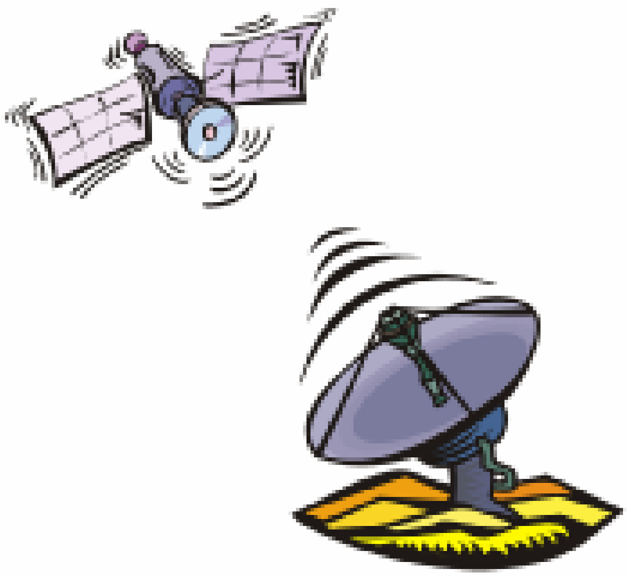
OFDM/OFDMA Tutorial
Introduction and Overview

Silicon DSP Corporation

Satellite Digital Multimedia Broadcasting System



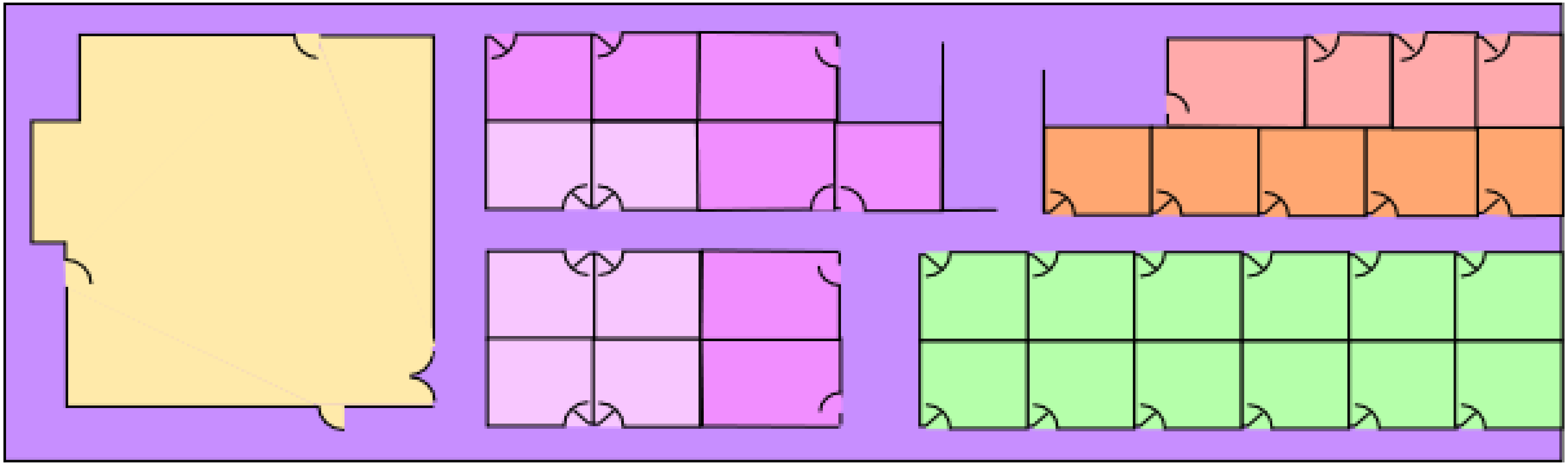
Fixed Wireless Access Networks

Point to Multi-Point Links

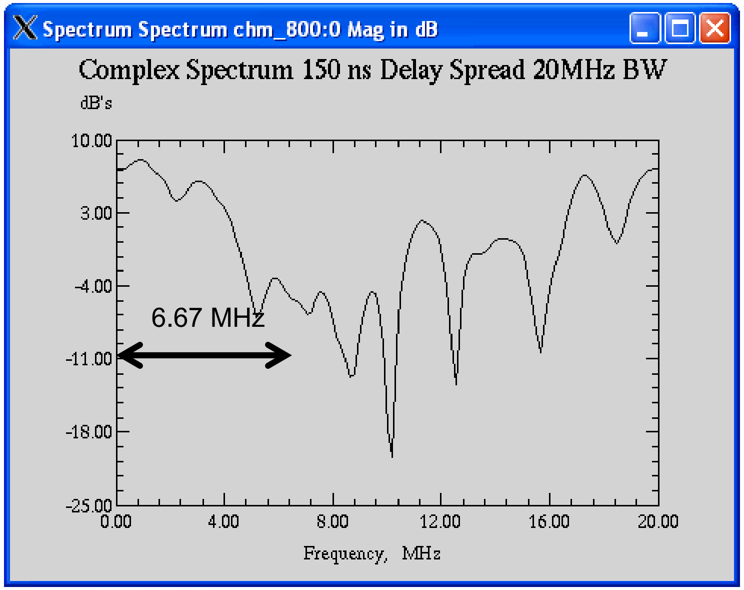
Mobile Wireless Access

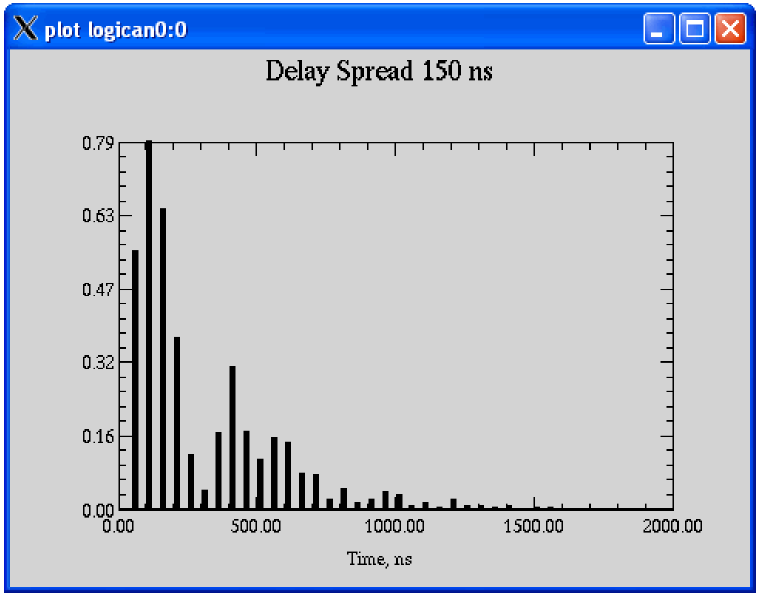
Non Line of Sight

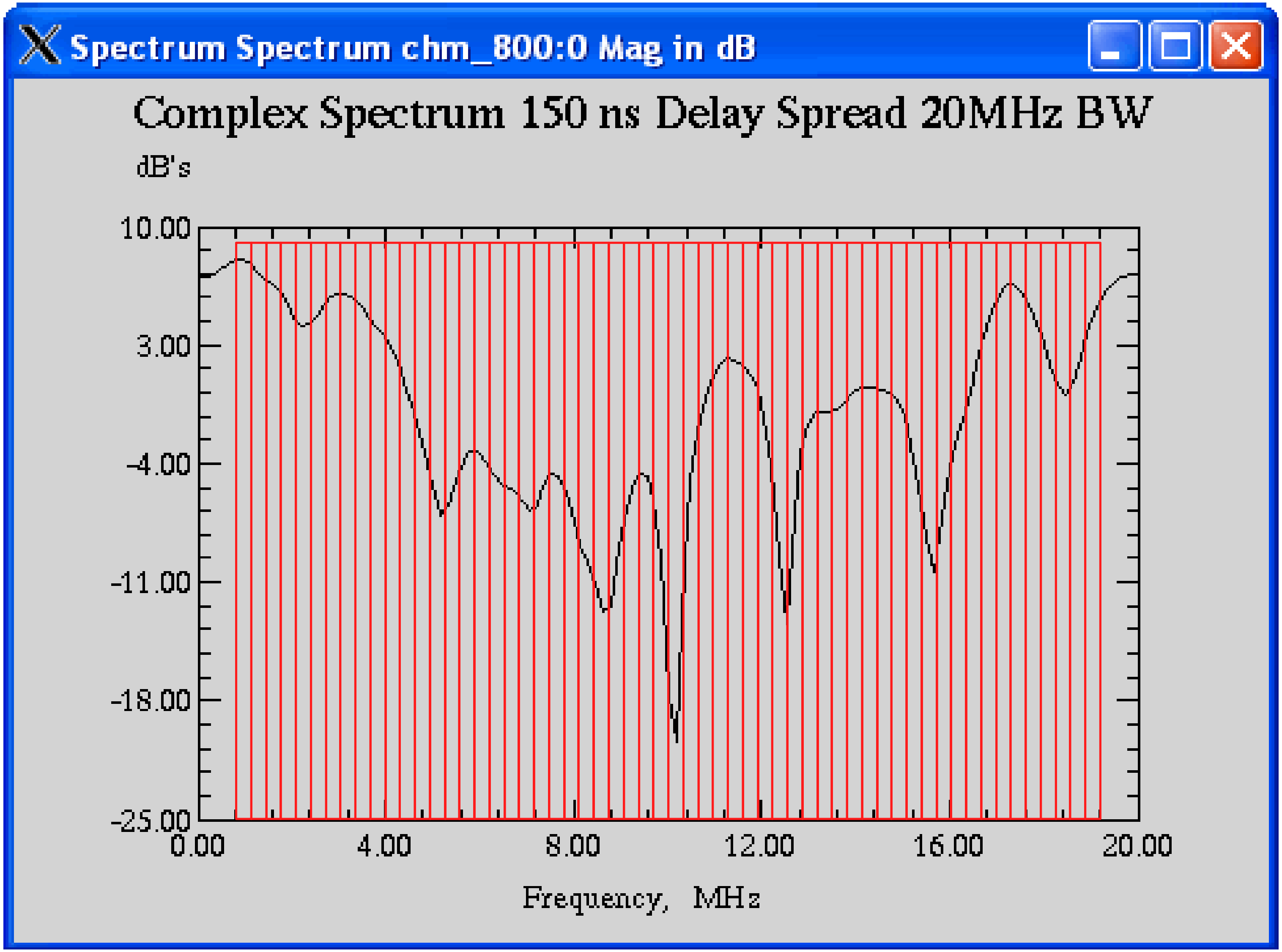
Indoor Wireless



Multipath Fading Channel

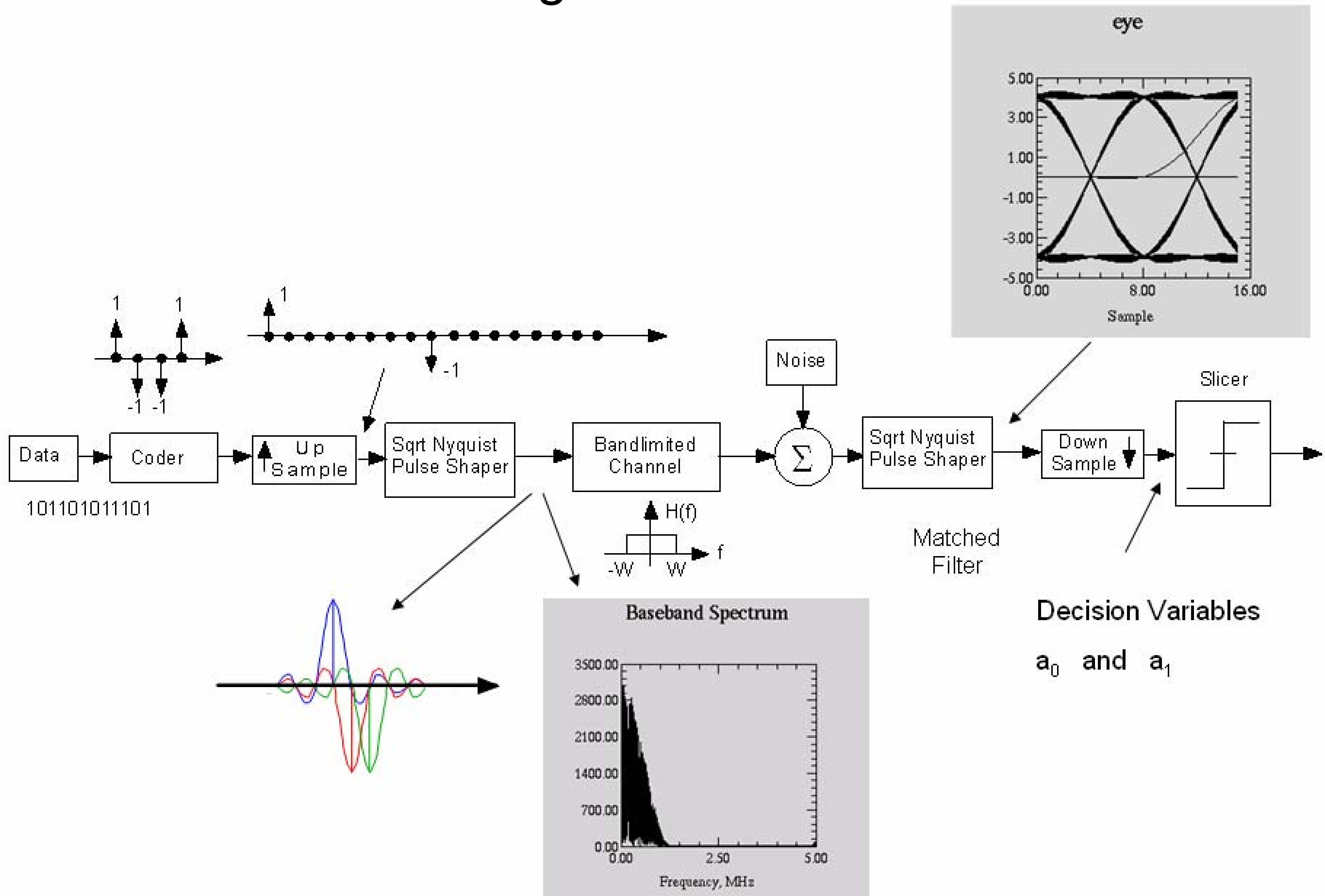


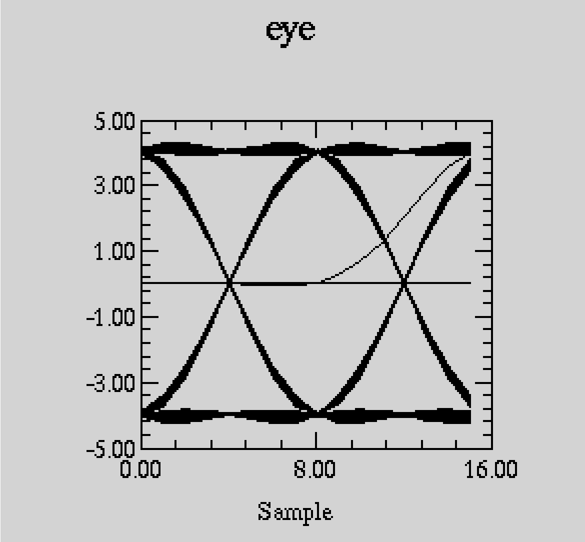


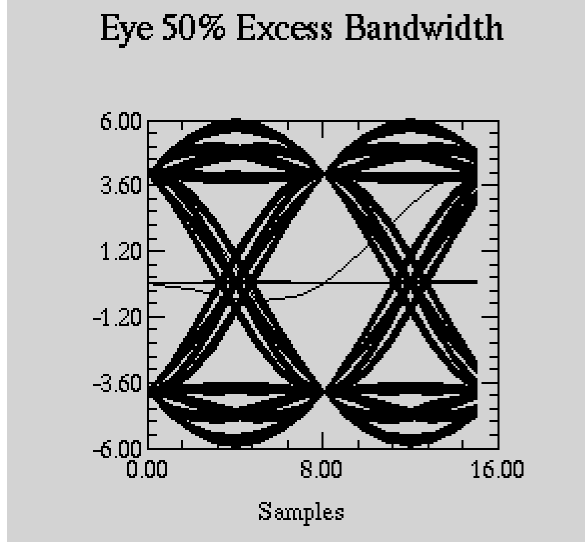


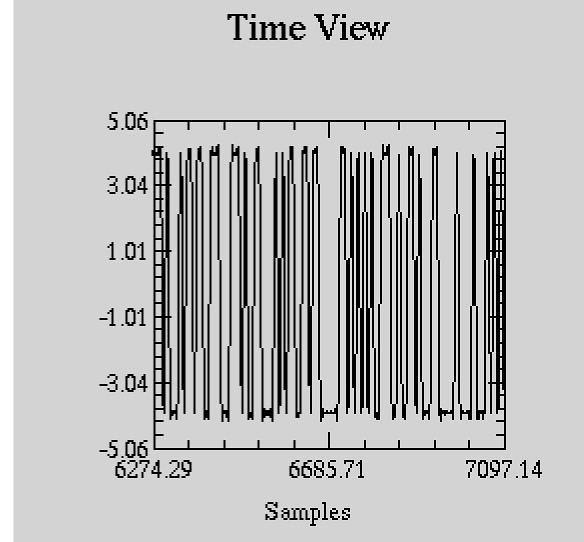
Carrier Spacing 312.5 kHz

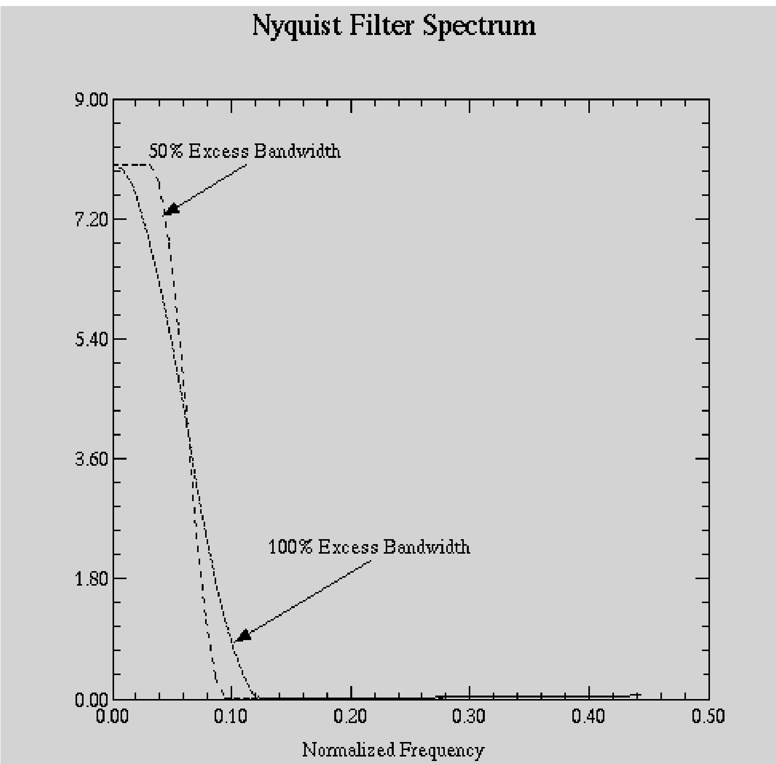
Baseband Digital Communication Link

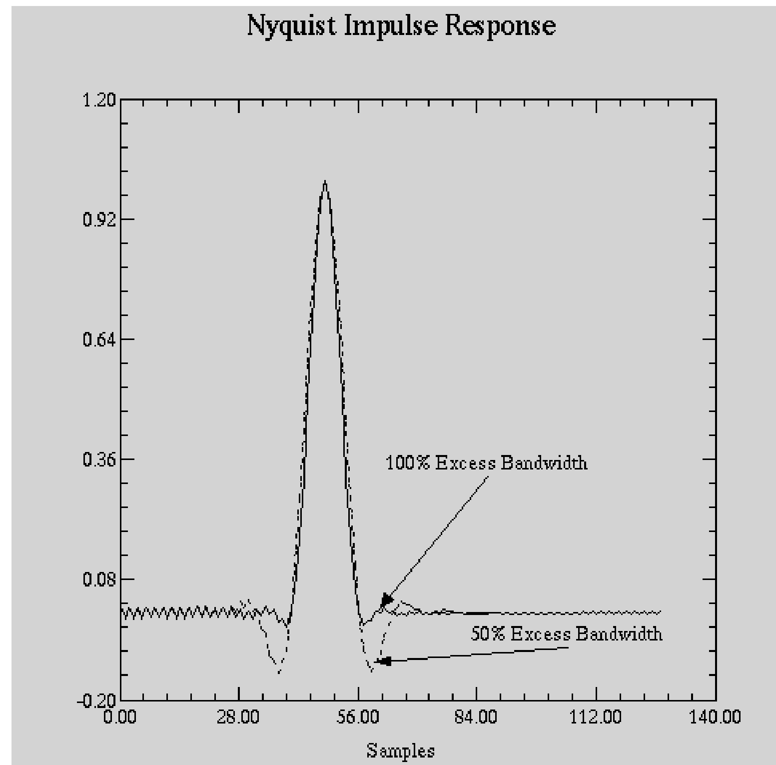



eye
5.00
3.00
1.00
-1.00
-3.00
-5.00
0.00
8.00
16.00
Sample


Eye 50% Excess Bandwidth
6.00
3.60
1.20
-1.20
-3.60
-6.00
0.00
8.00
16.00
Samples

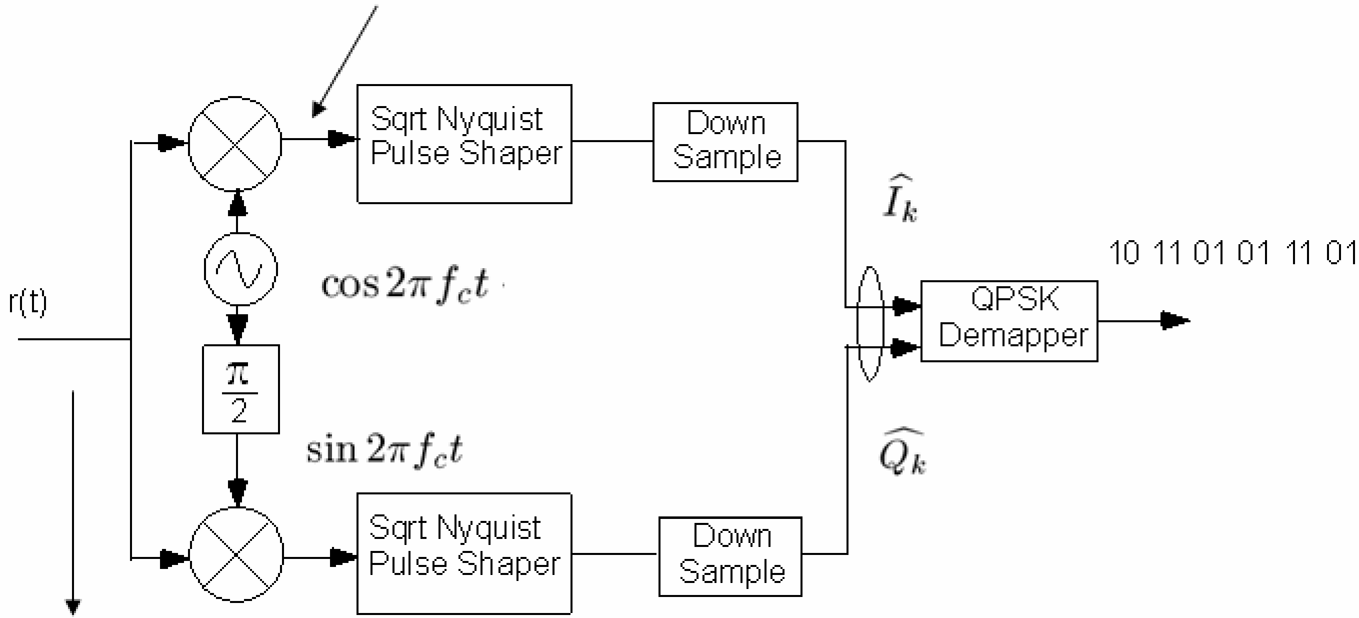

Time View
5.06
3.04
1.01
-1.01
-3.04
-5.06
6274.29
6685.71
7097.14
Samples


Nyquist Filter Spectrum
9.00
7.20
5.40
3.60
1.80
0.00
50% Excess Bandwidth
100% Excess Bandwidth
0.00
0.10
0.20
0.30
0.40
0.50
Normalized Frequency


Nyquist Impulse Response
