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The Association Of
WEBE
Washington Executive
Broadcast Engineers

2GHz BAS Relocation Tech-Fair

COFDM
Technology Basics

COFDM Topics

- Brief History
- Why use COFDM ?
- Importance of Orthogonality
  - Allows Coherent Demodulation
- Importance of Guard Interval (GI)
  - Used to mitigate ISI

Topics (cont)

- DVB-T COFDM Frame Structure
- DVB-T Pilot Carriers
  - Synchronization, Estimation, Signaling
- DVB-T FEC
  - Outer / Inner Codes
  - Punctured Inner Convolutional Coding
- Review DVB-T Parameter Selections
  - Bandwidth, # Carriers, GI, Modulation type, Inner FEC

Brief History (C)OFDM

- R.W. Chang “Synthesis of Band Limited Orthogonal Signals”
  - Bell System Tech Journal, Vol. 45 pp 1775-1796 (Dec. 1966)
  - Mostly Military Interest
- US Patent No. 3,488,455 filed Nov. 1966, issued (Jan. 1970)
- Early 80’s first patents Europe (CCETT, France)
  - OFDM + FEC = COFDM Is born

Brief History OFDM (cont)

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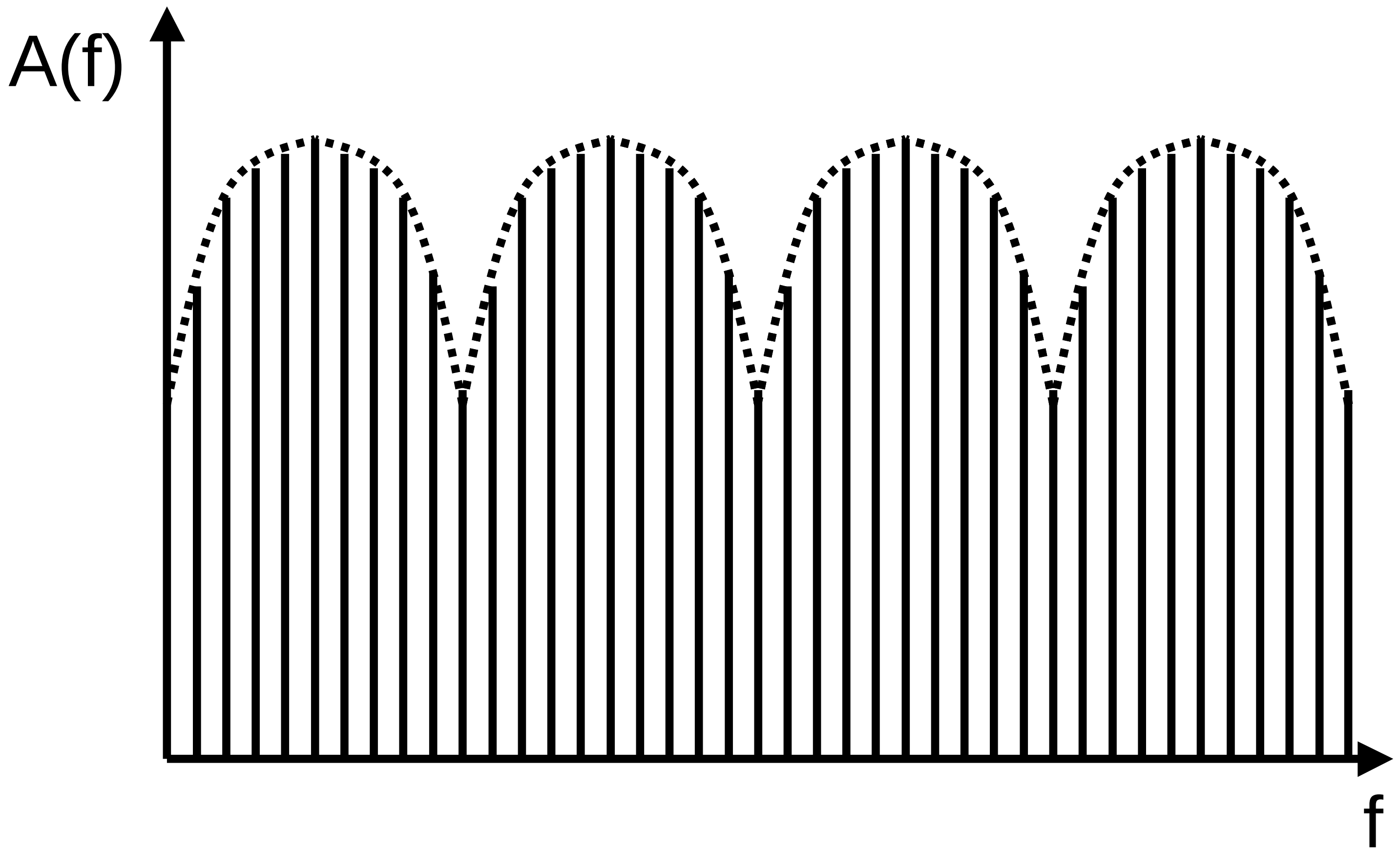
- 1993 DAB Standard (Eureka 147 Project)
- 1997 DVB-T Standard
- Today or Emerging
    - ISDB-T – Japanese Standard for Digital Terrestrial Television
    - DMB-T – Chinese Standard for Digital Terrestrial Television
    - DRM – Digital Radio Mondale
    - xDSL – Digital Subscriber Line
    - WLAN – Wireless LAN
    - DVB-H – Multimedia to Handheld
    - FLO - (Forward Link Only) Multimedia to Handheld (Qualcomm)

Why Use COFDM?

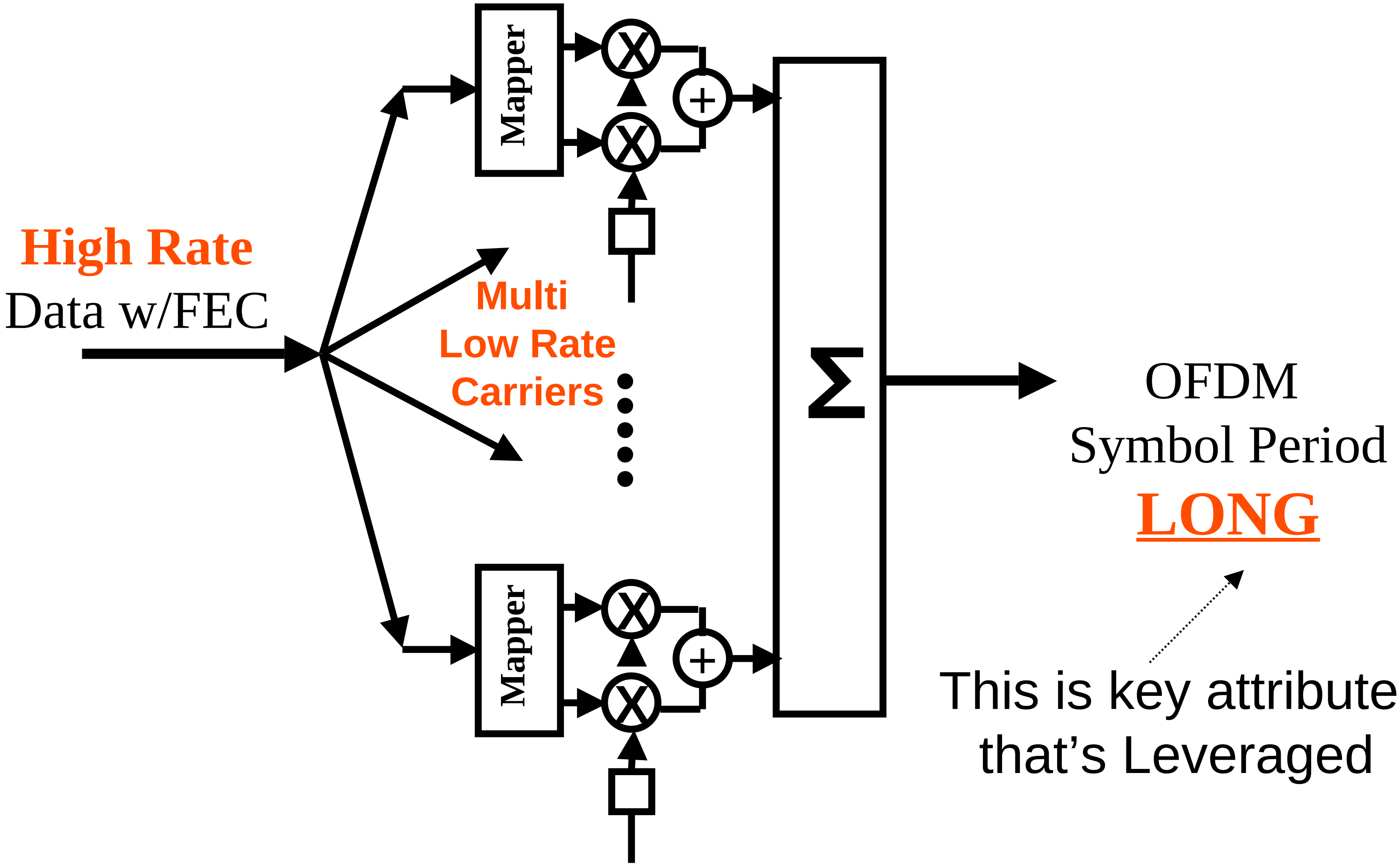
Multi-Carrier (Spread data)

- Robustness against frequency selective fading



Why Use COFDM?

Mitigate Inter-Symbol Interference



Acronym COFDM

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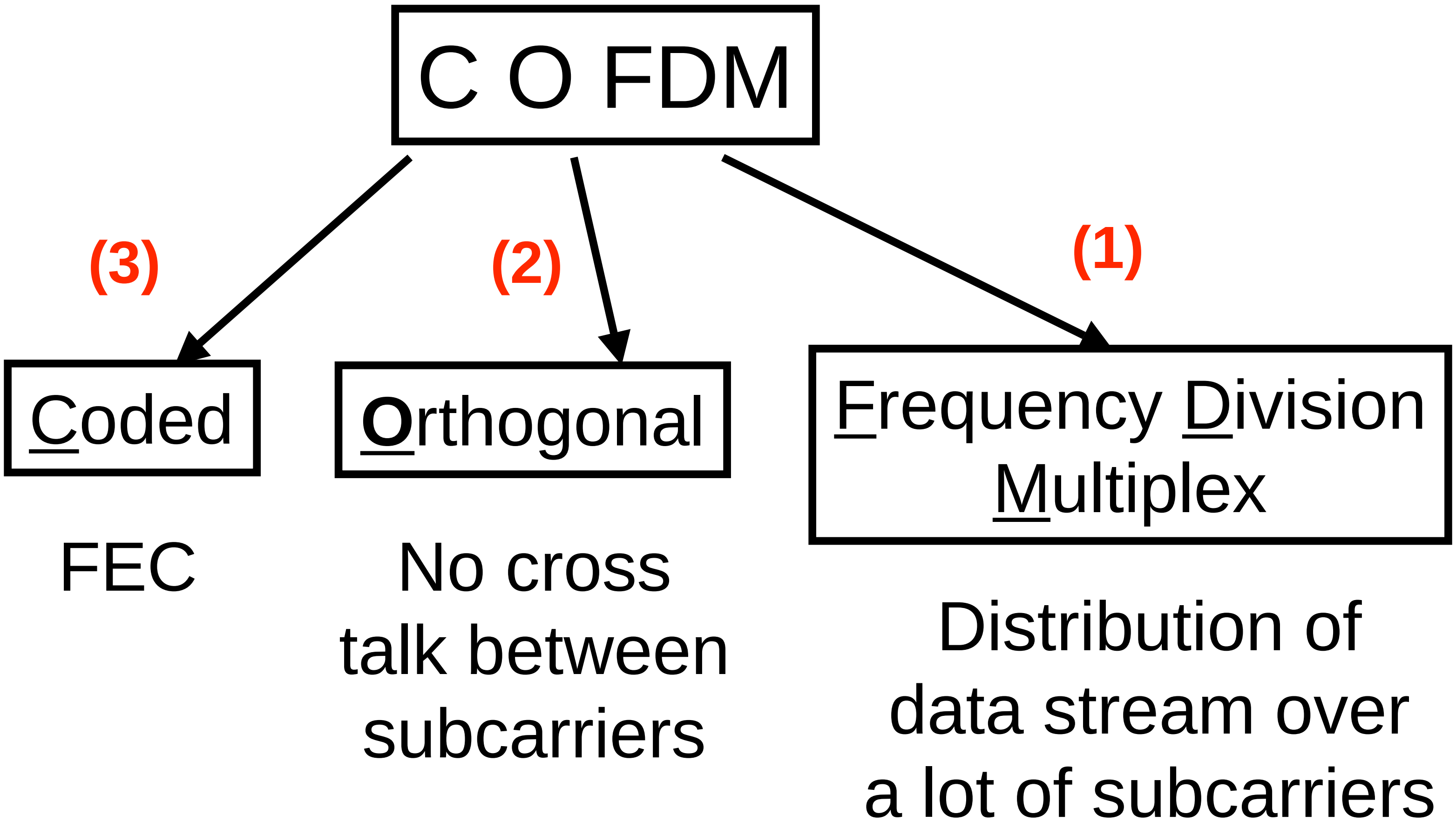
Subjects presented in order listed below



Muticarrier (FDM vs.OFDM)

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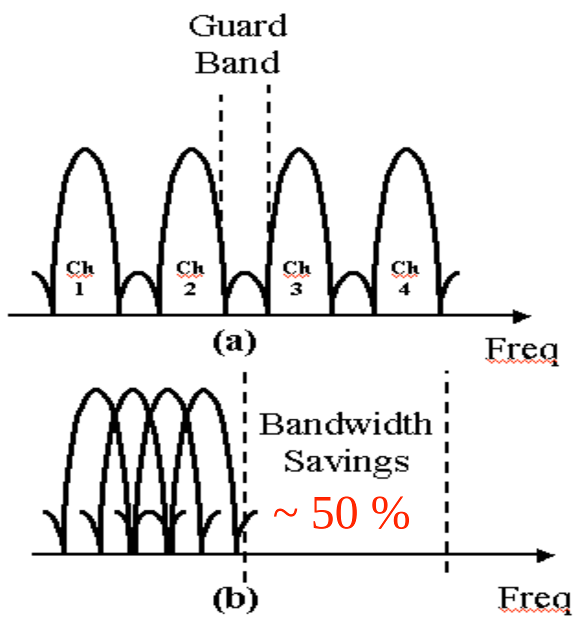
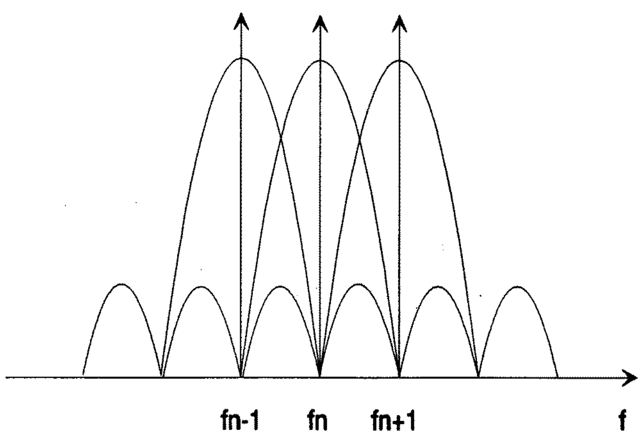


(a) FDM Non-Overlapping Carriers **(Guard Band)**
Spaced apart in such away that signals can be received with conventional filters and demodulators

(b) OFDM Technique uses Overlapping Carriers
Carriers can be received without Crosstalk

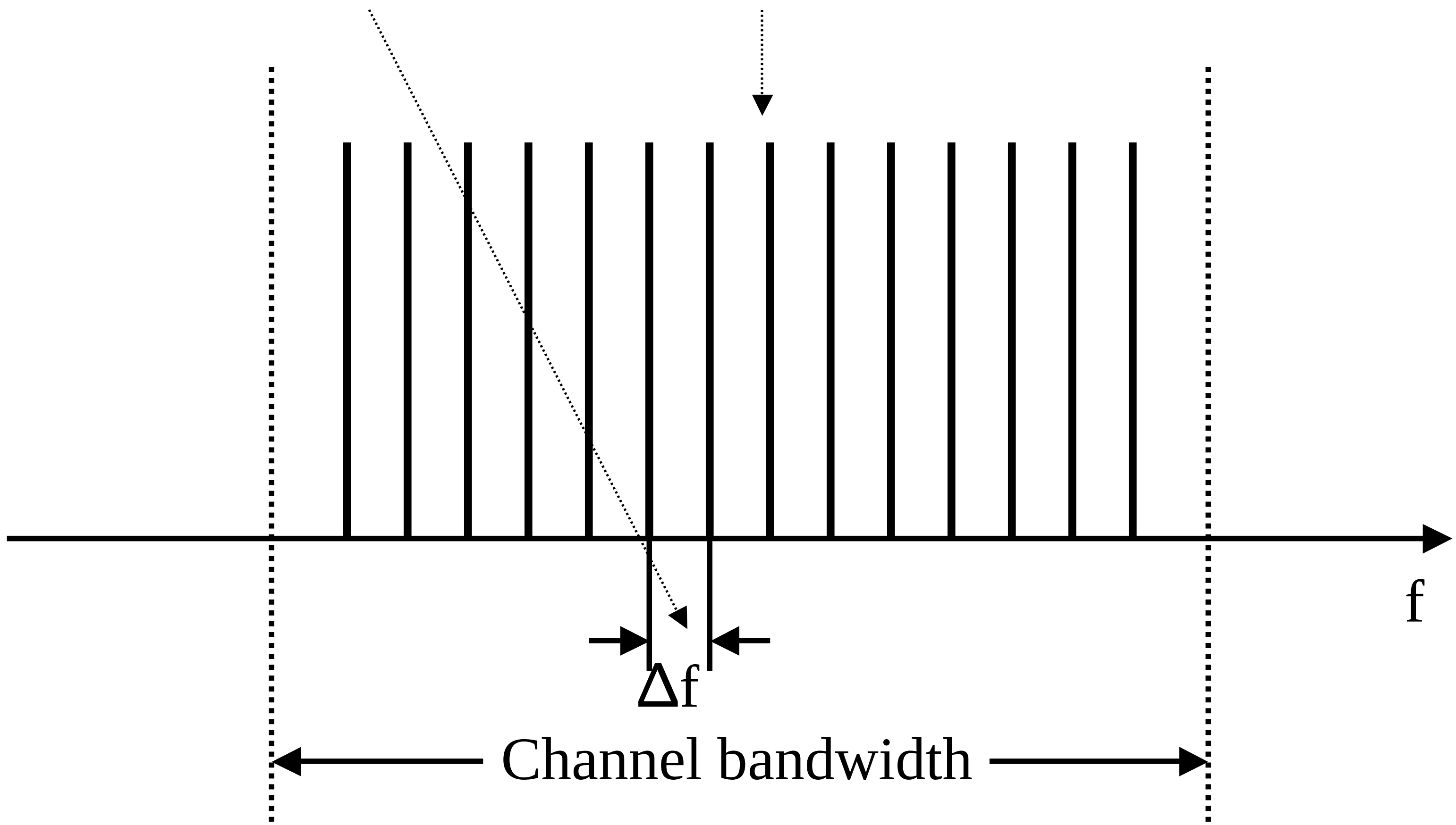


Orthogonality is the Key

The word **Orthogonal** indicates that there is a **precise mathematical relationship** between the carriers
The demodulation is performed in the digital domain
Using special DSP techniques (to be explained)

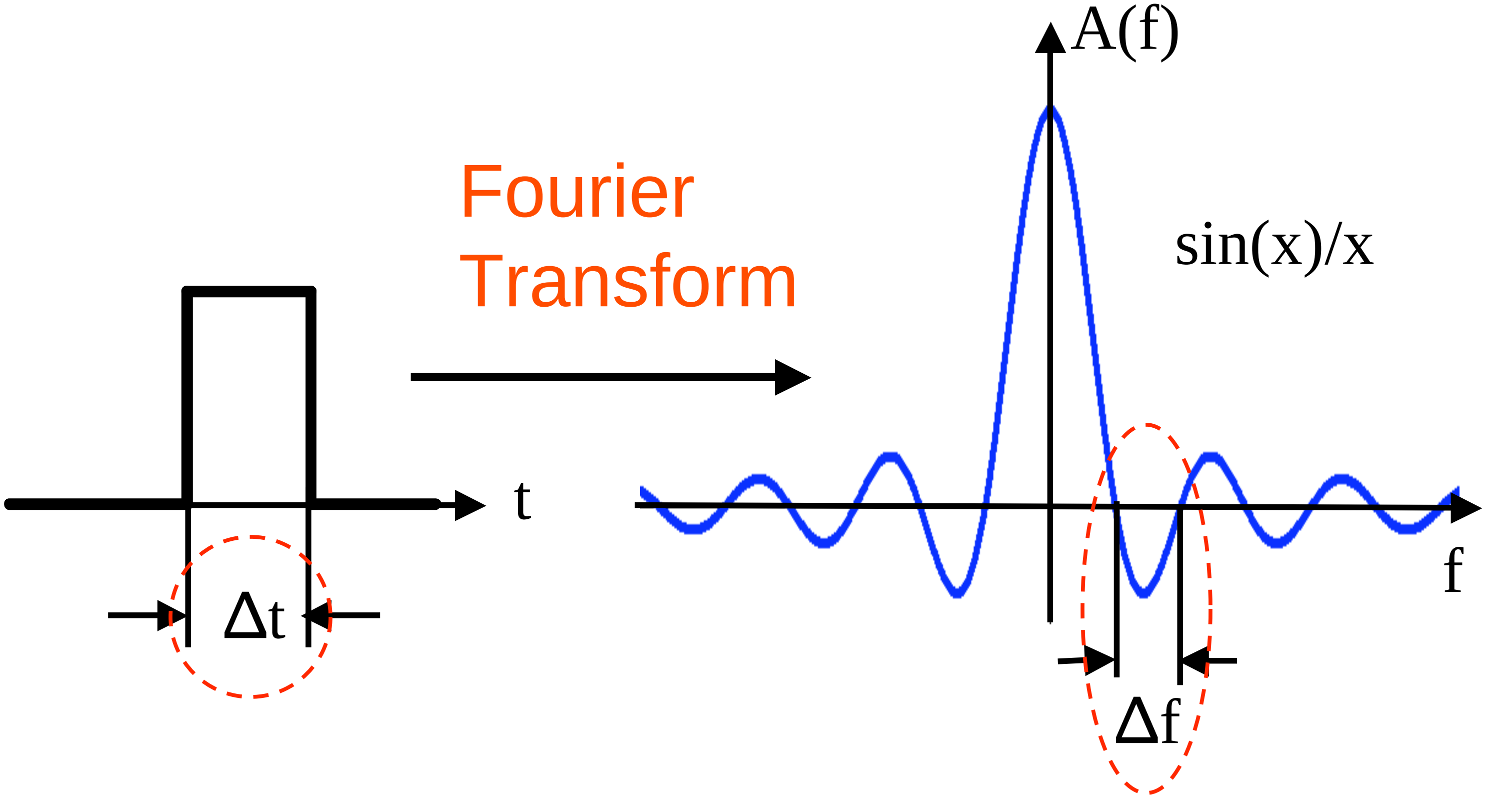
OFDM Subcarriers

What Carrier Spacing & Data Rate = Orthogonal relationship?



