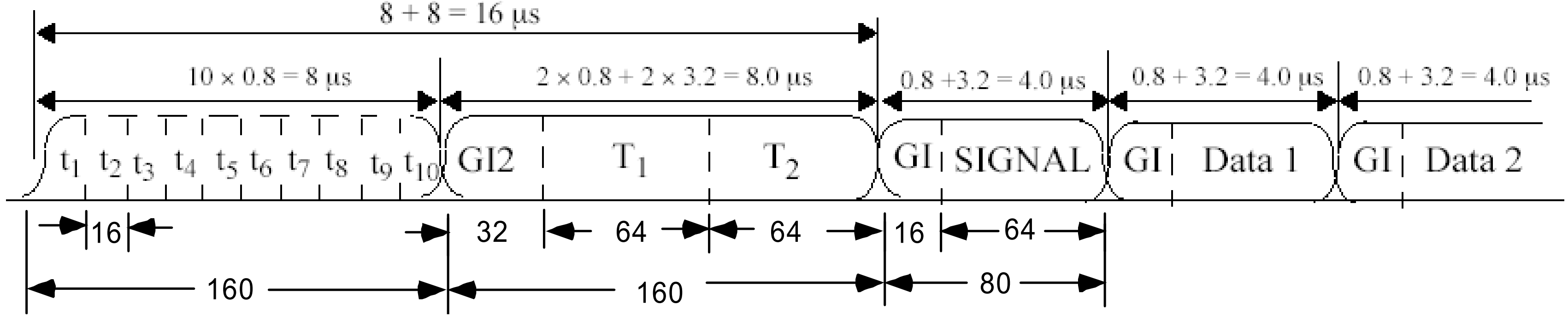
Packet Detection and Synchronization

Cross Correlation and Auto Correlation

Silicon DSP Corporation



8 + 8 = 16 μs
10 × 0.8 = 8 μs
2 × 0.8 + 2 × 3.2 = 8.0 μs
0.8 +3.2 = 4.0 μs
0.8 + 3.2 = 4.0 μs
0.8 + 3.2 = 4.0 μs
t1 t2 t3 t4 t5 t6 t7 t8 t9 t10
GI2
T1
T2
GI
SIGNAL
GI
Data 1
GI
Data 2
16
32
64
64
16
64
160
160
80

Cross Correlation Analysis

- XC SUM

$\hat{n}_{xcsum} = argmax_n(\sum_{p=0}^{L} |R(n+p)|)$ [5]

- XC MAX

$\hat{n}_{xcmax} = argmax_n(|R(n)|)$ [6]

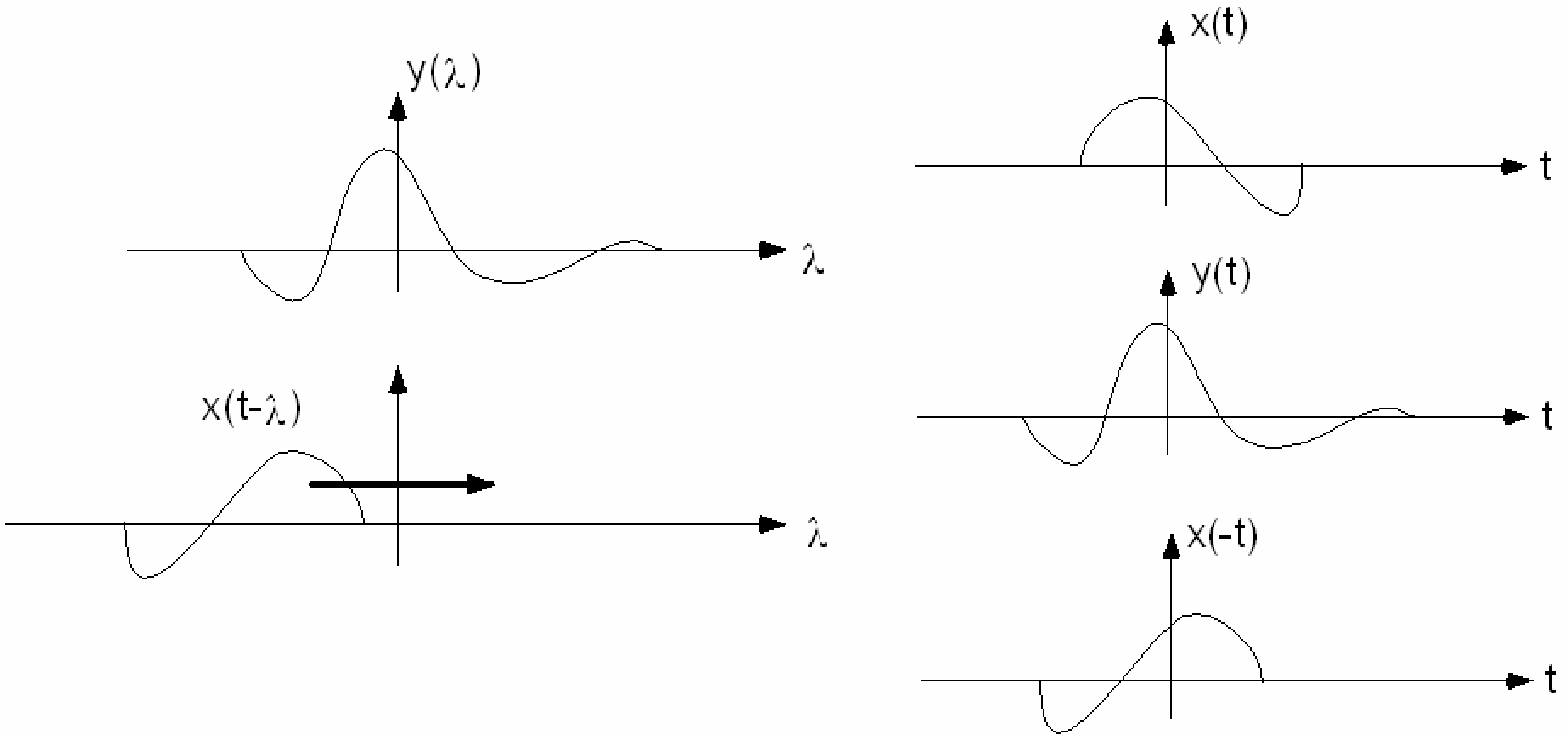
- XC PROPOSED

$\hat{n}_{xcp} = argmin_n(n) \mid |R(n)| \geq th \times |R(\hat{n}_{xcmax})|$

The XC Sum algorithm sums consecutive correlator outputs to locate a window of length L where the channel has the most energy. L is ideally the channel length. The XC Max algorithm selects the peak with the largest magnitude. Our proposal selects the earliest peak with a magnitude greater than some percentage of the largest peak. This improvement tends to select the first multipath component rather than later reflections thus reducing the variance of the timing estimate. The threshold must be chosen large enough to avoid selecting small noise peaks, but small enough to avoid selecting late multipath peaks. The performance of each algorithm is compared together with the auto-correlation algorithm in section 4.

