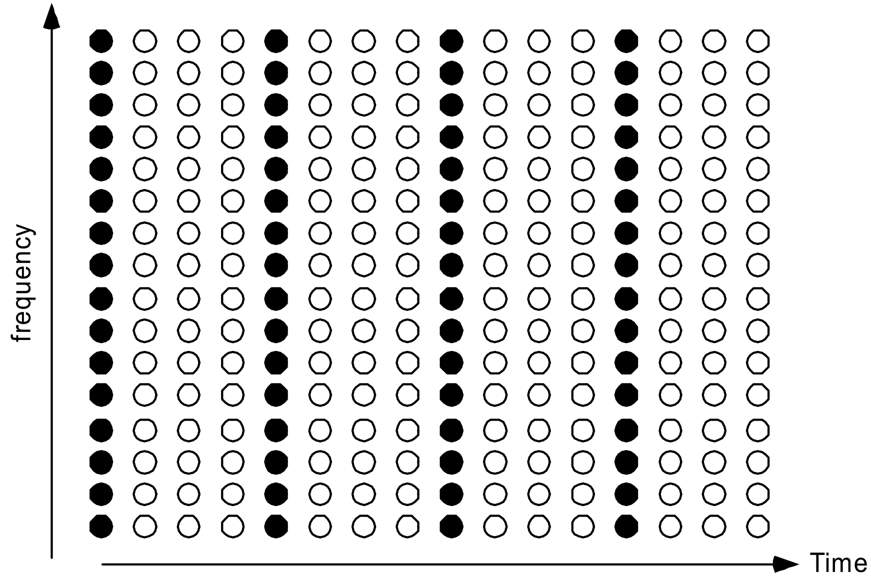
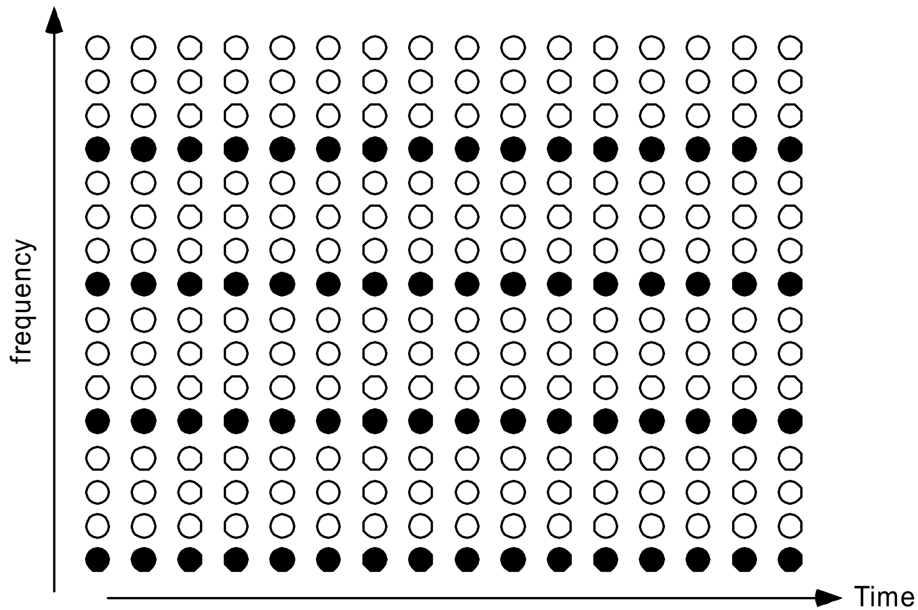
Pilot Tracking

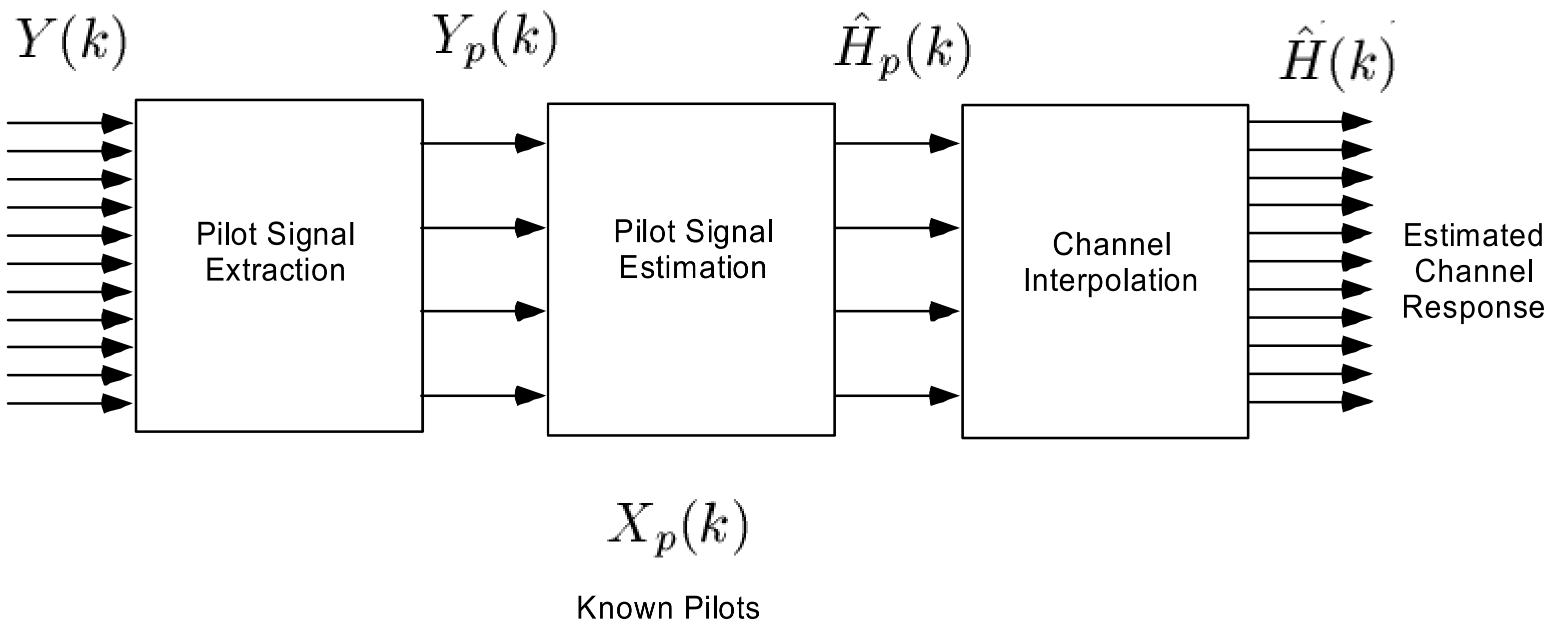
Silicon DSP Corporation



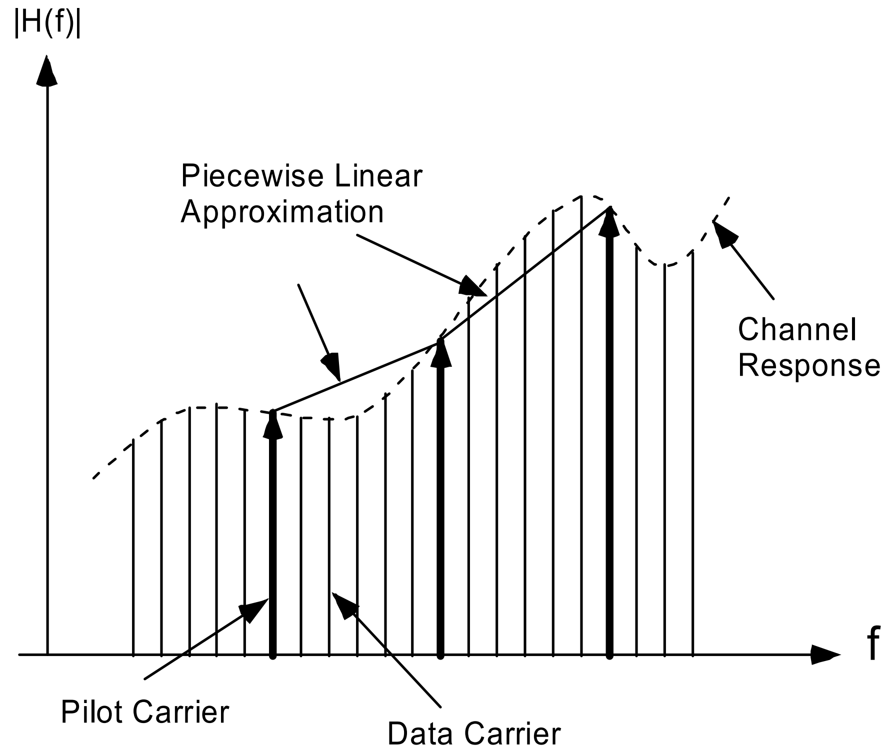
Block-type pilot sub-carrier arrangement



Comb-type pilot sub-carrier arrangement



Meng-Han Hsieh; Che-Ho Wei, **Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels**, *IEEE Transactions on Consumer Electronics* Volume 44, Issue 1, Date: Feb 1998, Pages: 217 - 225



Rinne, J.; Renfors, M.,"Pilot spacing in orthogonal frequency division multiplexing systems on practical channels,"*IEEE Transactions on Consumer Electronics* ,Volume 42, Issue 4, Date: Nov 1996, Pages: 959 - 962

L: Maximum length of channel in samples

$$Y_{k,m} = H_{k,m}X_{k,m} + V_{k,m} \quad k = 0, 1, \cdots, N-1$$

$$R_{k,m} = H_{k,m} + \frac{S_{k,m}}{|X_{k,m}|} \quad k = 0, 1, \cdots, N-1$$

$$S_{k,m} = \frac{V_{k,m}}{e^{\angle X_{k,m}}} \quad k = 0, 1, \cdots, N-1$$

$$\mathbf{h_m} = (h_{0,m}, \cdots, h_{L-1,m})^T$$

Set of L pilot tones.
$k_l, k_2, \cdots, k_L$

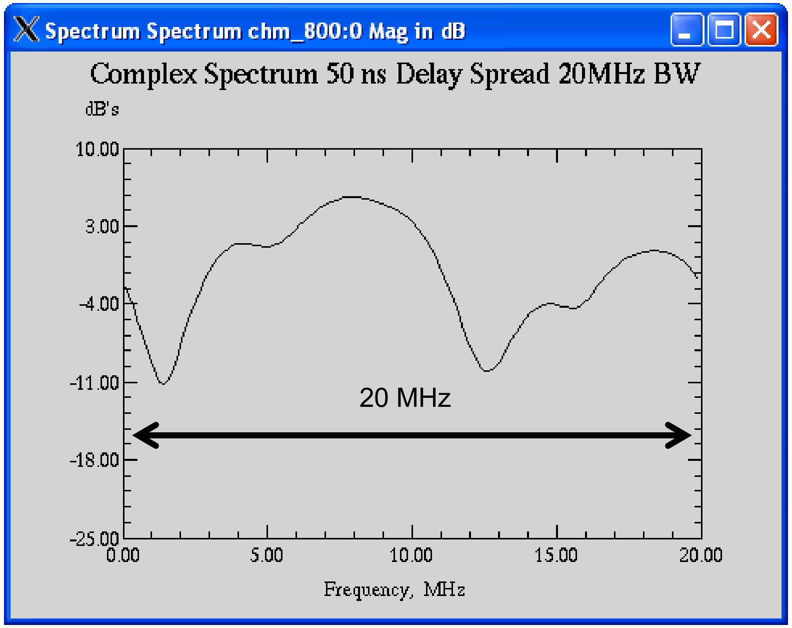
$$\mathbf{H}^{(pt)} = (H_{k_1}, \cdots, H_{k_L})^T$$