Carrier Spacing

Fact varying the duration Δt of the rectangular pulse
can change the spacing Δf between
the zero points in the spectrum



Time Domain

Frequency Domain

Orthongonality (Frequency Domain)

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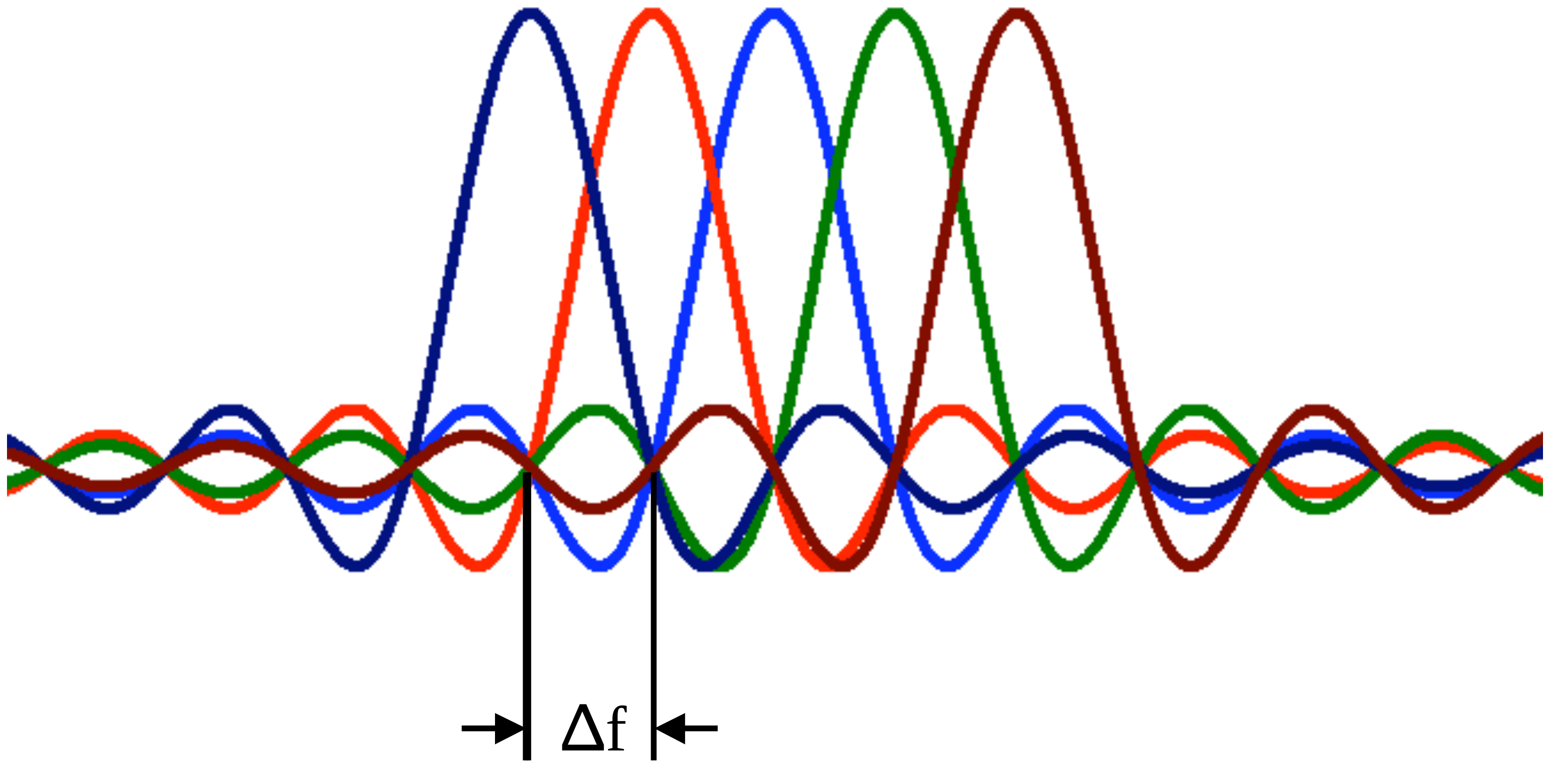
Orthogonality condition: $\Delta f = 1/\Delta t$



Orthongonality (Time Domain)

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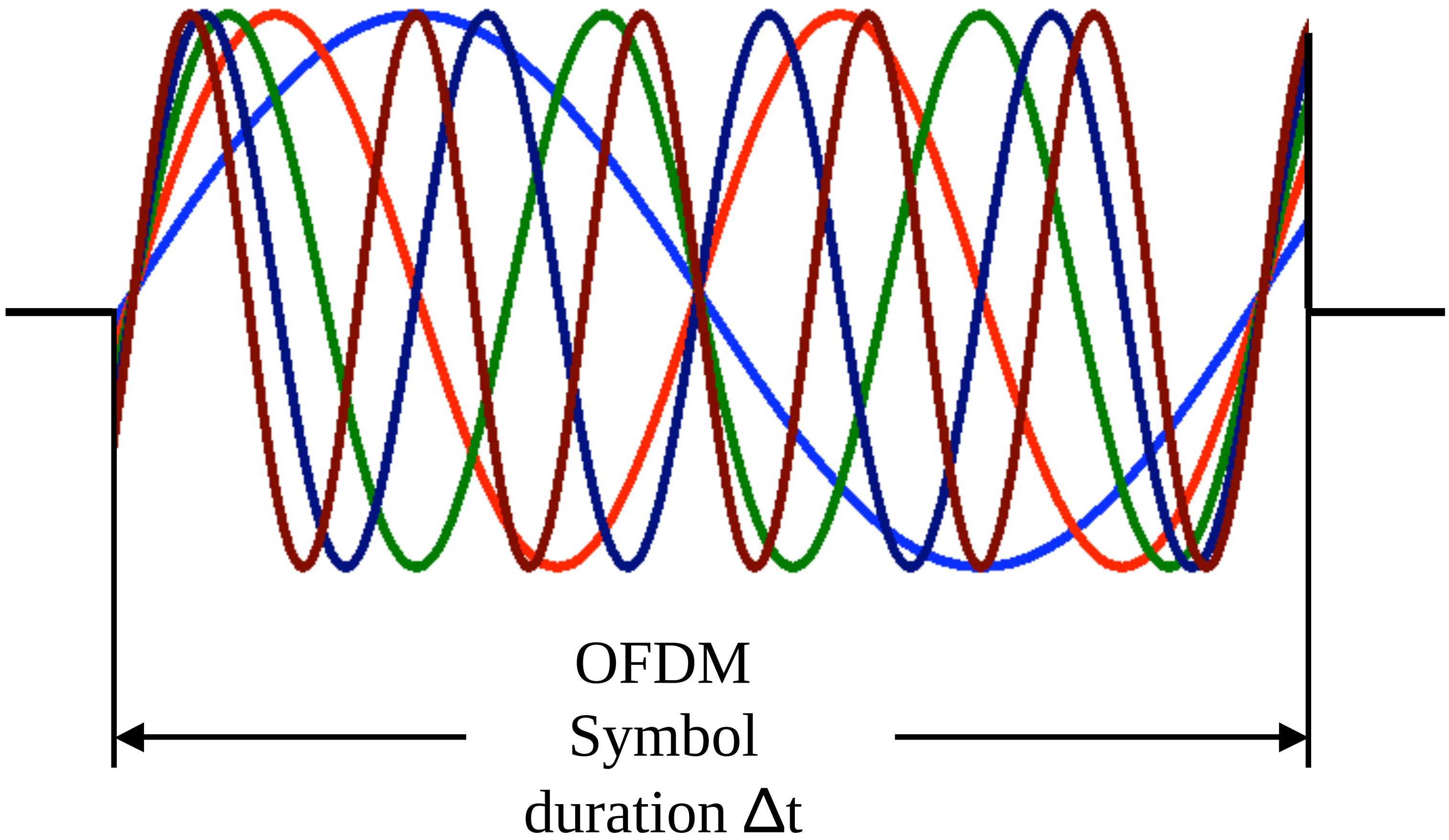
Note each carrier is an Integer # of cycles in Δt
cycles between adjacent carriers = 1



Important Observations (Orthogonality)

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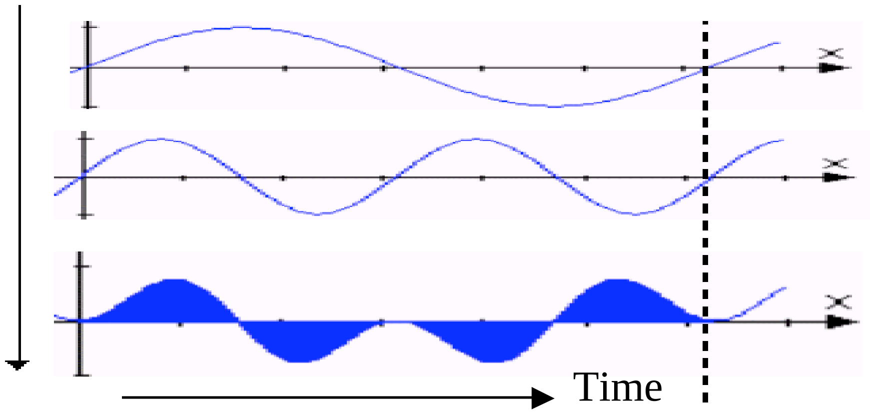
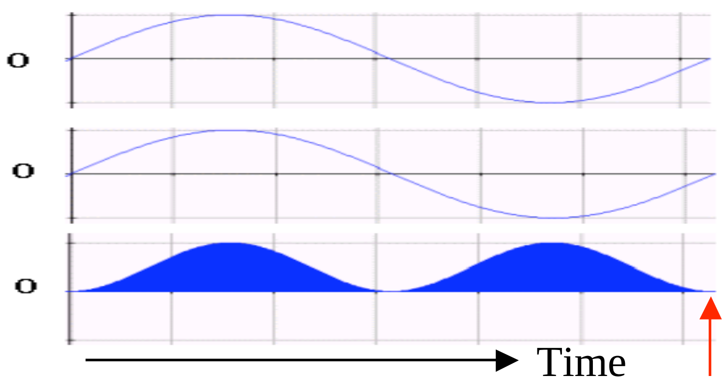
Multiply and sum (integrate) two sine waves of *different frequencies*



$$\int_0^{2\pi k} \sin(\omega t)\,dt = 0$$

These Two Observations Are Key To Understanding COFDM Coherent Demodulation

Multiply and sum (integrate) two sine waves of the *same frequency*



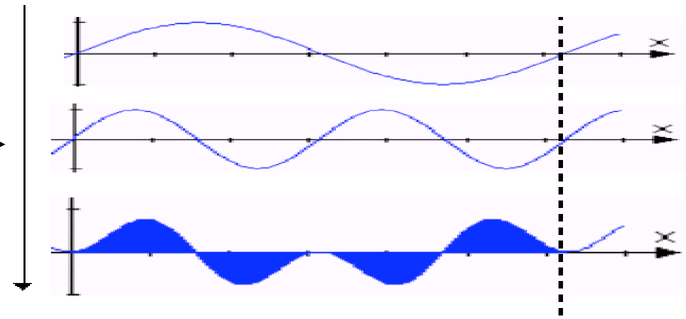
$$\int_0^{2\pi k} \sin(\omega t)\,dt \neq 0$$

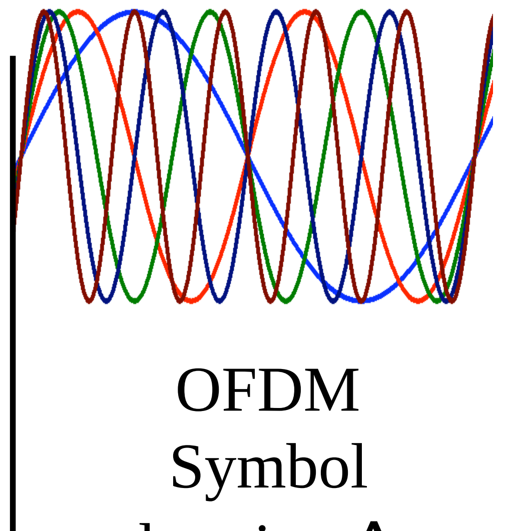
Resultant Not Equal to Zero

Resultant Shifted Above Zero DC Axis

Principle Coherent Demodulation

FFT → Multiply and Sum (Integrate) →





OFDM Symbol duration Δt

$$\int_0^{2\pi k} \sin(\omega t)\, dt = 0$$

All Energy sums to Zero

Integer # of cycles in Δt

Principle Coherent Demodulation

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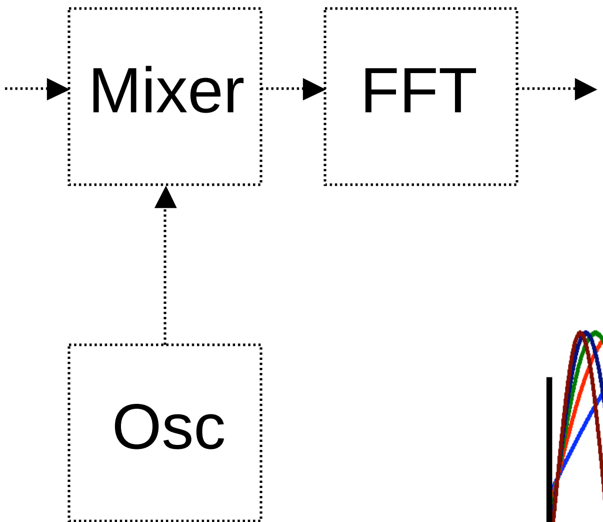
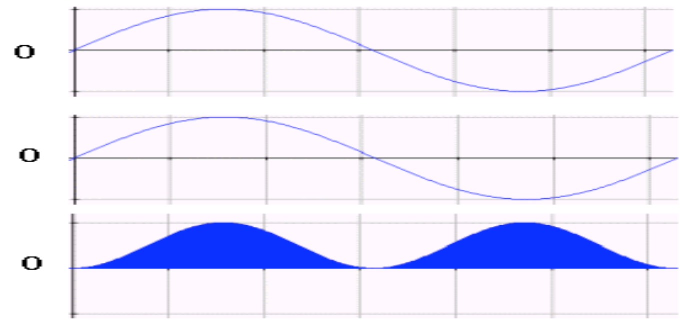
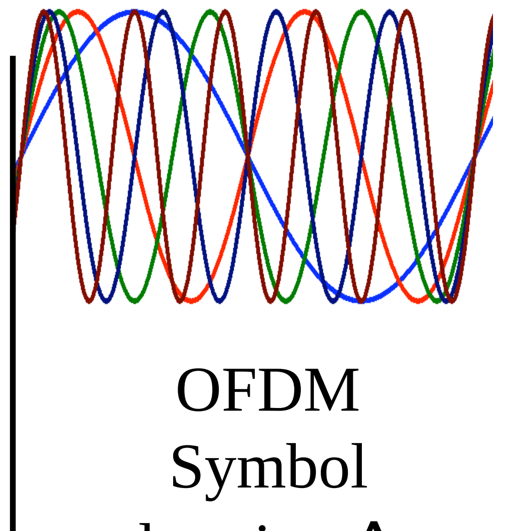


Multiply and Sum (Integrate)



$$\int_0^{2\pi k} \sin(\omega t)\, dt \neq 0$$

Locally generated Carrier N



OFDM Symbol duration Δt

All Energy sums to Zero Except the Carrier N Mixed in it is separated

Integer # of cycles in Δt

Coherent Demodulation Process

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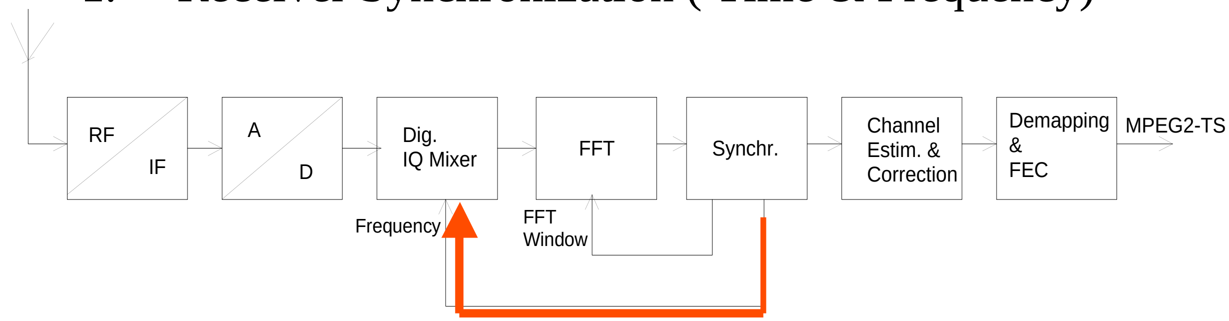
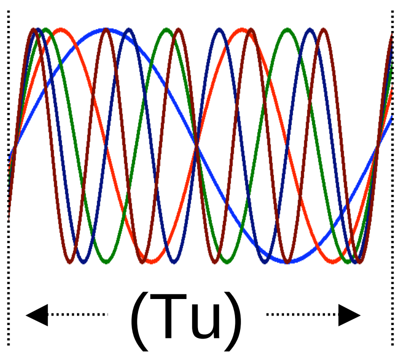
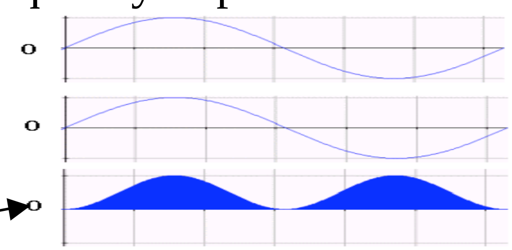
1. Receiver Synchronization (Time & Frequency)



DVB-T Receiver : simplified Block Diagram

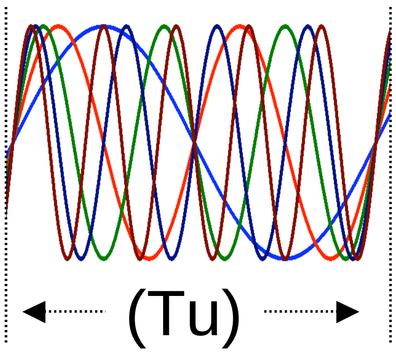


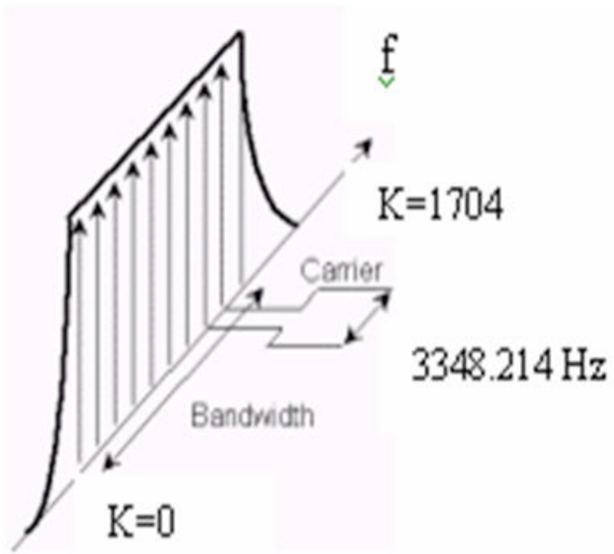
2. Perform FFT (Convert to Freq Domain), Locally generate a carrier equal in frequency & phase to the first carrier, mix with received COFDM symbol Integrate over the period Tu The first carrier will be *shifted vertically (beat down zero dc)* and hence separated, Modulation recovered, Other carriers Integrate to Zero



3. Very rapidly repeat step two above (1704 times 2K mode) for each carrier frequency in turn until all carriers have been effectively separated