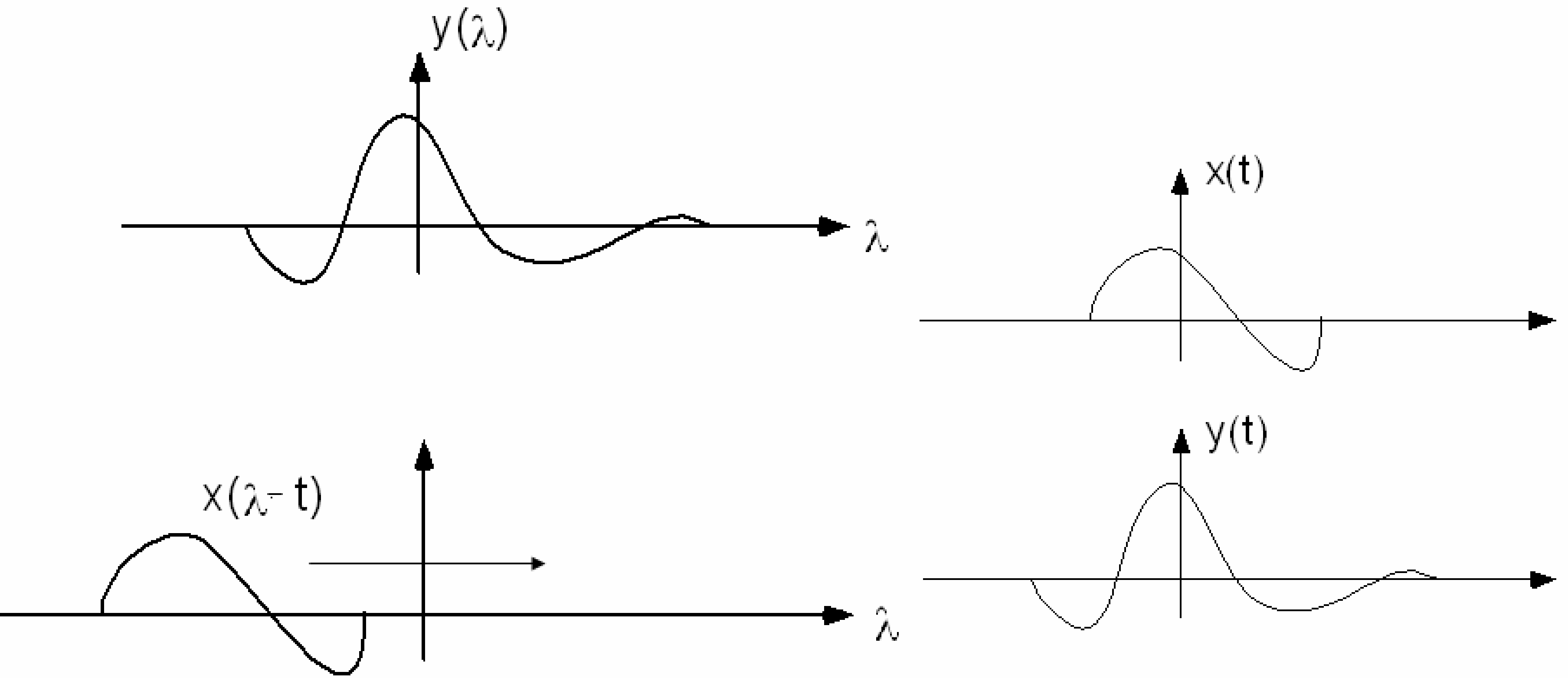
A Performance and Complexity Comparison of Auto-Correlation and Cross-Correlation and OFDM Burst Synchronization
Andrew Fort, Jan-Willem Weijers, Veerle Derudder, Wolfgang Eberle, Andre Bourdoux
IMEC, IEEE ICASSP 2003

Convolution



$$z(t) = y(t) * x(t) = \int_{-\infty}^{\infty} y(\lambda)x(t-\lambda)d\lambda \qquad Z(f) = Y(f)X(f)$$