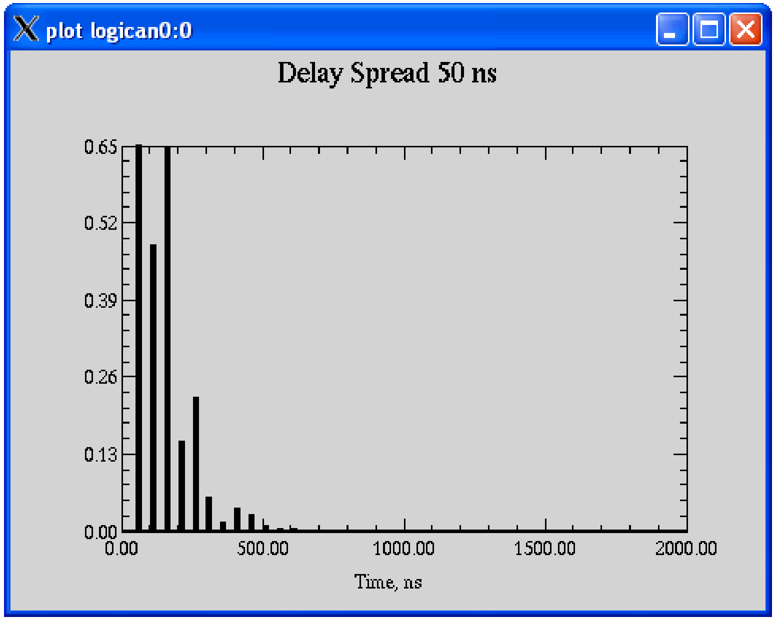
Lemma 1: In the absence of noise, any L of the N available tones can be used for training to recover the channel h exactly.

$$\mathbf{H}^{(pt)} = \frac{1}{\sqrt{N}} \begin{bmatrix} 1 & W_N^{k_1} & \ldots & W_N^{k_1(L-1)} \\ 1 & W_N^{k_2} & \ldots & W_N^{k_2(L-1)} \\ \ldots & \ldots & \ldots & \ldots \\ 1 & W_N^{k_L} & \ldots & W_N^{k_L(L-1)} \end{bmatrix} \mathbf{h}$$

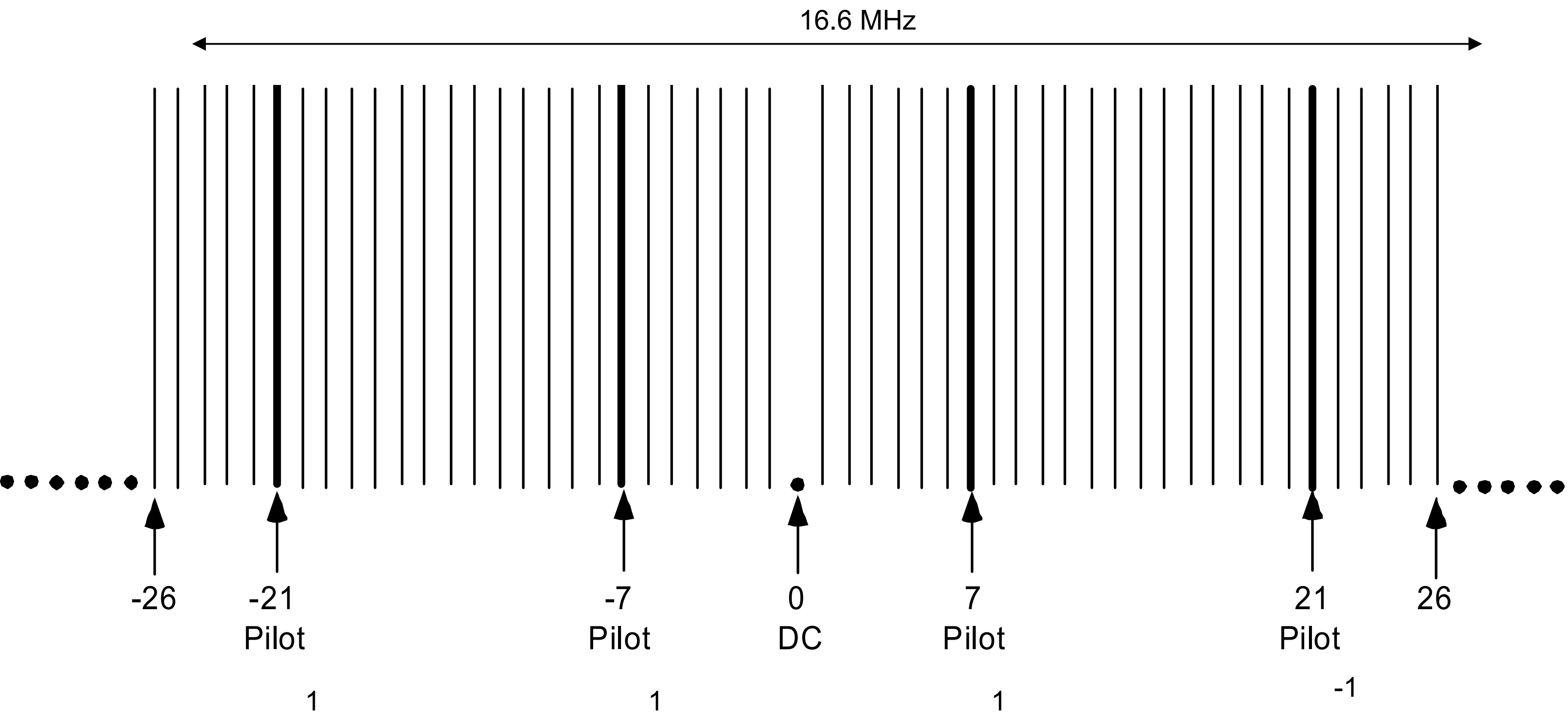
Theorem 1: When the noise is AWGN, then the MMSE estimate of $\mathbf{h}$ occurs when the set of L pilot tones is one of the sets $(i, i+\frac{N}{L}, \cdots, i+\frac{(L-1)N}{L}),\quad i = 0, 1, ..., \frac{N}{L}-1$.

Negi, R.; Cioffi, J.,"Pilot tone selection for channel estimation in a mobile OFDM system",
IEEE Transactions on Consumer Electronics, Volume 44, Issue 3, Date: Aug 1998, Pages: 1122 - 1128


Spectrum Spectrum chm_800:0 Mag in dB
Complex Spectrum 50 ns Delay Spread 20MHz BW
dB's
10.00
3.00
-4.00
-11.00
-18.00
-25.00
20 MHz
0.00
5.00
10.00
15.00
20.00
Frequency, MHz

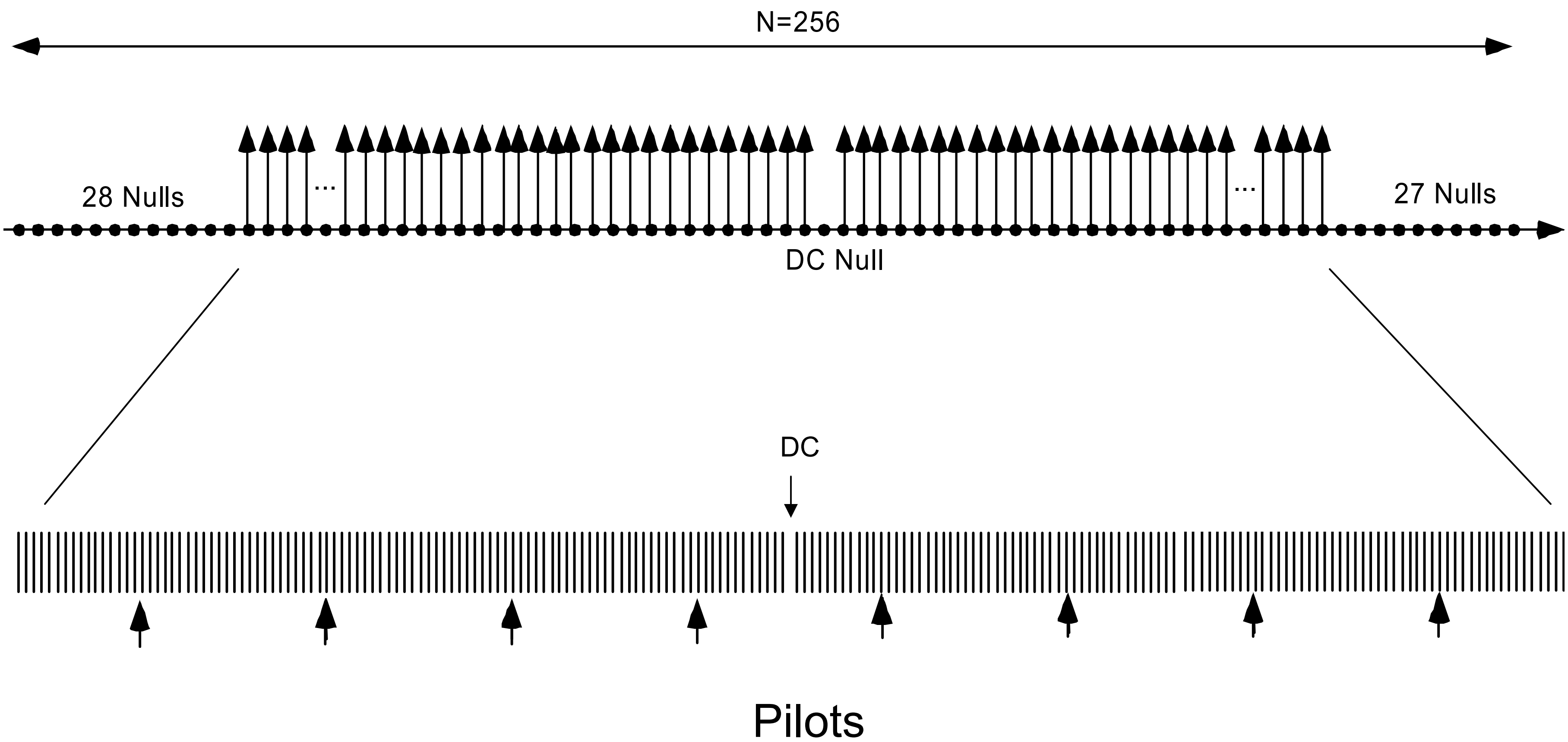

plot logican0:0
Delay Spread 50 ns
0.65
0.52
0.39
0.26
0.13
0.00
0.00
500.00
1000.00
1500.00
2000.00
Time, ns