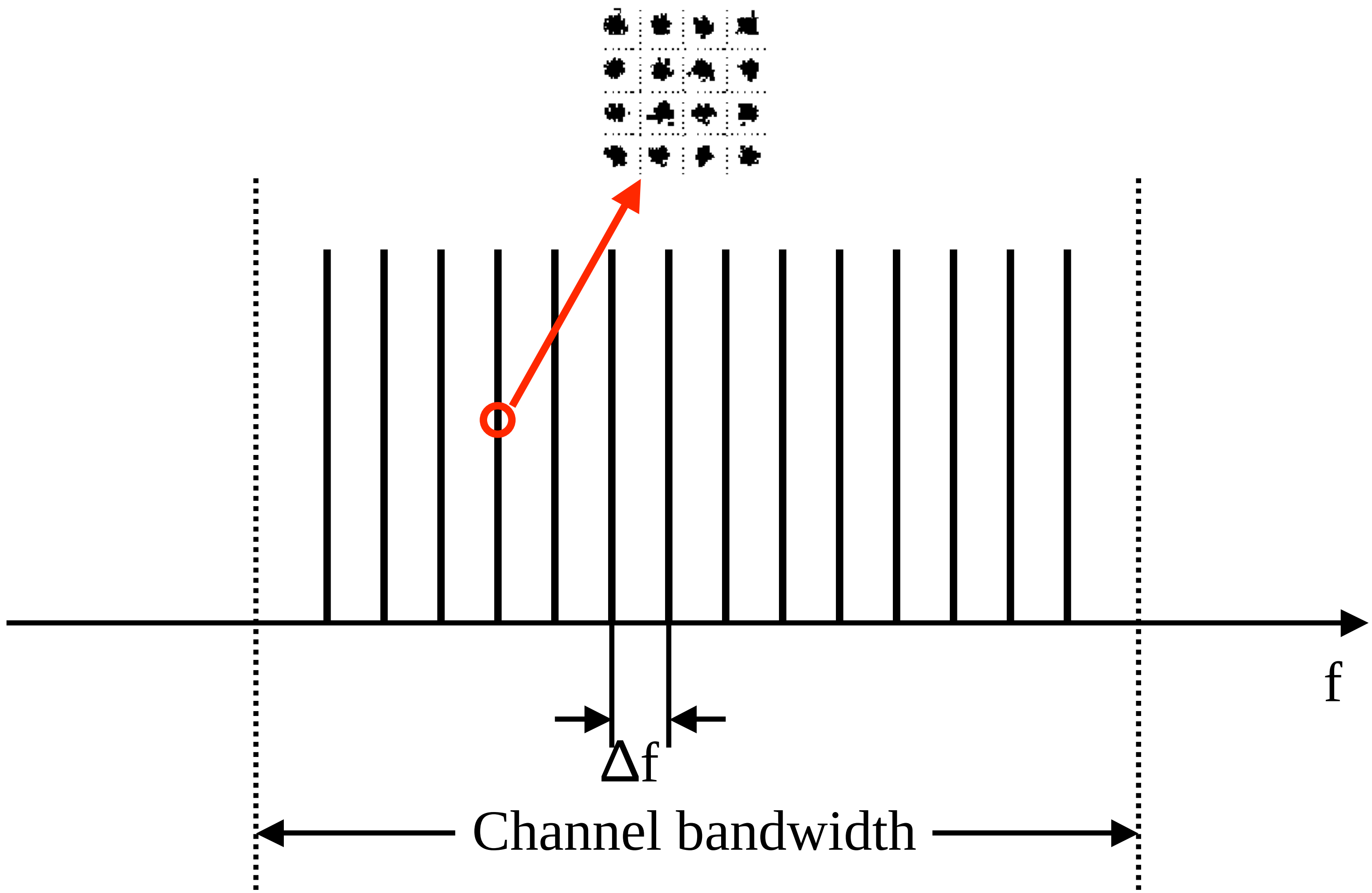
Example: DVB-T 2K (6MHz)



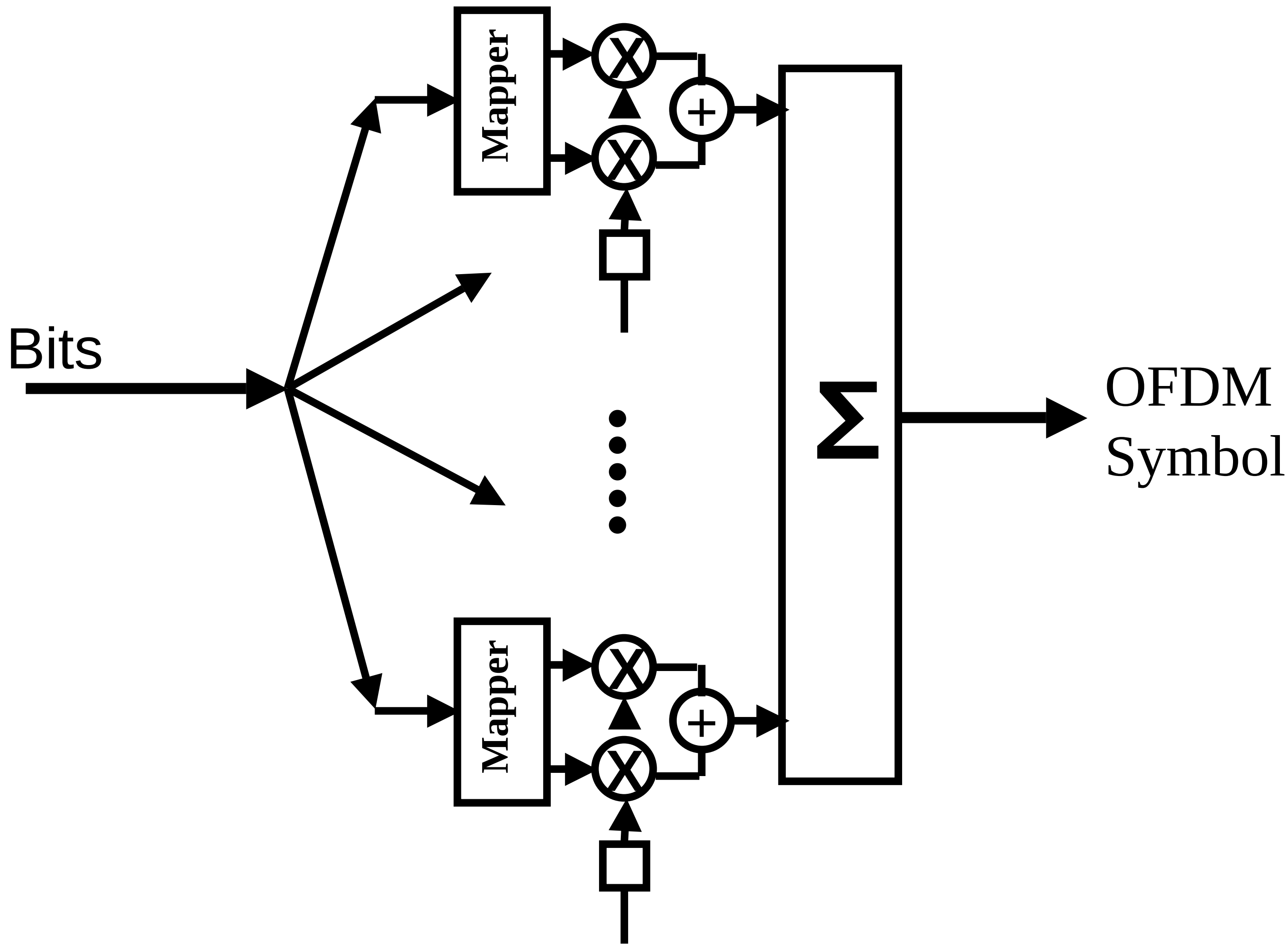


Useful Bandwidth (BW) = 5.705357 MHz
Number Carriers (K) = 1,705
Symbol Duration (Tu) = (K-1)/BW = 298.667 uS
Carrier Spacing (Hz) = 1/Tu = 3,348.214 Hz

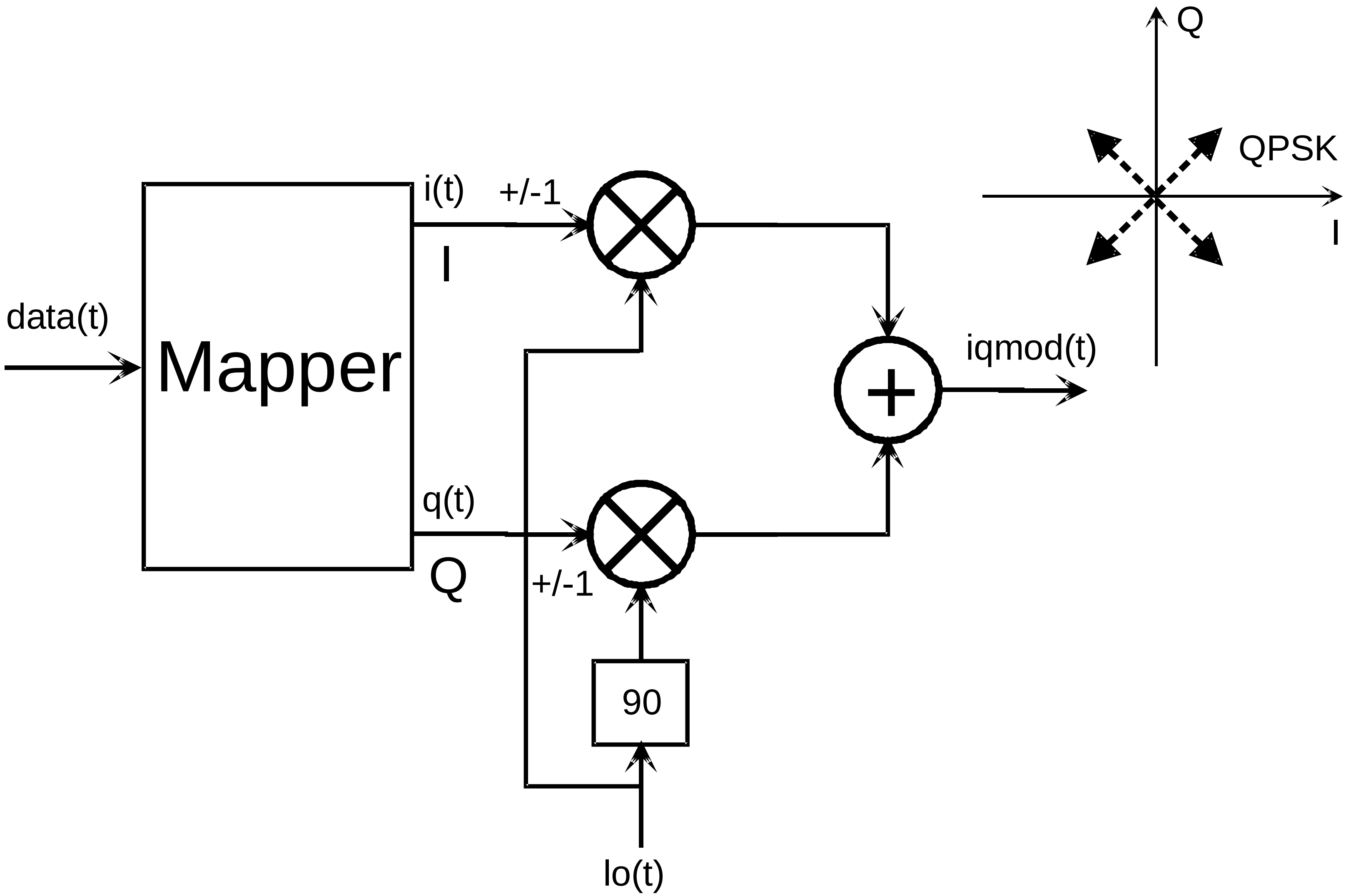
Modulation



Mapping Bits into Symbols



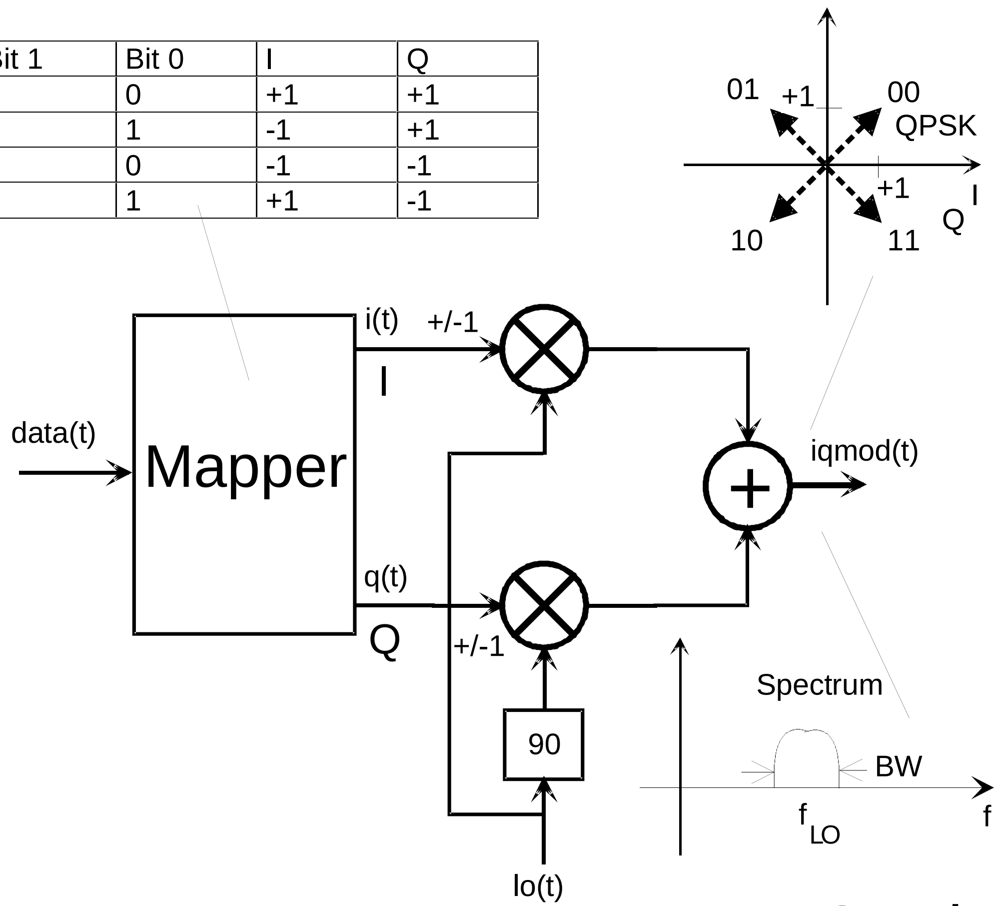
Digital Modulation of a Single Carrier

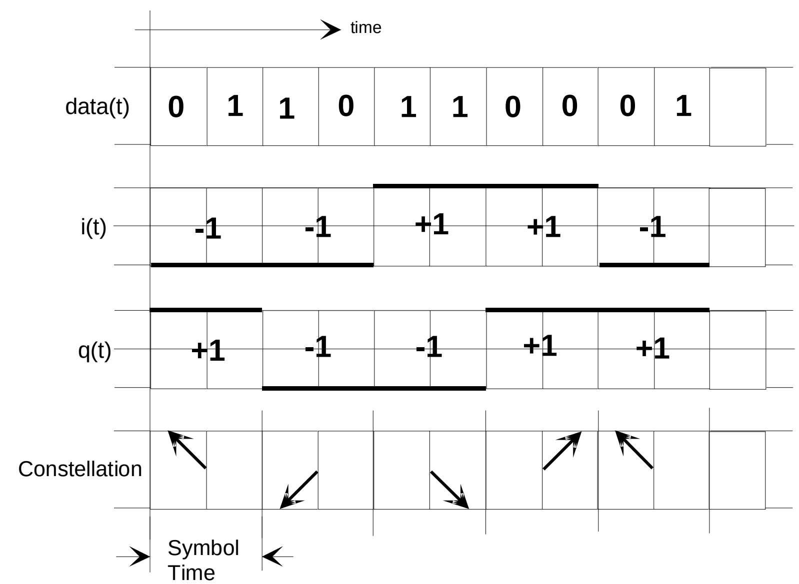


Digital Modulation of a Single Carrier

Mapping Table

Bit 1	Bit 0	I	Q
0	0	+1	+1
0	1	-1	+1
1	0	-1	-1
1	1	+1	-1





Symbol Rate = 1 / Symbol Time

Needed Bandwidth = Symbol Rate

QPSK, 16QAM, 64QAM

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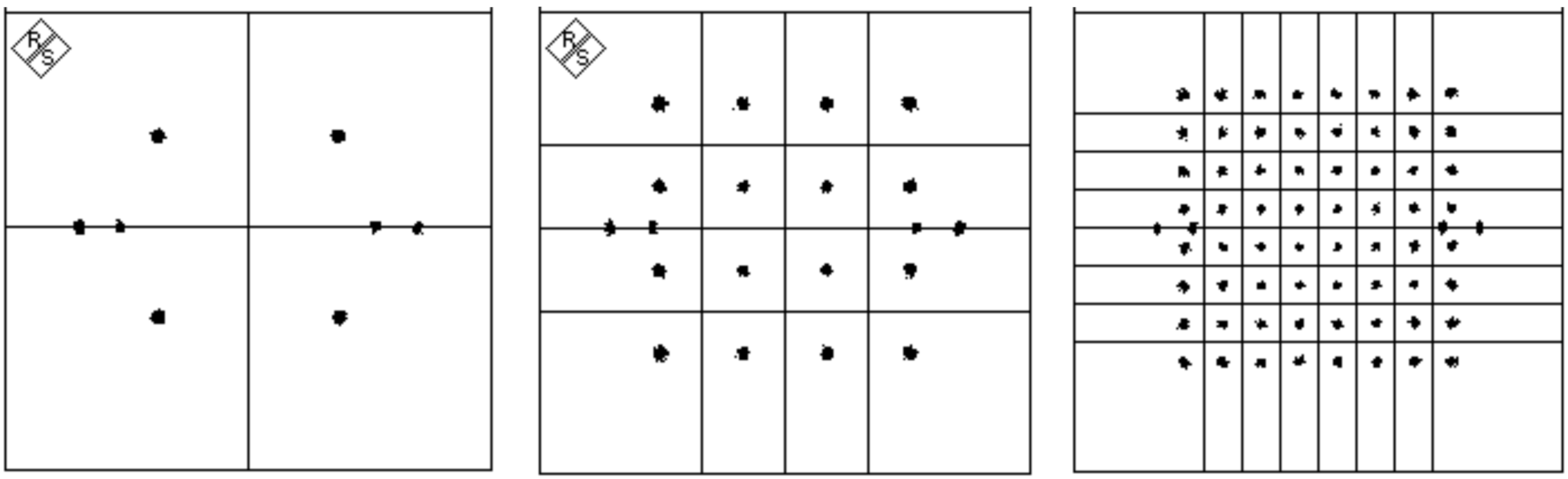
DVB-T Constellations



QPSK = 4QAM
2 Bit / Symbol

16QAM
4 Bit / Symbol

64QAM
6 Bit / Symbol

Maintaining Orthogonality

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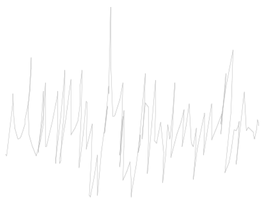
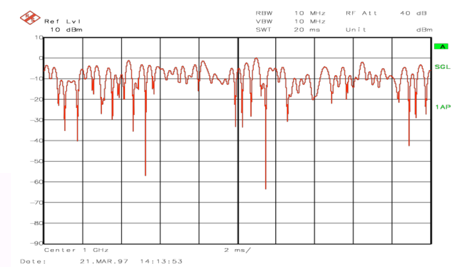
- How to Handle Multi-path Environment
  - Use a Long Symbol Period w/ respect to speed of light (RF Propagation)
  - Insert Guard Interval (GI)
  - GI Mitigates Inter-Symbol Interference (ISI)
- A contrasting comparison is given
  - Single vs. Multiple Carrier System

Propagation Models



Additive White Gaussian Noise (AWGN): *When there is only a single RF path to the receiver, the system can be viewed as operating over an AWGN channel*

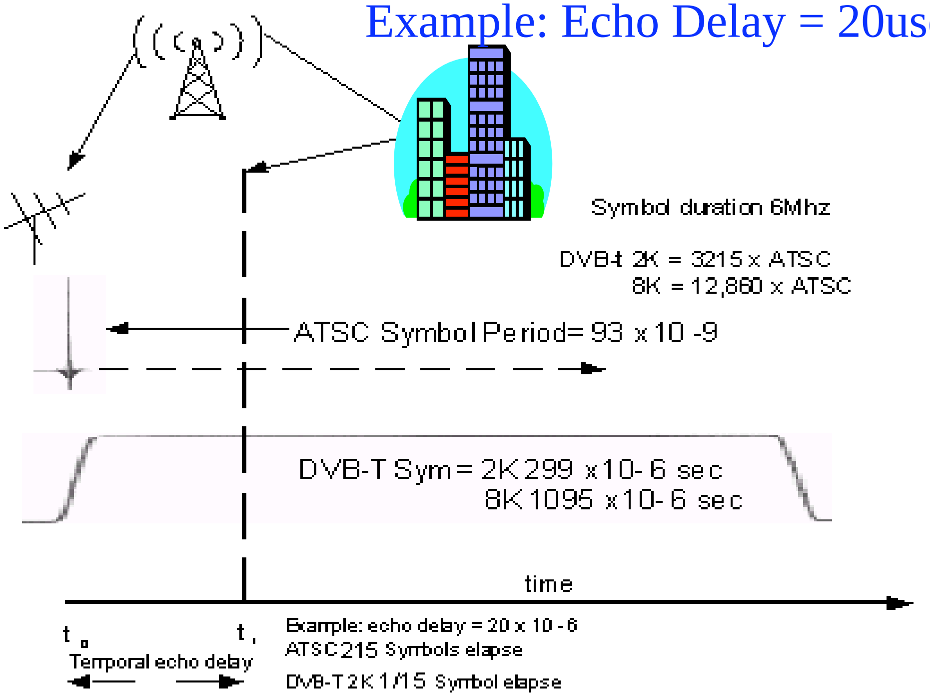


Rician Fading Channel: *Consists of a direct RF path and one or more indirect paths that may be static or dynamic in nature. Most urban and indoor reception environments qualify.*