Cross Correlation

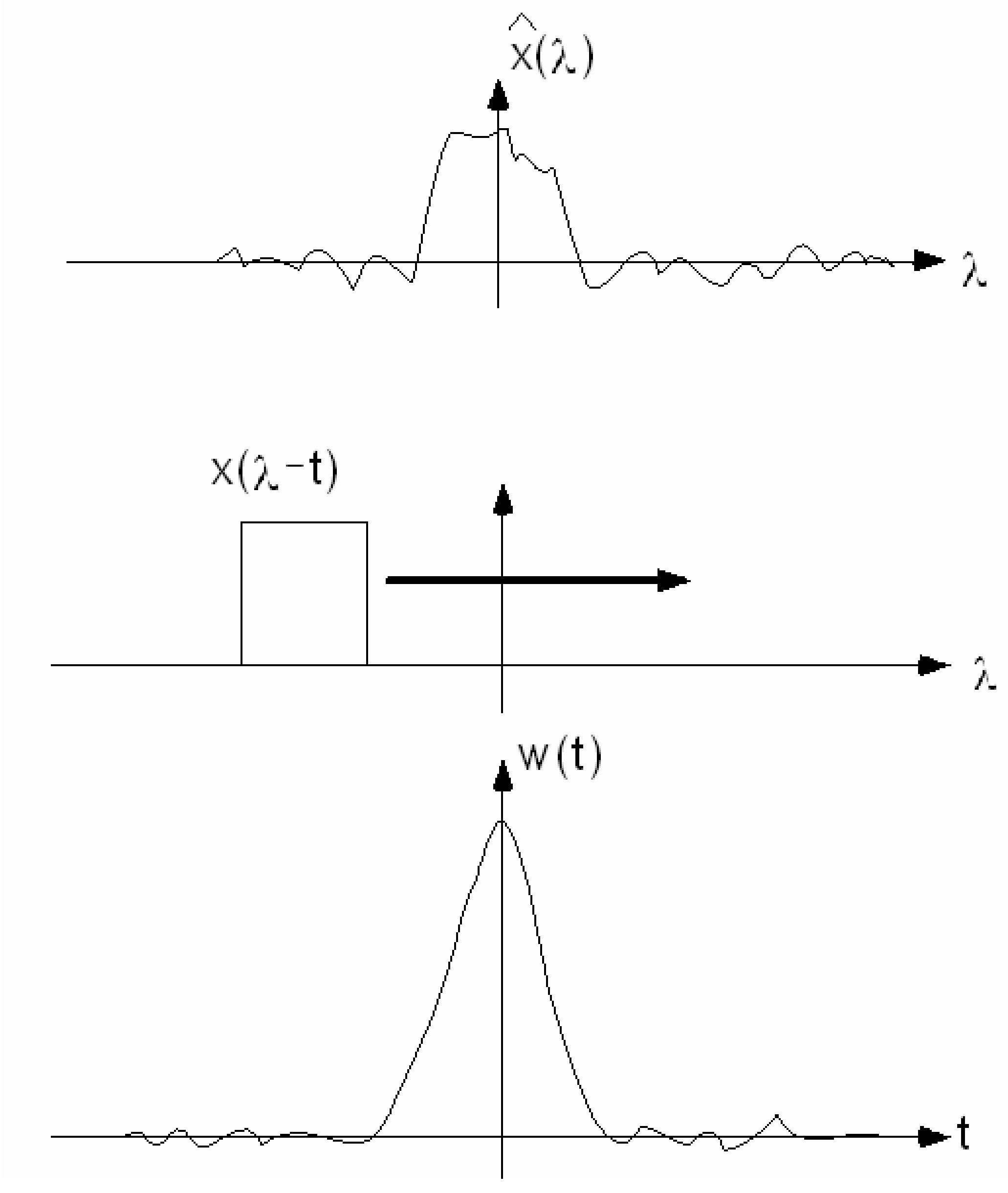


$$z(t) = y(t) * x(t) = \int_{-\infty}^{\infty} y(\lambda) x(t-\lambda) d\lambda$$

$$W(f) = Y(f) X^*(f)$$

$$w(t) = y(t) * x(-t) = \int_{-\infty}^{\infty} y(\lambda) x(\lambda - t) d\lambda$$