1.20
0.92
0.64
0.36
0.08
-0.20
100% Excess Bandwidth
50% Excess Bandwidth
0.00
28.00
56.00
84.00
112.00
140.00
Samples

Quadrature Demodulation

$$r(t)\cos 2\pi f_c t = I_k \cos^2 2\pi f_c t - Q_k \sin 2\pi f_c t \cos 2\pi f_c t$$



$$r(t) = I_k \cos 2\pi f_c t - Q_k \sin 2\pi f_c t$$

$$\cos^2 \alpha = \frac{1}{2}(1 + \cos 2\alpha)$$

$$\cos\alpha \sin\beta = \frac{1}{2}\sin(\alpha - \beta) + \frac{1}{2}\sin(\alpha + \beta)$$

Baseband

Filtered Out

$$r(t)\cos 2\pi f_c t = \frac{1}{2} I_k + \frac{1}{2} I_k \cos 4\pi f_c t - \frac{1}{2} Q_k \sin 4\pi f_c t$$

Original Paper on OFDM 1971

628 IEEE TRANSACTIONS ON COMMUNICATION TECHNOLOGY, VOL. COM-19, NO. 5, OCTOBER 1971

Data Transmission by Frequency-Division Multiplexing Using the Discrete Fourier Transform

S. B. WEINSTEIN, MEMBER, IEEE, AND PAUL M. EBERT, MEMBER, IEEE

Original Paper Introducing Cyclic Prefix

DIGITAL SOUND BROADCASTING TO MOBILE RECEIVERS

Bernard Le Floch, Roselyne Halbert-Lassalle, Damien Castelain
CCETT (Centre Commun d'Etudes de Télédiffusion et Télécommunications)
35512 Cesson Sévigné, France

IEEE Transactions on Consumer Electronics, Aug. 1989.

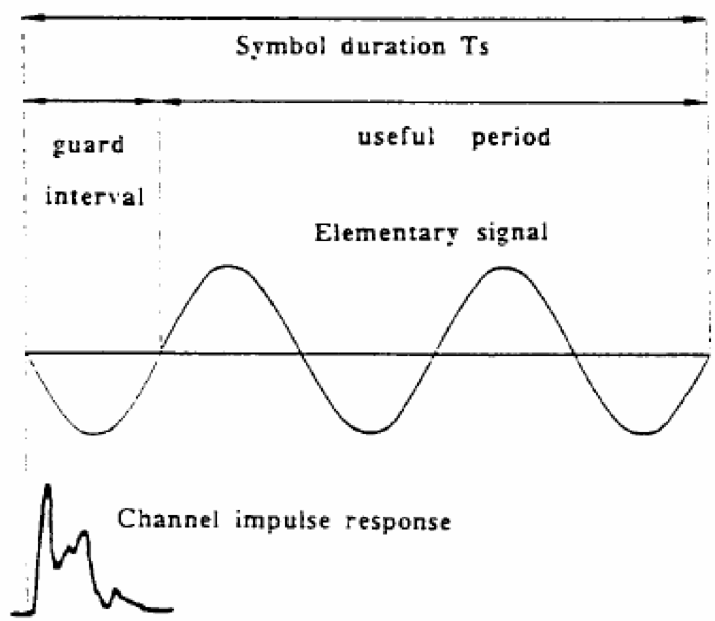
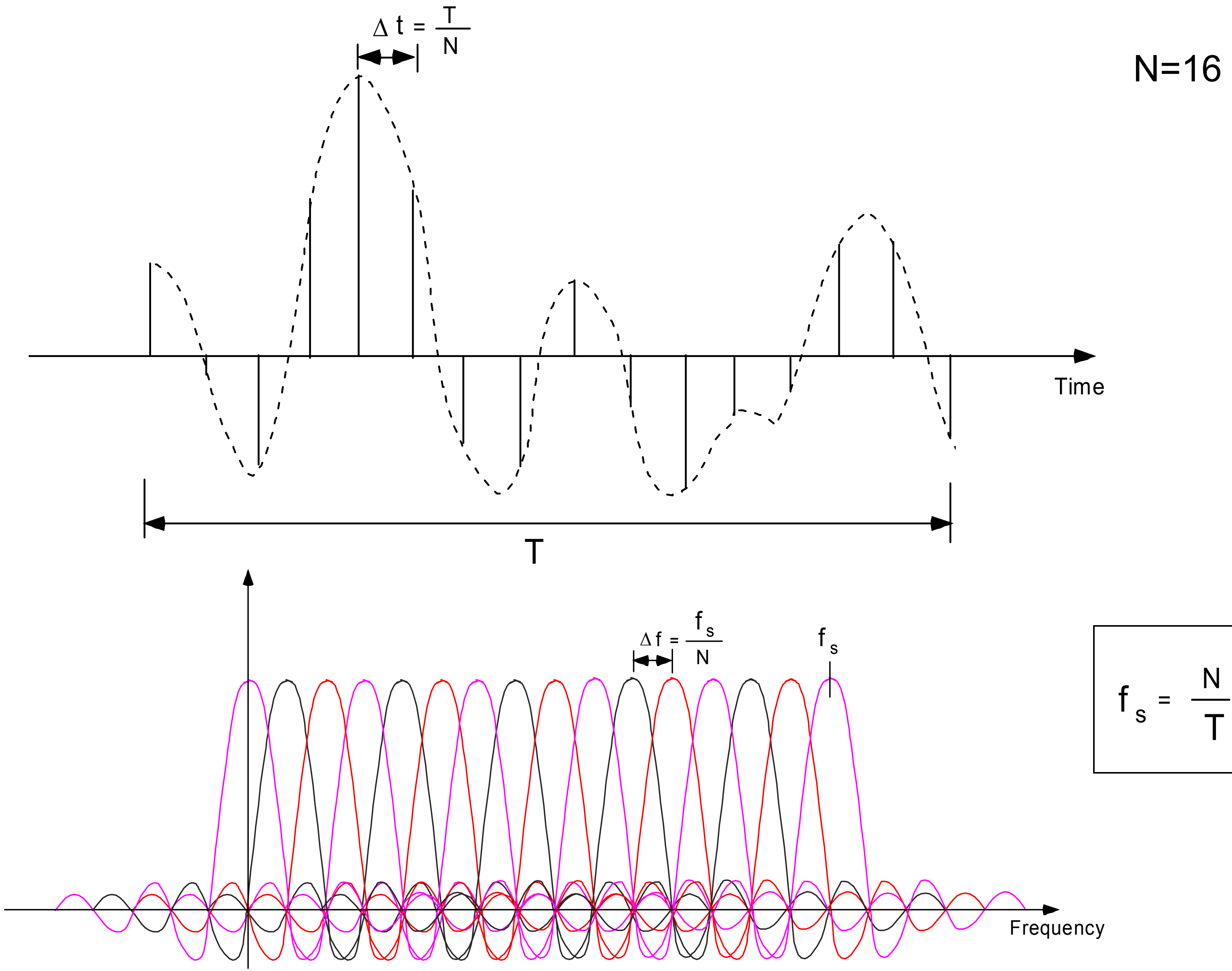