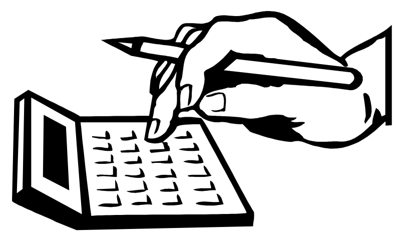
Rayleigh Fading Channel: *When there is no direct RF path to the receiver, only echoes (static or time varying) are received. Applies to urban outdoor and all indoor sites when no direct RF path to the receiver exists. Also, a portable or mobile receiver if used, would most likely exhibit Rayleighian channel characteristics.*

Comparison Symbol Period (6 MHz)

Example: Echo Delay = 20usec



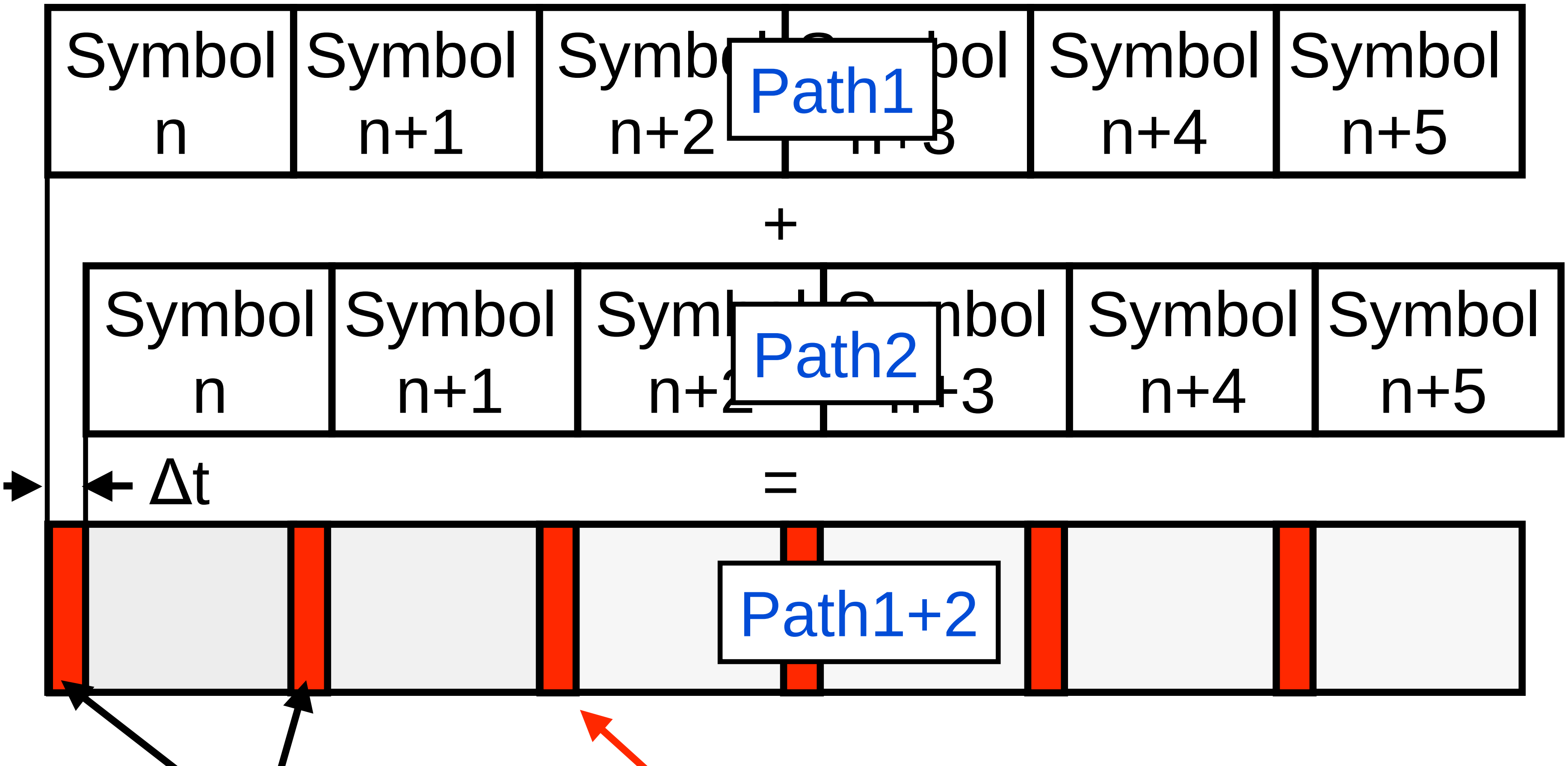
SYSTEM	Symbol Period
ATSC 8-VSB	~ 93 nsec
DVB-T 2K	~ 299 usec
DVB-T 8K	~ 1195 usec



SYSTEM	Echo Delay = 20usec
ATSC 8-VSB	~ 215 Symbols Elapse
DVB-T 2K	~ 1/15 Symbol Elapse
DVB-T 8K	~ 1/60 Symbol Elapse

DVB-T 2K ~ 3215 x ATSC
DVB-T 8K ~ 12,860 x ATSC

Intersymbol Interference (ISI)

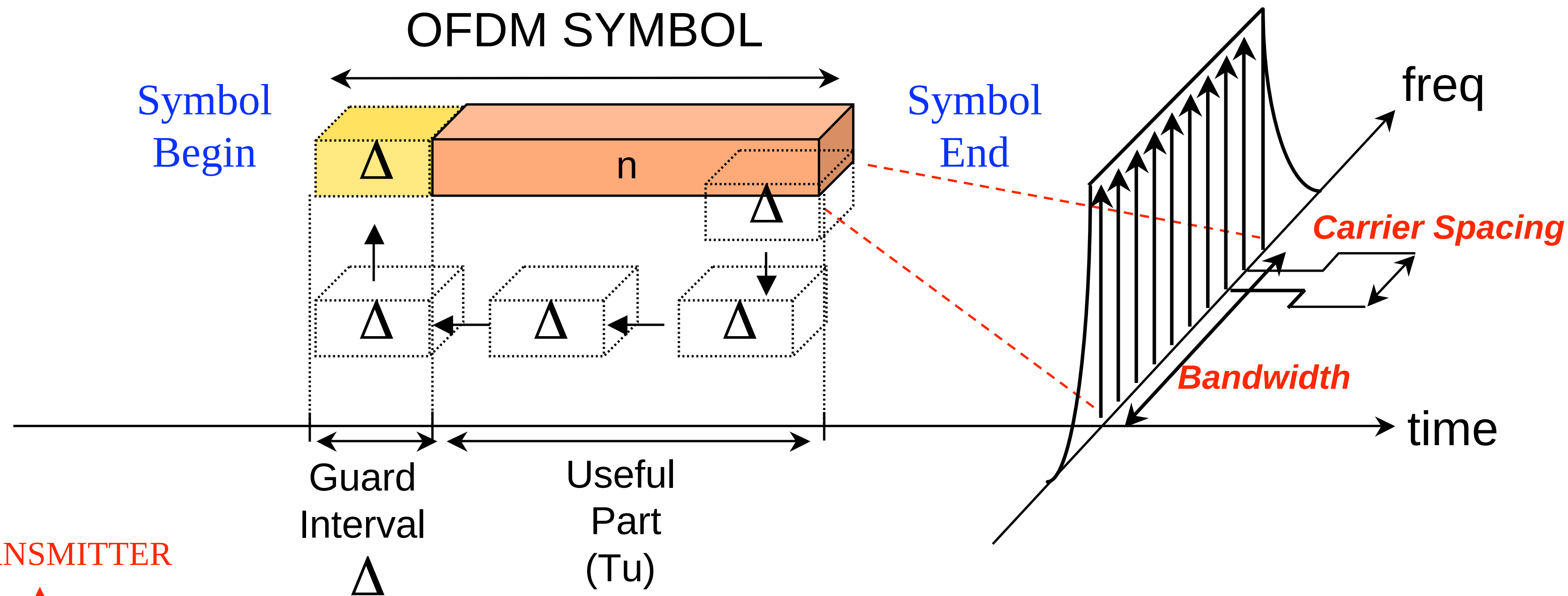


Intersymbol interference

Only beginning portion of Symbol ISI

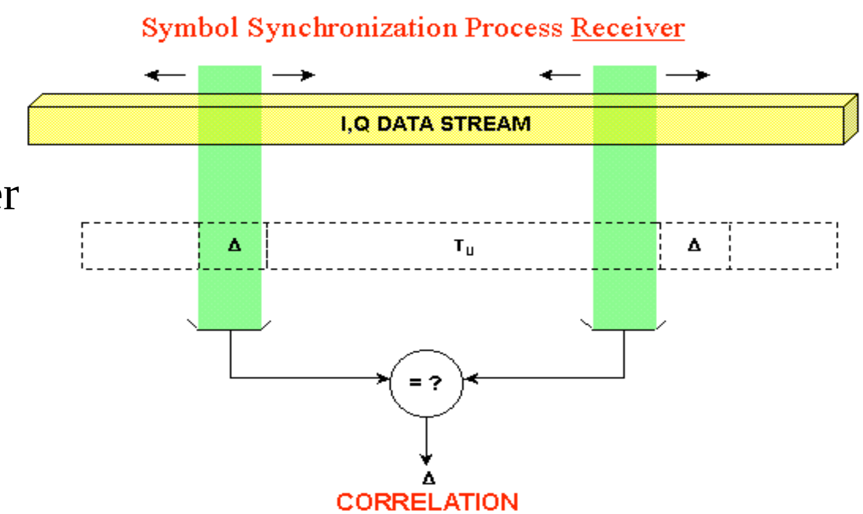
Δt = Echo delay time

OFDM Symbol + Guard Δ



TRANSMITTER

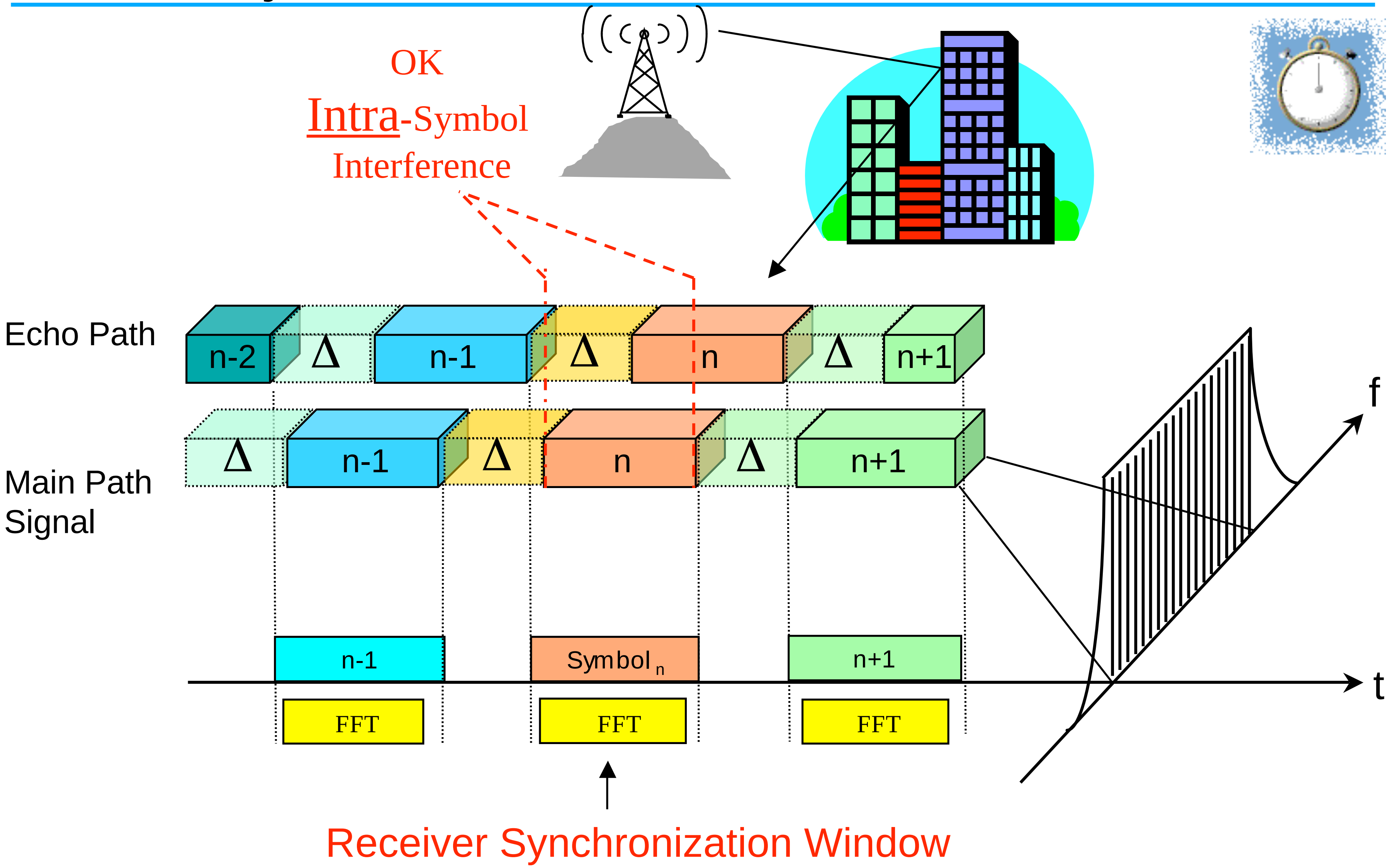
RECEIVER



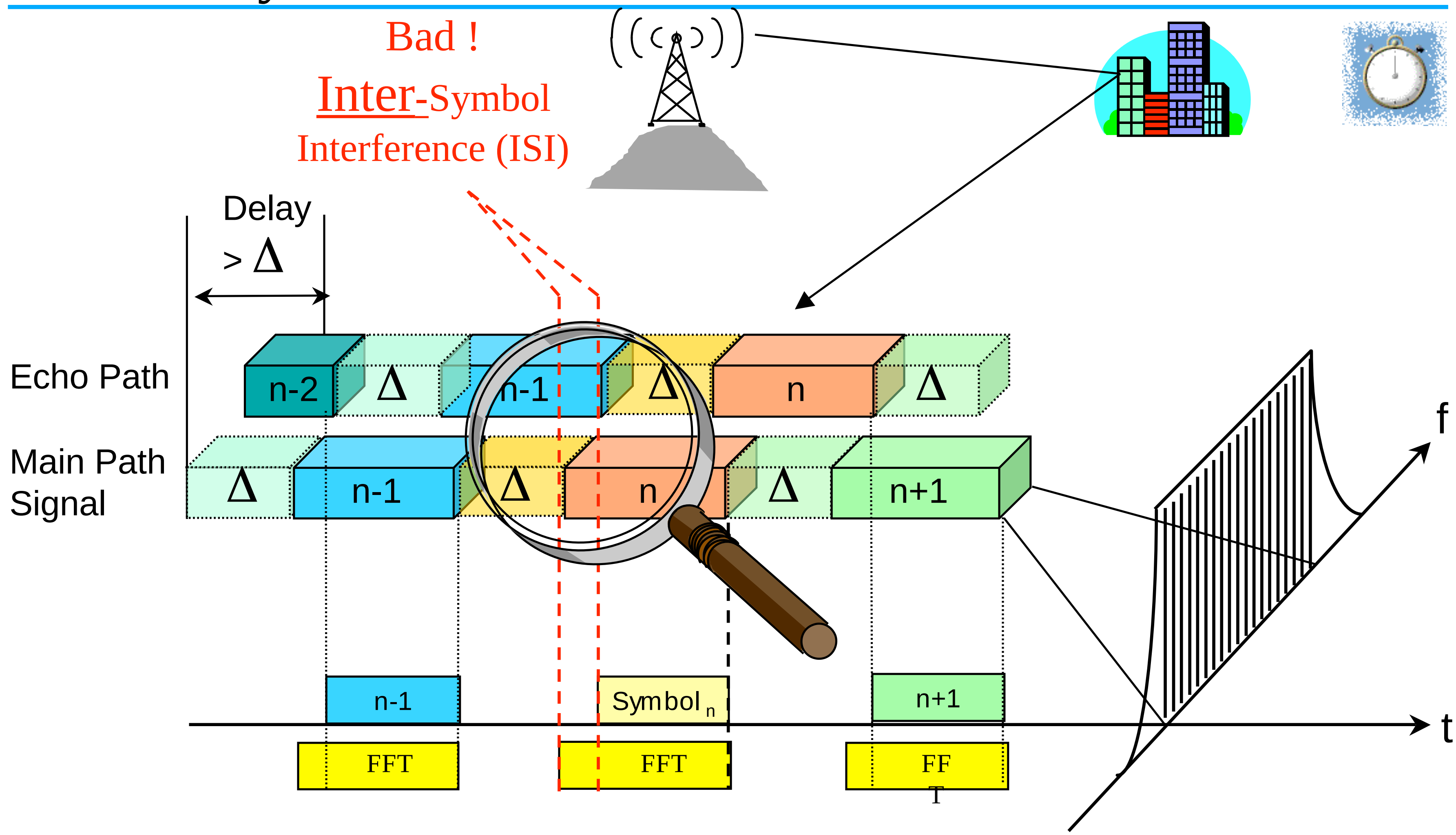
Correlation Technique used at receiver

- Identify FFT Size
- Identify Guard Value

Echo Delay < Guard Interval

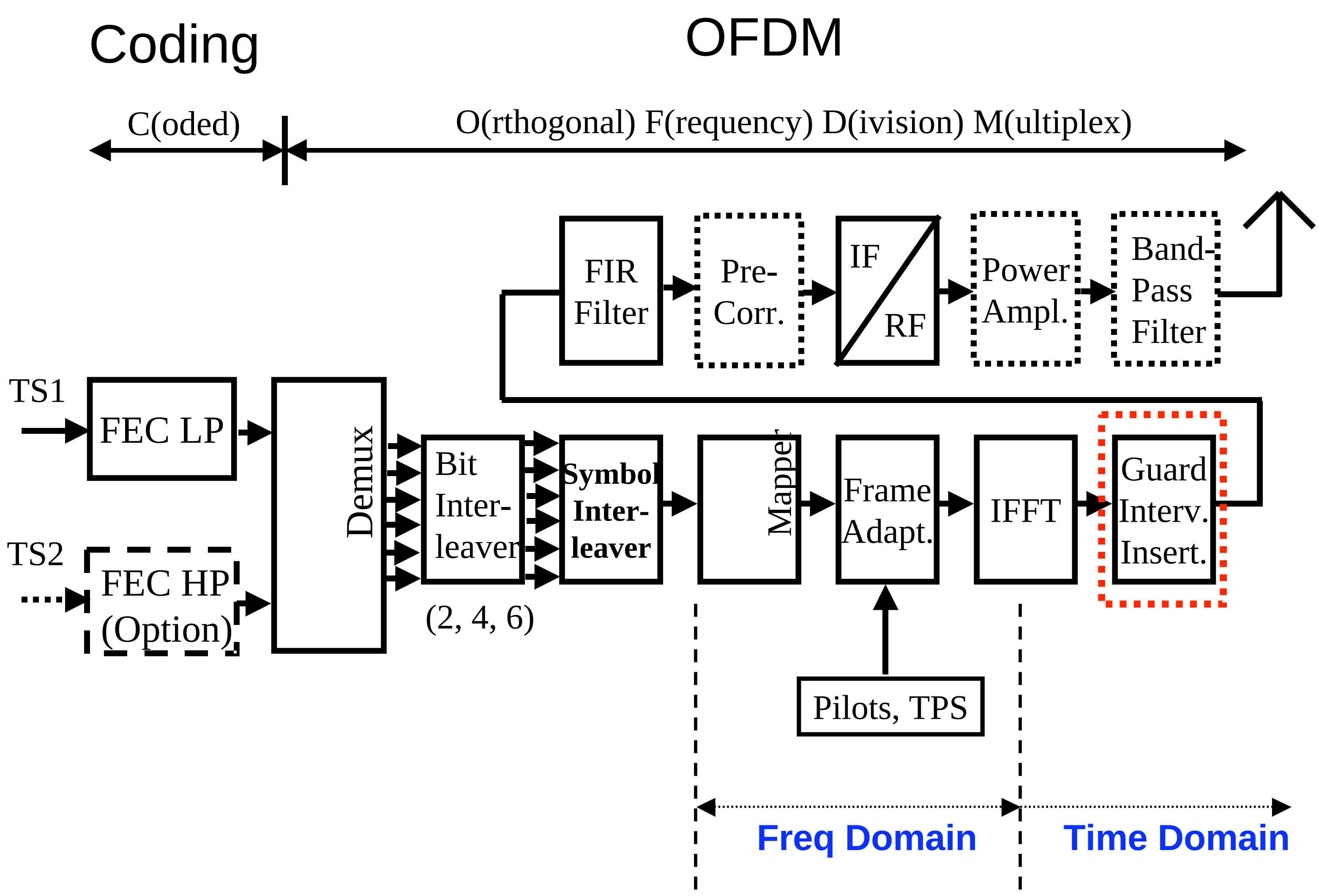


Echo Delay > Guard Interval



No Synchronization of the Receiver !