Pilots IEEE 802.11a

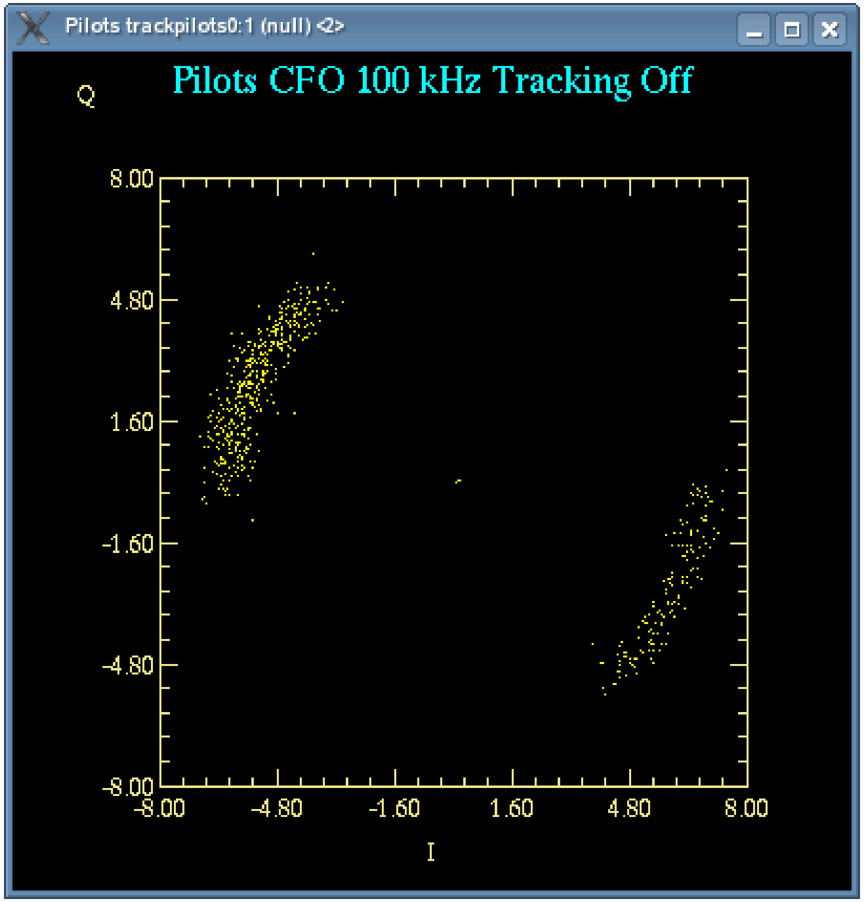


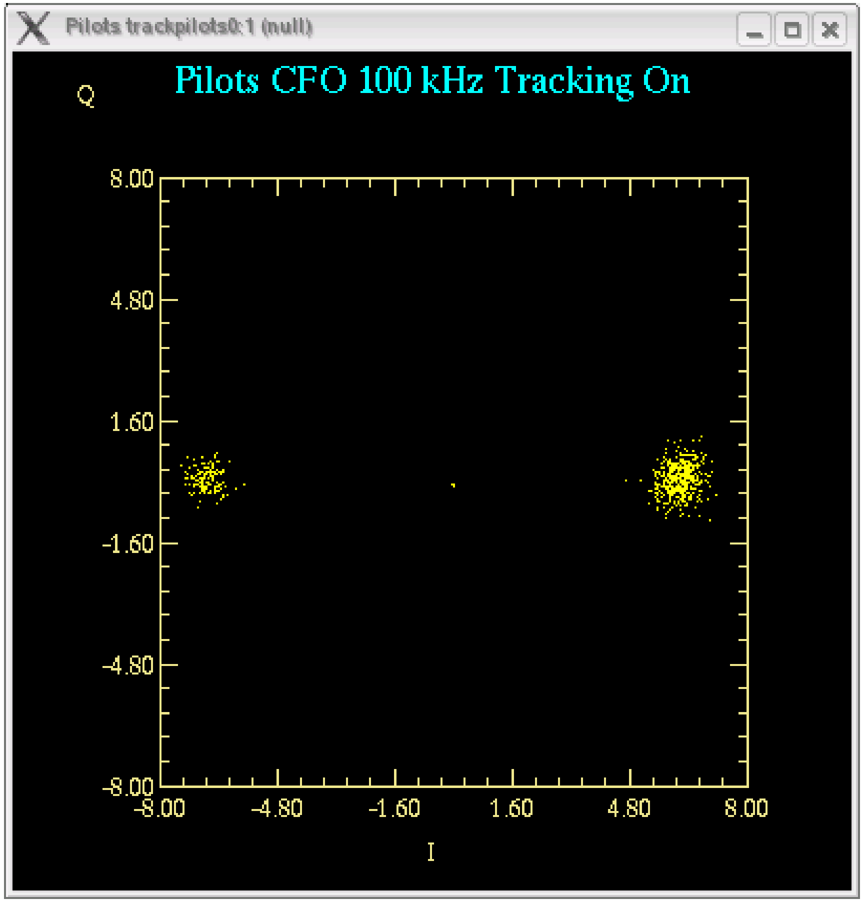
Δf=312.5 kHz

OFDM Carrier Description IEEE 802.16a



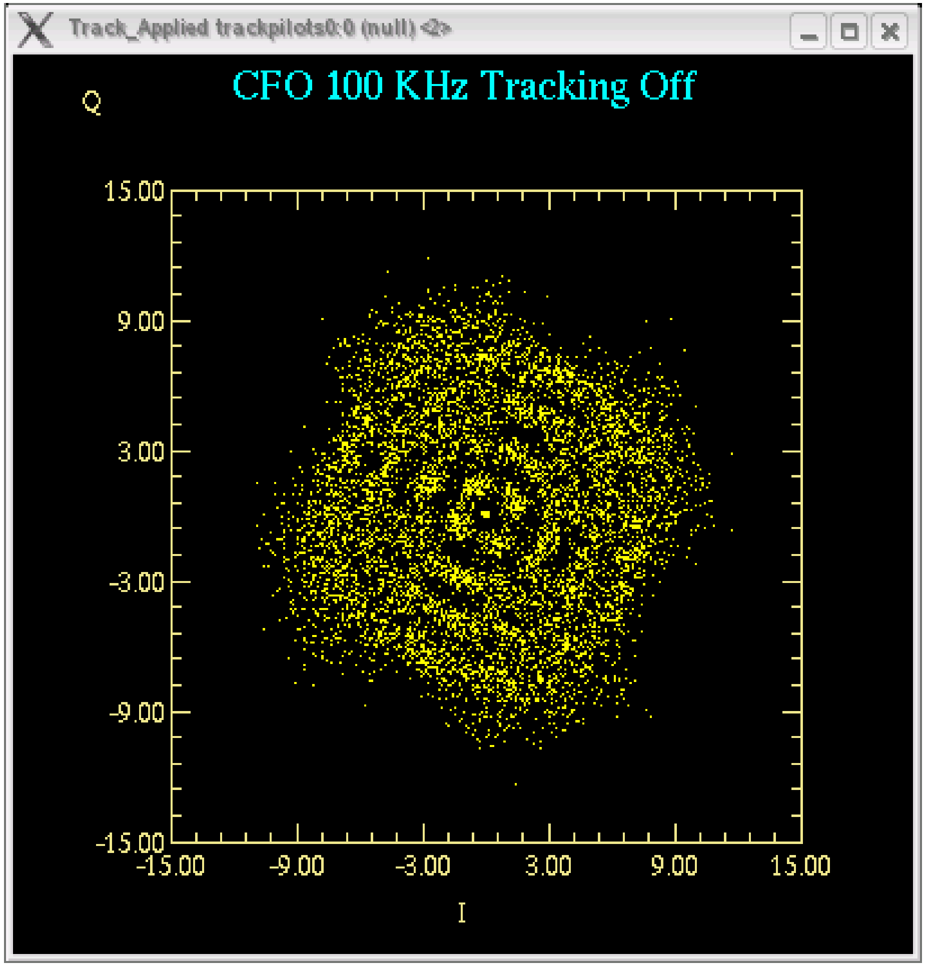
Residual CFO Correction with Pilot Tracking