Figure 3

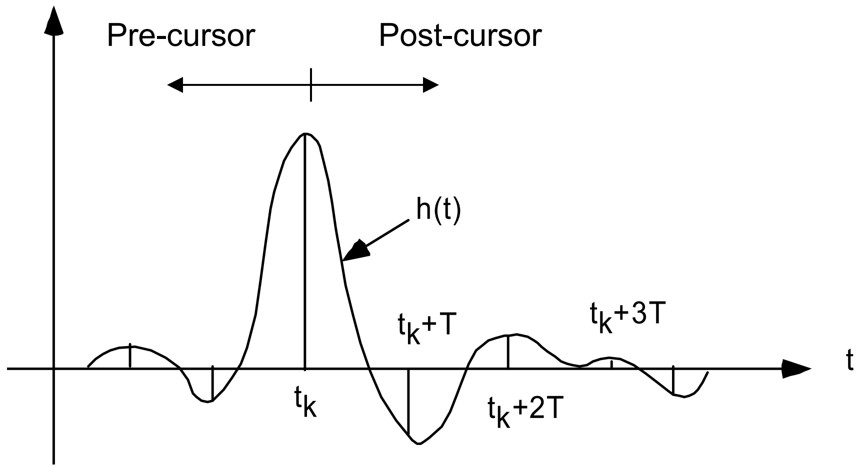
Use of a guard interval to suppress the intersymbol interference

OFDM and Sampling Rate

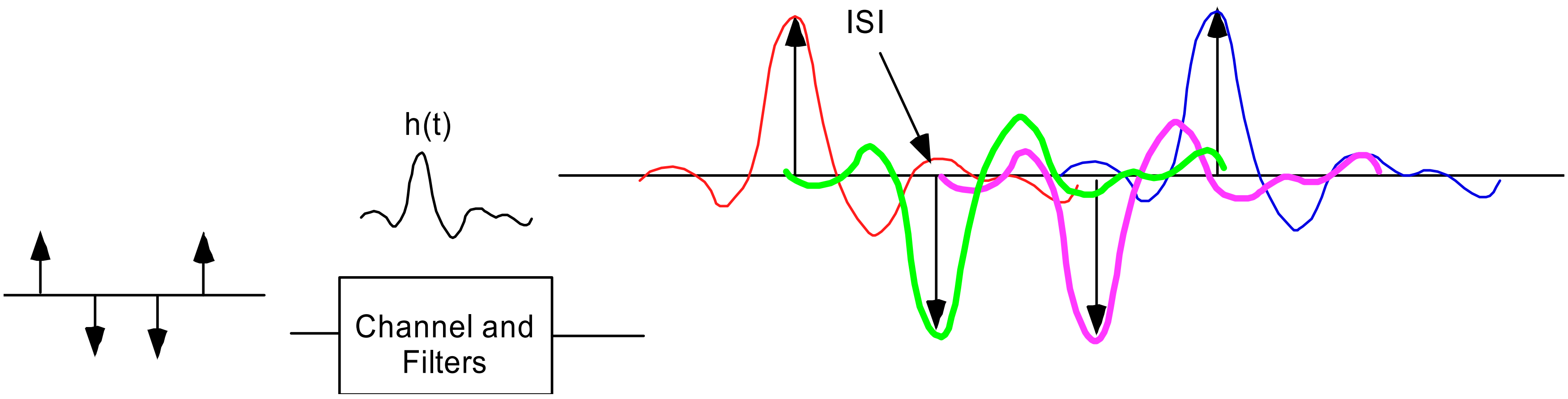


$$f_s = \frac{N}{T}$$

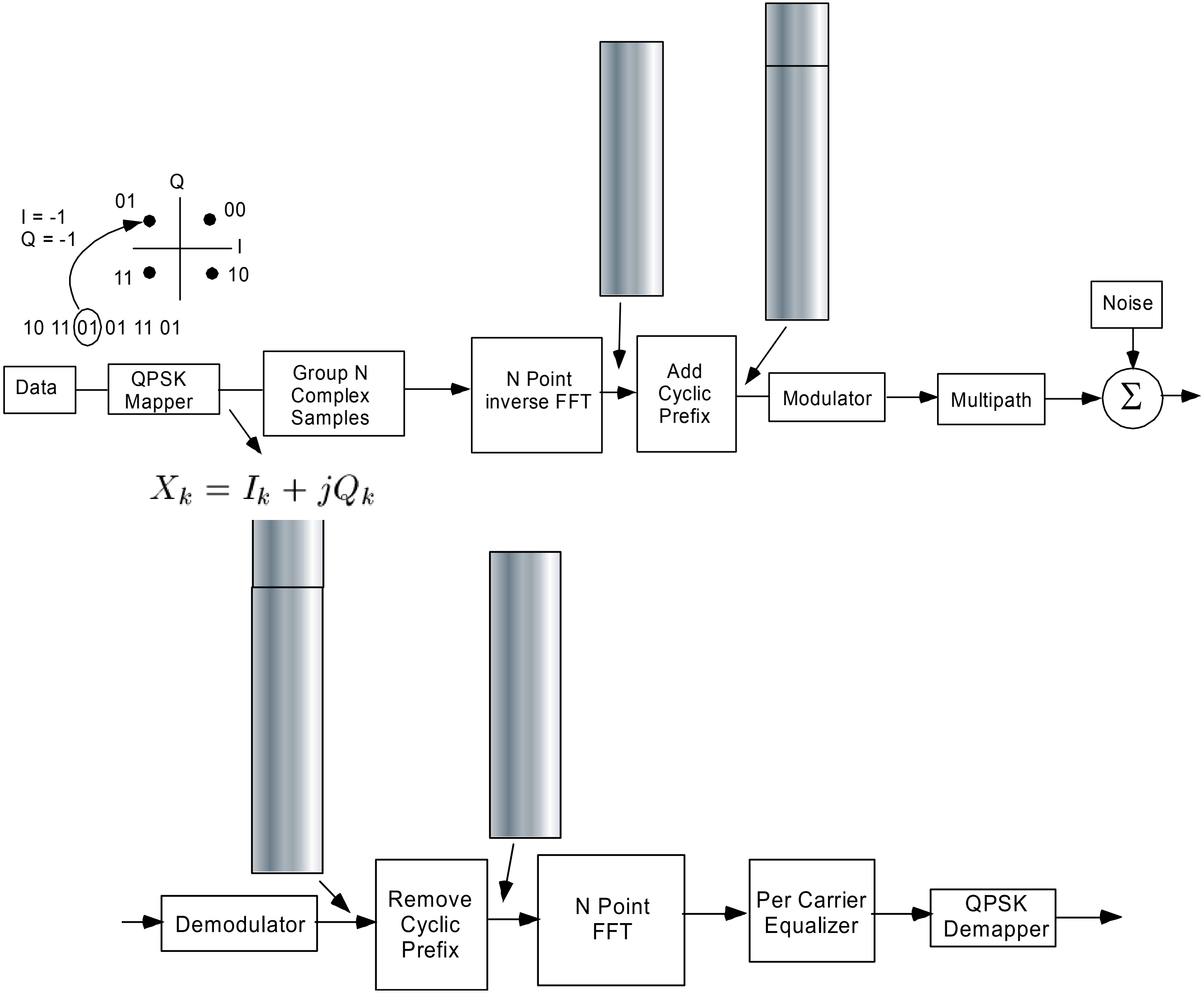
Intersymbol Interference (ISI) in Fading Multipath Channel



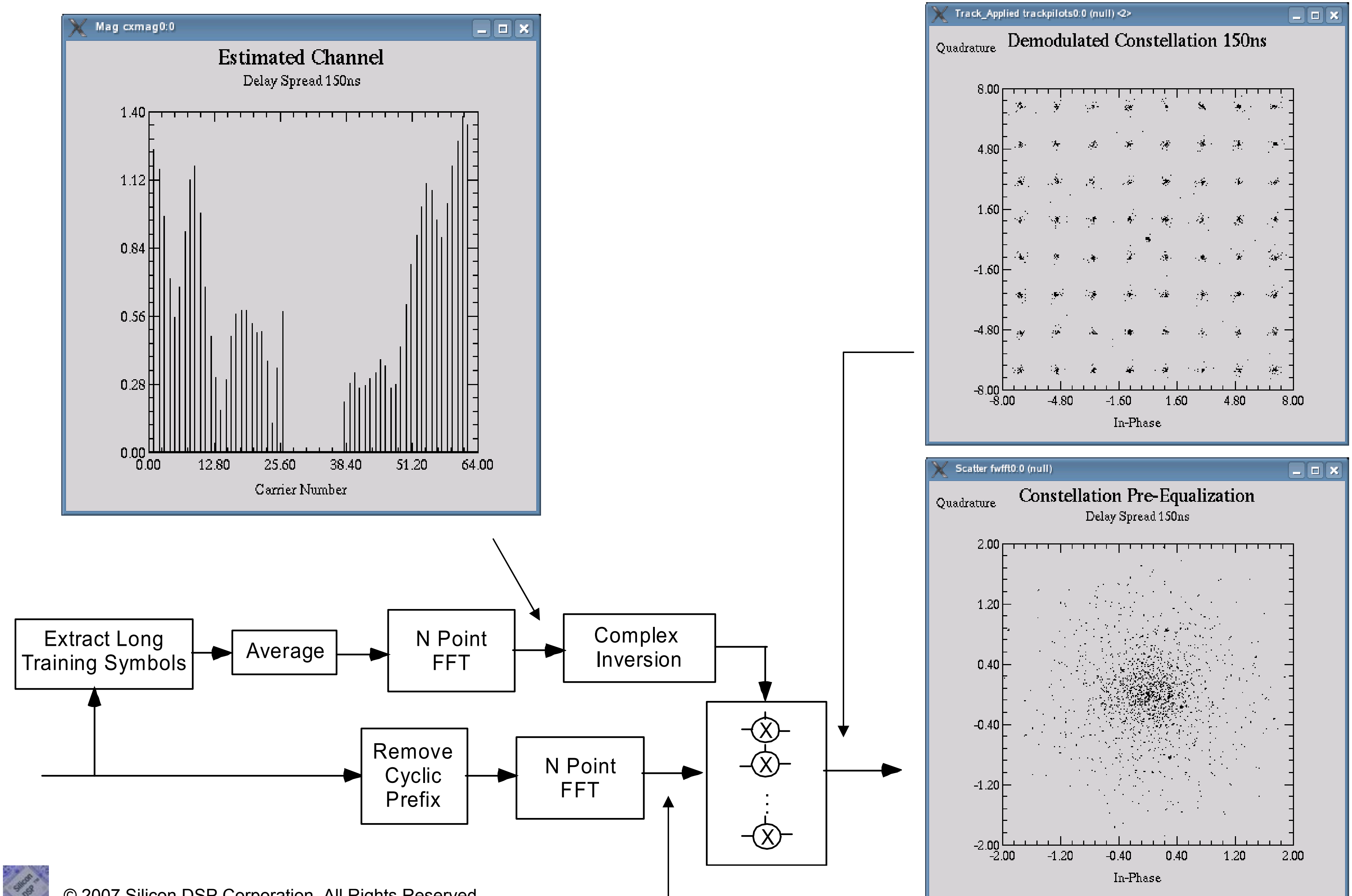
Channel Impulse Response

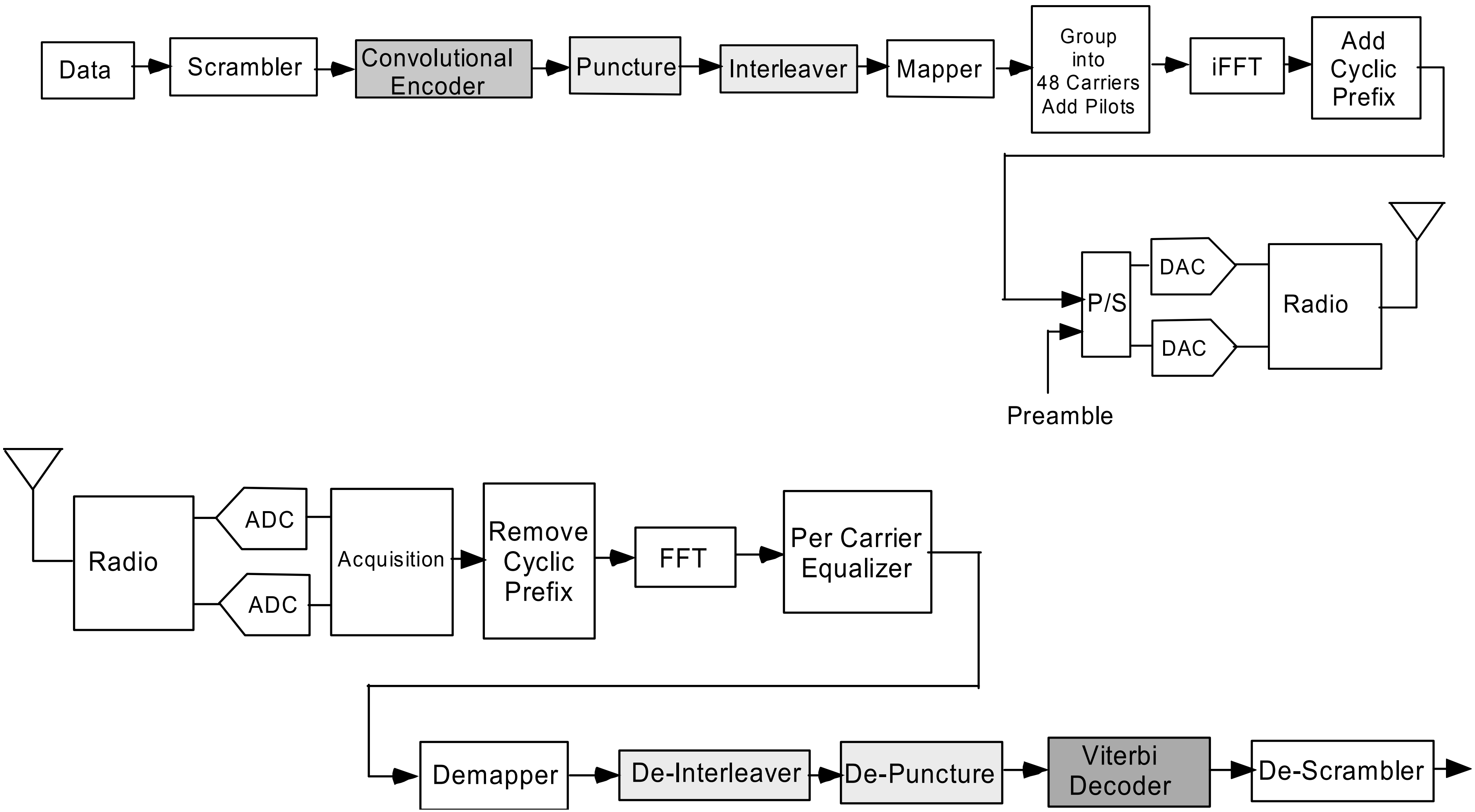


OFDM Modulation/Demodulation Cyclic Prefix

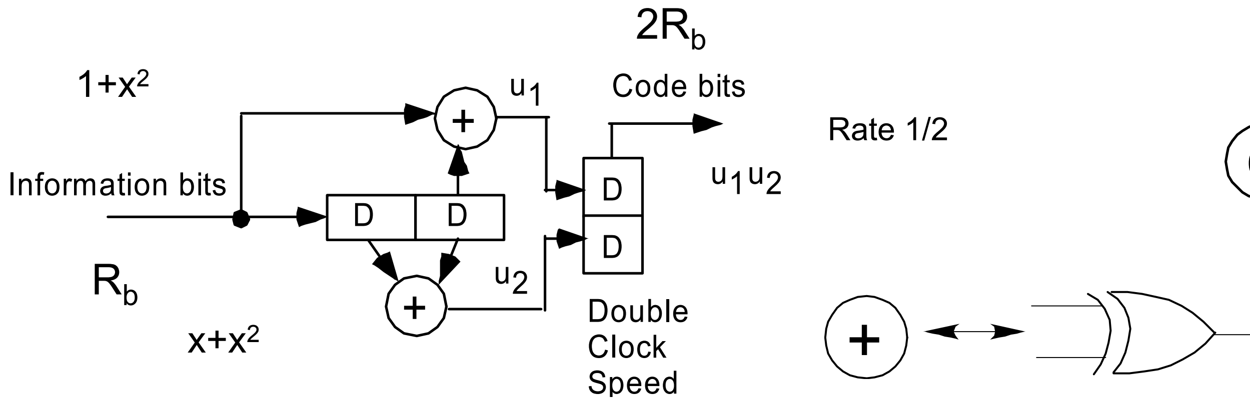


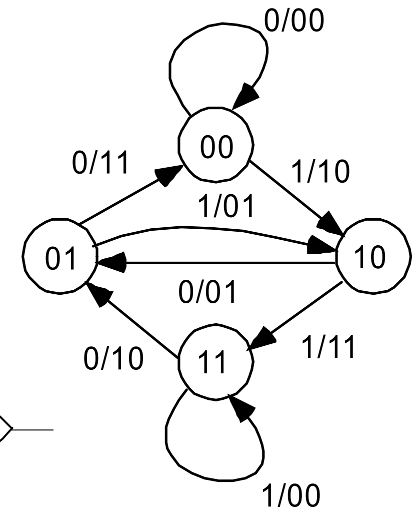
Frequency Domain Per Carrier Equalization