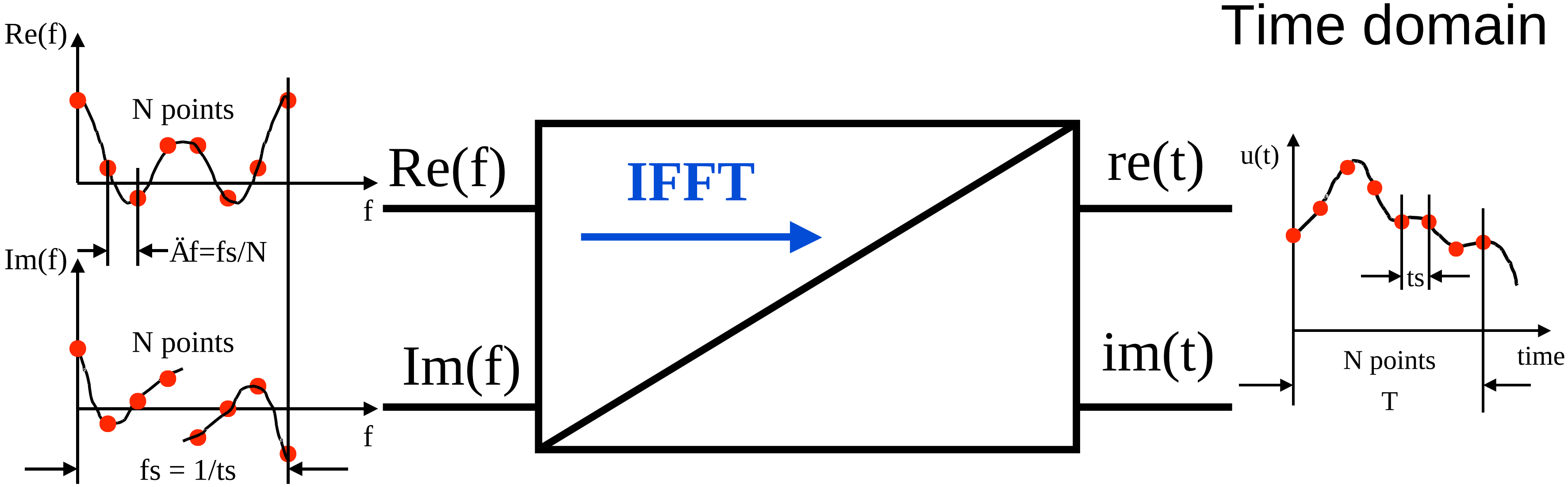
DVB-T Transmitter Block



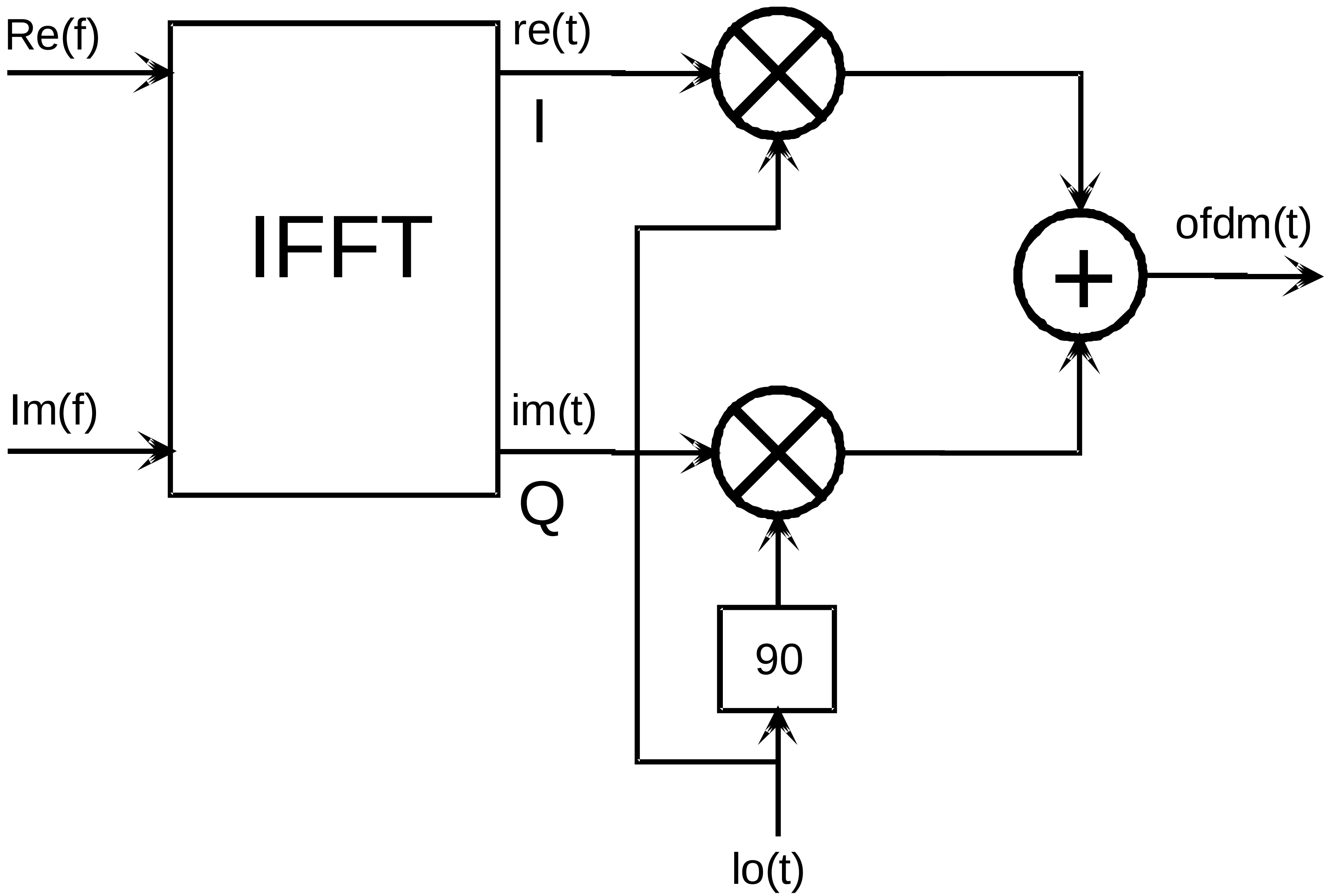
COFDM DSP (IFFT)

Frequency domain

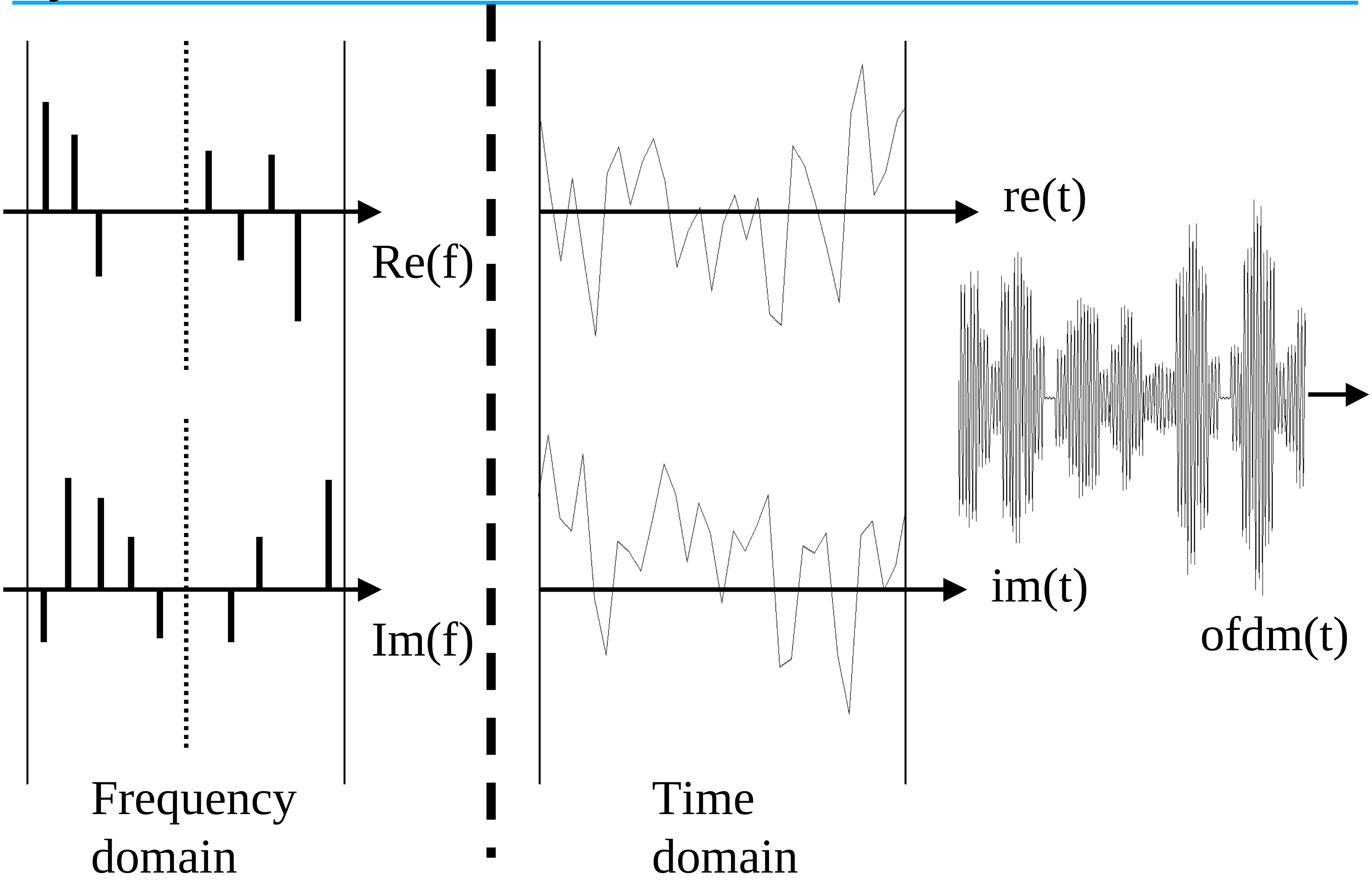
Time domain



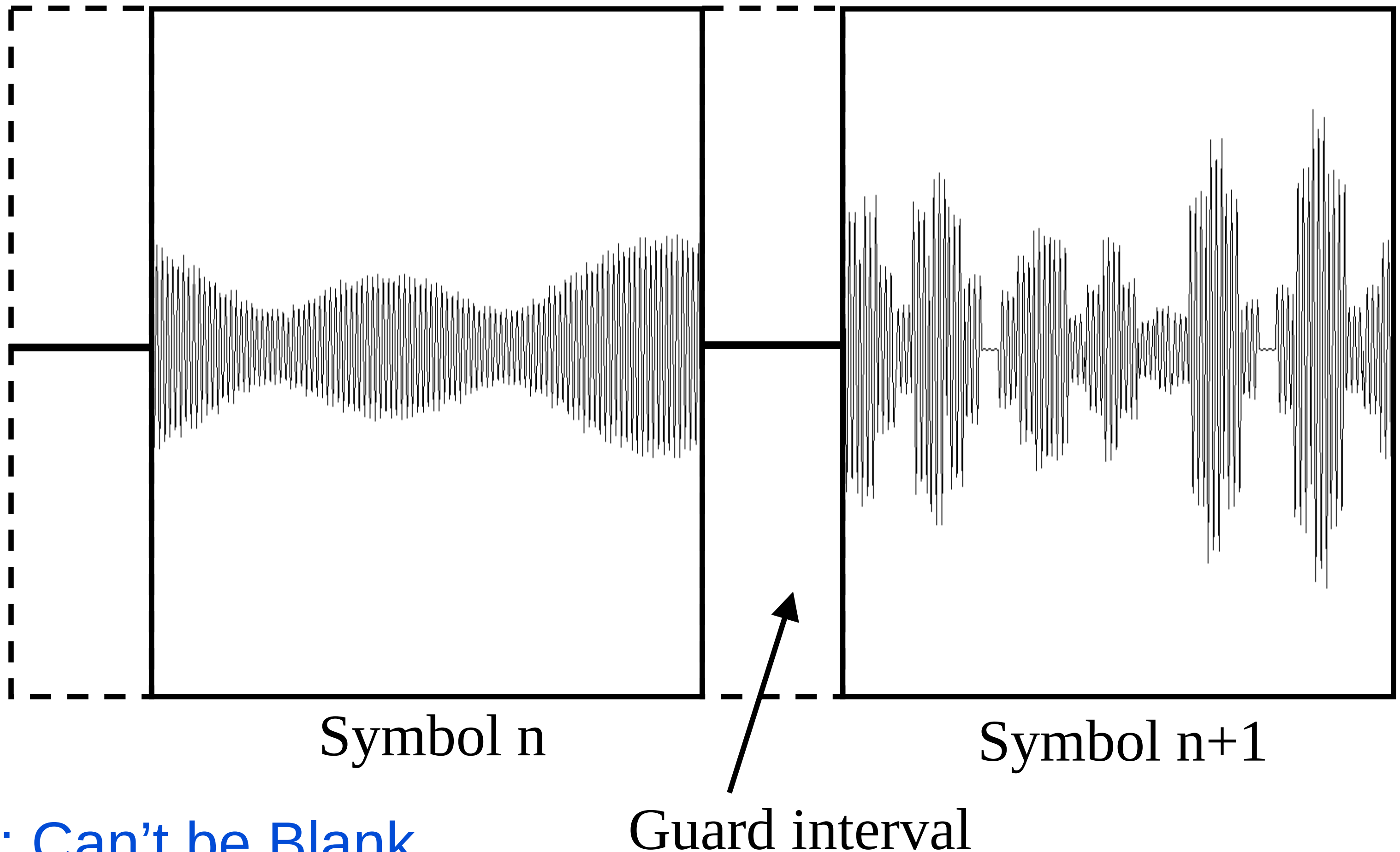
IFFT



Symbol / No GI

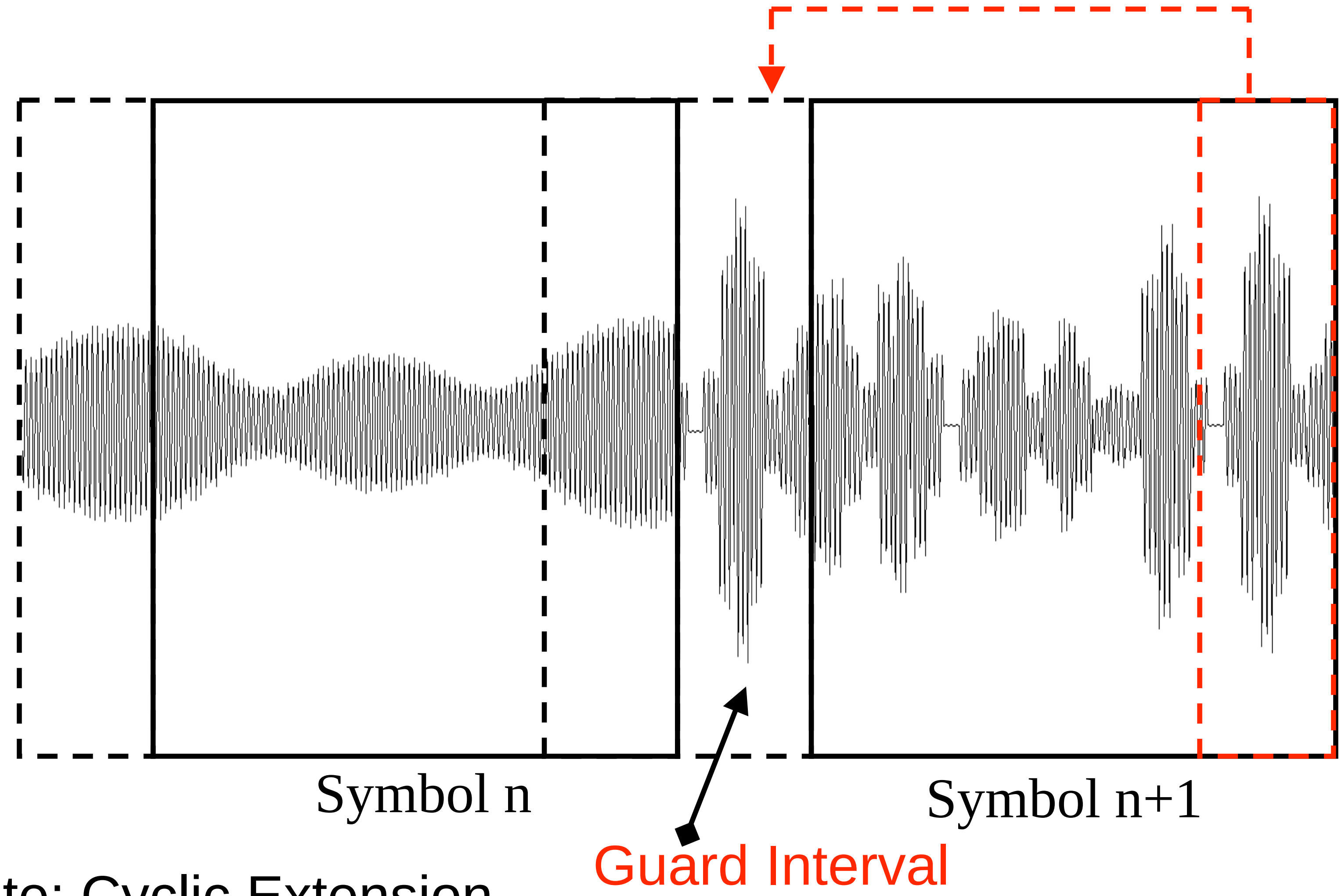


Symbols /w Guard Interval (GI)



Note: Can't be Blank
This will destroy Orthogonality

Symbols /w Guard Interval (GI)