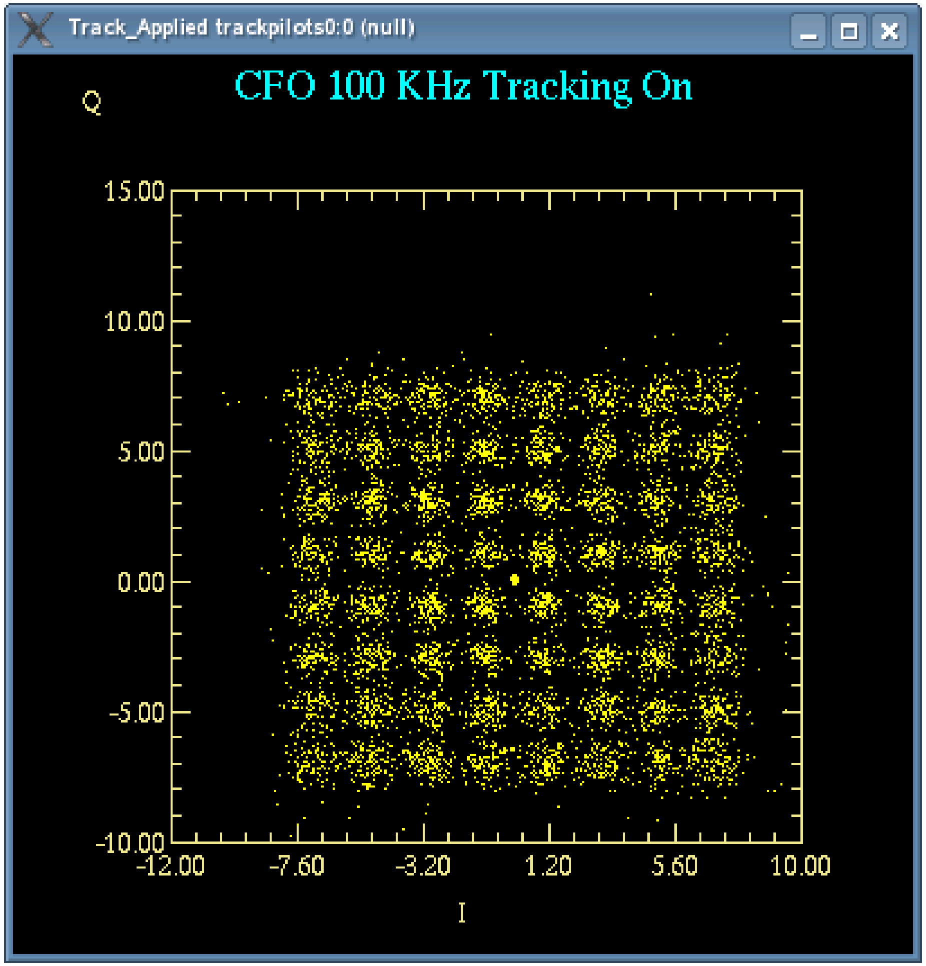




4000 Bytes   SNR=24 dB

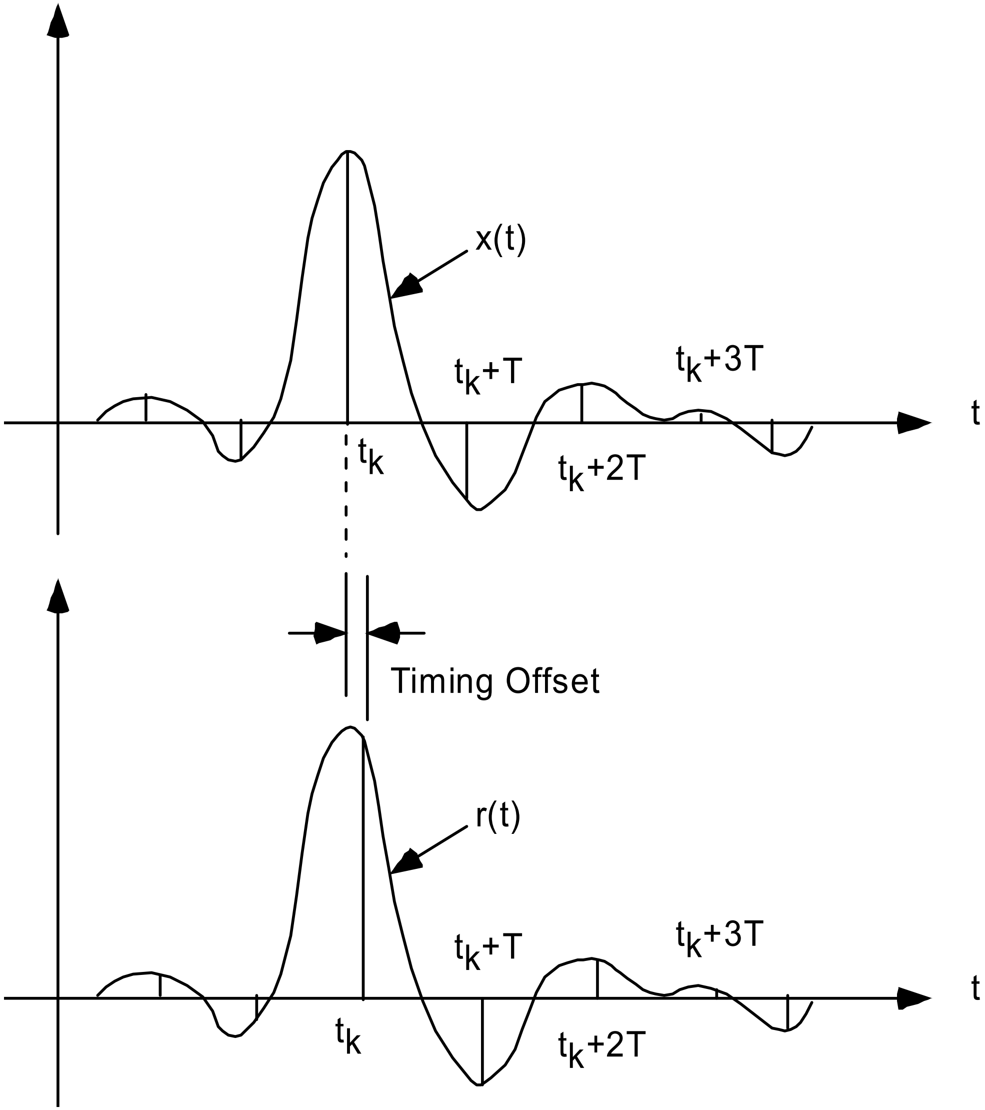
Residual CFO Correction with Pilot Tracking





4000 Bytes SNR=24 dB

Timing Offset

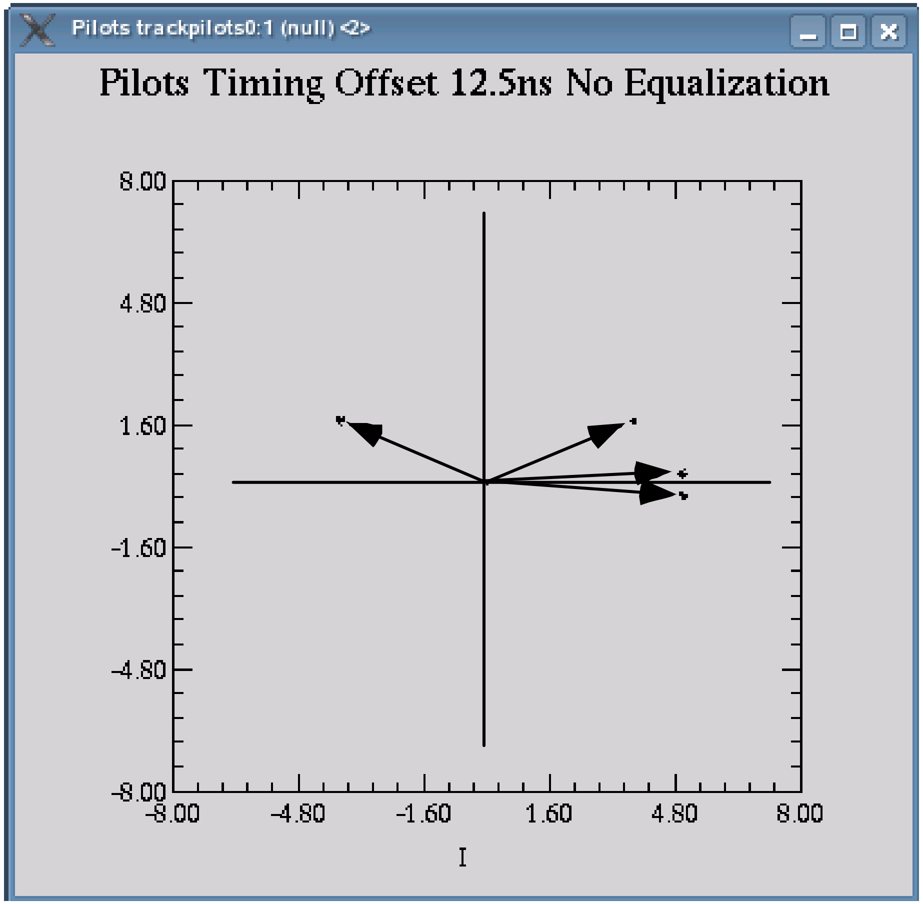


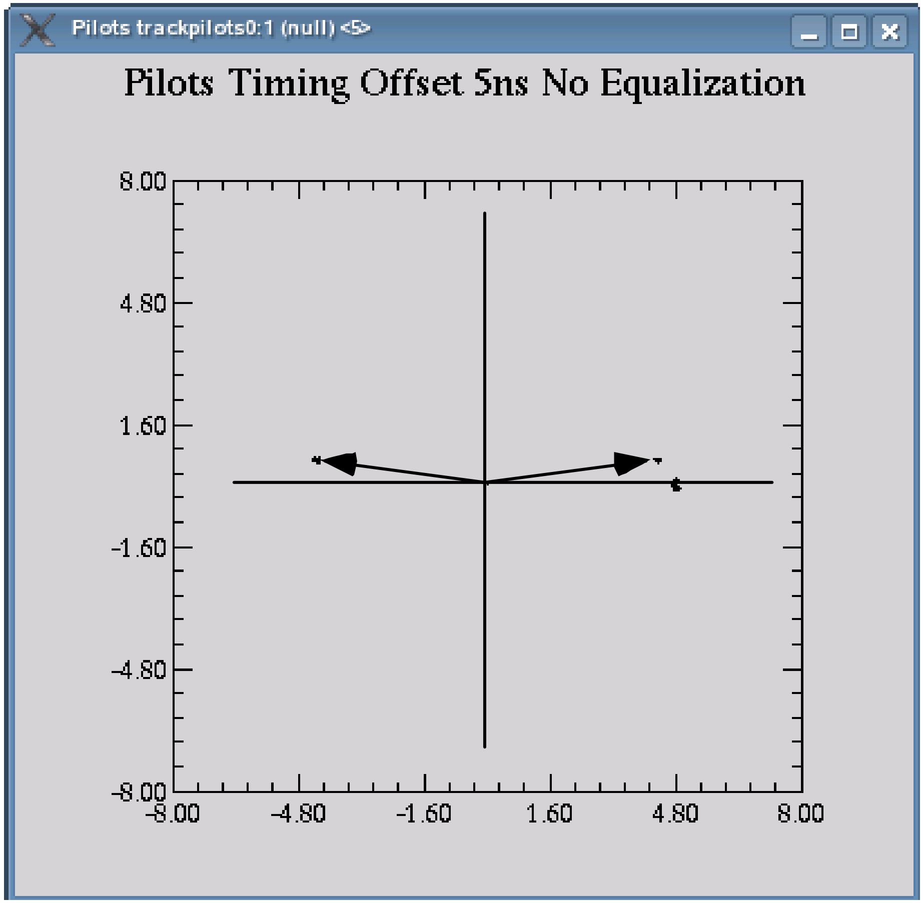
$$x(t - t_d) \longleftrightarrow X(f)e^{j2\pi f t_d}$$

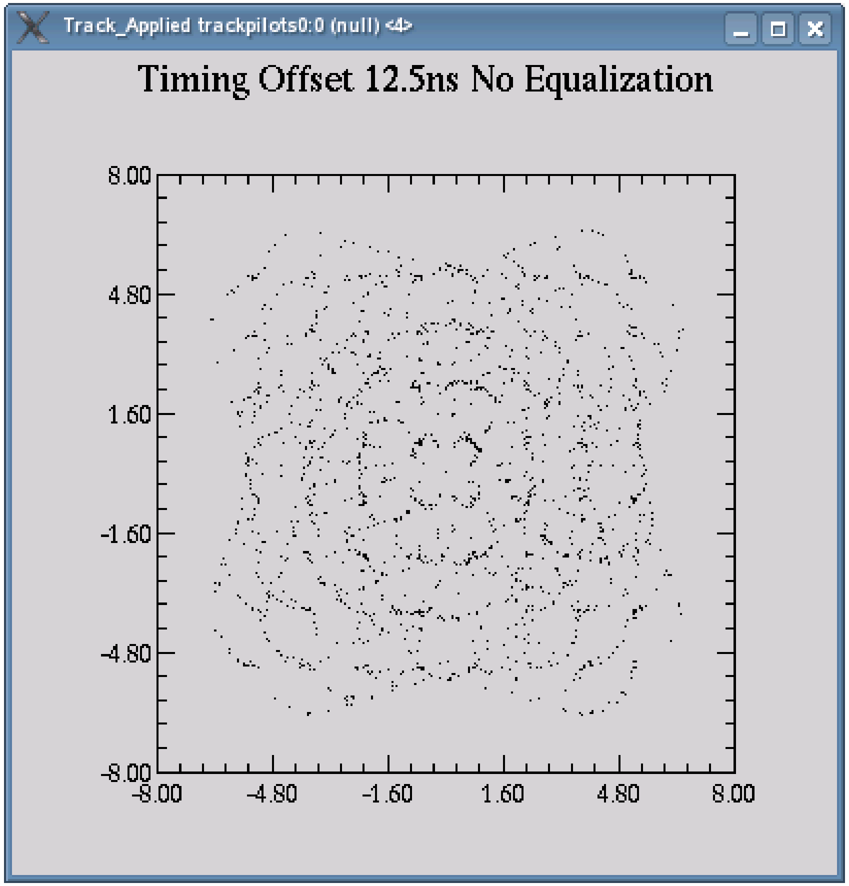
$$x(t - t_d) \longleftrightarrow X(f)e^{j2\pi f t_d}$$