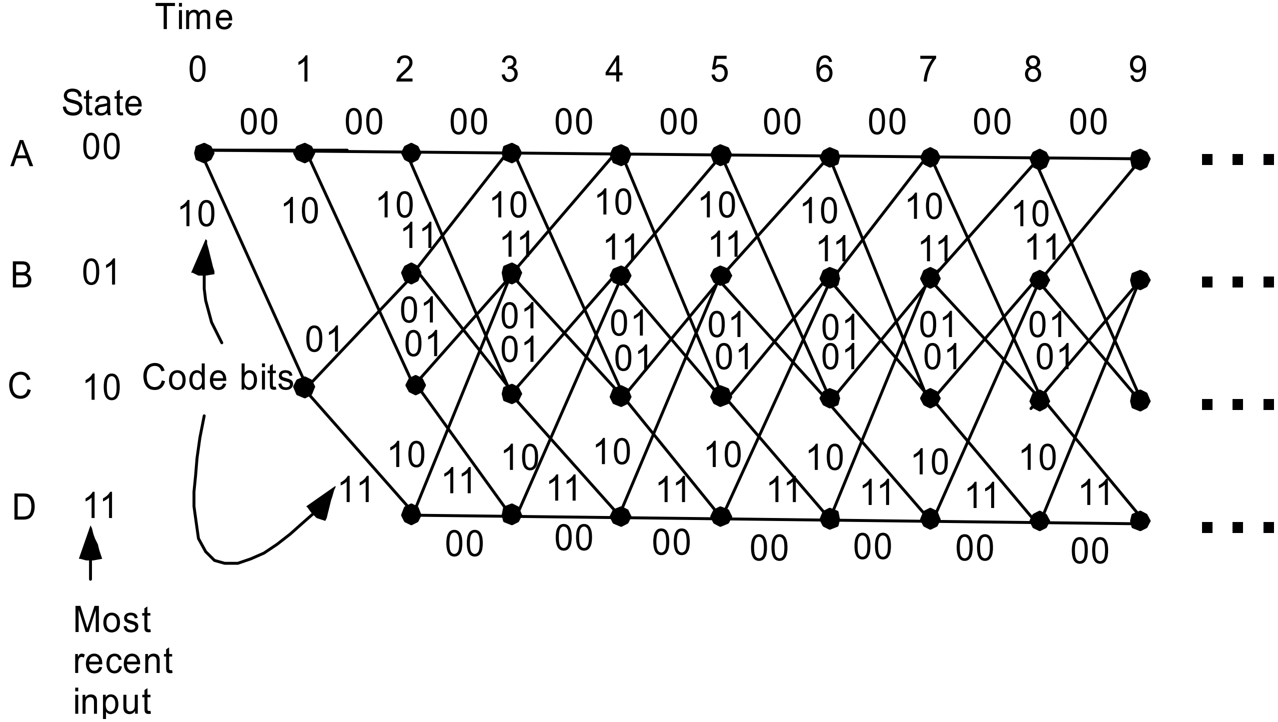



Data
Scrambler
Convolutional Encoder
Puncture
Interleaver
Mapper
Group into 48 Carriers Add Pilots
iFFT
Add Cyclic Prefix
P/S
DAC
DAC
Radio
Preamble
Radio
ADC
ADC
Acquisition
Remove Cyclic Prefix
FFT
Per Carrier Equalizer
Demapper
De-Interleaver
De-Puncture
Viterbi Decoder
De-Scrambler

Convolutional Encoder







Puncturing

Convolutional Encoder Output

1010110101011000010...1101...0110110001

N_{CBPS} 288=6*48bits One OFDM Symbol

Punctured Input to Mapper

101110010100...1101...01101001

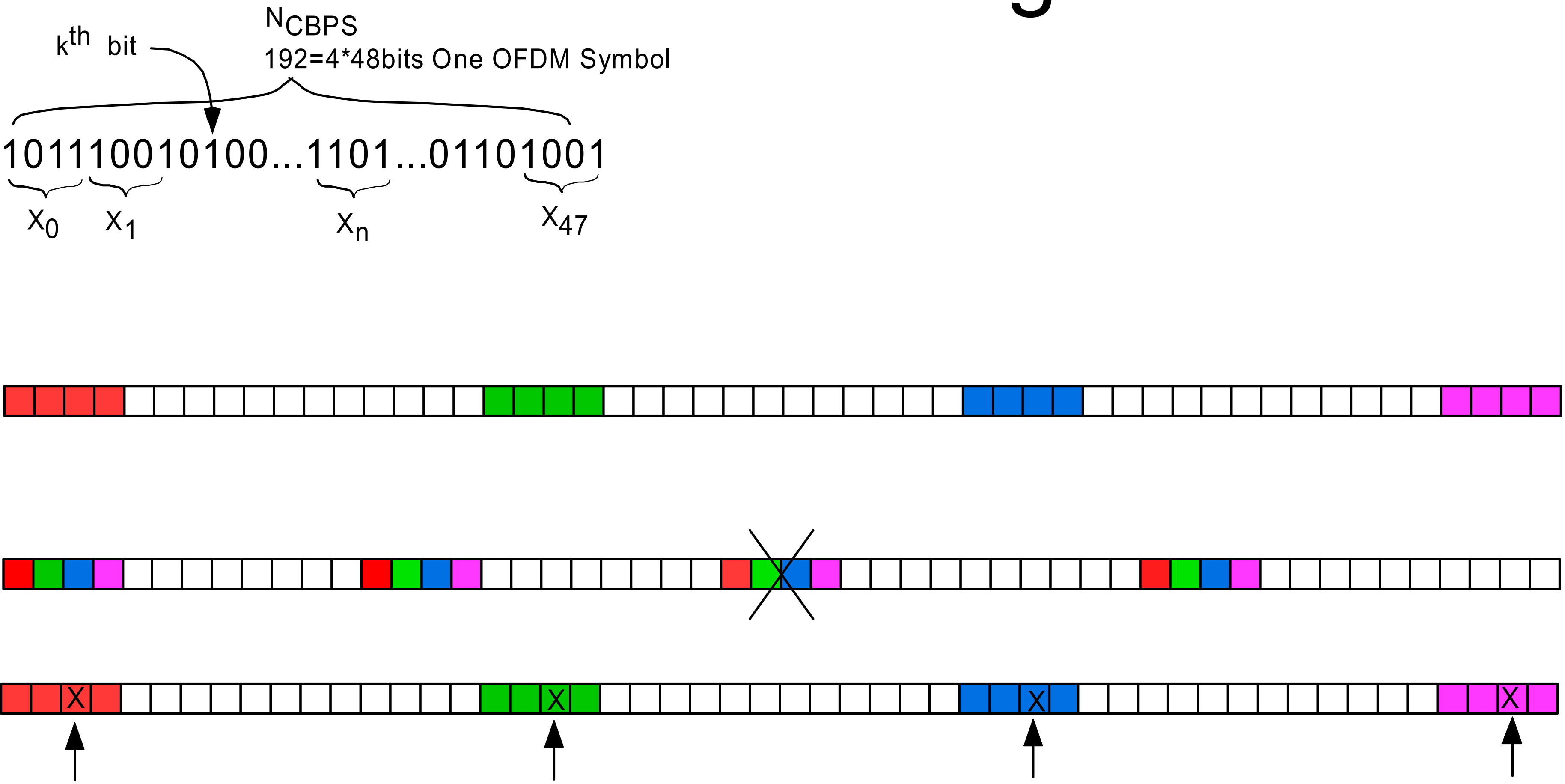
X_0 X_1 X_{47}

64 QAM

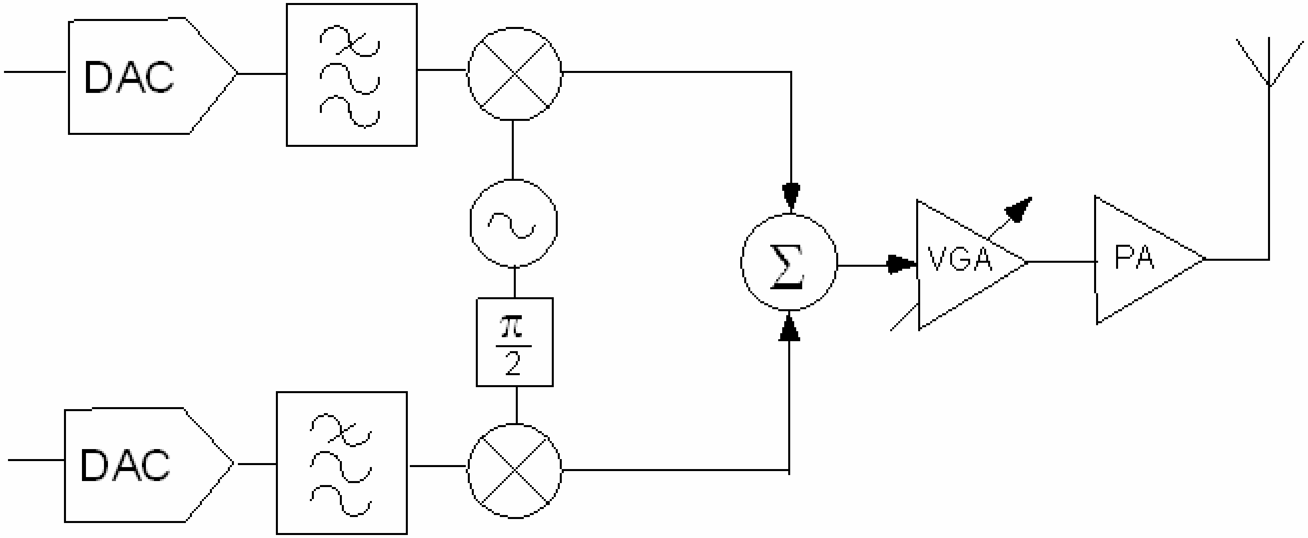
Dummy Bits Inserted Input to Viterbi Decoder

1010110001001000010...1101...0110100001

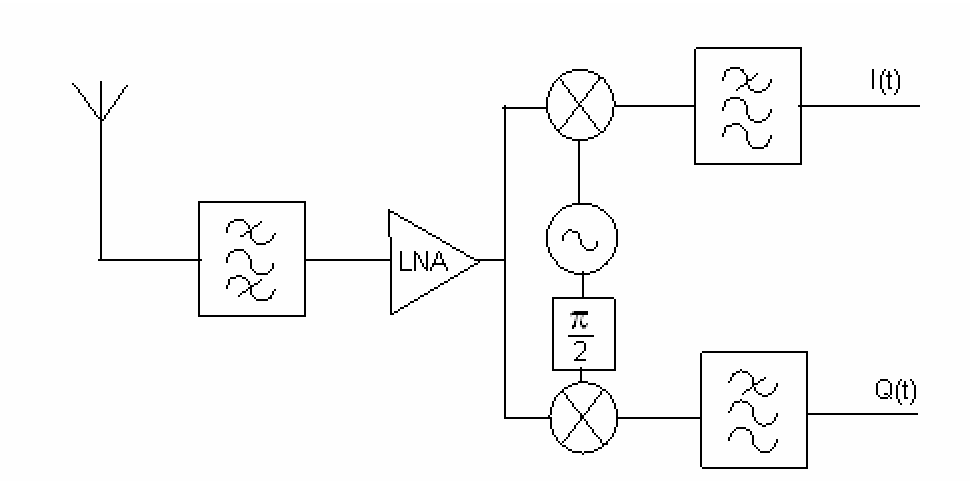
Interleaving

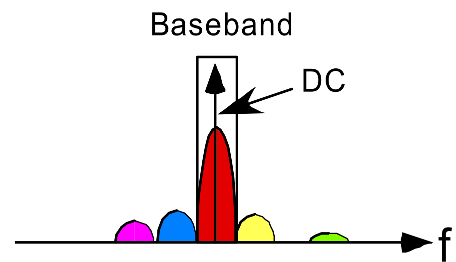


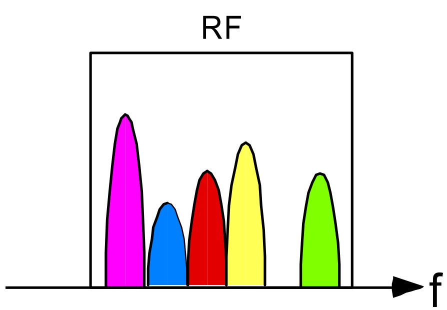
RF Transmitter



Direct Conversion Receiver



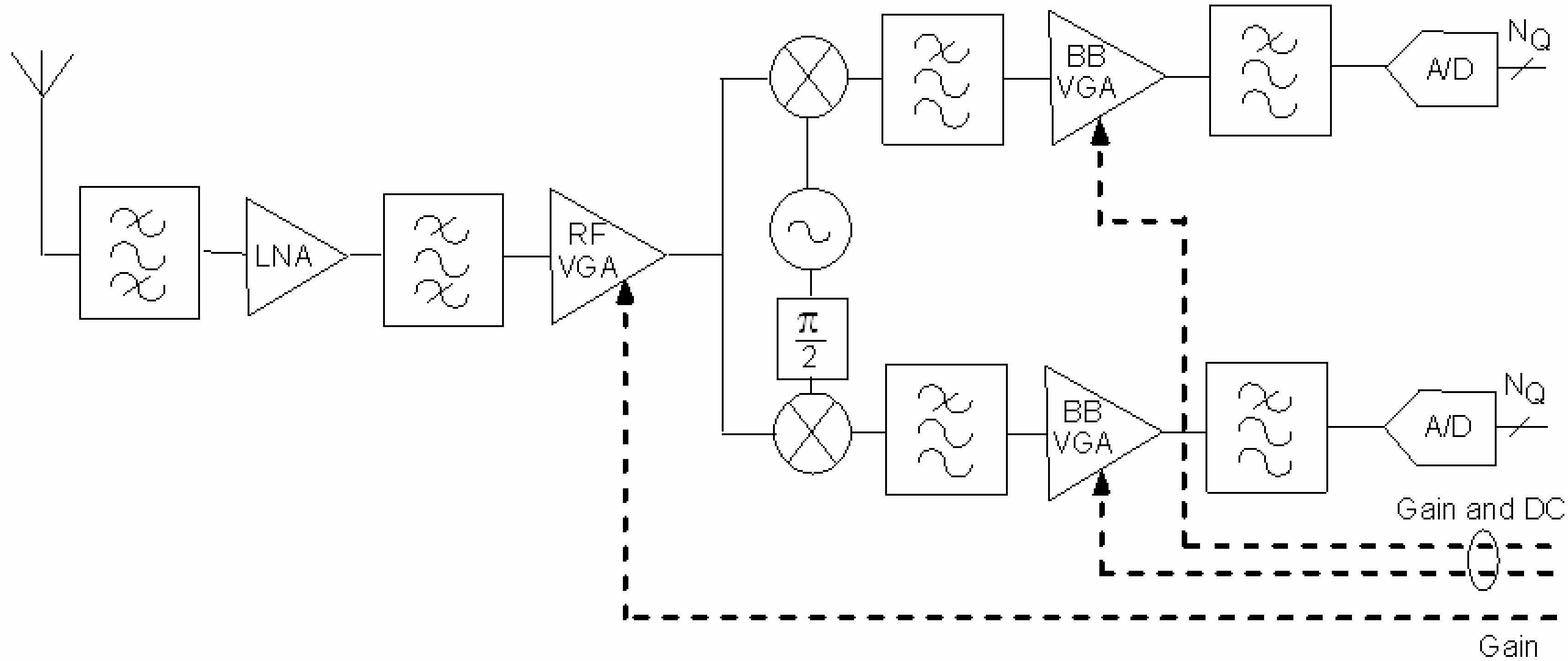




Homodyne Receiver

On the Direct Conversion Receiver -- A Tutorial, Ashkan Mashhour, William Domino and Norman Beamish, Conexant Systems, Microwave Journal, June 2001