Cross Correlation Example



Cross Correlation and Channel Impulse Response

$$y(t) = h(t) * s(t)$$

$$Y(f) = H(f)S(f)$$

$$r(t) = y(t) * s(-t)$$

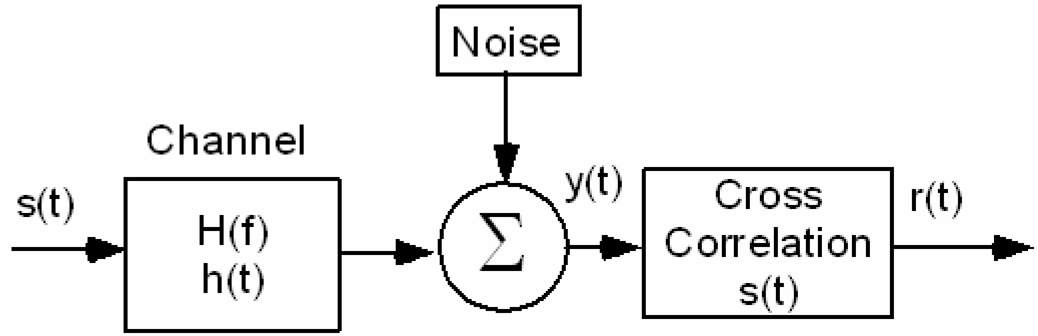
$$R(f) = Y(f)S^*(f)$$

$$R(f) = H(f)S(f)S^*(f)$$

$$R(f) = |S(f)|^2 H(f)$$

$$|S(f)|^2 = 1$$

