100)  x 8

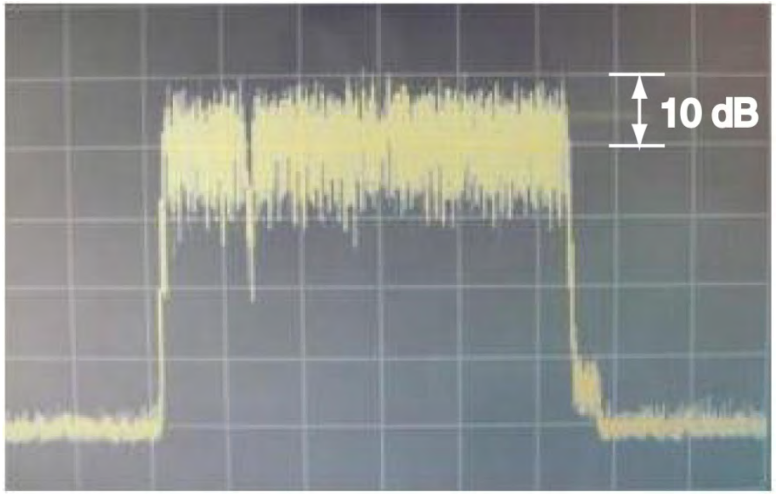
DAC 8ch
ADC 4ch } 14 bit, 125MHz



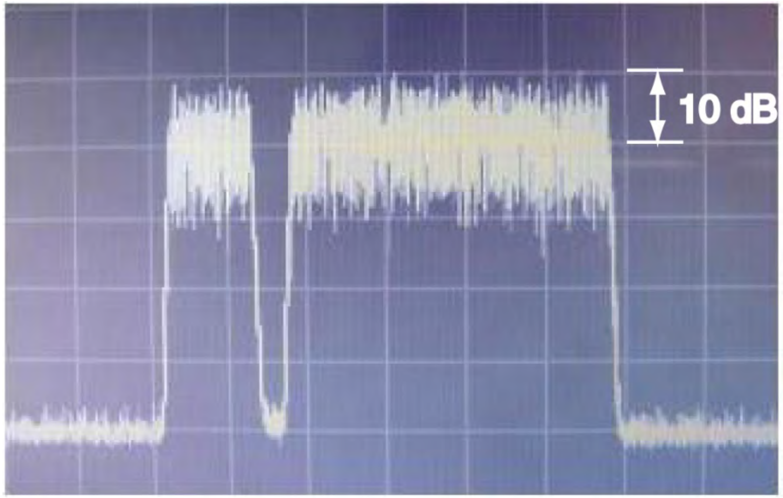

Circuit size：About 10% of the total system-gate

# Measured Spectrum




One subcarrier hole

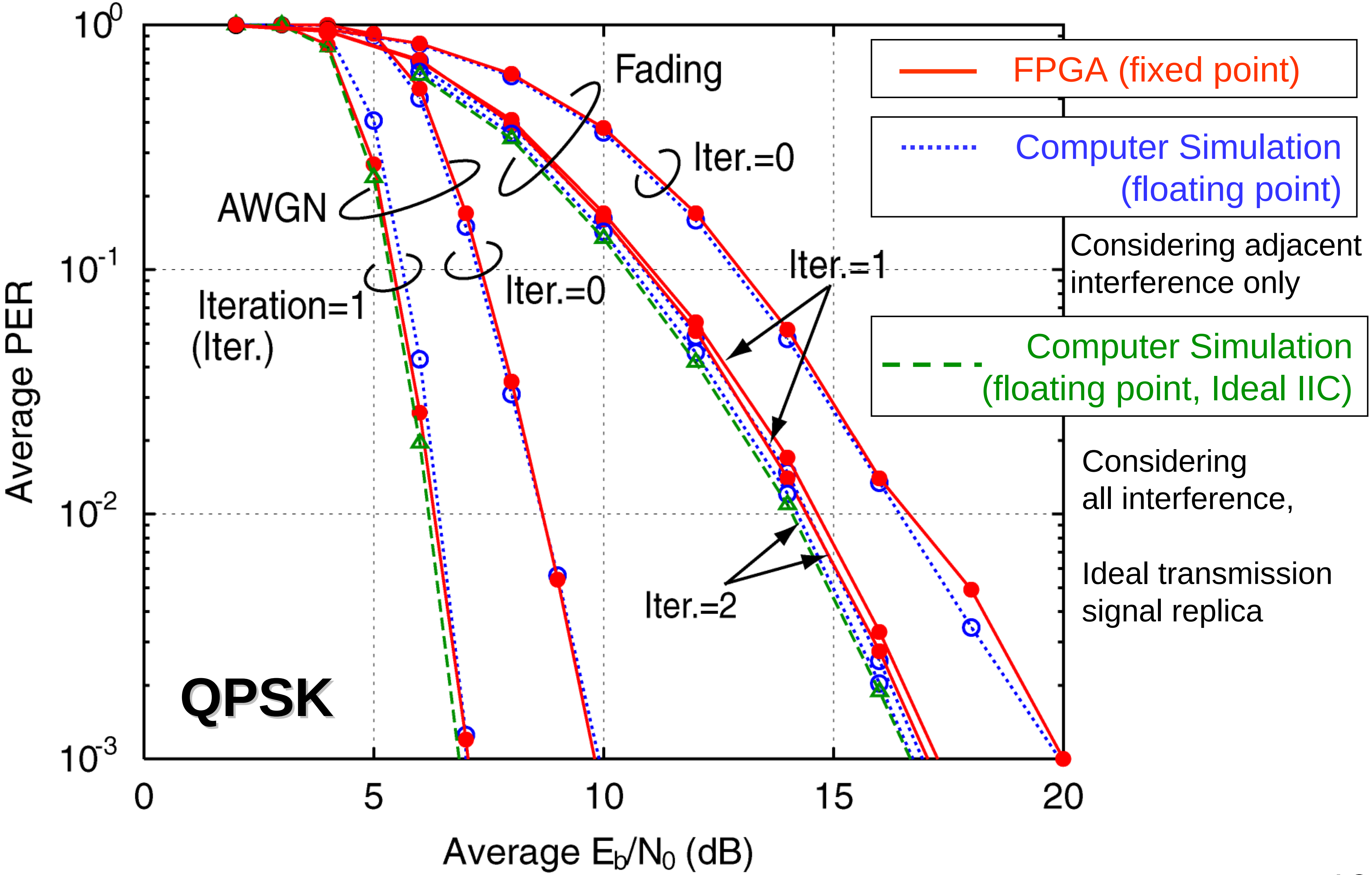

Three subcarrier holes




Five subcarrier holes

Achieved 40 dB spectral dip with three subcarrier holes