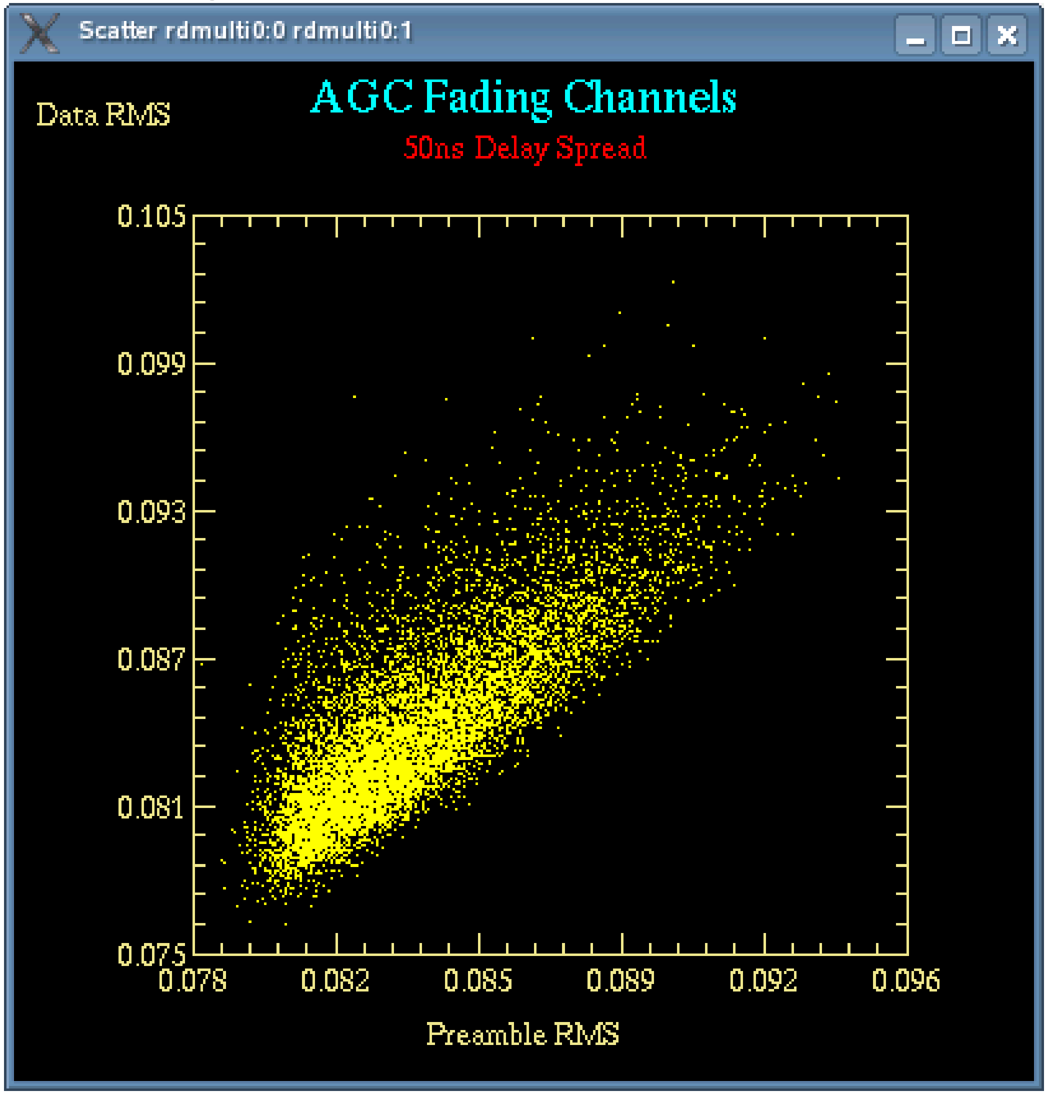
AGC



Baseband VGA : -8 to +8 dB gain range in 2 dB steps

Reference:
OFDM-WLAN Receiver Performance Improvement using Digital Compensation Techniques
Wolgang Eberle, Jan Tubbax, Boris Come, Stephane Donnay, Hugo De Man, Georges Gielen, IMEC and KU Leuven, IEEE, 2002

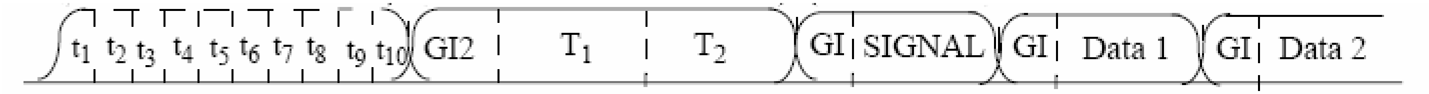
AGC Fading Characteristic



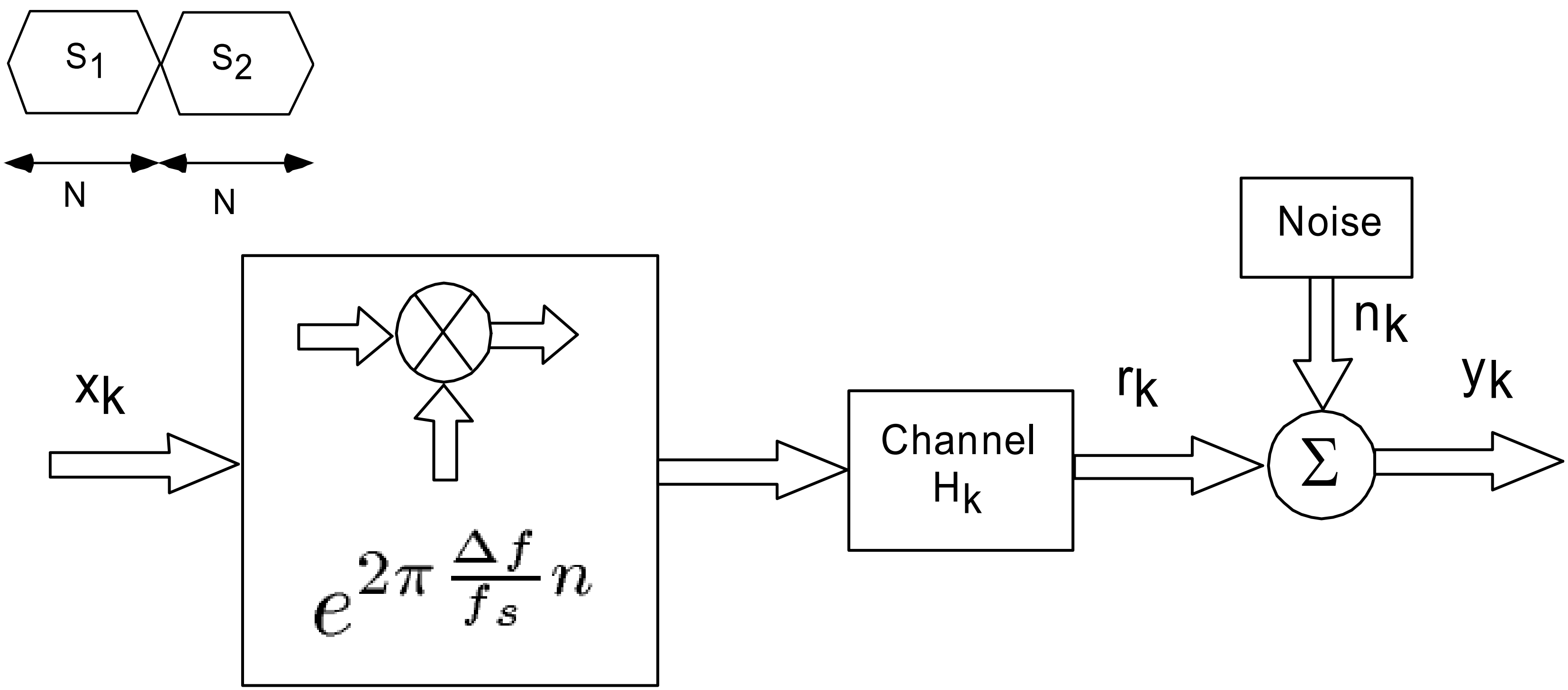
AGC done on Preamble.

Yet Data rms varies across many fading multipath realizations.

Must allow 5-7 dB for variation.

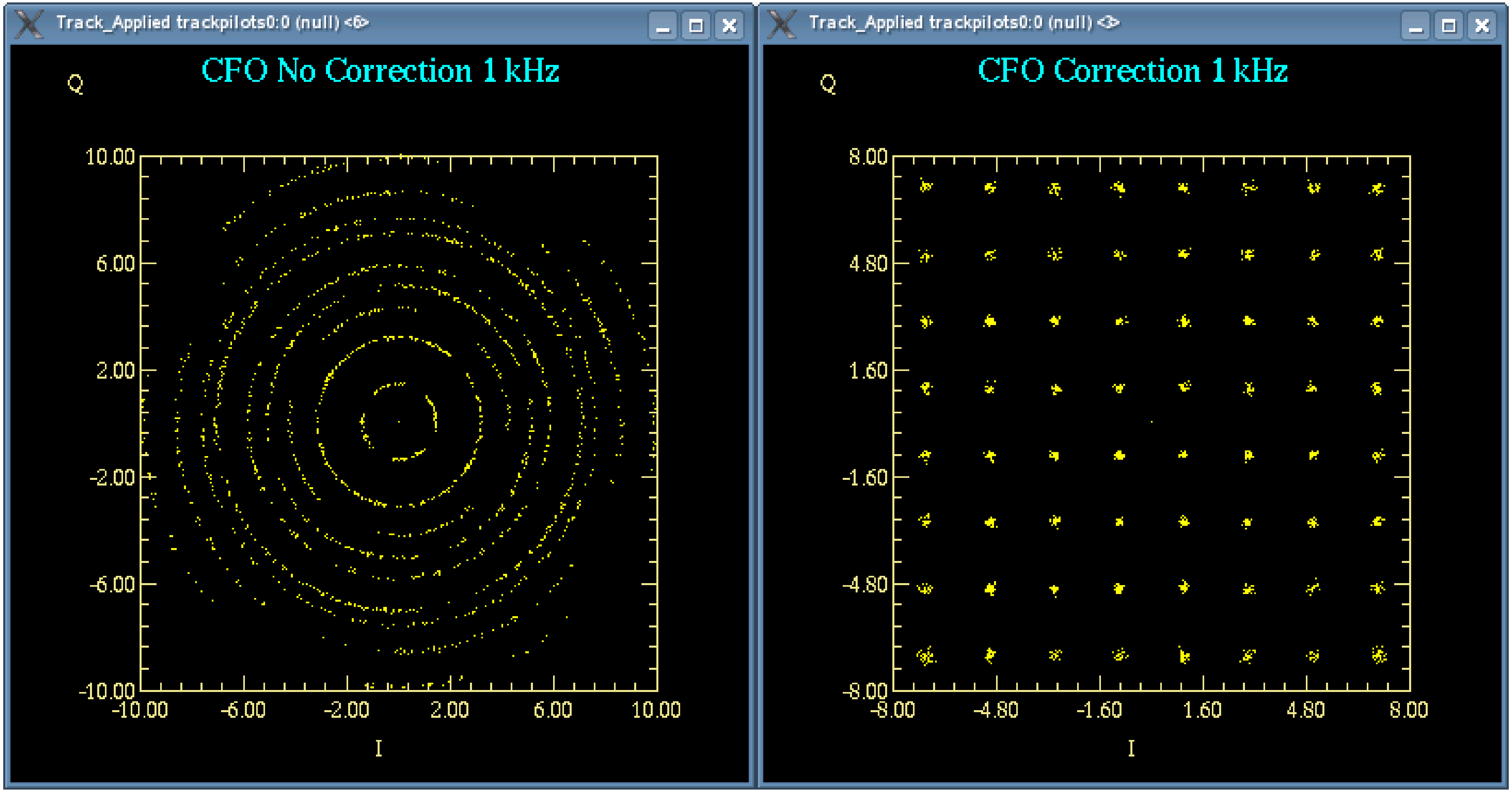


Algorithm for the Estimation of Carrier Offset Frequency



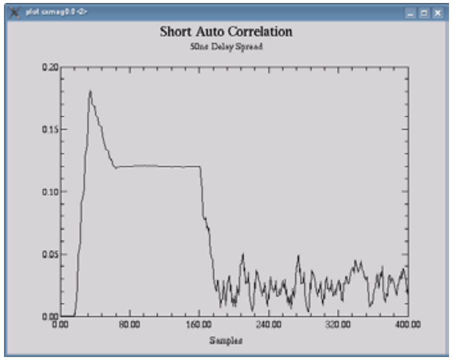
Paul Moose,"A Technique for Orthogonal Frequency Division Multiplexing Frequency Offset Correction," *IEEE Transcations on Communications*, Vol. 42, No. 10, October 1994