12.5ns

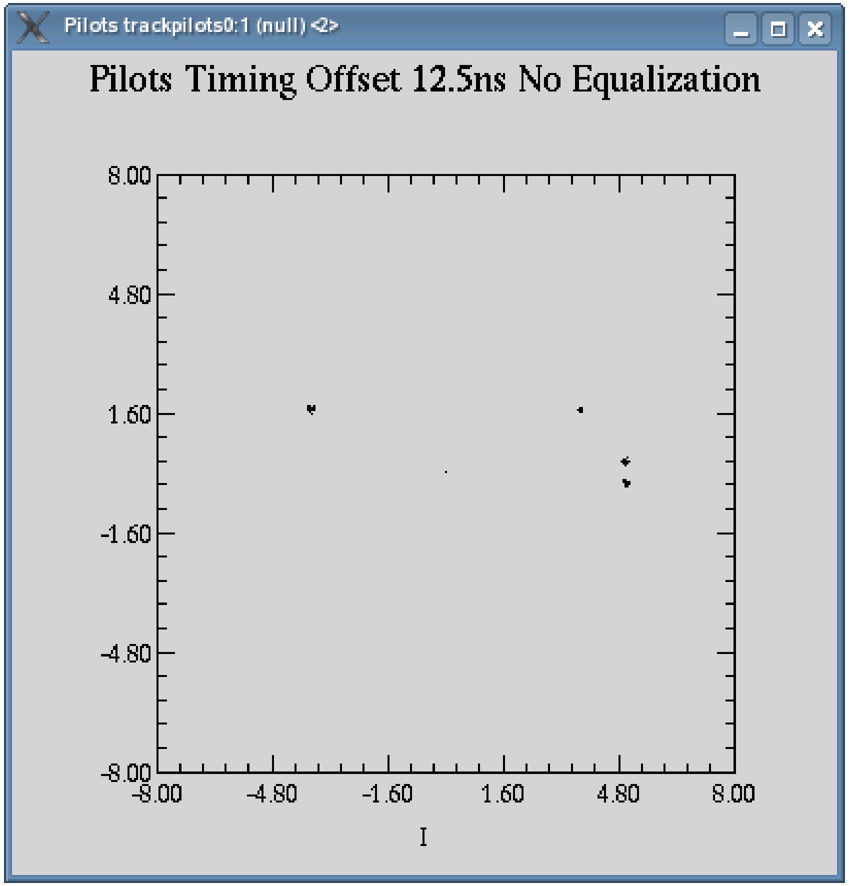
5ns



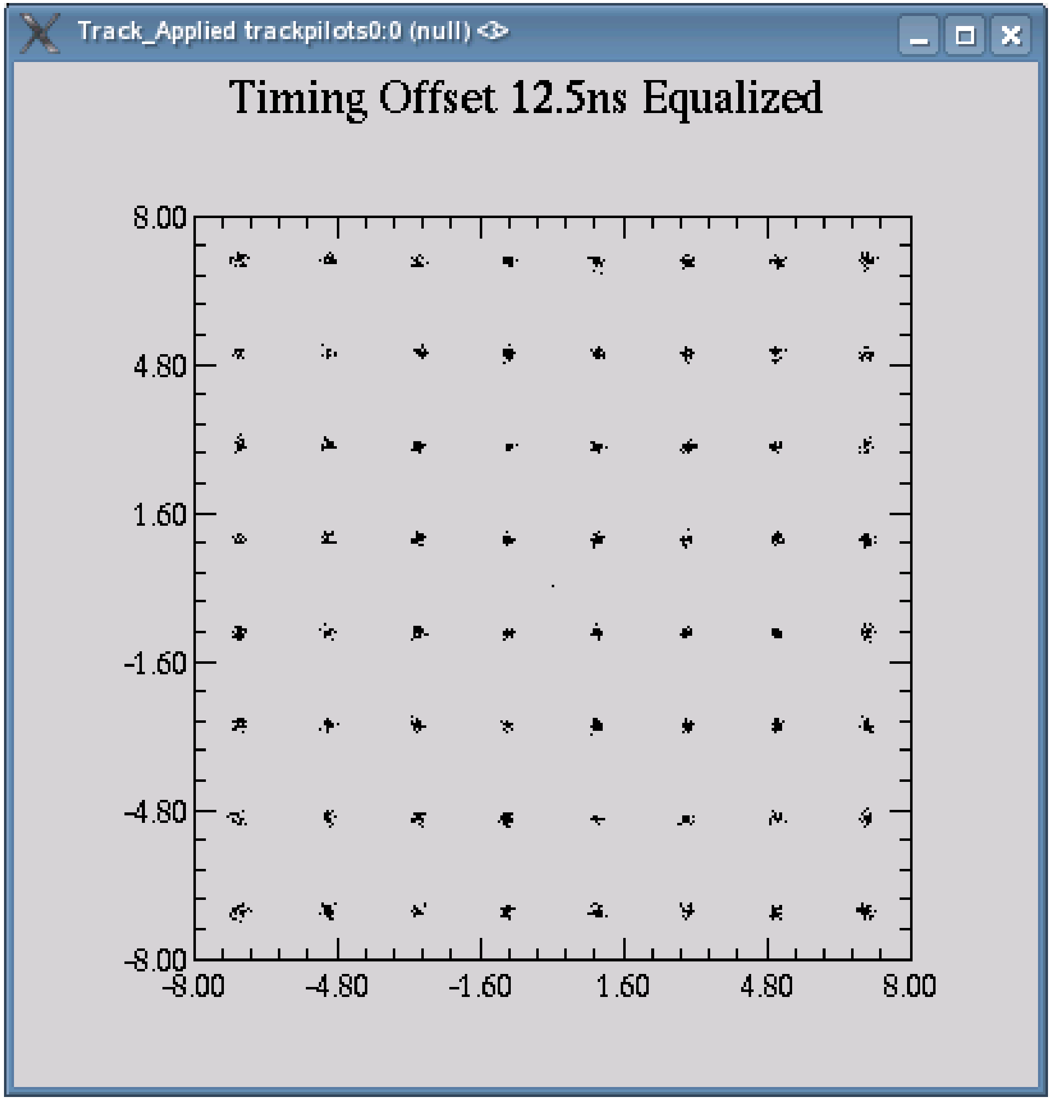




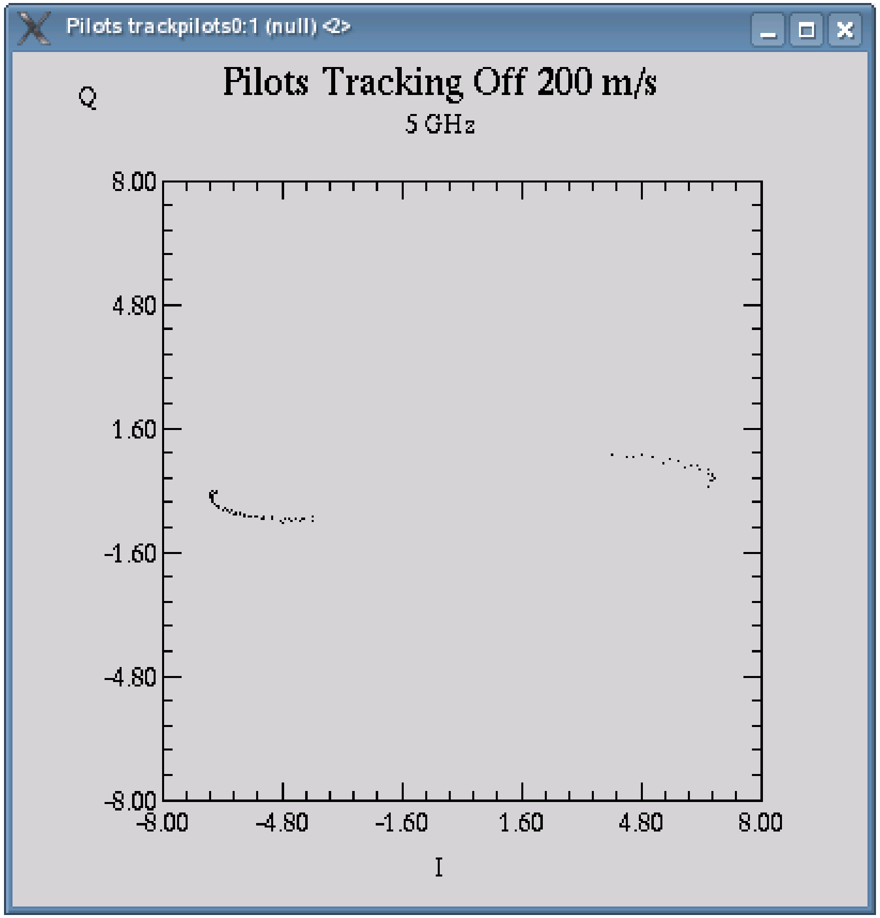
Track_Applied trackpilots0:0 (null) <4>
Timing Offset 12.5ns No Equalization
8.00
4.80
1.60
-1.60
-4.80
-8.00
-8.00
-4.80
-1.60
1.60
4.80
8.00