$$R(f) = H(f) \longrightarrow r(t) = h(t)$$

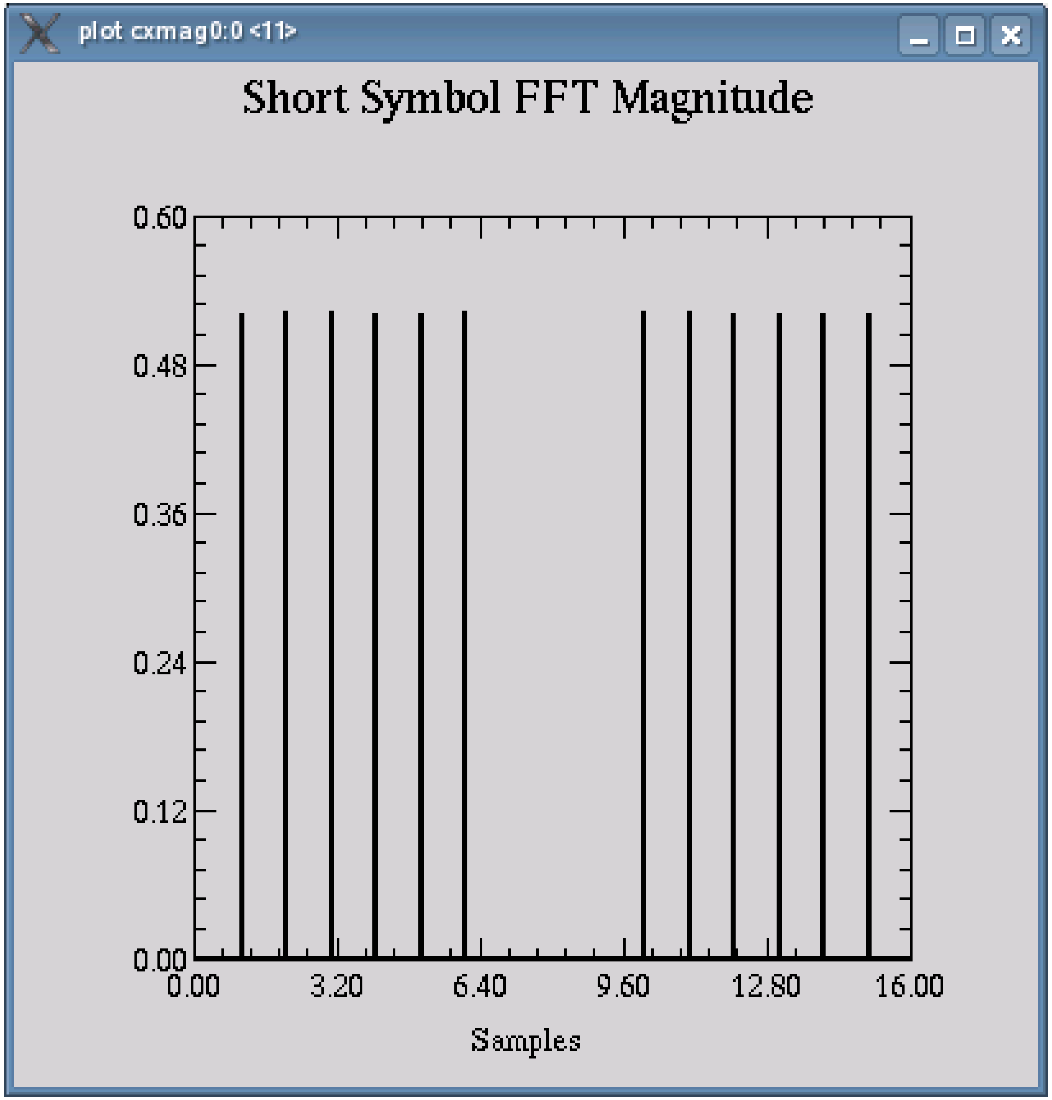


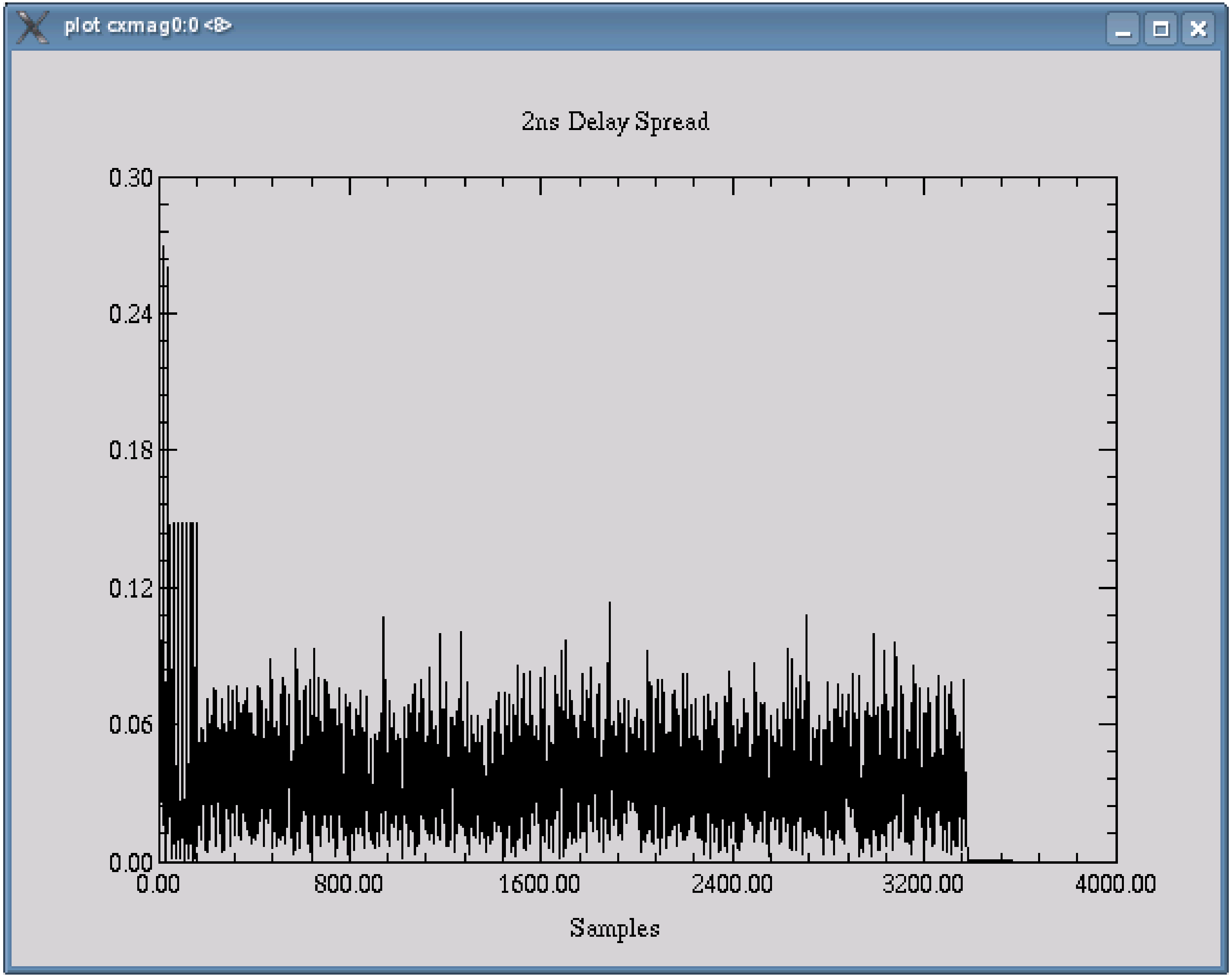
0,1+j,-1-j,1+j,-1-j,-1-j,1+j,0,

0,0,-1-j,-1-j,1+j,1+j,1+j,1+j

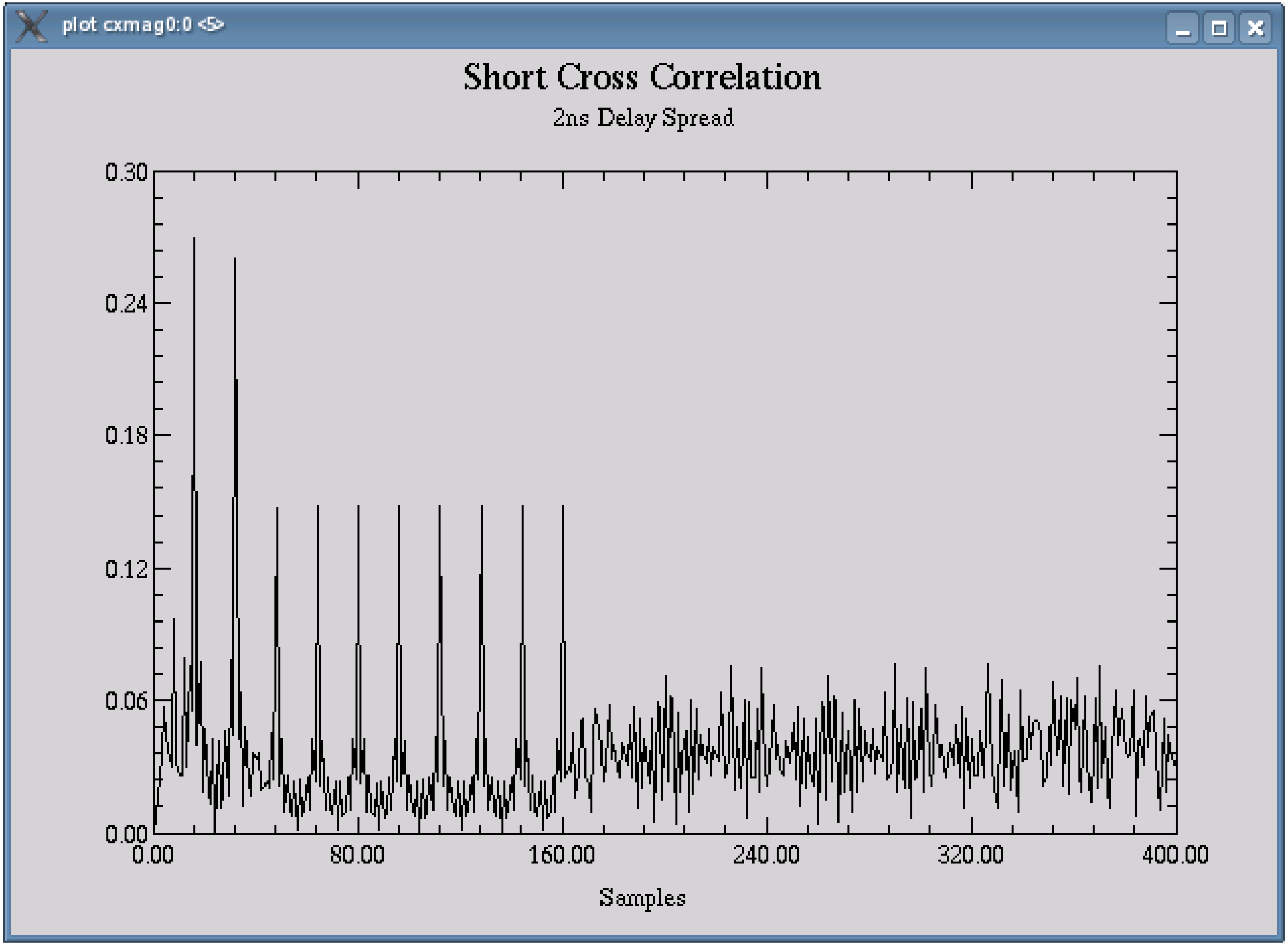
$$R(n) = \sum_{m=0}^{N-1} t^*(m) r(n+m)$$