Note: Cyclic Extension
Preserves Orthogonality

Processing of Guard Interval

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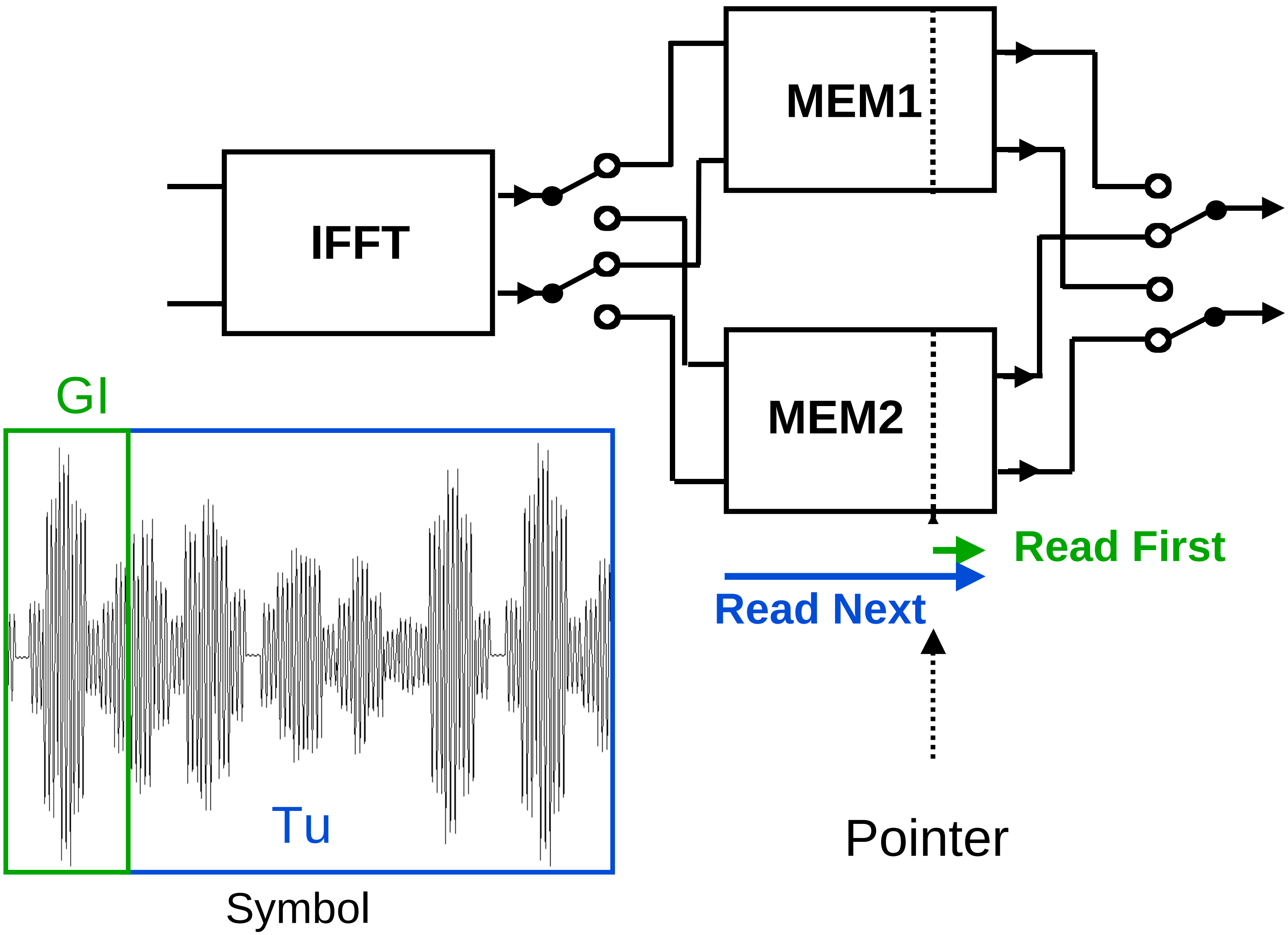
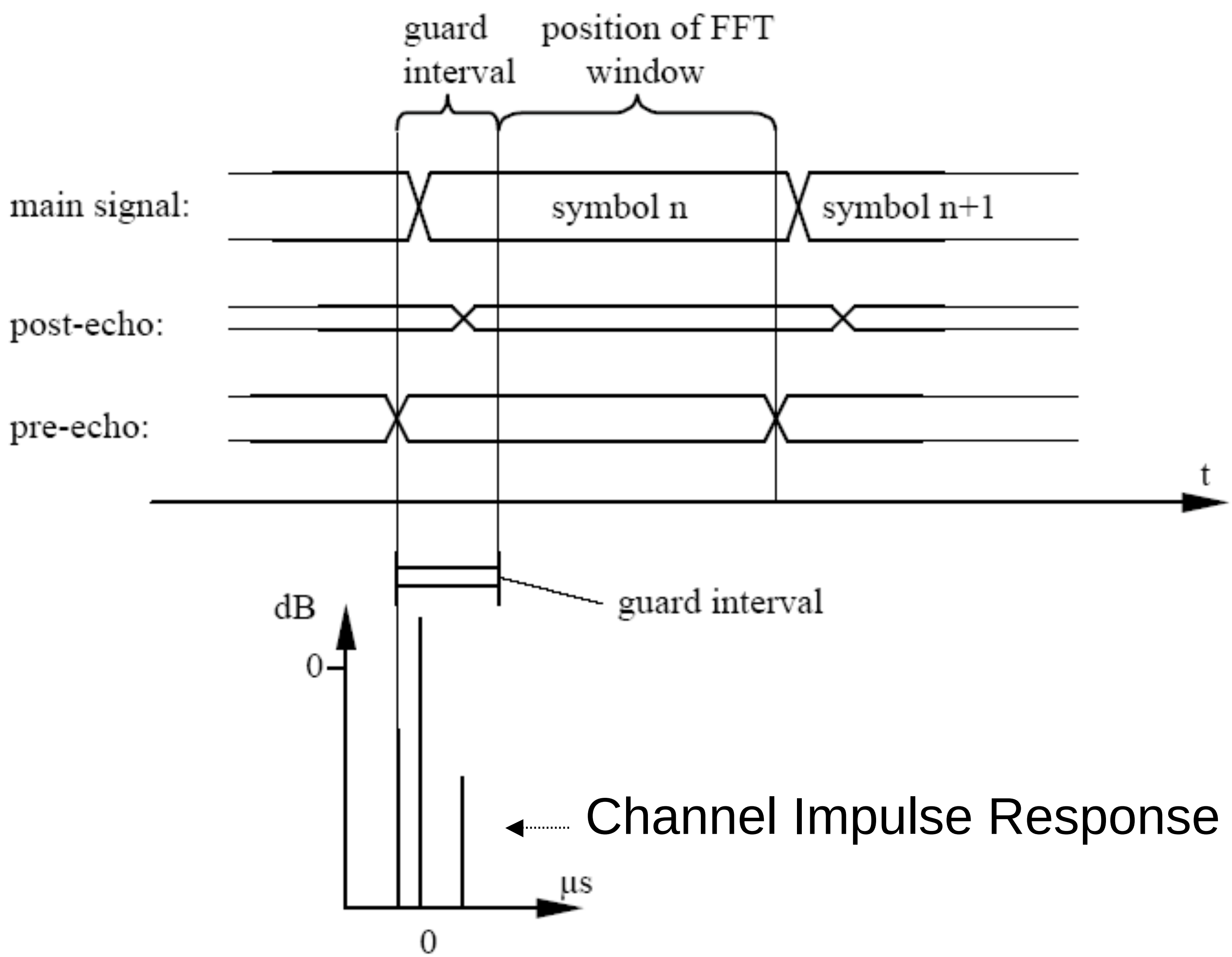
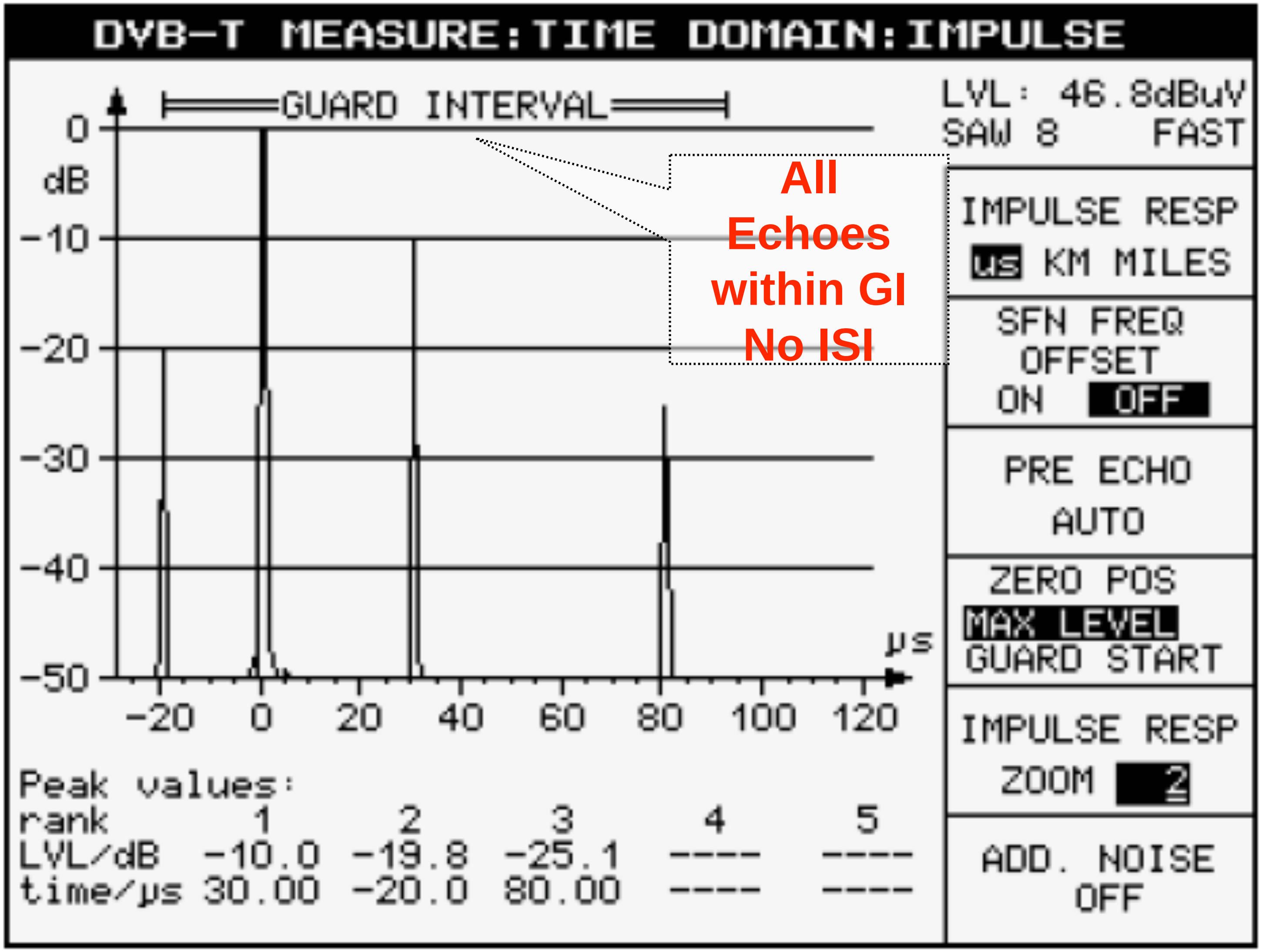


Receiver Positions FFT Window



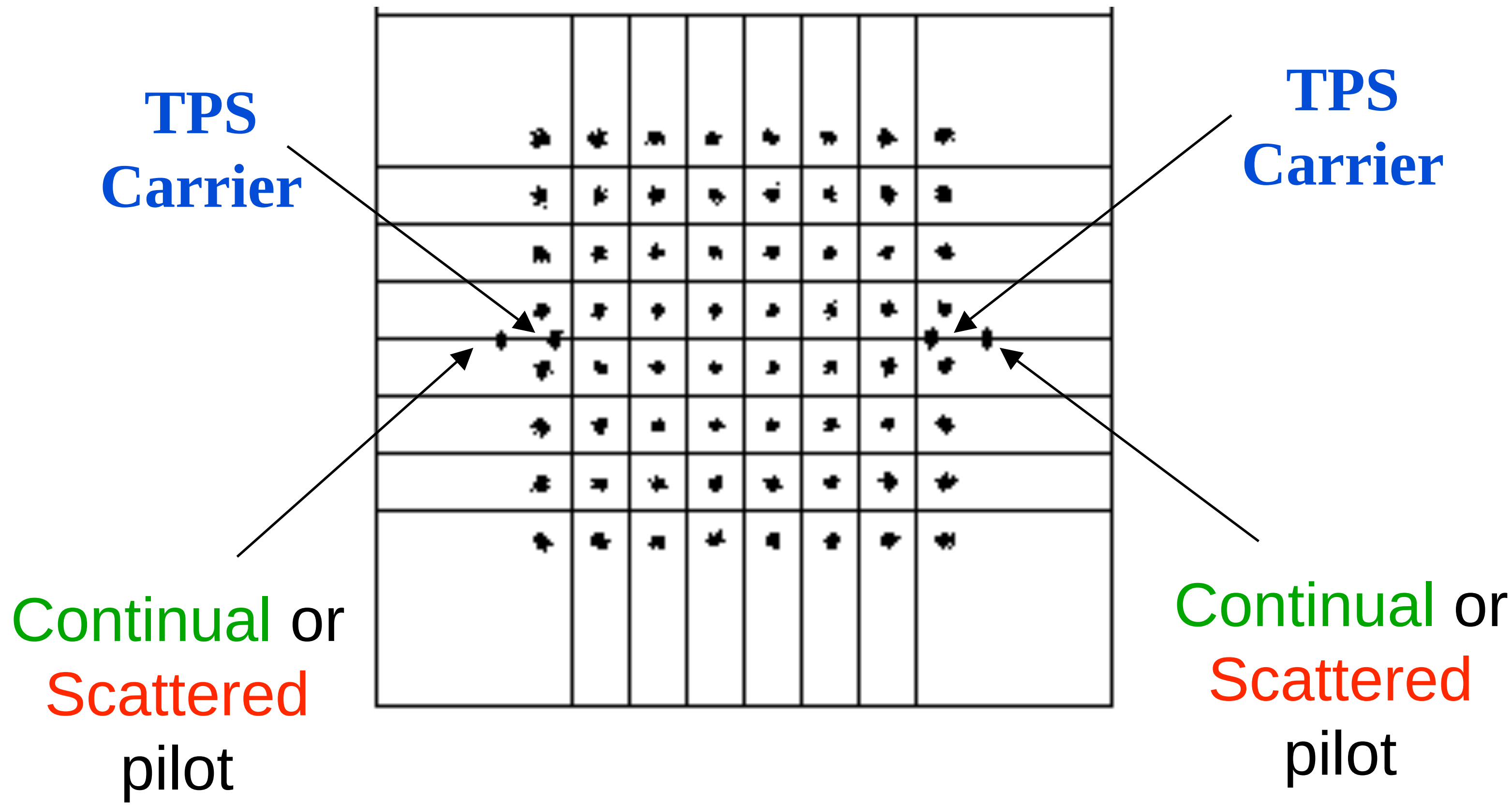
Channel Impulse Response

Measure Guard Interval

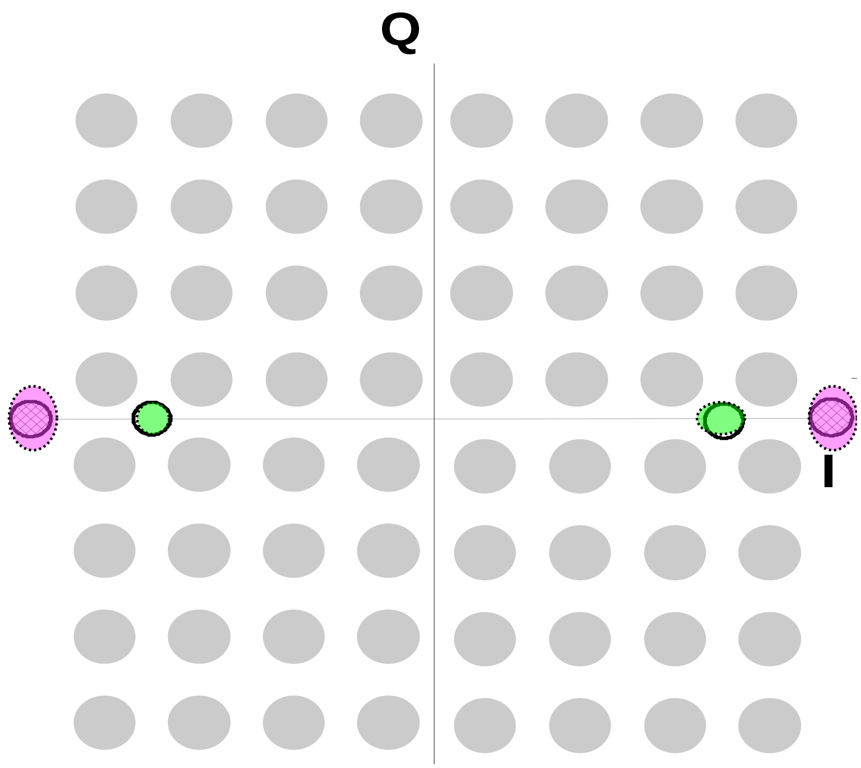


Channel Impulse response DVB-T Test receiver Display

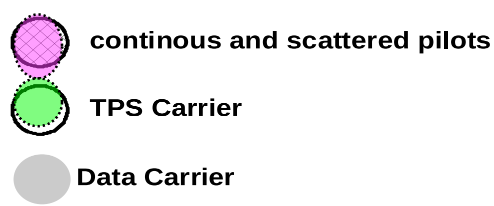
Special Carriers in DVB-T



Pilots inside constellation diagram



64 QAM not hierarchical



Special pilot Carriers in DVB-T

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Continual pilots

- fixed position in spectrum
- fixed postion in constellation diagram
- used for automatic frequency control (AFC)

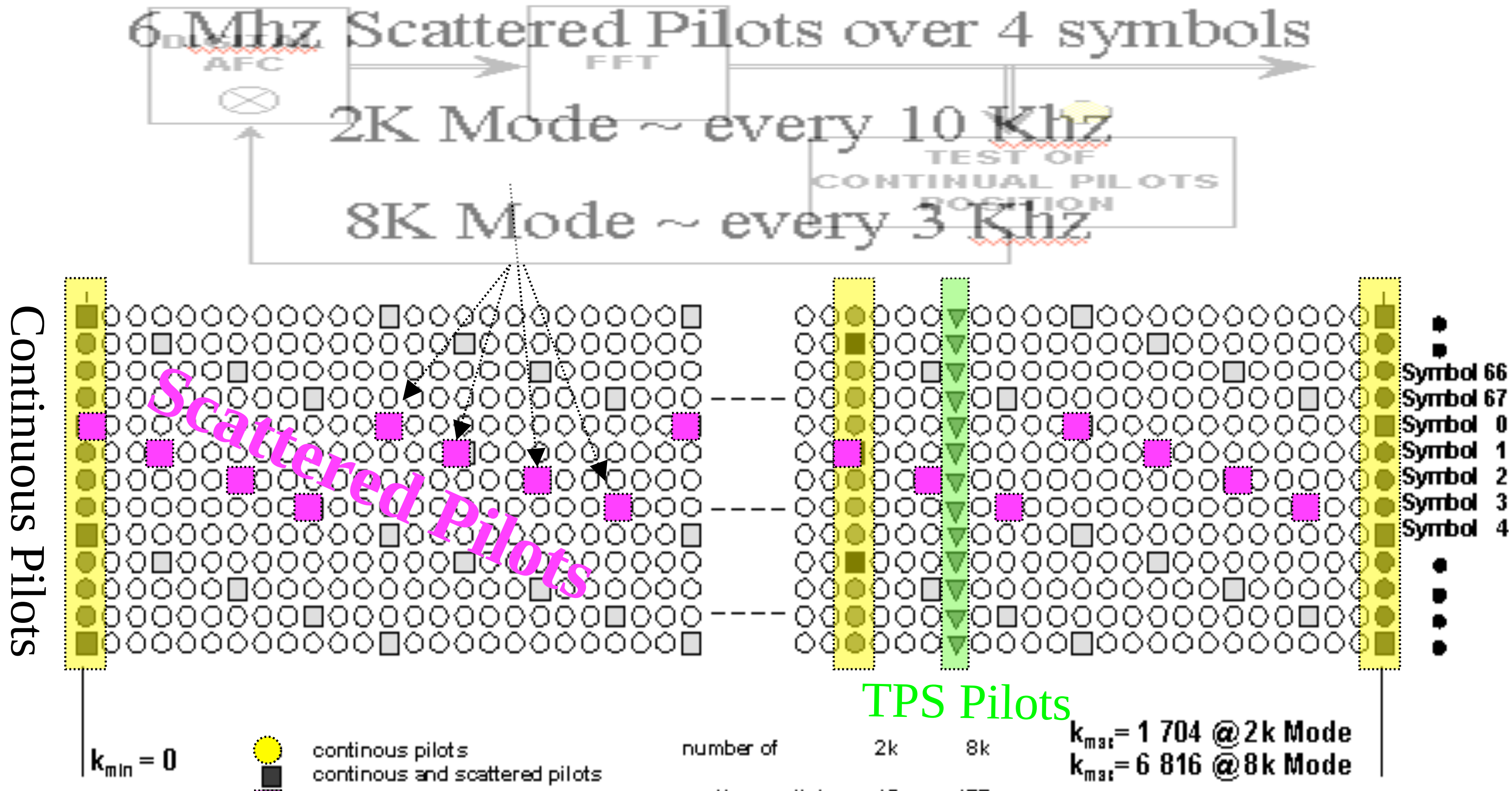
Scattered pilots

- var. position in spectrum
- fixed position in constellation diagram
- „sweeping“ over spectrum
- used for channel estimation & correction

TPS carrier

- fixed position in spectrum
- BPSK modulation
- transmission parameter signalling (TPS)
- fast information channel from Tx to Rx

Pilots inside 6 MHz Channel

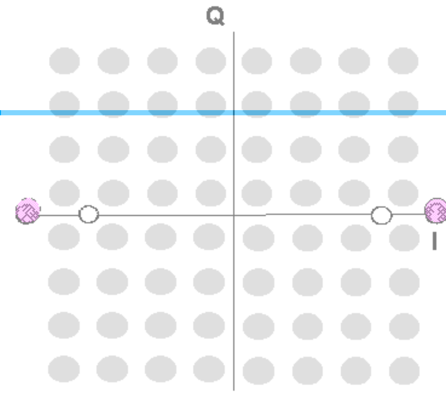


- continous pilots
- continous and scattered pilots
- scattered pilots
- TPS carriers
- data carriers

number of	2k	8k
continous pilots	45	177
scattered pilots	131	524
TPS carriers	17	68
data carriers	1512	6048