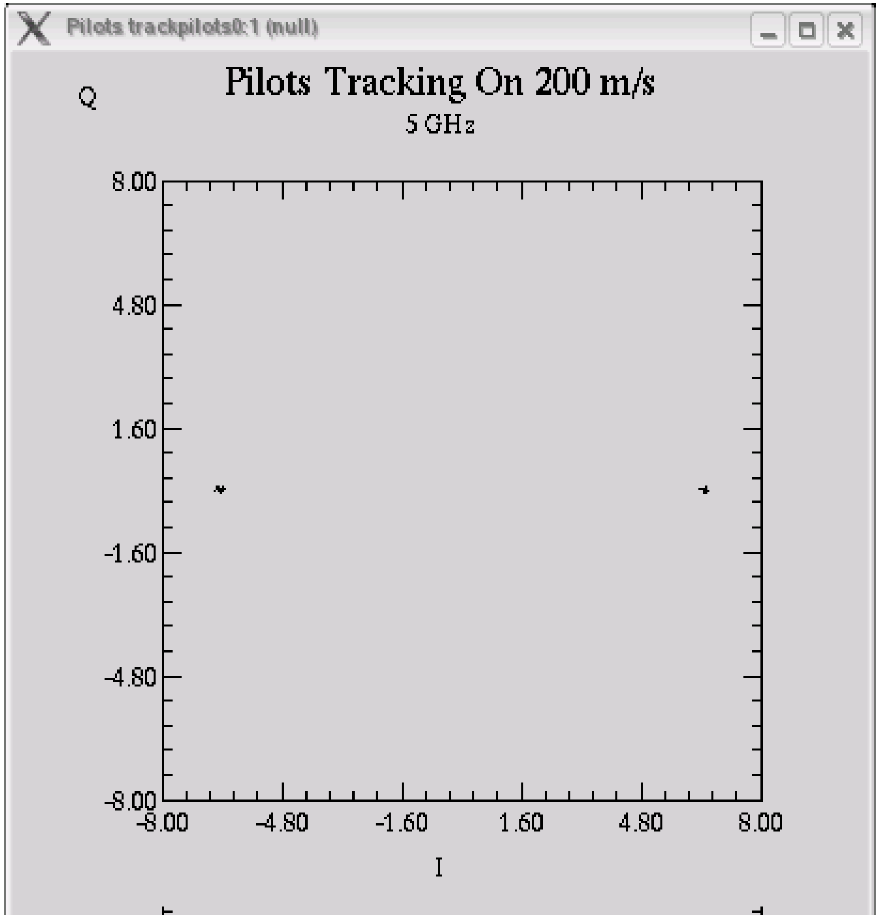


Pilots trackpilots0:1 (null) <2>
Pilots Timing Offset 12.5ns No Equalization
8.00
4.80
1.60
-1.60
-4.80
-8.00
-8.00
-4.80
-1.60
1.60
4.80
8.00
I

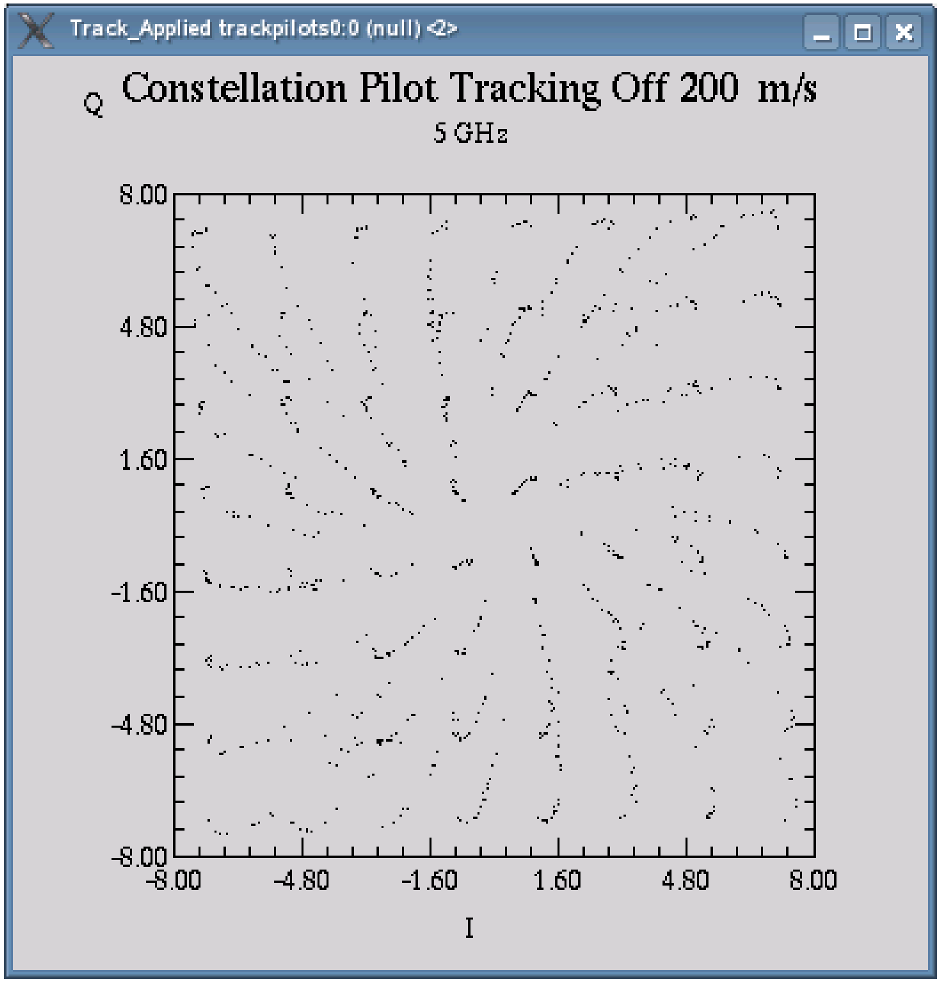

Track_Applied trackpilots0:0 (null) <3>
Timing Offset 12.5ns Equalized
8.00
4.80
1.60
-1.60
-4.80
-8.00
-8.00
-4.80
-1.60
1.60
4.80
8.00

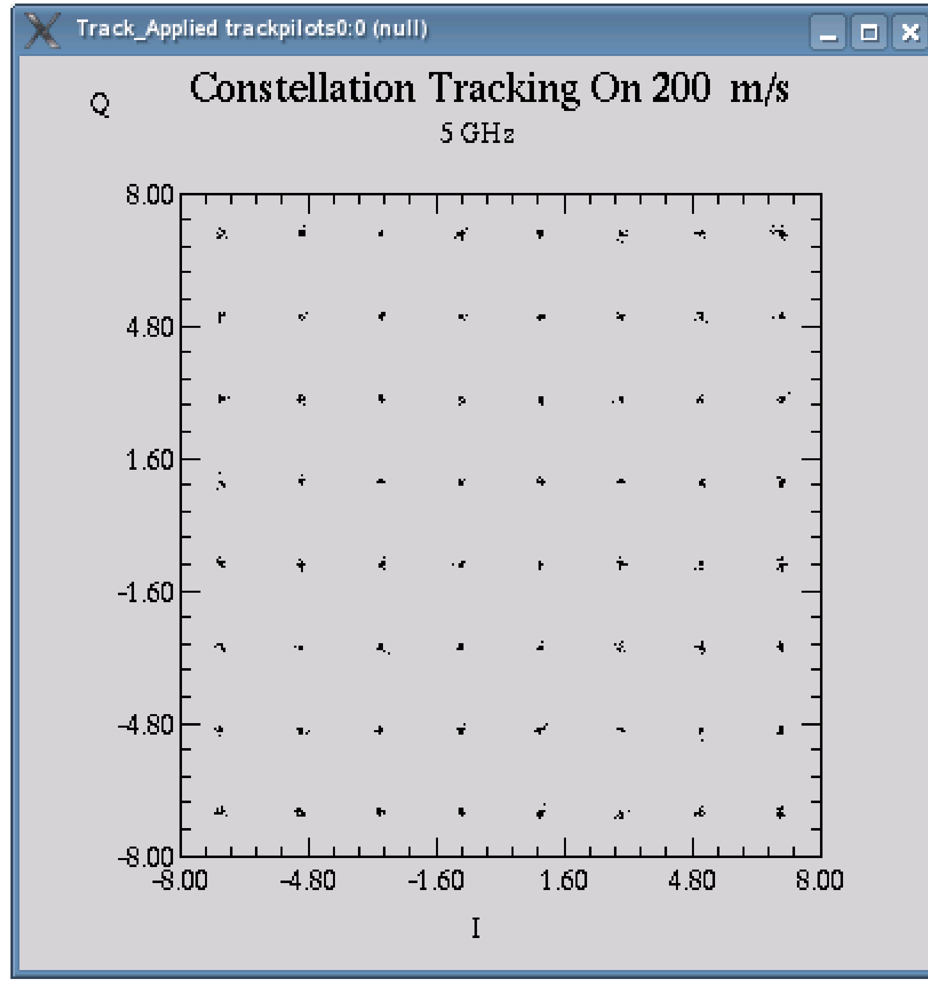
Doppler Shift and Pilot Tracking





Doppler Shift and Pilot Tracking





Fast Fading Channel OFDM

$\widehat{\mathbf{Hr}}_n$ the channel estimate for the n^{th} OFDM symbol

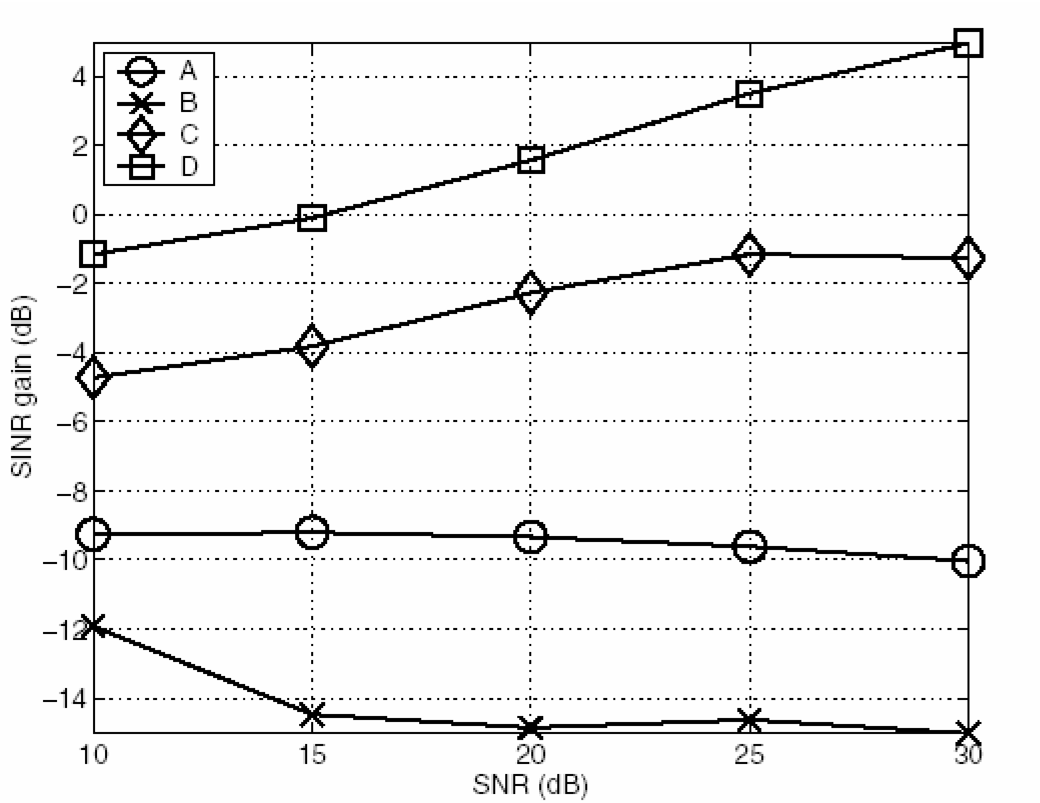
α forgetting factor

$$\widehat{\mathbf{H}}_n = \alpha\widehat{\mathbf{H}}_{n-1} + (1-\alpha)\widehat{\mathbf{Hr}}_n$$