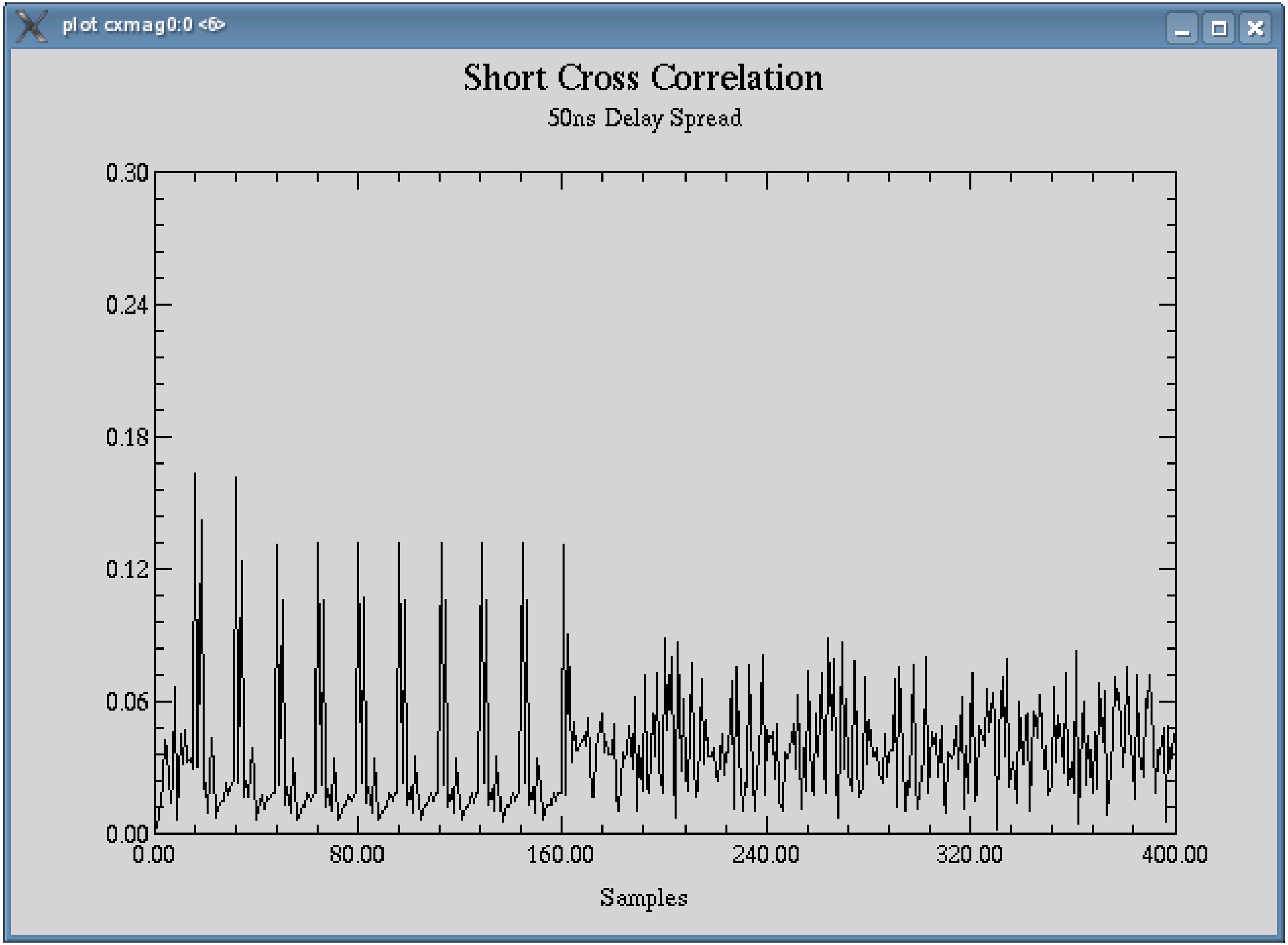
N length of short training symbol

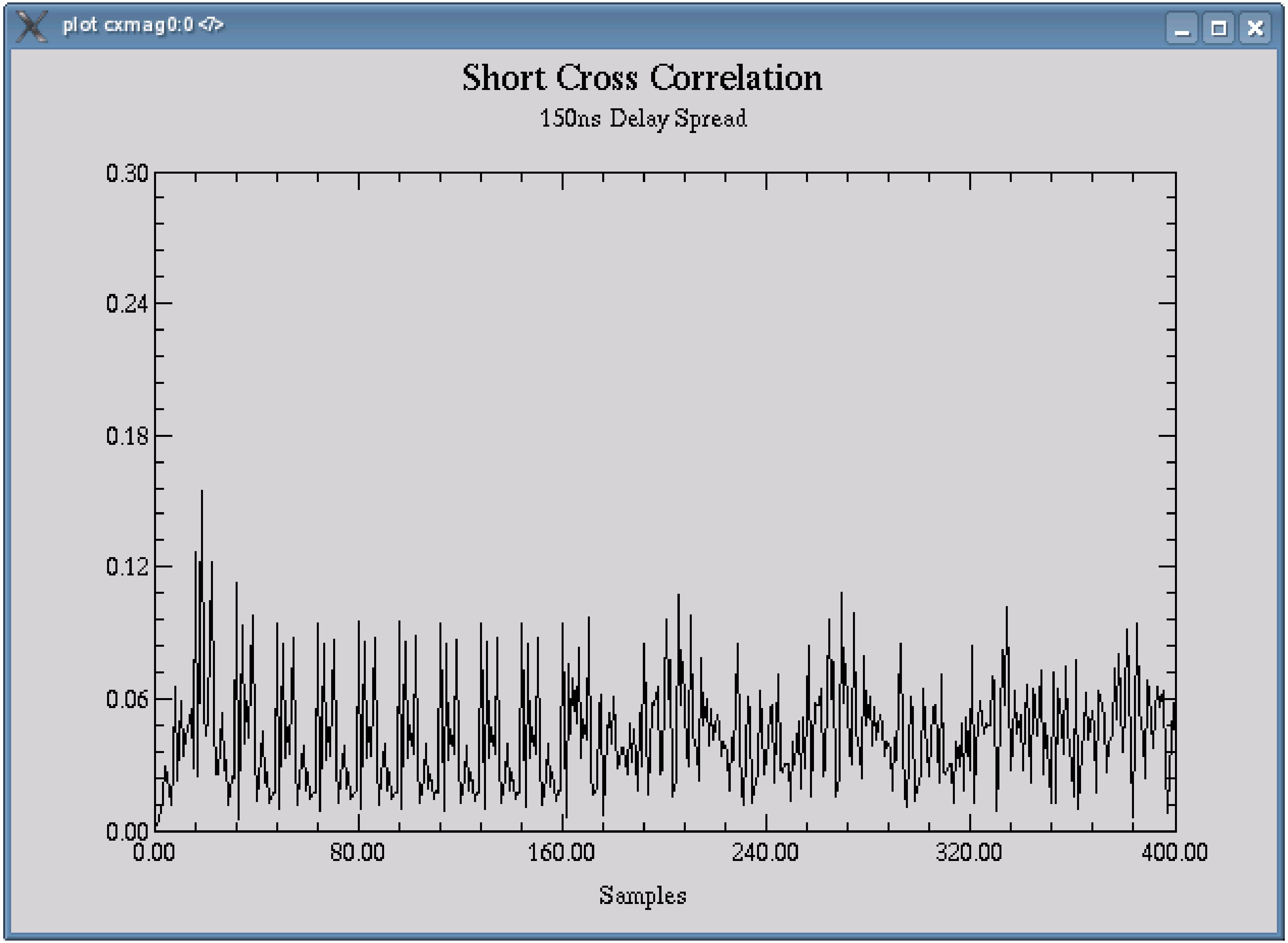

plot cxmag0:0 <11>
Short Symbol FFT Magnitude
0.60
0.48
0.36
0.24
0.12
0.00
0.00
3.20
6.40
9.60
12.80
16.00
Samples