# Packet Error Rate (PER) Performance

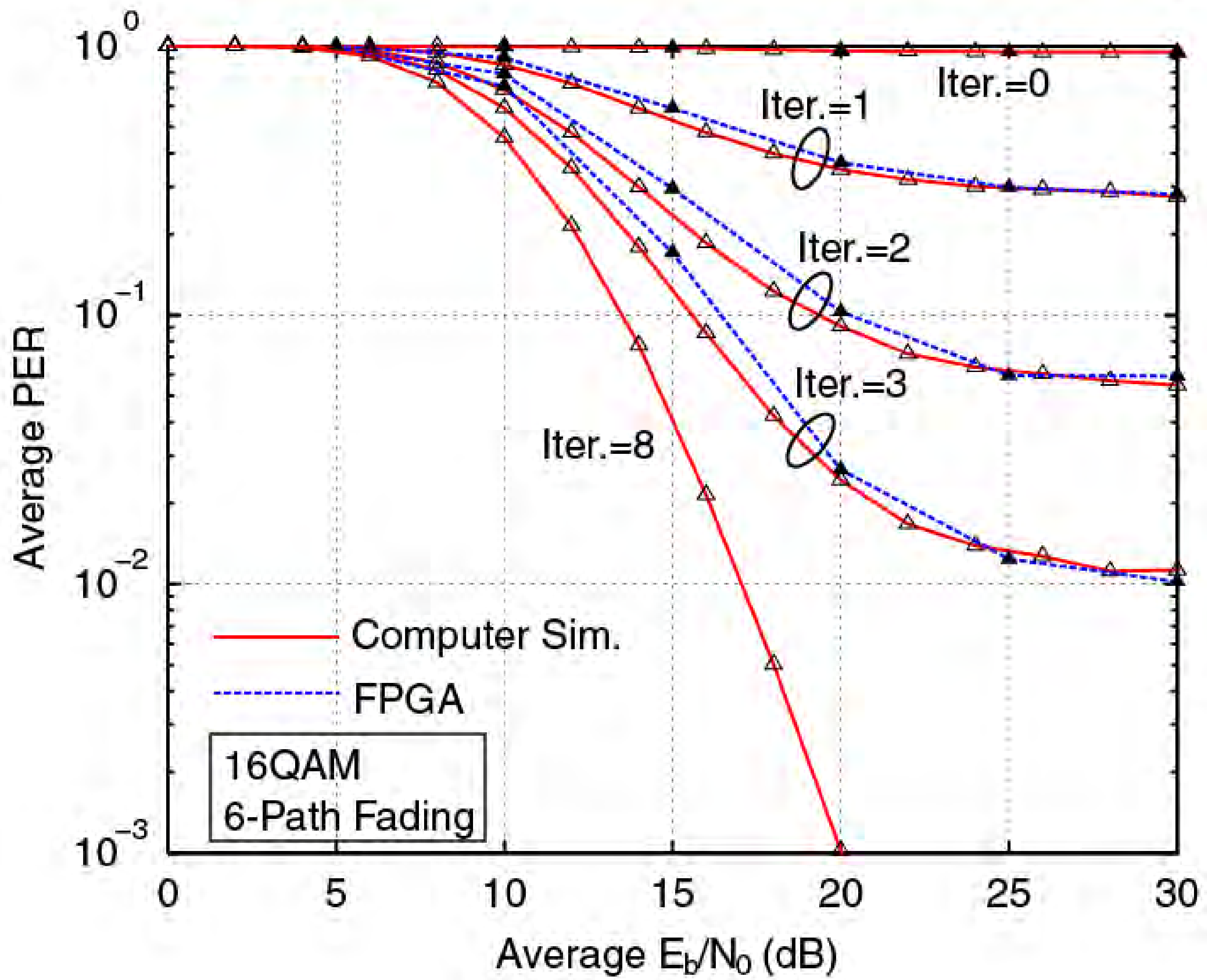



Considering adjacent interference only

Considering all interference,

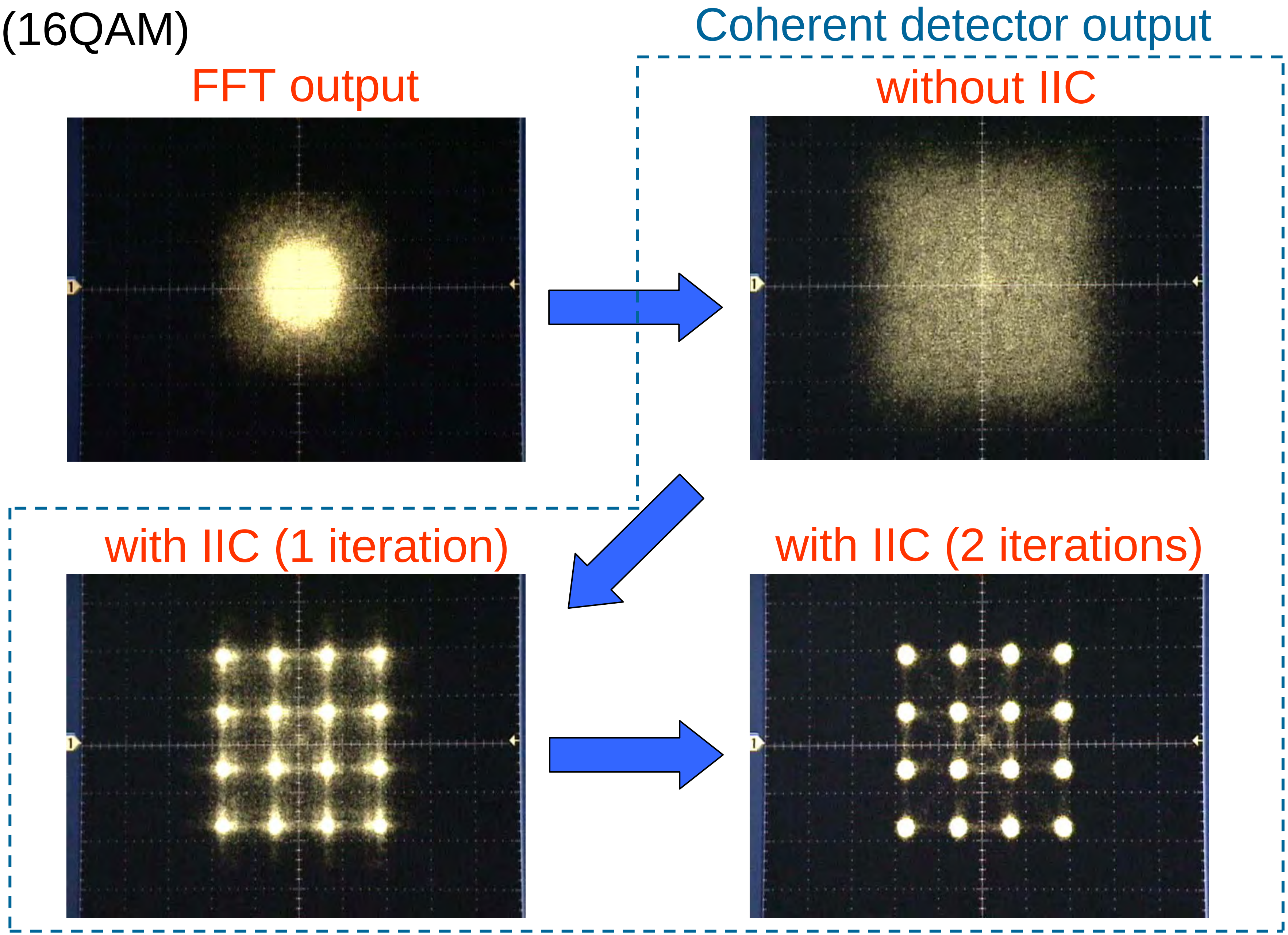
Ideal transmission signal replica

# PER Performance with 16QAM



# Effect of Iterative Interference Canceller (IIC)

(16QAM)



# Conclusion

GMC can realize sharp spectral attenuation.

## Implementation

- GMC transmitter and receiver
- Iterative interference canceller (IIC) with 3 iterations

## Real-time evaluation on FPGA Board

- Measured PER results agree with those of computer simulation.
- IIC with 2 iterations can almost cancel interference with QPSK.
- Real-time performance up to 135 Mbps (16QAM)

*Special Thanks to Mr. Terao, Mr. Onodera, and Mr. Goto*