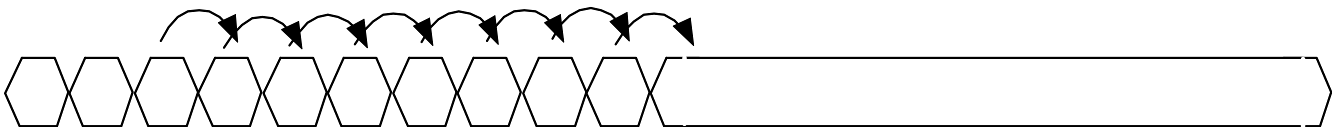
Carrier Frequency Offset Correction

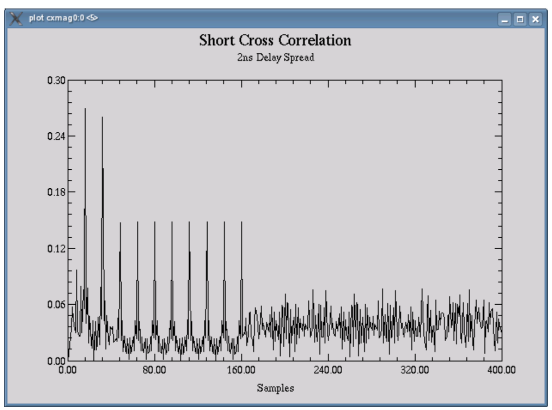


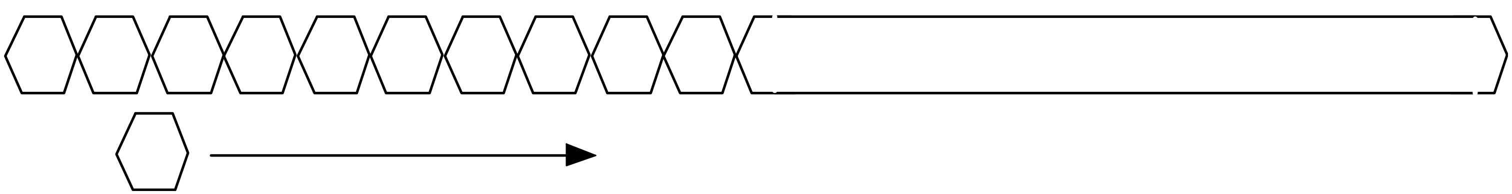
1000 Bytes SNR= 40dB

Auto Correlation versus Cross Correlation in Packet Detection

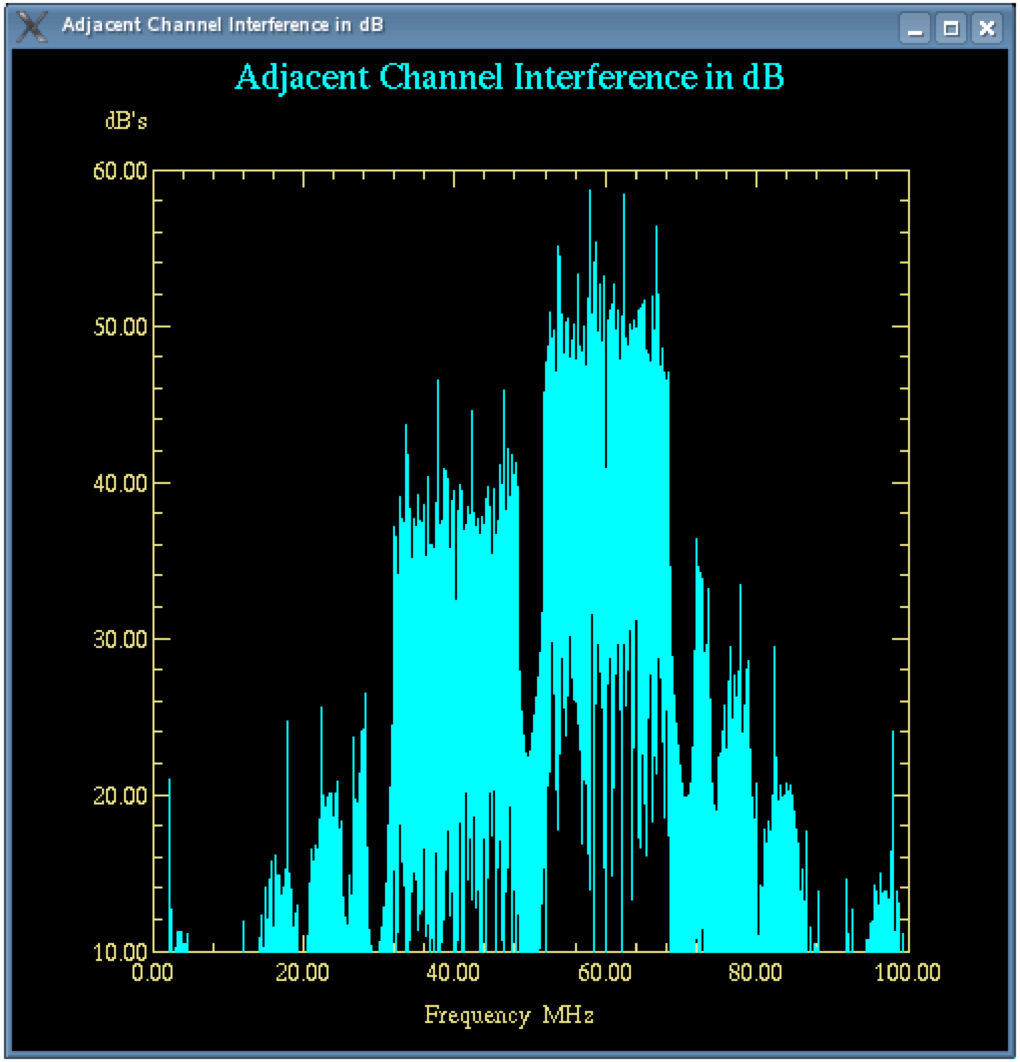




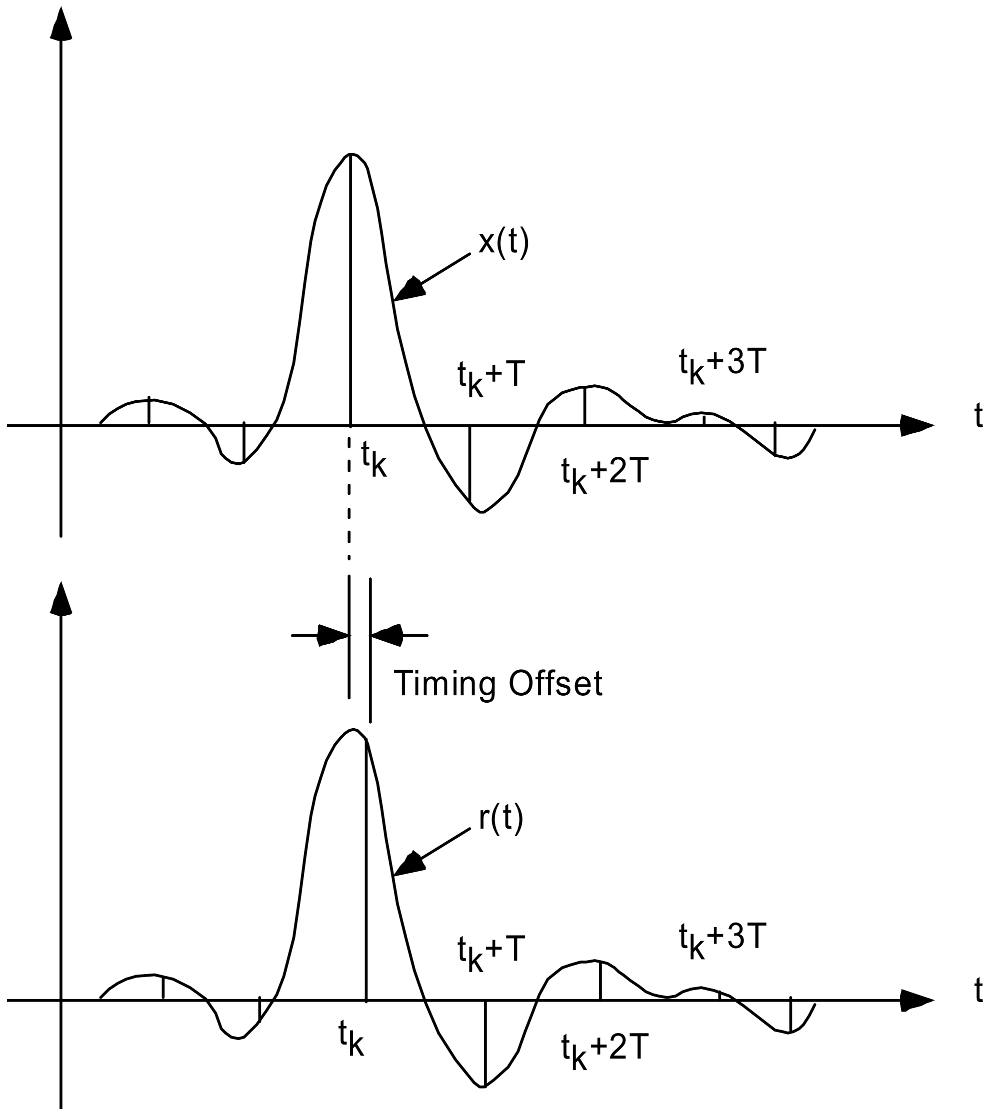




Adjacent Channel Interference

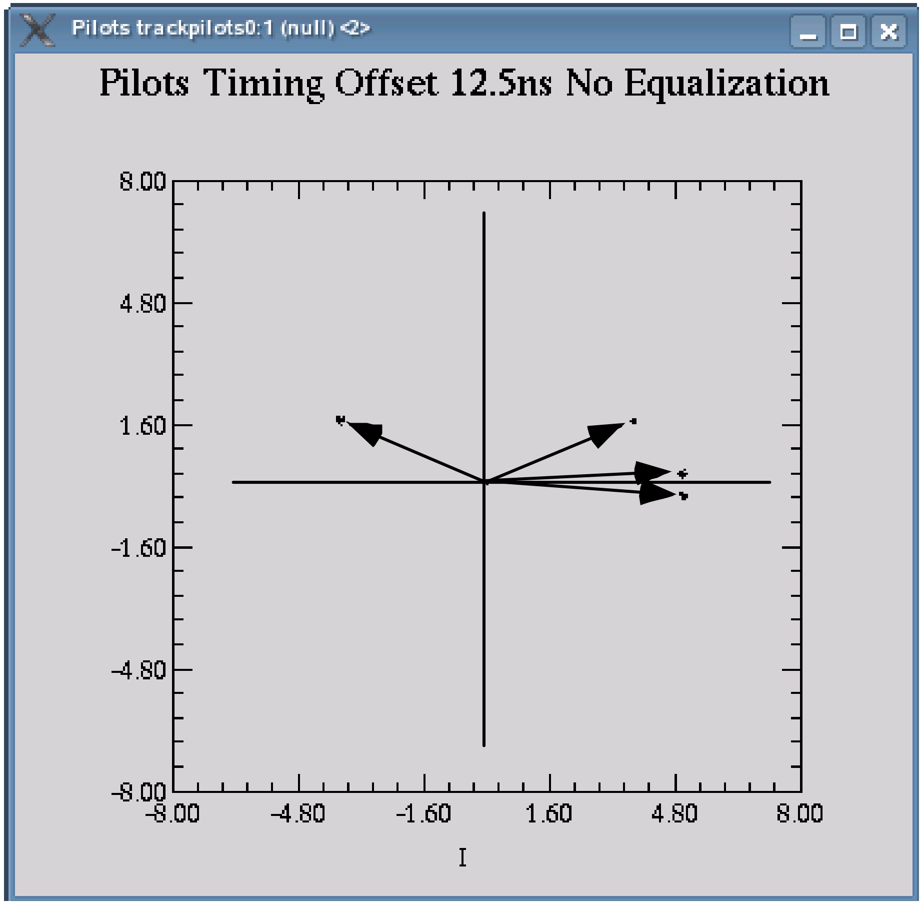


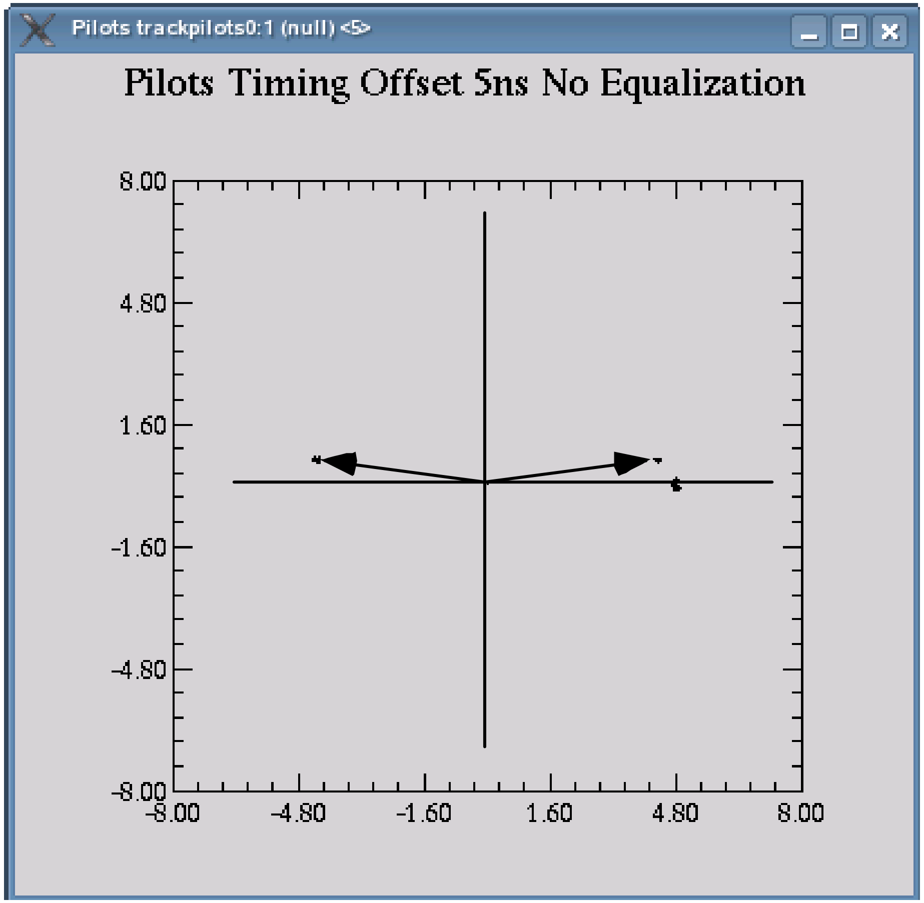
Timing Offset



Timing Offset

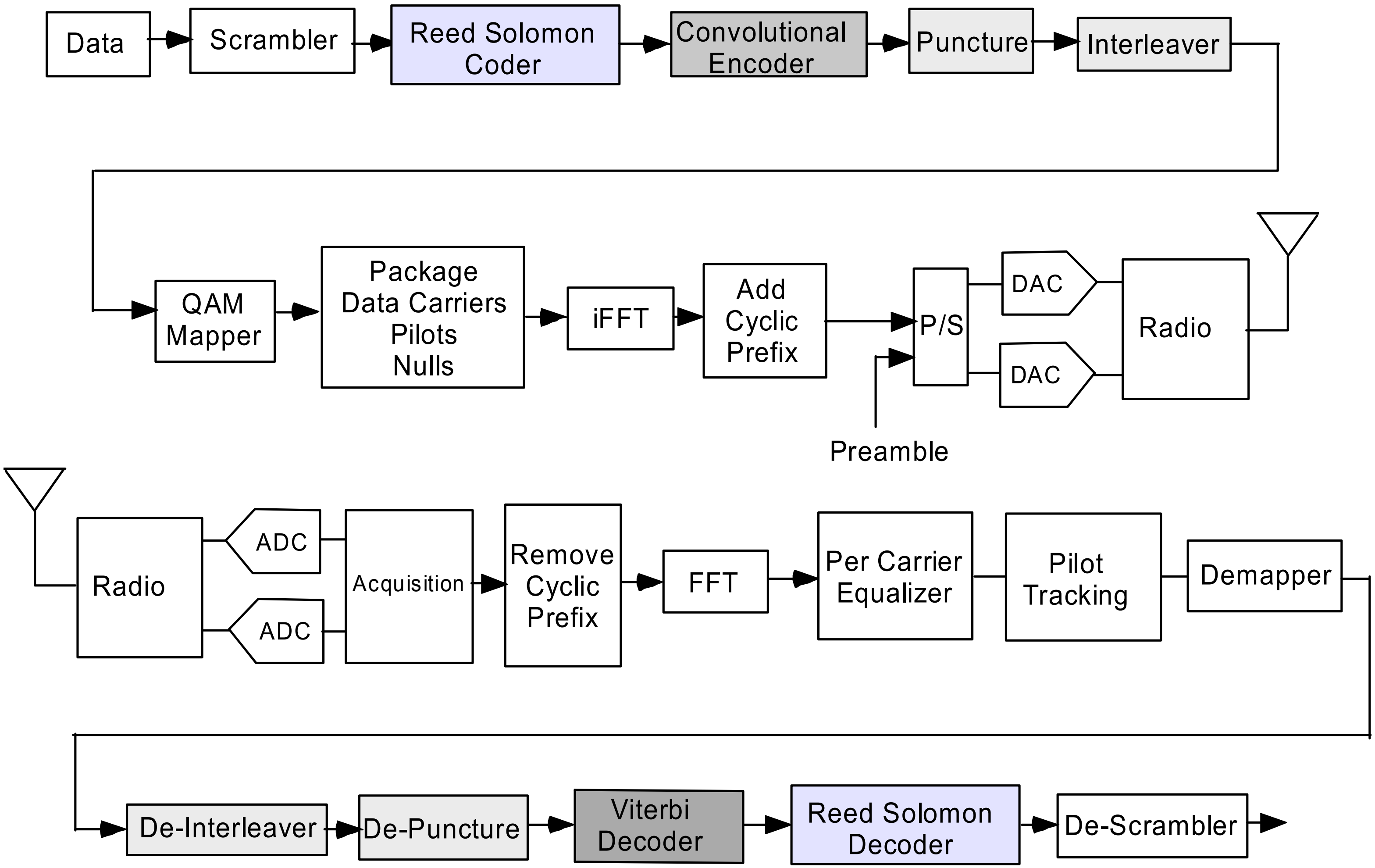
12.5ns **5ns**





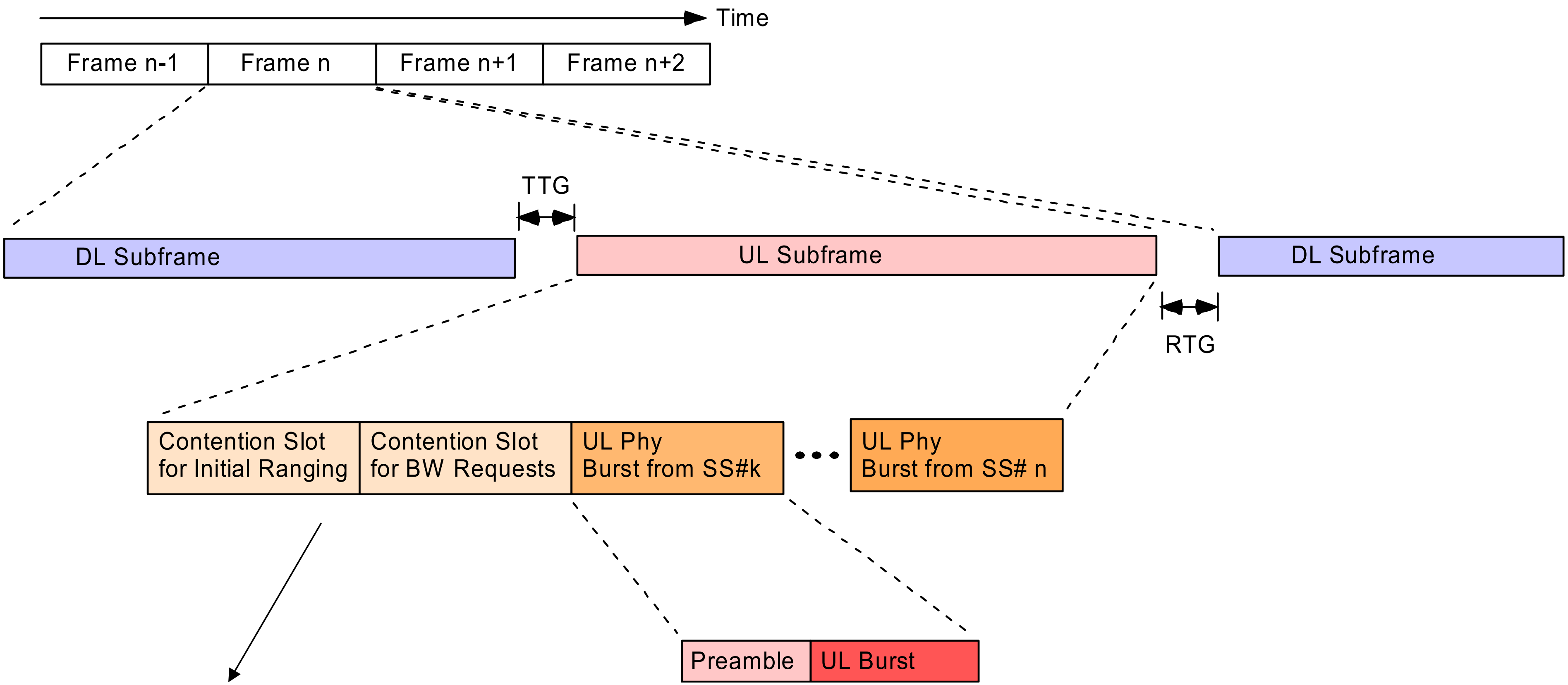
Point to Multi-Point Links

IEEE 802.16-2004 256 Point FFT
Concatenated FEC Reed-Solomon Outer Code
Convolutional Inner Code



Simplified Block Diagram for SS

TDD OFDM MAN



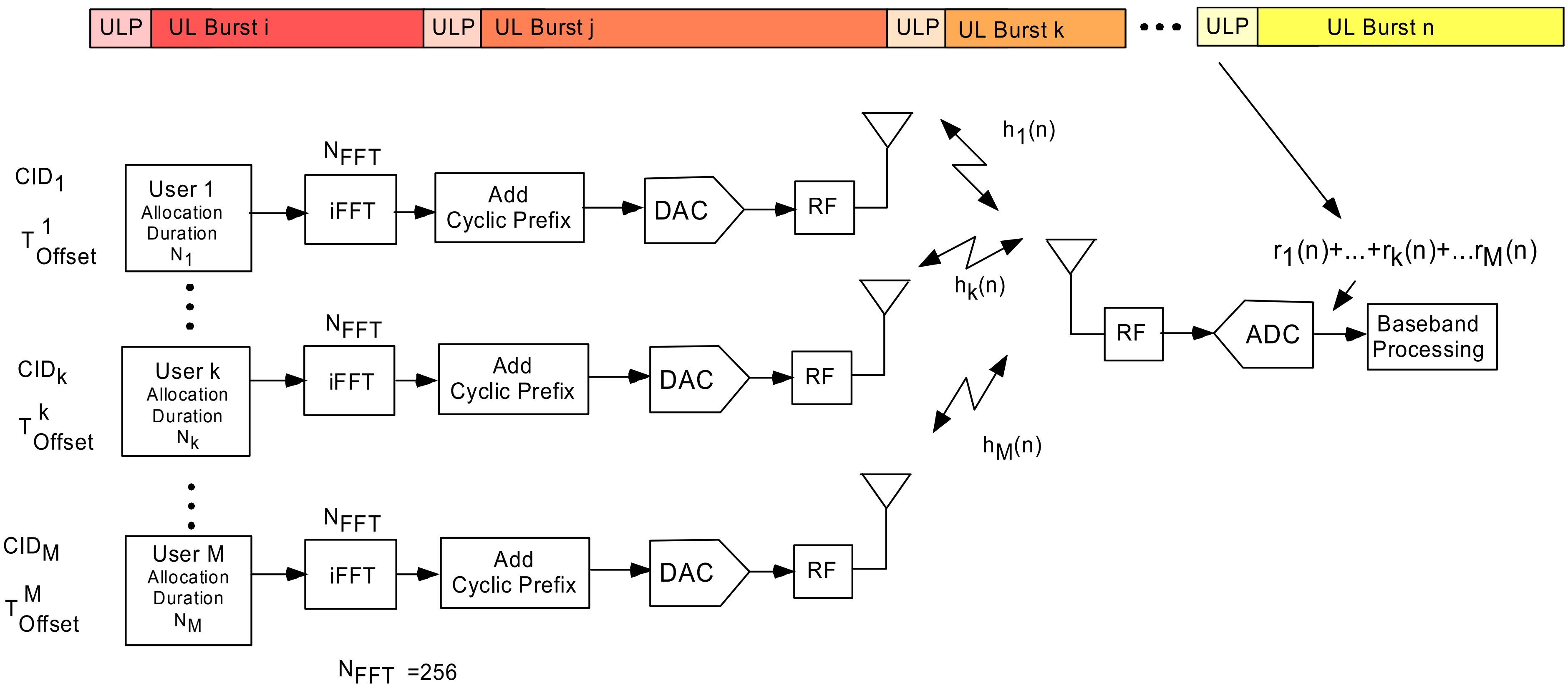
"Initial ranging transmissions shall consist of a long preamble and one OFDM symbol using the most robust mandatory burst profile."

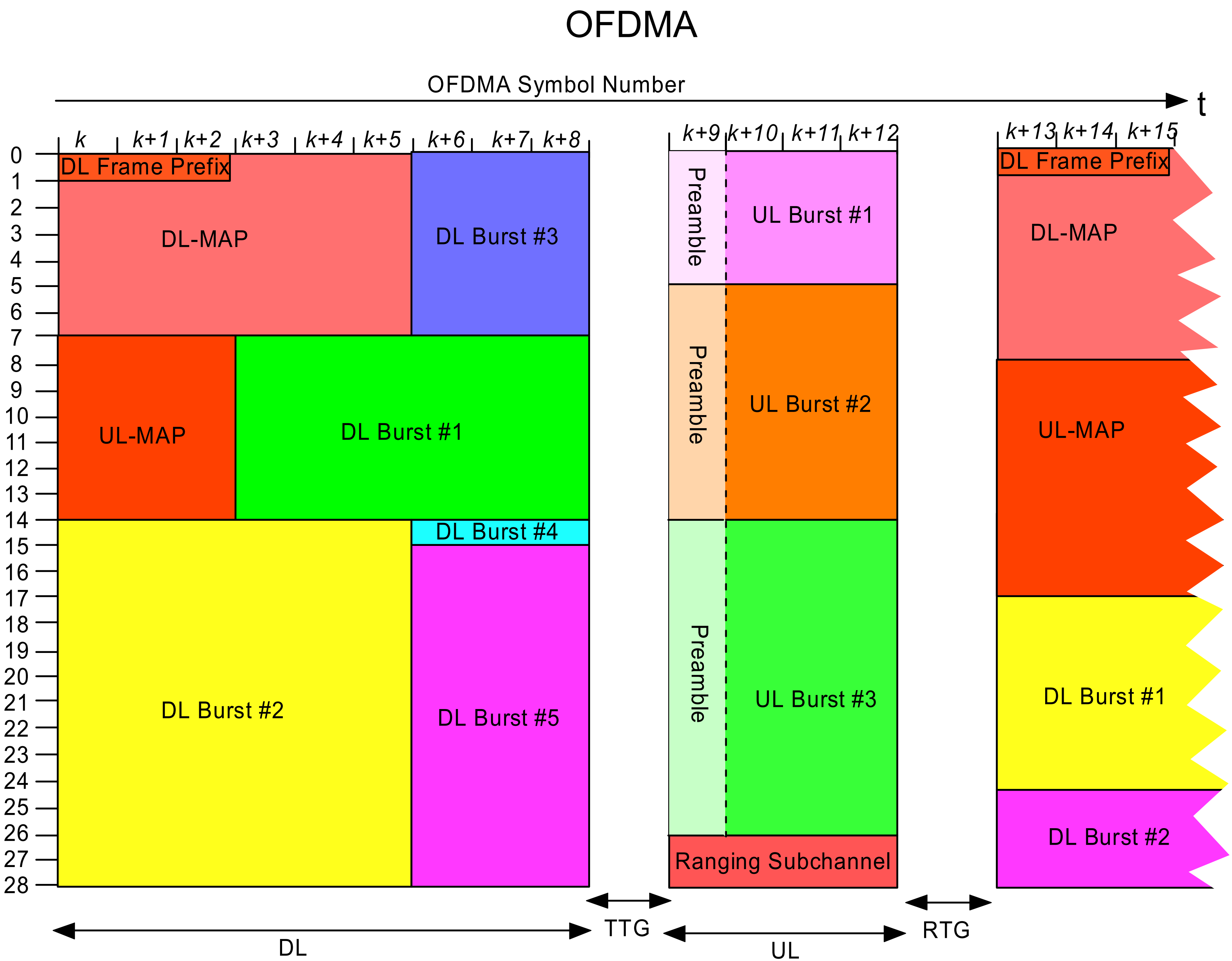
RTG Receive/Transmit Transition Gap

TTG Transmit/Receive Transition Gap

FCH Frame Control Header