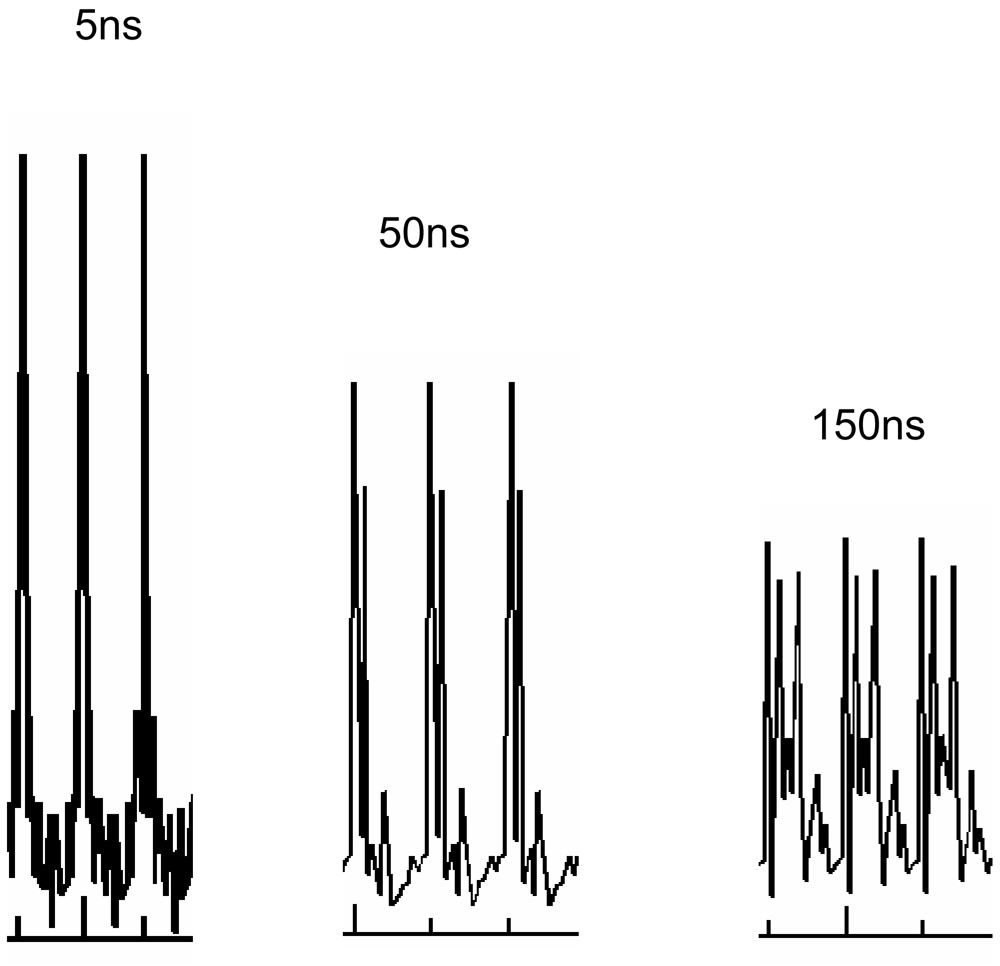


plot cxmag0:0 <8>
2ns Delay Spread
0.30
0.24
0.18
0.12
0.06
0.00
0.00
800.00
1600.00
2400.00
3200.00
4000.00
Samples

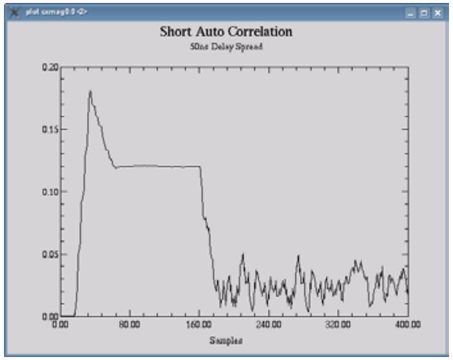

plot cxmag0:0 <5>
Short Cross Correlation
2ns Delay Spread
0.30
0.24
0.18
0.12
0.06
0.00
0.00
80.00
160.00
240.00
320.00
400.00
Samples

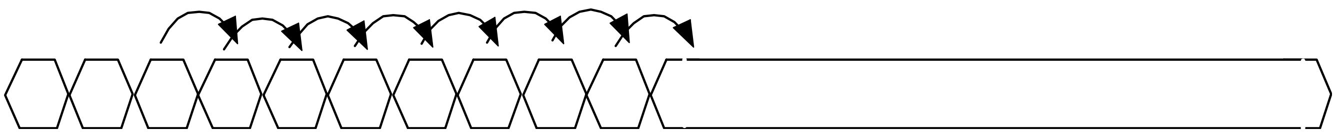

plot cxmag0:0 <6>
Short Cross Correlation
50ns Delay Spread
0.30
0.24
0.18
0.12
0.06
0.00
0.00
80.00
160.00
240.00
320.00
400.00
Samples

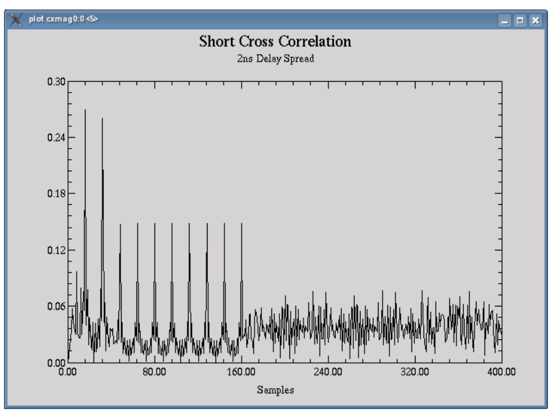

plot cxmag0:0 <7>
Short Cross Correlation
150ns Delay Spread
0.30
0.24
0.18
0.12
0.06
0.00
0.00
80.00
160.00
240.00
320.00
400.00
Samples