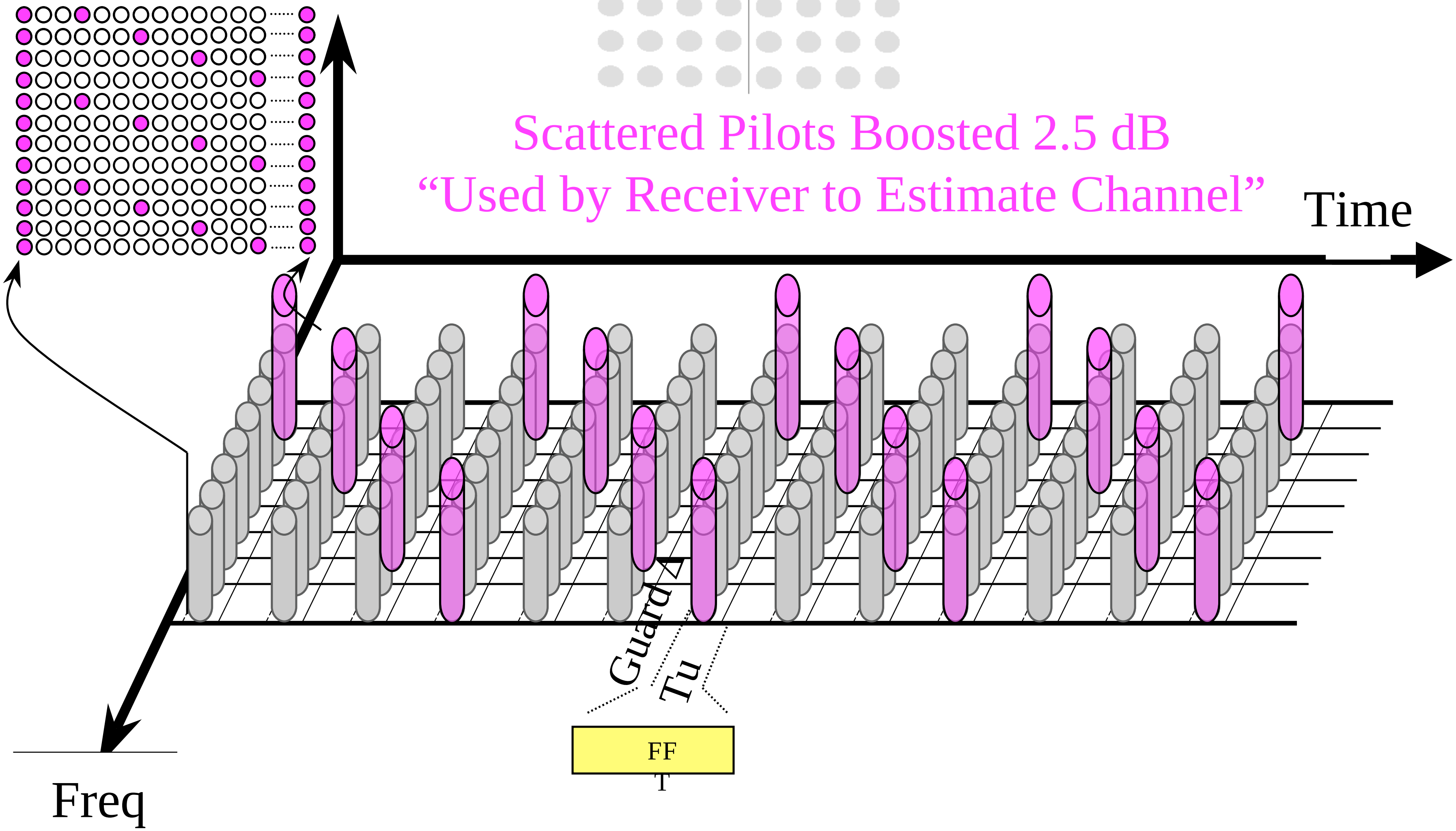
◄ Channel BW ►

Scattered Pilots

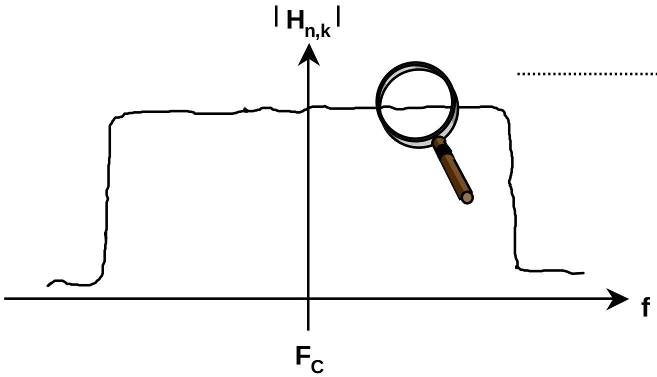


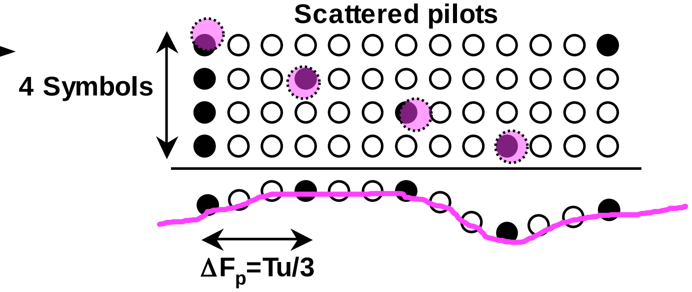
Scattered Pilots Boosted 2.5 dB

“Used by Receiver to Estimate Channel”

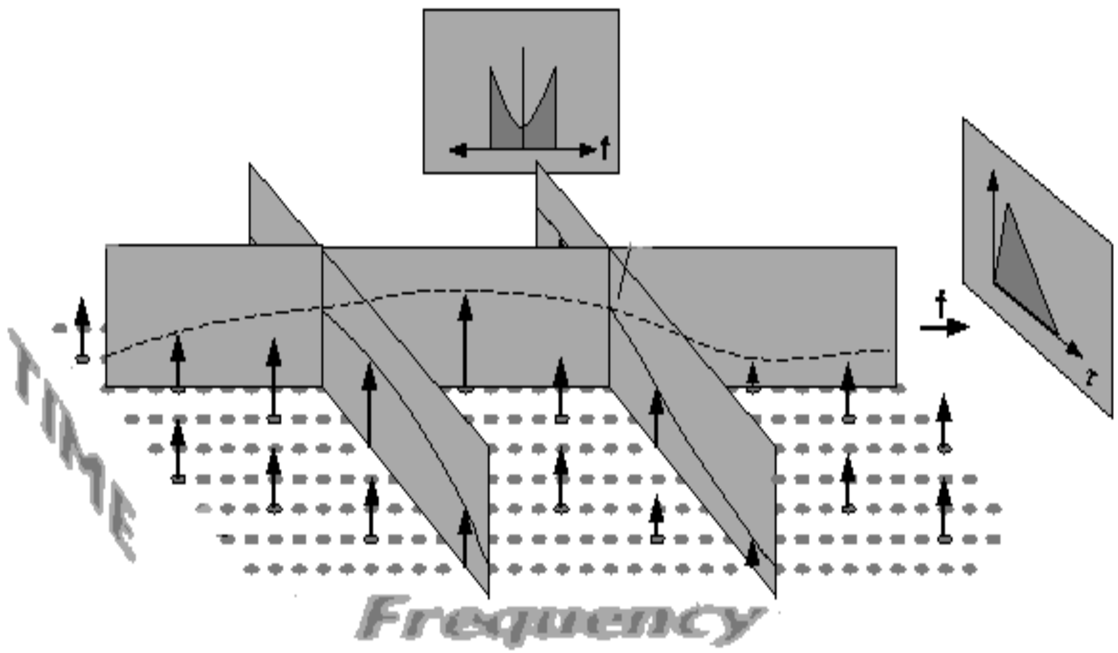


Channel Estimation using Pilots

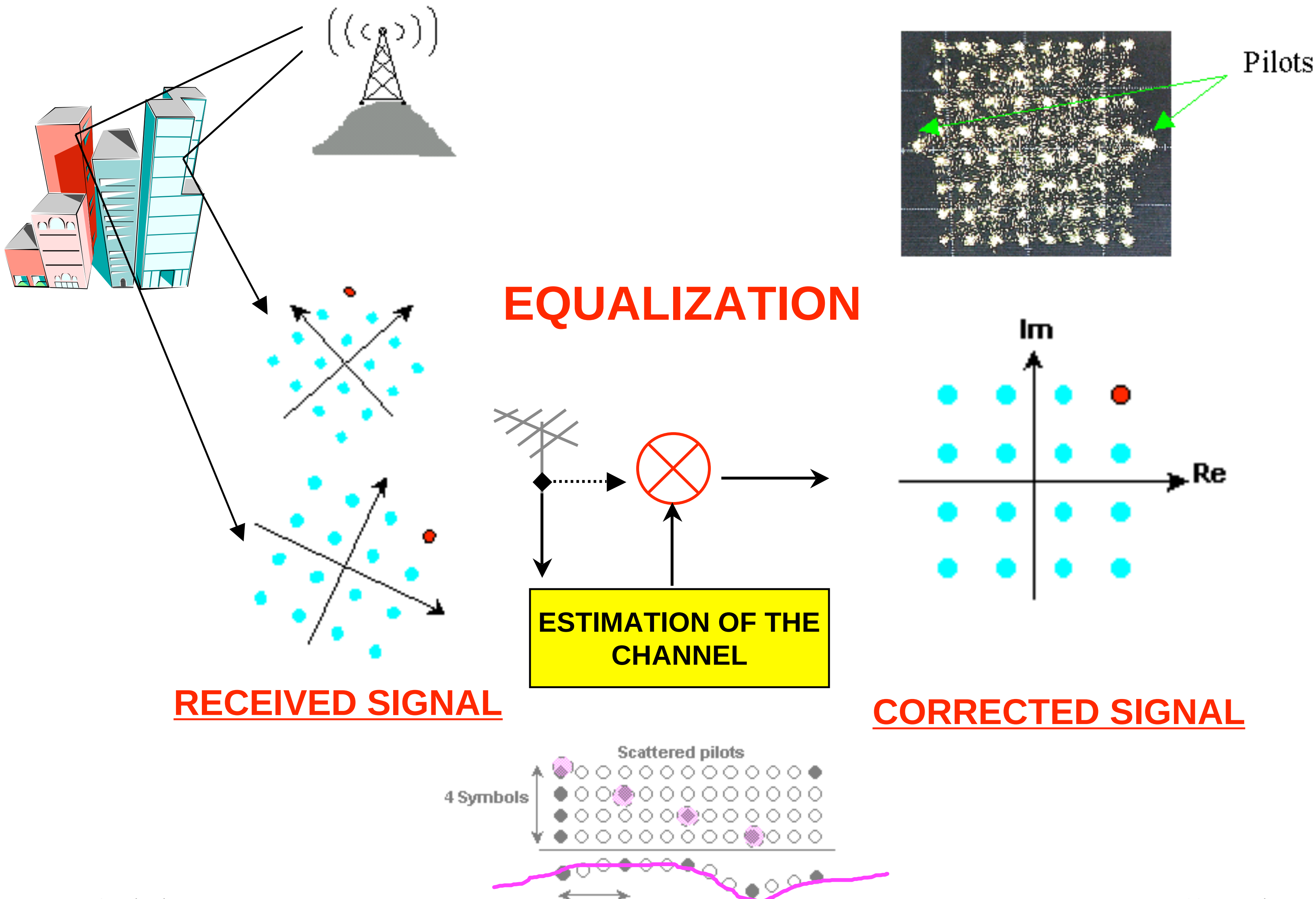




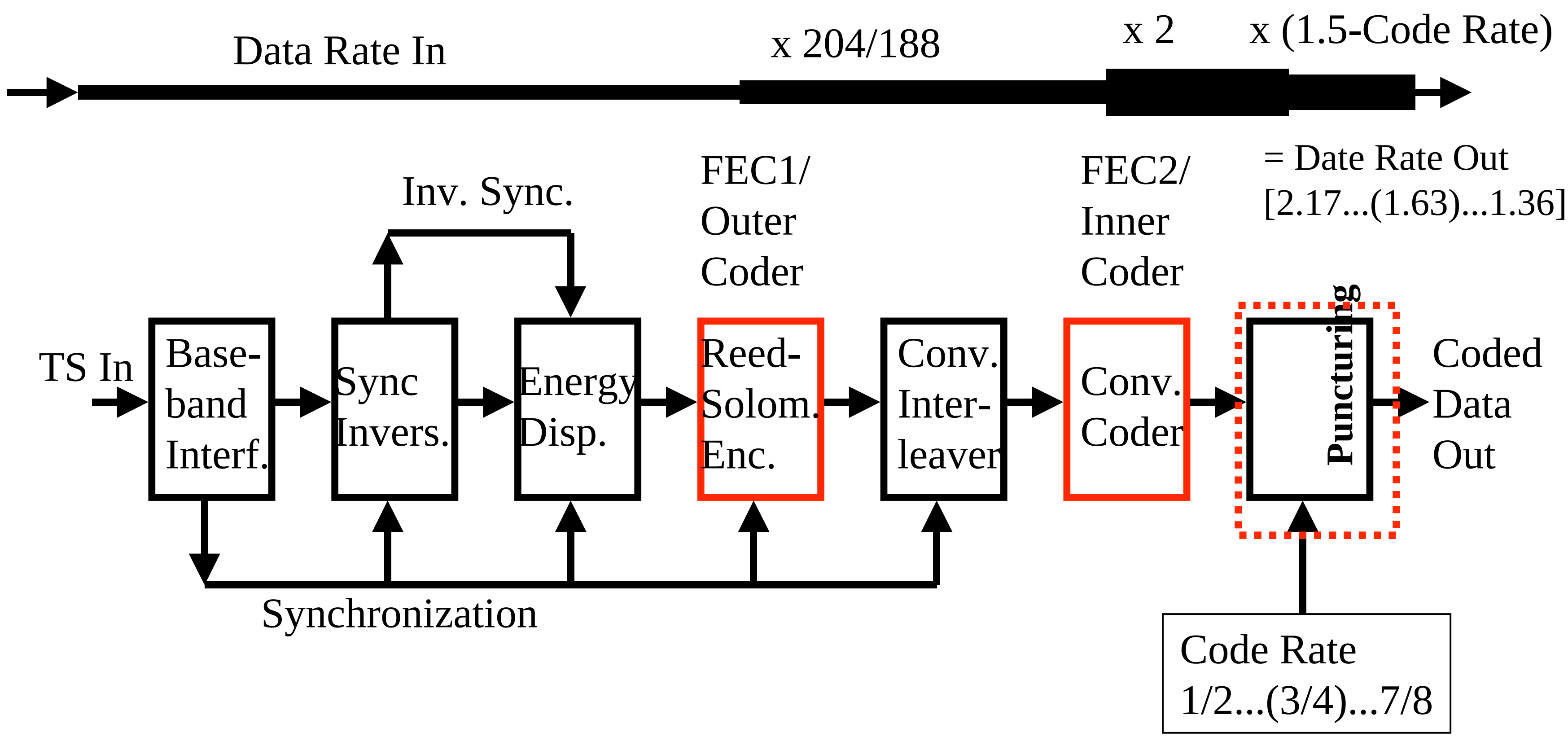
INTERPOLATION OF THE CHANNEL RESPONSE



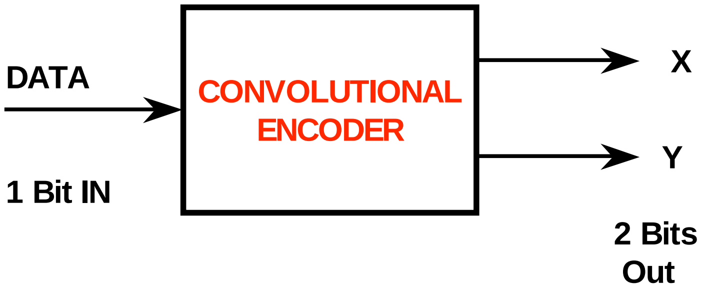
Freq Domain Equalization

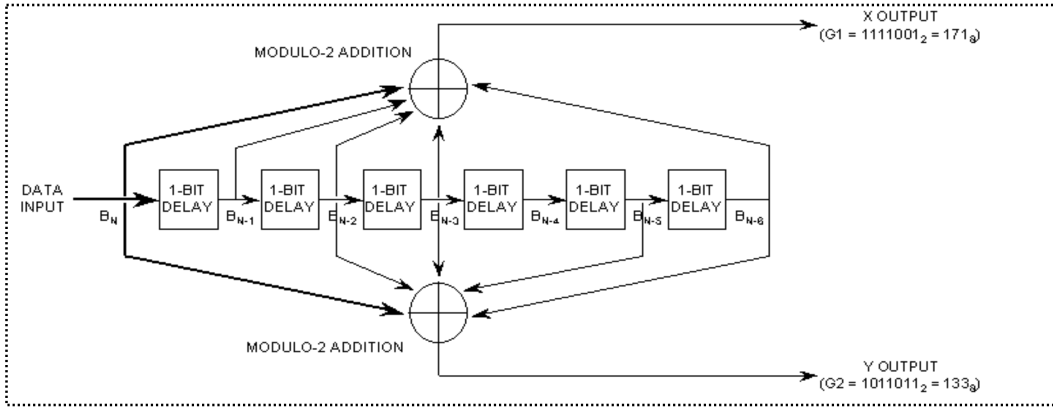


DVB-T Transmitter (FEC)



INNER CONVOLUTIONAL CODING





- The Convolutional Code is used over a noisy channel
- The basic code rate is ½ (called the Mother Code)
- The encoder is very simple to implement
- But the decoding is quite complex !