Uplink Burst Transmissions from Subscriber Stations




OFDMA
OFDMA Symbol Number
t
k
k+1
k+2
k+3
k+4
k+5
k+6
k+7
k+8
k+9
k+10
k+11
k+12
k+13
k+14
k+15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
DL Frame Prefix
DL-MAP
DL Burst #3
UL-MAP
DL Burst #1
DL Burst #4
DL Burst #2
DL Burst #5
Preamble
UL Burst #1
Preamble
UL Burst #2
Preamble
UL Burst #3
Ranging Subchannel
DL Frame Prefix
DL-MAP
UL-MAP
DL Burst #1
DL Burst #2
TTG
RTG
DL
UL

Type C Terrain

Path Loss

$$PL = A + 10\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_f + X_h + s \quad \text{for } d > d_0$$

d Distance from BS to CPE $\quad d_0 = 100 \text{ m}$

s is a lognormally distributed factor that is used to account for the shadow fading owing to trees and other clutter and has a value between 8.2 dB and 10.6 dB.

$$A = 20 \log_{10}\left(\frac{4\pi d_0}{\lambda}\right)$$

$$\gamma = a - bh_b + c/h_b$$

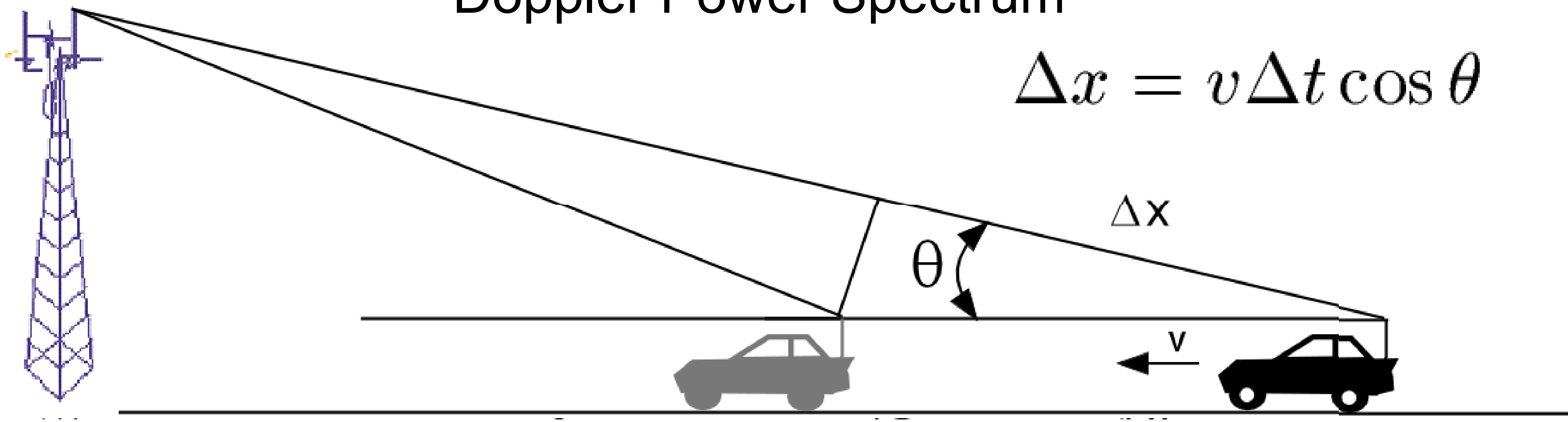
Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

TABLE I

NUMERICAL VALUES FOR THE SUI MODEL PARAMETERS

h_b Base station height above ground in meters and should be between 10 m and 80 m.