$\widehat{\mathbf{H}}_n$ Matrix constructed from sampled time-varying channel impulse response

Stamoulis, A.; Diggavi, S.N.; Al-Dhahir, N.,"Estimation of fast fading channels in OFDM," *Wireless Communications and Networking Conference*, 2002. WCNC2002. 2002 IEEE
Volume 1, Date: 17-21 Mar 2002, Pages: 465 - 470 vol.1

Pilot Placement

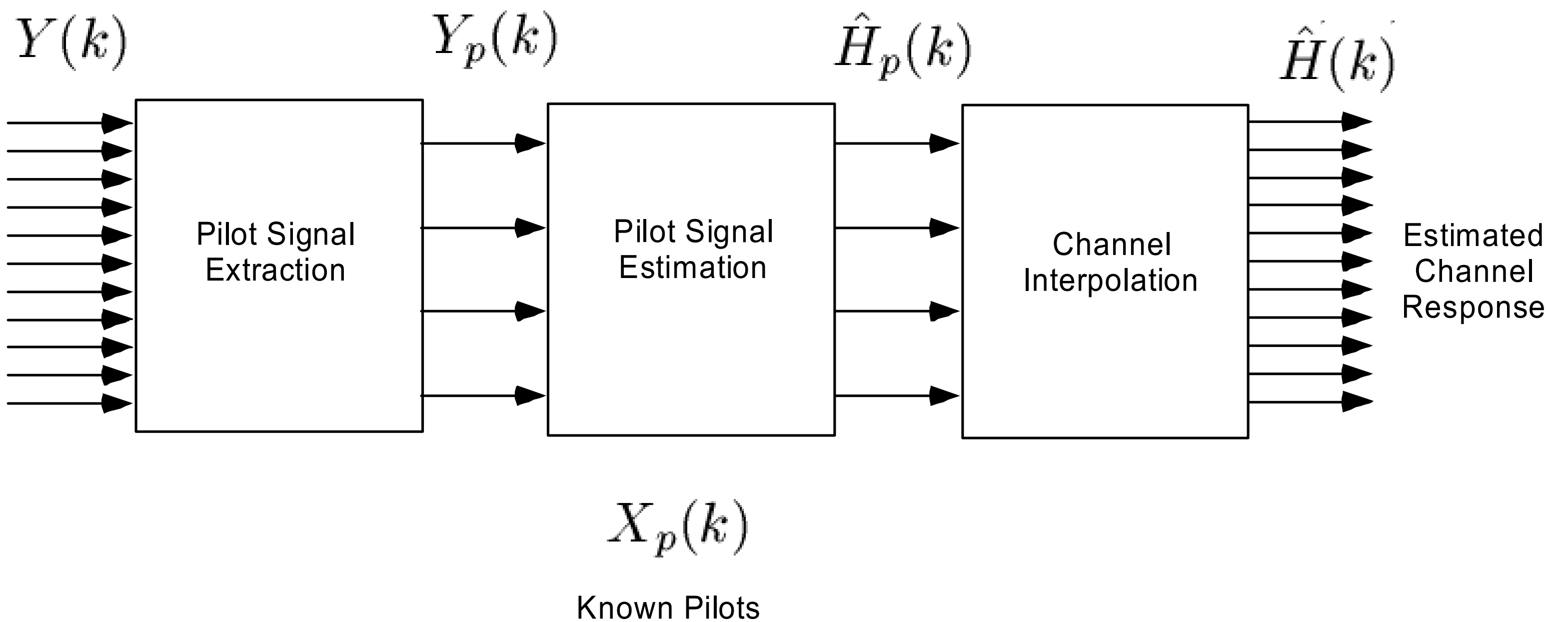


A Equispaced

1,5,9,13,17,21,25,29,33,37,41,45,49,53,57,61 A

6,7,8,9,22,23,24,25,38,39,40,41,54,55,56,57 D

Stamoulis, A.; Diggavi, S.N.; Al-Dhahir, N.,"Estimation of fast fading channels in OFDM," *Wireless Communications and Networking Conference*, 2002. WCNC2002. 2002 IEEE
Volume 1, Date: 17-21 Mar 2002, Pages: 465 - 470 vol.1

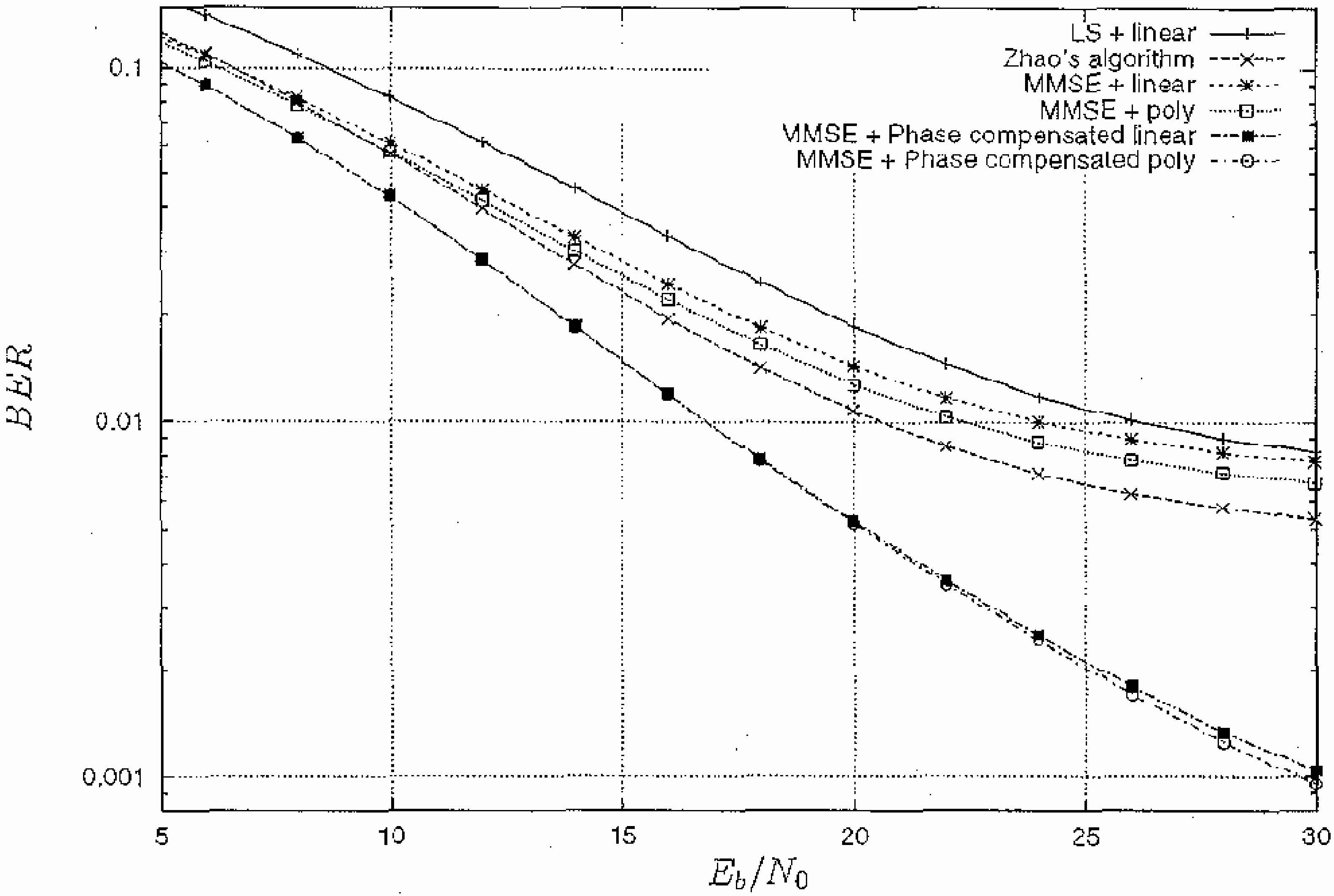


Meng-Han Hsieh; Che-Ho Wei, **Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels**, *IEEE Transactions on Consumer Electronics* Volume 44, Issue 1, Date: Feb 1998, Pages: 217 - 225

“In this method, the additive white Gaussian noise (AWGN) and the inter-carrier interference (ICI) in the pilot sub-carriers are reduced by low-pass filtering in a transform domain, and the channel transfer function for all the subcarriers is obtained by the high-resolution interpolation realized by zero padding and DFT/iDFT. Comparing to the conventional linear interpolation method, this method provides about 1 dB and 3 dB improvement in Eb/No for the same bit error rate values in slow- and fast-fading noisy radio channel, respectively.”

Meng-Han Hsieh; Che-Ho Wei, **Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels**, *IEEE Transactions on Consumer Electronics* Volume 44, Issue 1, Date: Feb 1998, Pages: 217 - 225

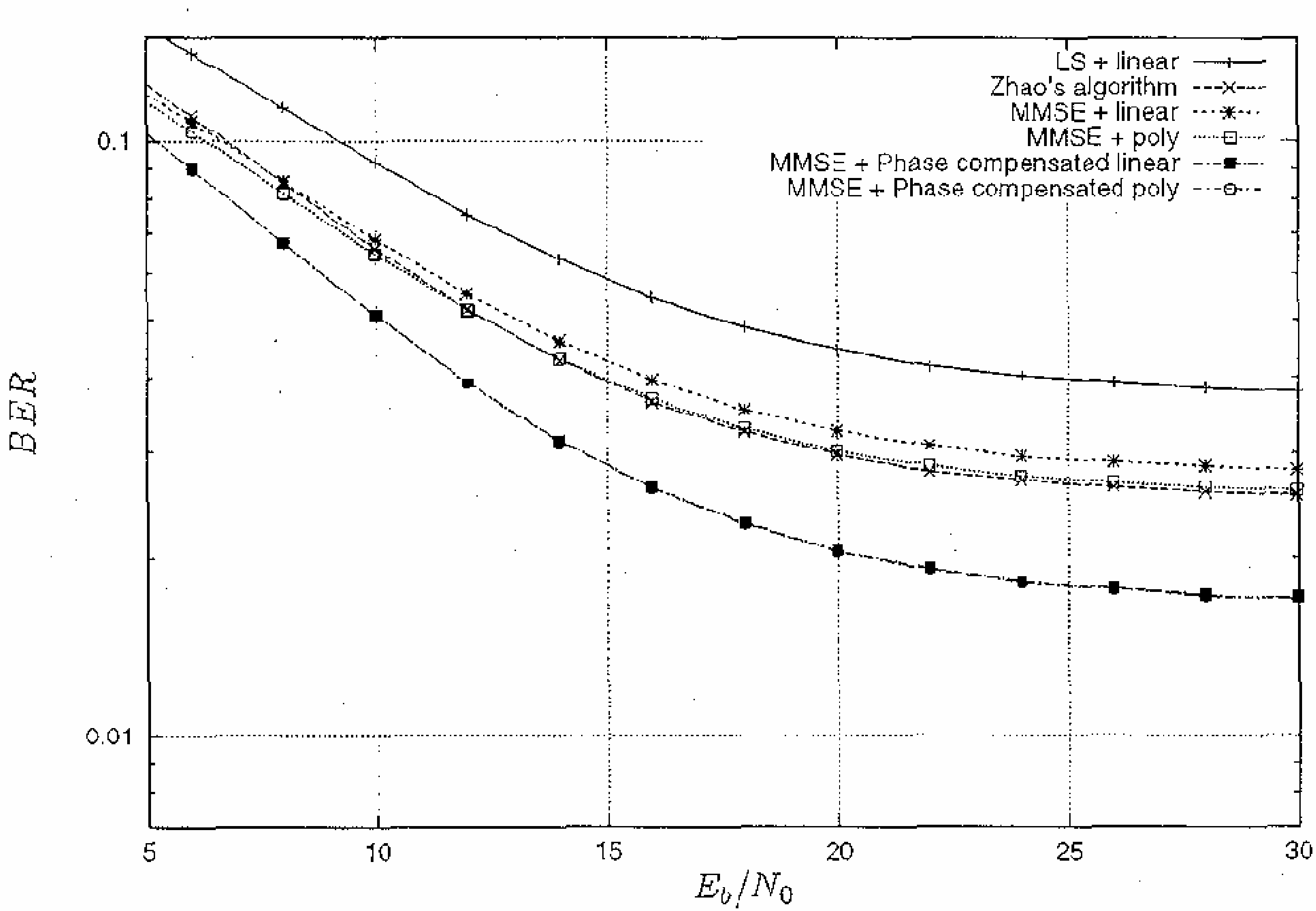
.Zhao and A. Huang, “**A novel channel estimation method for OFDM mobile communication systems based on pilot signals and transform- domain processing**,” in *Proc . IEEE 47th Vehicular Technology Conference*,
Phoenix, USA, May 1997, pp. 2089-2093.