The Viterbi algorithm is currently used for decoding

Punctured coding techniques can be applied to allow higher bit rates

Tradeoff Robustness vs. DataRate

1/2, 2/3, 3/4, 5/6, 7/8 coding rates available

PUNCTURING The Mother Code

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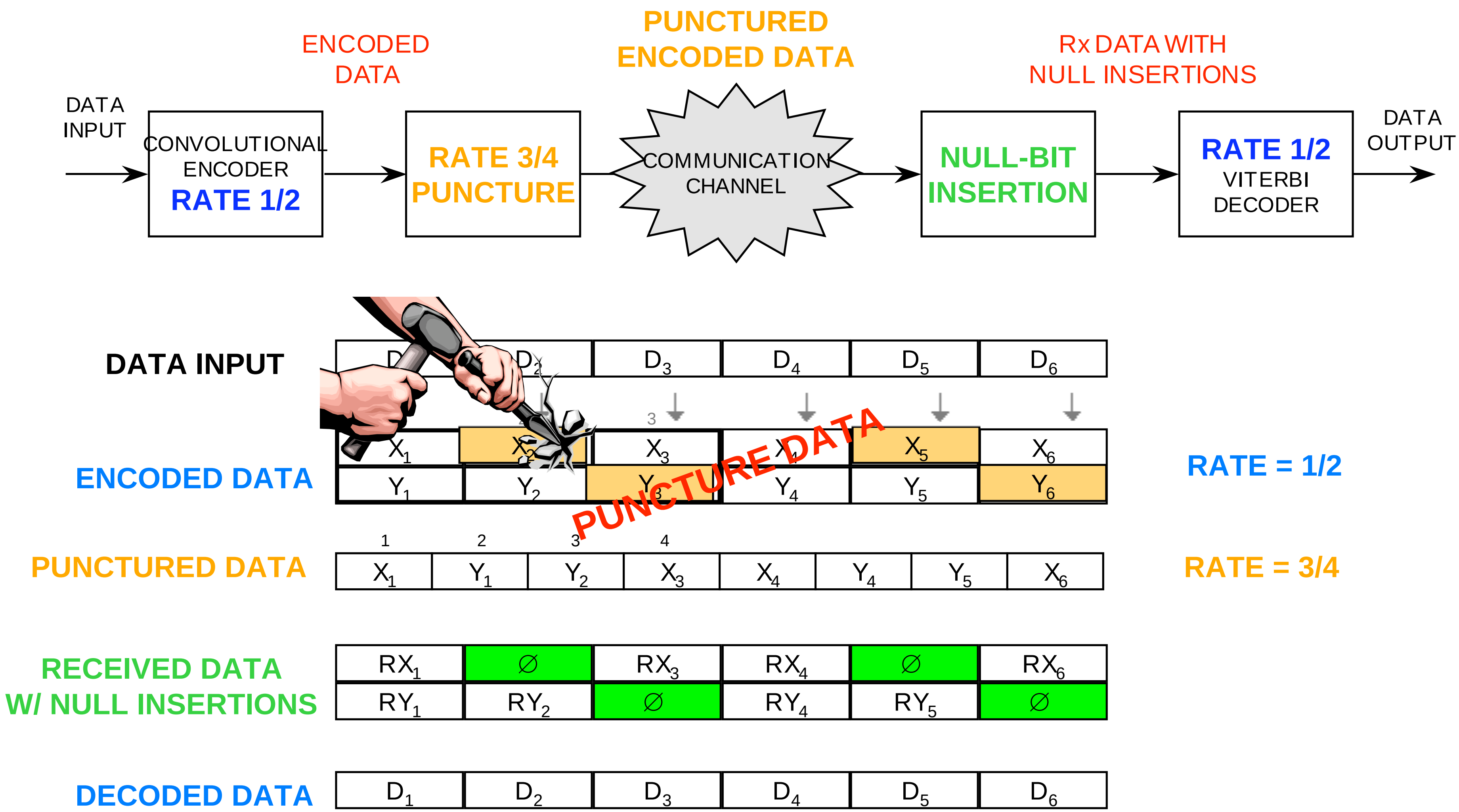
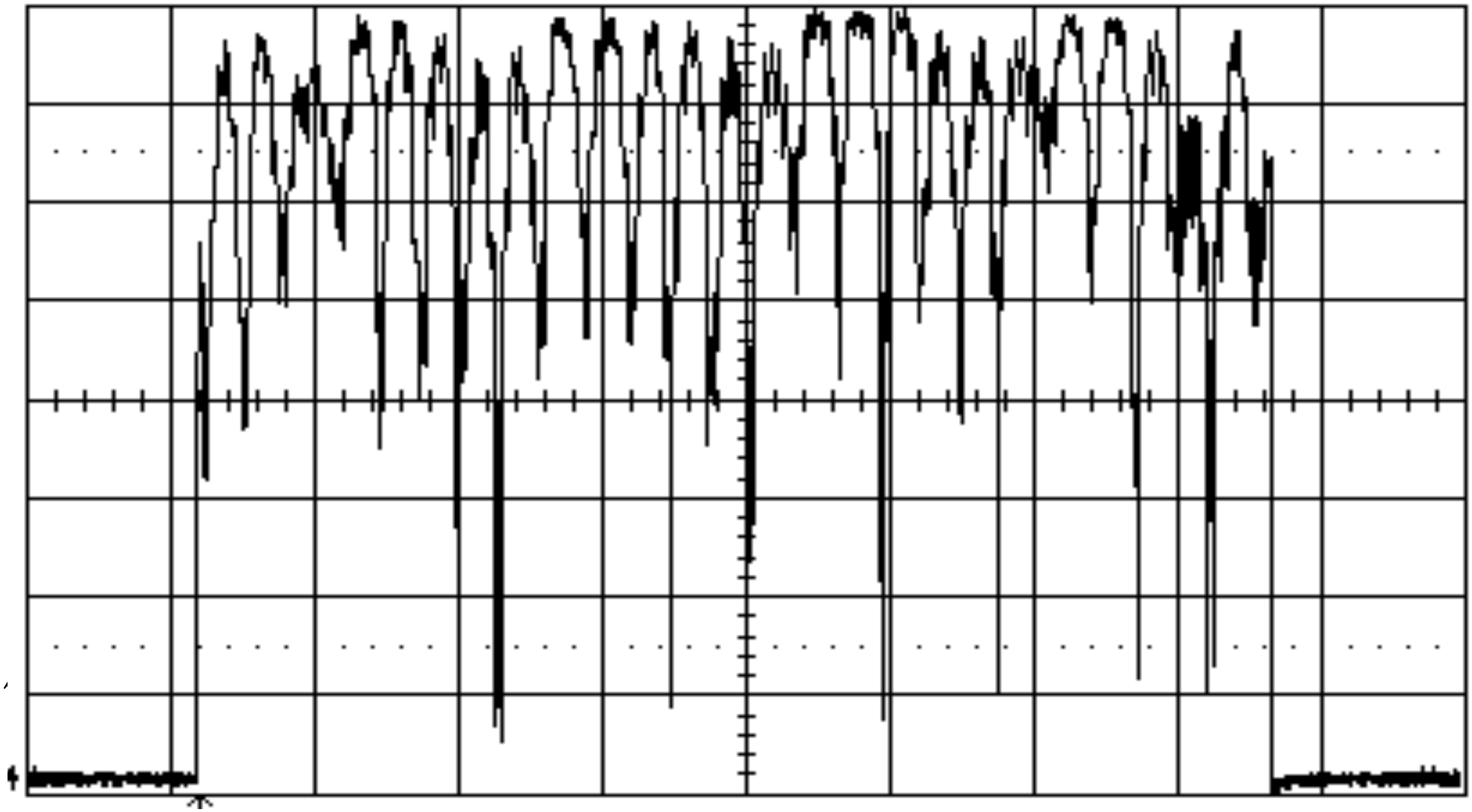
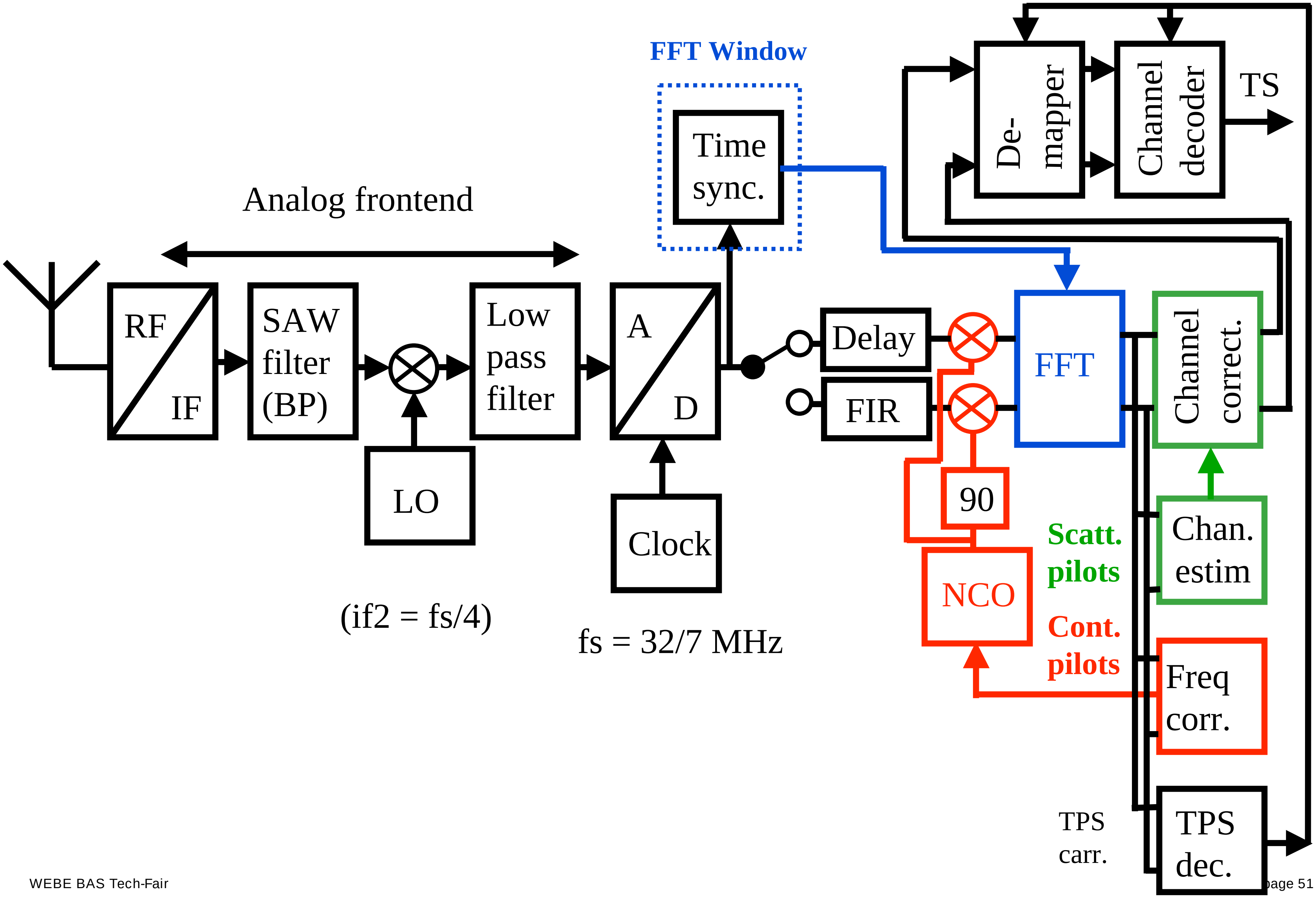


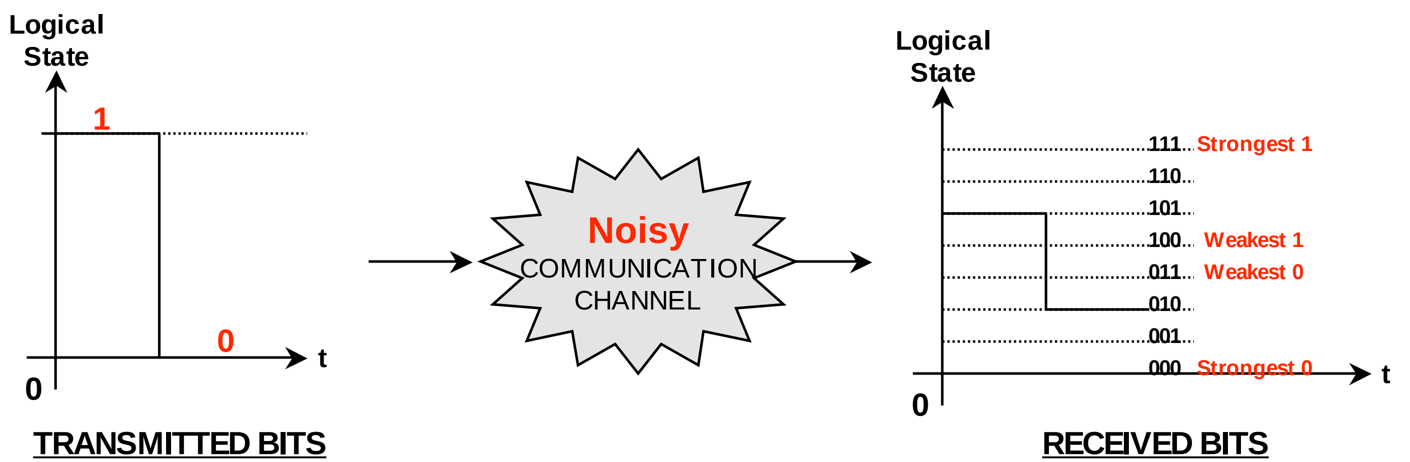
Create frequency diversity to improve robustness against fading

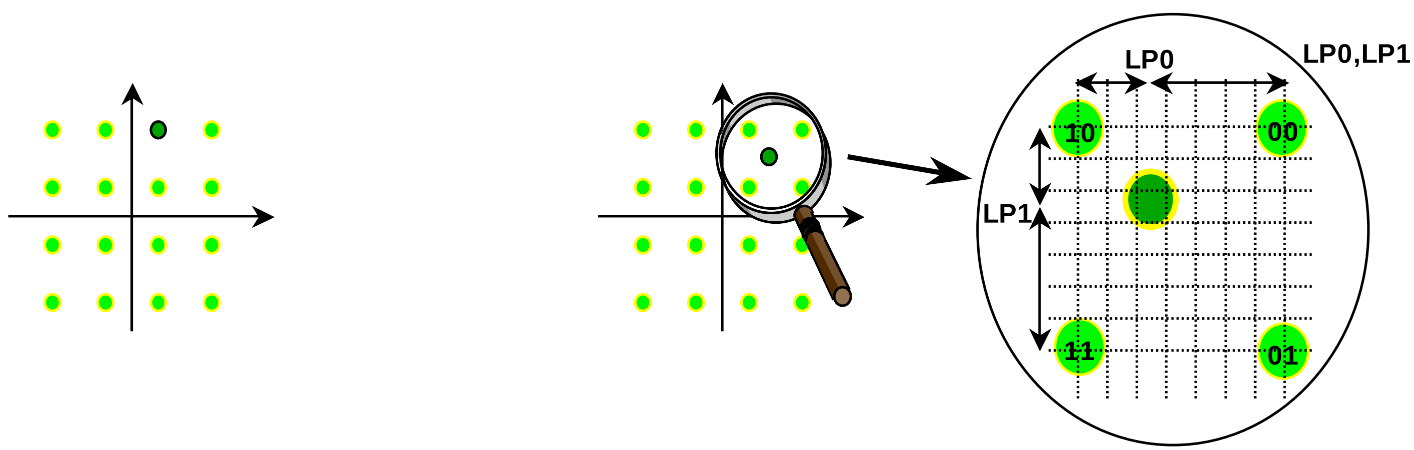


DVB-T Receiver



Receiver Technique





Using Channel State Info

Channel State Information (CSI)

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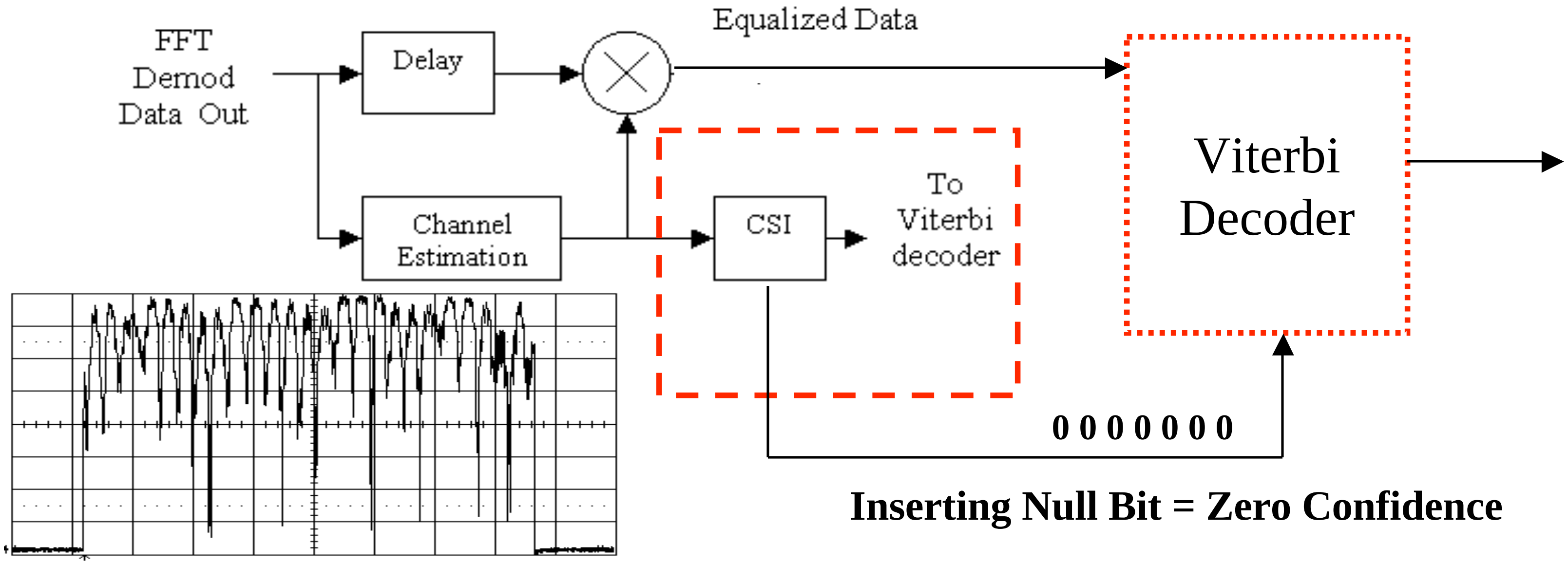

- Some carrier frequencies will be experiencing a low SNR (in a spectral notch), while others will actually be boosted in power
- CSI metric is generated in the receiver for each and every received carrier, and is used to aid the Error Correction process
- Generated at receiver based on SNR of each carrier
  - If SNR Good = Equalize as normal
  - If SNR Lower = Use CSI
  - If SNR Bad = Insert Null bit (as in Puncture Coding)

DVB-T Frame Review

	2k FFT	8k FFT
Data Carriers:	1705	6817
Scattered Pilots:	142	568
Continual Pilots:	45	177
Cont. TPS Pilots:	17	68

1.) Scattered pilots are used for channel estimation and correction

2.) Continual pilots are used for time and frequency synchronization

3.) TPS pilots carry COFDM parameter information

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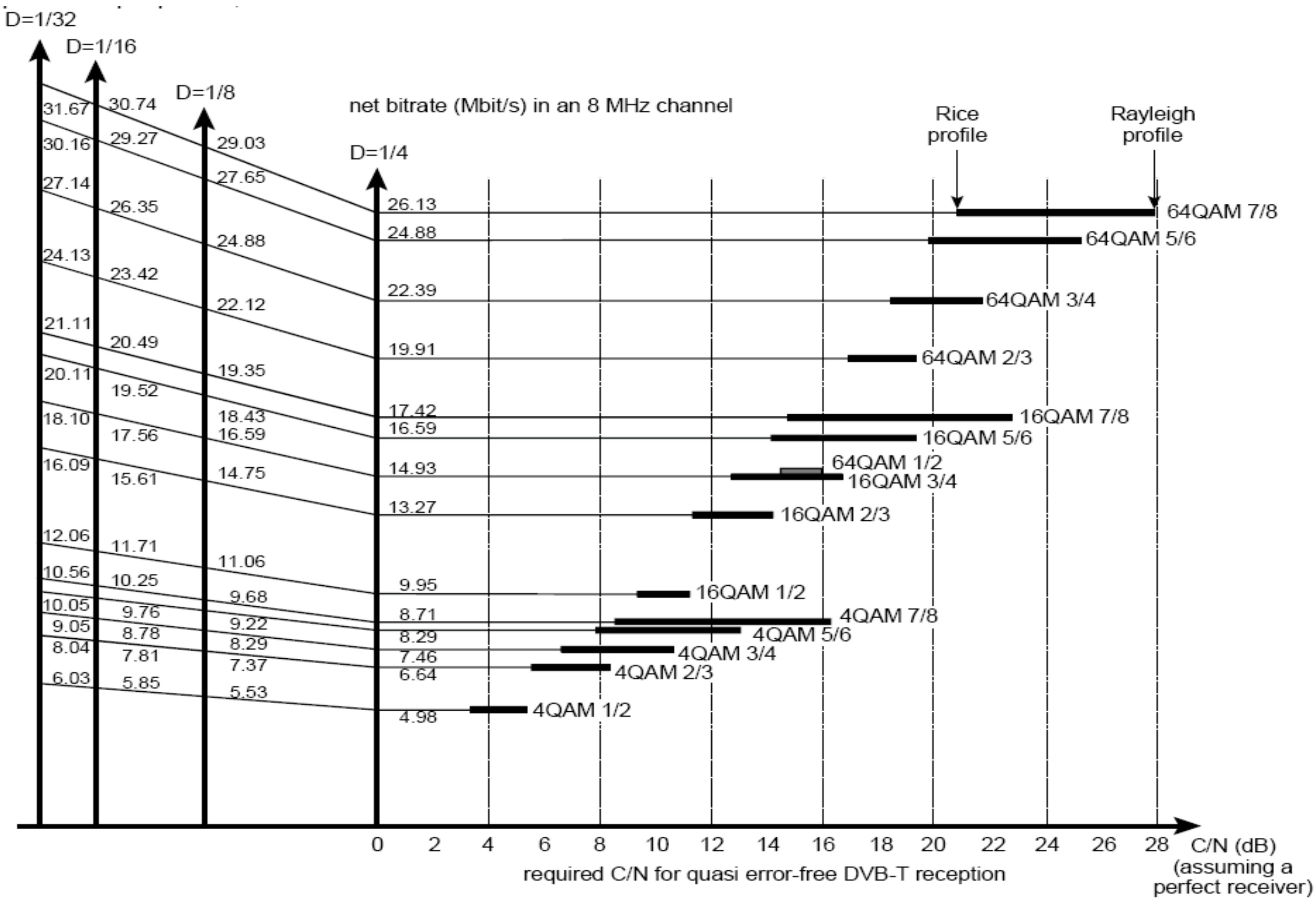
COFDM Encoding and Modulation

- Robustness against multipath propagation
- Single Frequency Network capability
- Mobile reception

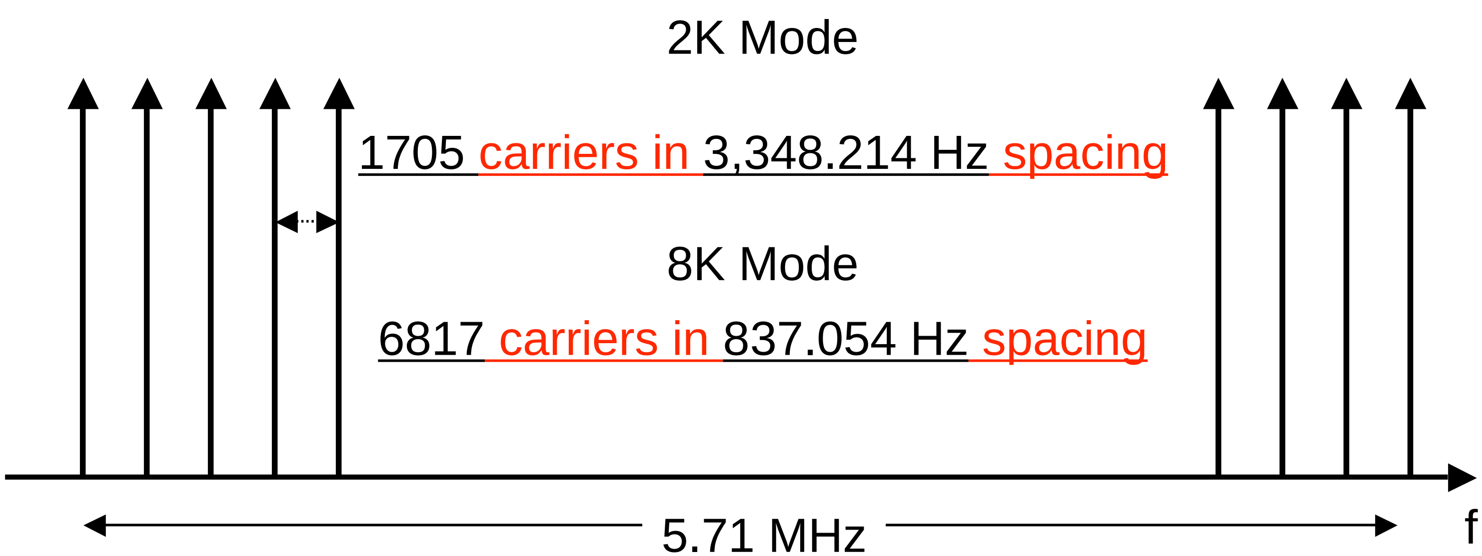
DVB-T Standard ETSI EN 300 744

- 6, 7 , 8 MHz
- 2K and 8K carriers OFDM
- 1/4, 1/8, 1/16, 1/32 guard intervals (multipath - «echo» protection)
- 4 QAM, 16 QAM, 64 QAM modulation
- 1/2, 2/3, 3/4, 5/6, 7/8 coding rates (error correction)
- Hierarchical modulation option

Which COFDM Parameters to use ?



DVB-T Carrier Spacing (6 MHz)



Parameter	8K mode	2K mode
Number of carriers K	6 817	1 705
Value of carrier number K_{min}	0	0
Value of carrier number K_{max}	6 816	1 704
Duration T_U	*1194,667 µs*	*298,6667 µs*
Carrier spacing $1/T_U$	*0,837054 kHz*	*3,348214 kHz*
Spacing between carriers K_{min} and K_{max}, $(K-1)/T_U$	*5,71 MHz*	*5,71 MHz*

Parameter to Consider for Mobile

Thank You

Mike Simon
mike.simon@rohde-schwarz.com