Doppler Power Spectrum



$$\Delta x = v \Delta t \cos\theta$$

$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x = \frac{2\pi}{\lambda} v \Delta t \cos\theta$$

$$\frac{\Delta\phi}{\Delta t} = \frac{2\pi}{\lambda} v \cos\theta$$

$$f = \frac{1}{2\pi}\frac{d\phi}{dt}$$

$$f_m = \frac{v}{\lambda}$$

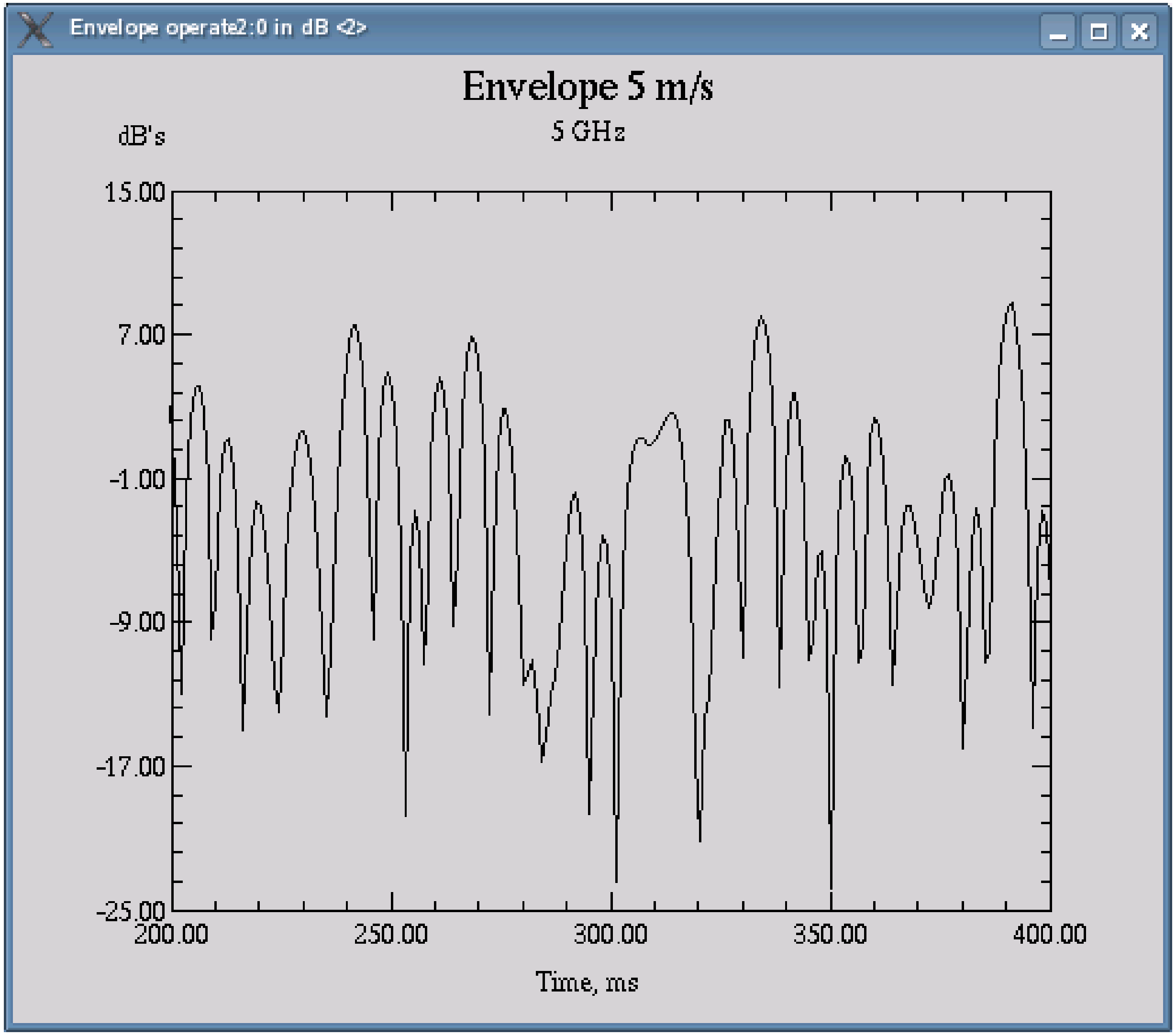
$$f_d = \frac{1}{2\pi}\frac{d\phi}{dt} = \frac{v}{\lambda}\cos\theta$$

$$f_d = \frac{v f_c}{c}\cos\theta$$

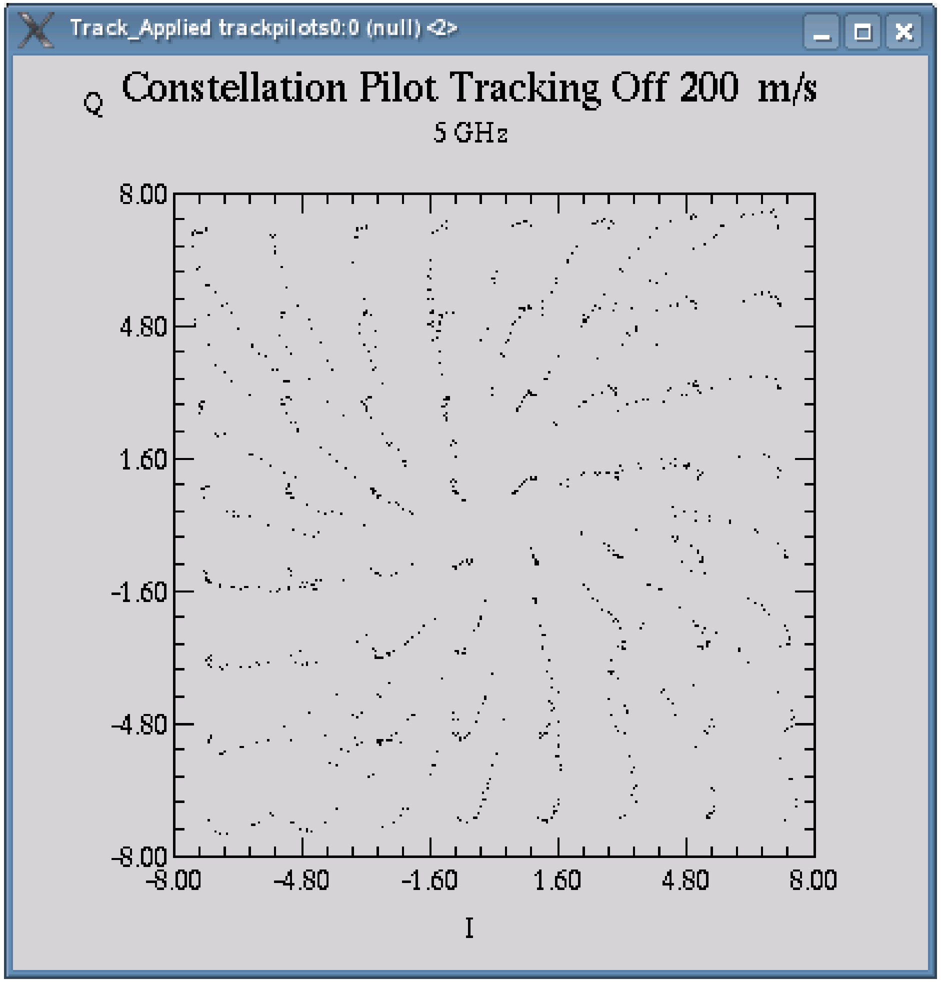
Fading Due to Vehicle Motion

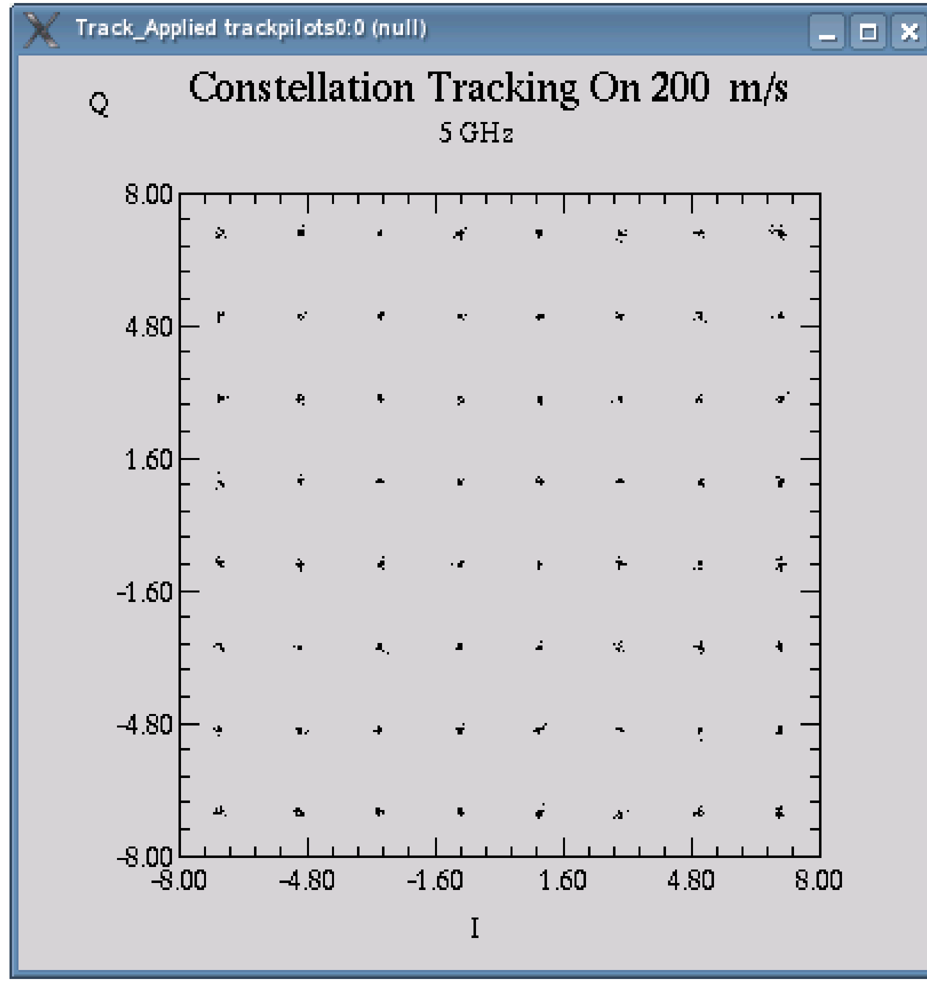
f_m=83.3 Hz

T_c=12 ms

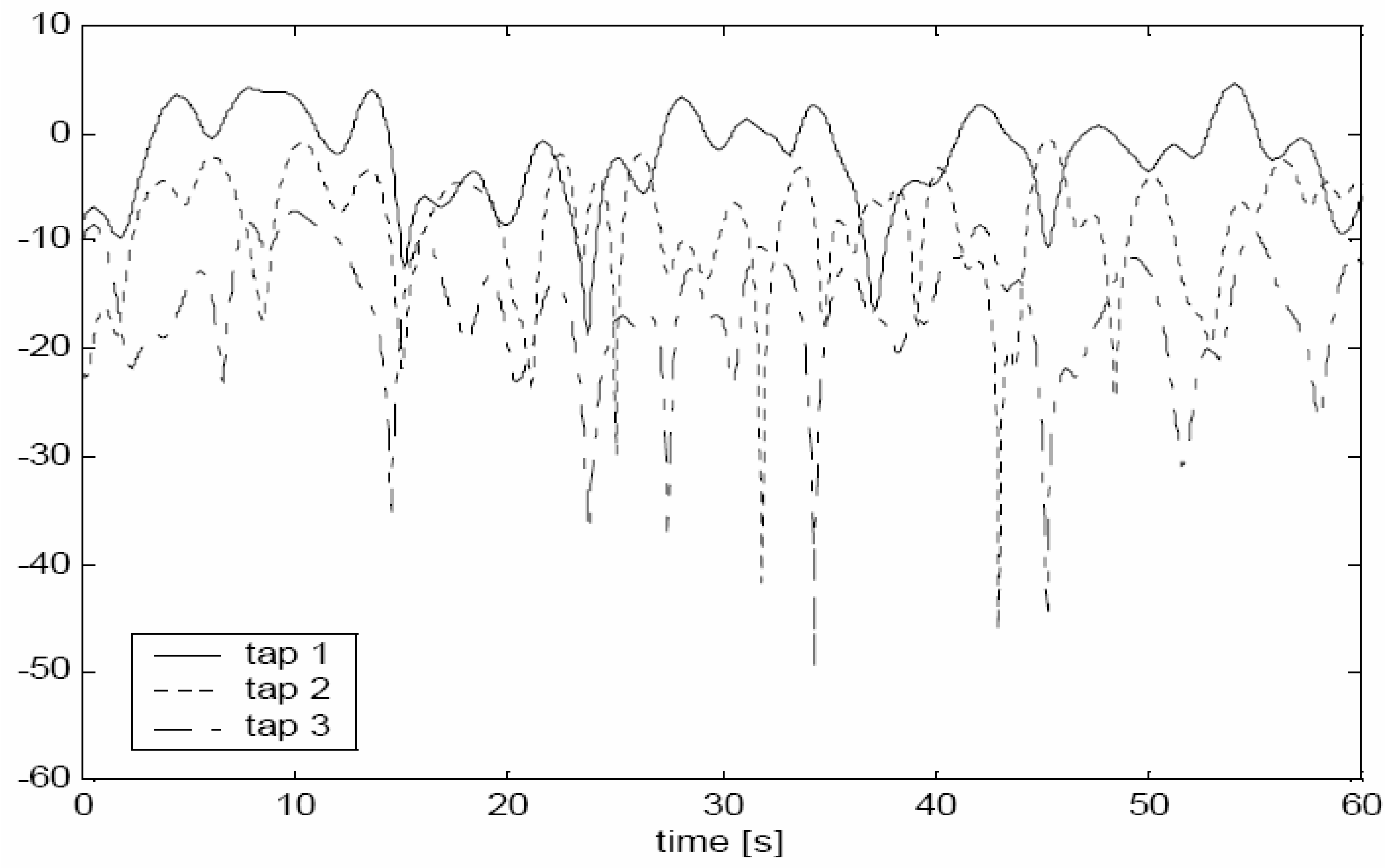


Pilot Tracking with Doppler Shift





Fixed Wireless Access Doppler Fading



SNR

$$NoisePower = 10\log_{10} 3010 - 228.6 + 10\log_{10} 20^6$$

-120.8 dBW

-90.8 dBm

Required Sensitivity -65 dBm at 54 Mbps

$$SNR = S_{dBm} - N_{dBm} = 25.8\ dB$$

Account for Bandwidth of 16.5 MHz
takes 0.835 dB off

$$SNR = 24.96 \text{ dB}$$