BER slow Rayleigh fading channel (v= 6 km/hr)

$16\ QAM,\ \ N_{FFT} = 1024, N_p = 128, f_c = 1\ GHz, BW = 2\ MHz$

Meng-Han Hsieh; Che-Ho Wei, **Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels**, *IEEE Transactions on Consumer Electronics* Volume 44, Issue 1, Date: Feb 1998, Pages: 217 - 225



BER fast Rayleigh fading channel (v= 150 km/hr)

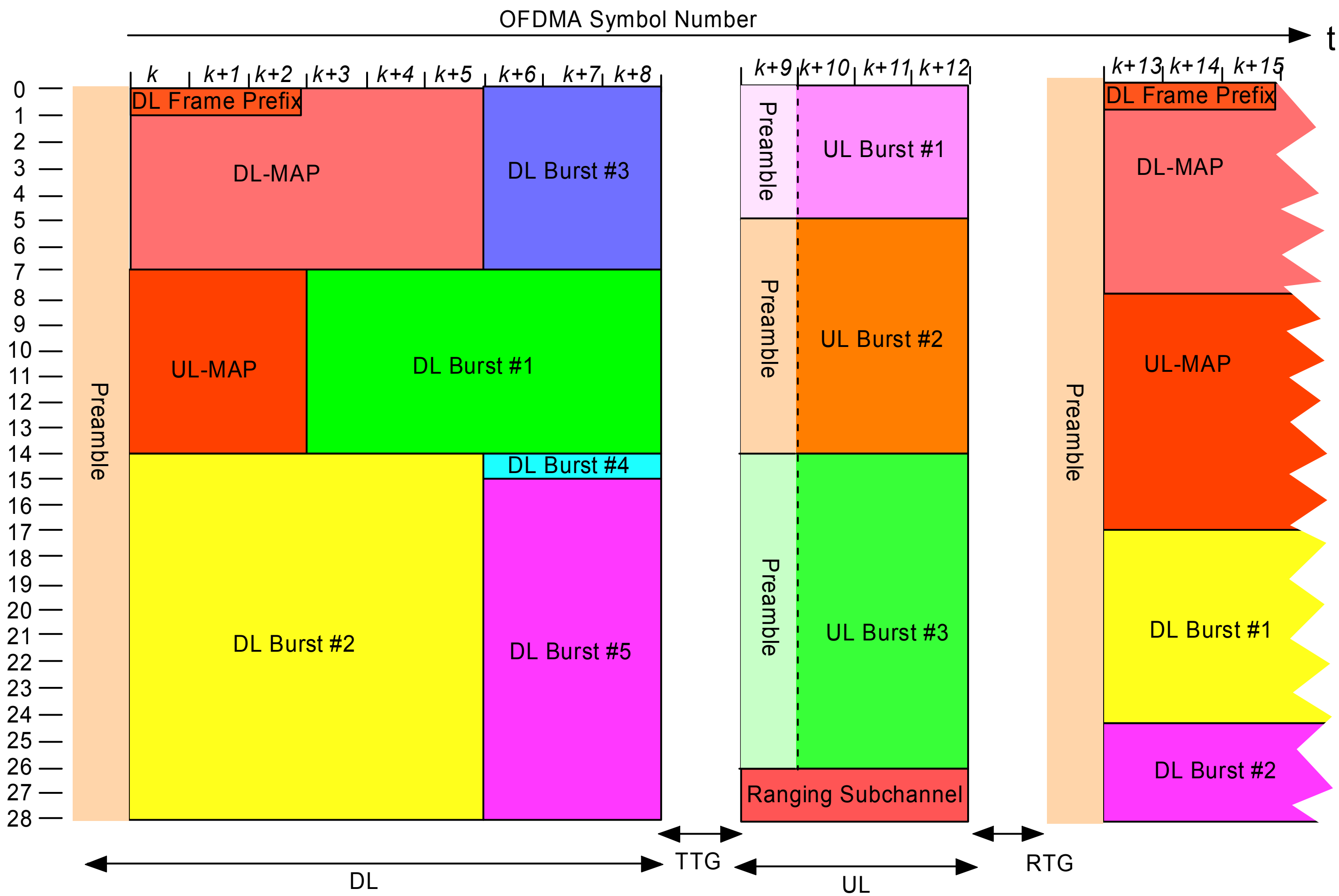
$$16\ QAM,\ \ N_{FFT} = 1024, N_p = 128, f_c = 1\ GHz, BW = 2\ MHz$$

Meng-Han Hsieh; Che-Ho Wei, **Channel estimation for OFDM systems based on comb-type pilot arrangement in frequency selective fading channels**, *IEEE Transactions on Consumer Electronics* Volume 44, Issue 1, Date: Feb 1998, Pages: 217 - 225

Pilot Allocation OFDMA IEEE 802.16a

IEEE 802.16a OFDMA

“For both uplink and downlink these used carriers are allocated to pilot carriers and data carriers. However, there is a subtle difference between uplink and downlink. This difference is that, in the downlink, the pilot tones are allocated first; what remains are subchannels that are used exclusively for data. In the uplink, however, the set of used carriers is first partitioned into subchannels, and then the pilot carriers are allocated from within each subchannel. **Thus, in the downlink, there is one set of common pilot carriers, but in the uplink, each subchannel contains its own set of pilot carriers.** This is necessary since, in OFDMA, the BS downlink is broadcast to all SS, but in the uplink, each subchannel may be transmitted from a different SS.”



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
Preamble
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
Preamble
DL Frame Prefix
DL-MAP
UL-MAP
DL Burst #1
DL Burst #2
TTG
RTG
DL
UL

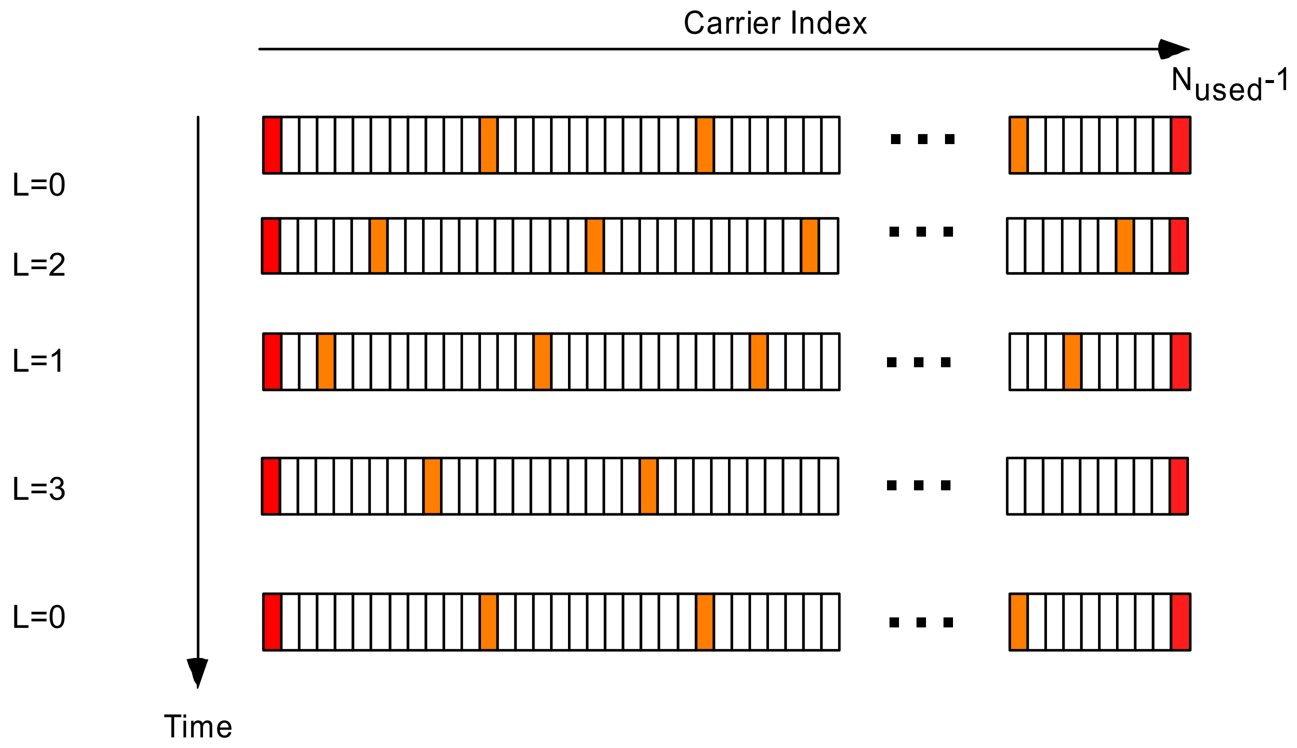
DL Pilots IEEE 802.16a OFDMA

Total number of carriers	2048
Number of variable Location Pilots	142
Number of fixed-location pilots	32
Number of variable -location pilots which coincide with fixed-location pilots	8
Total number of Pilots	166

N_{used}=1702

N_{data}=1536

DL Pilot Allocation IEEE802.16a OFDMA



UL Pilots IEEE802.16a OFDMA

N_{used}	1696
$N_{subchannels}$	32
$N_{subcarriers}$	53
Number of Data Carriers per Subchannel	48

Pilot Allocation UL IEEE802.16a