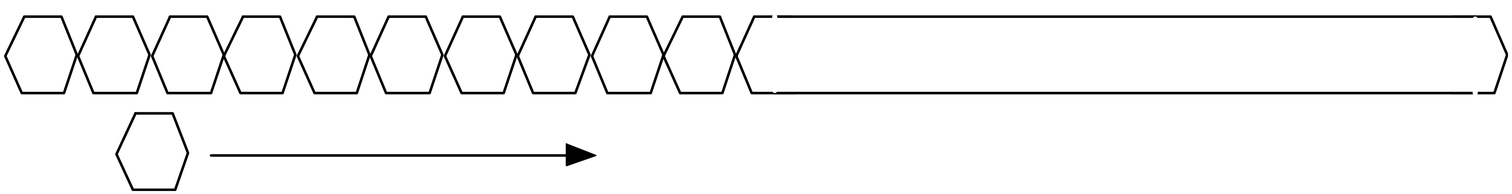

5ns
50ns
150ns

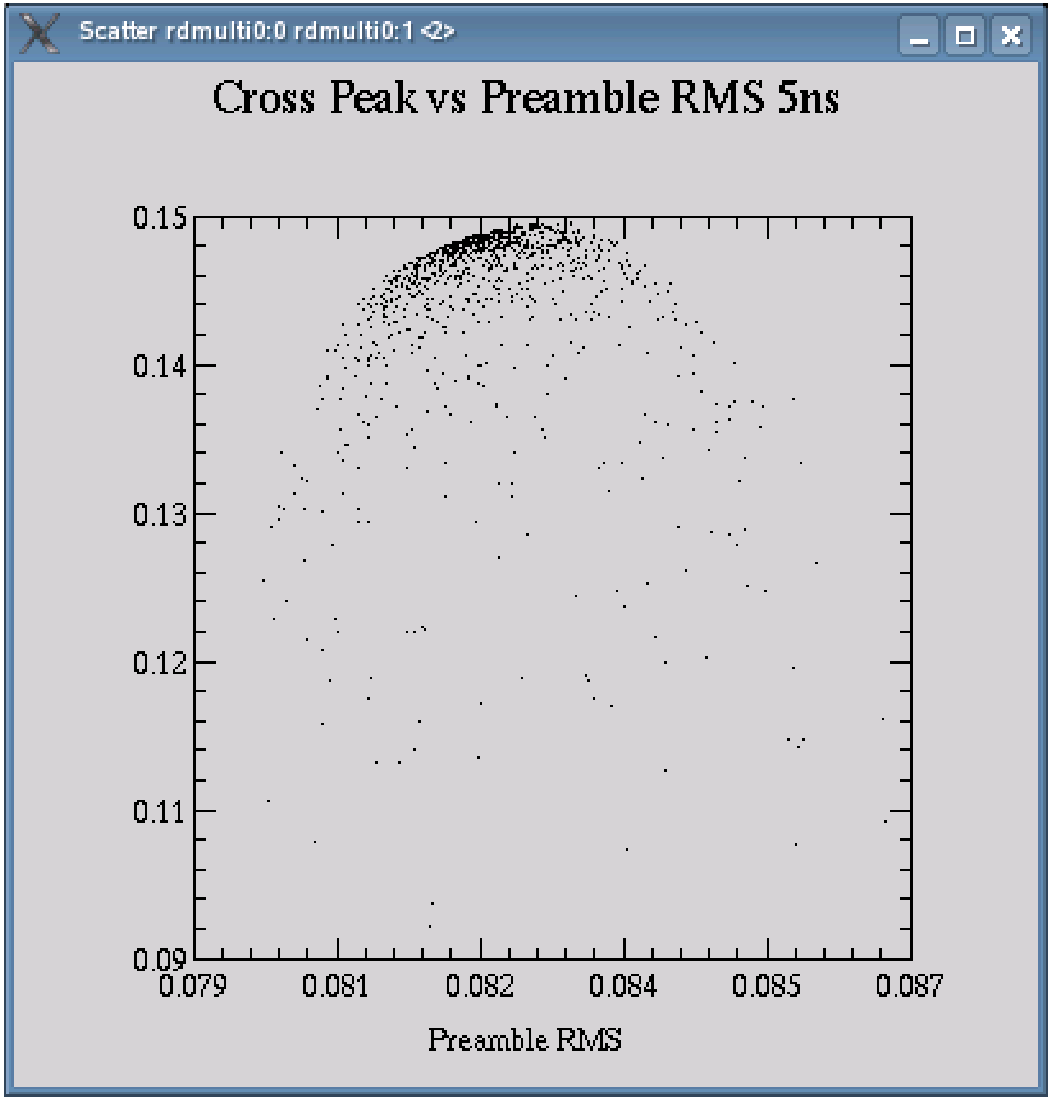
Auto Correlation versus Cross Correlation in Packet Detection



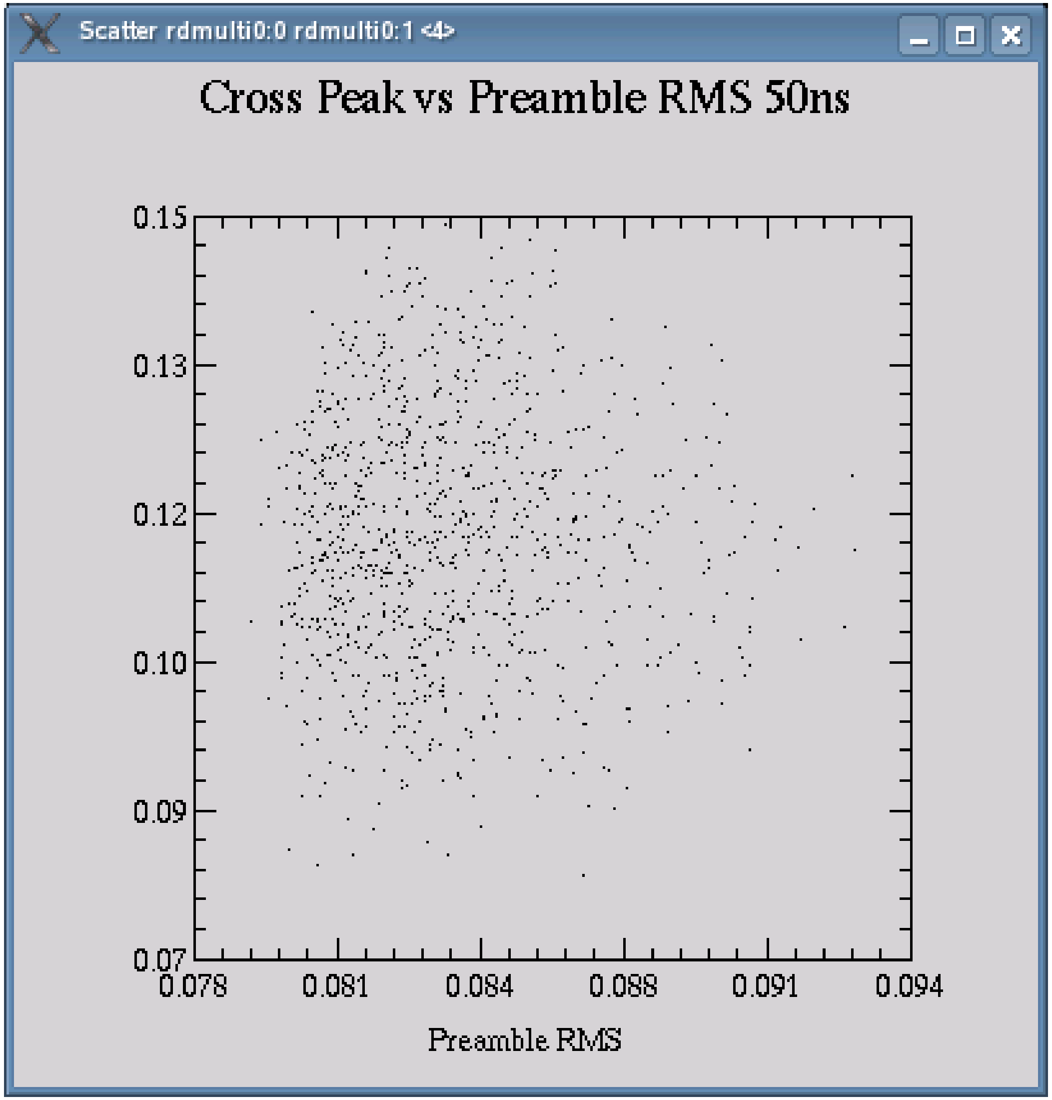


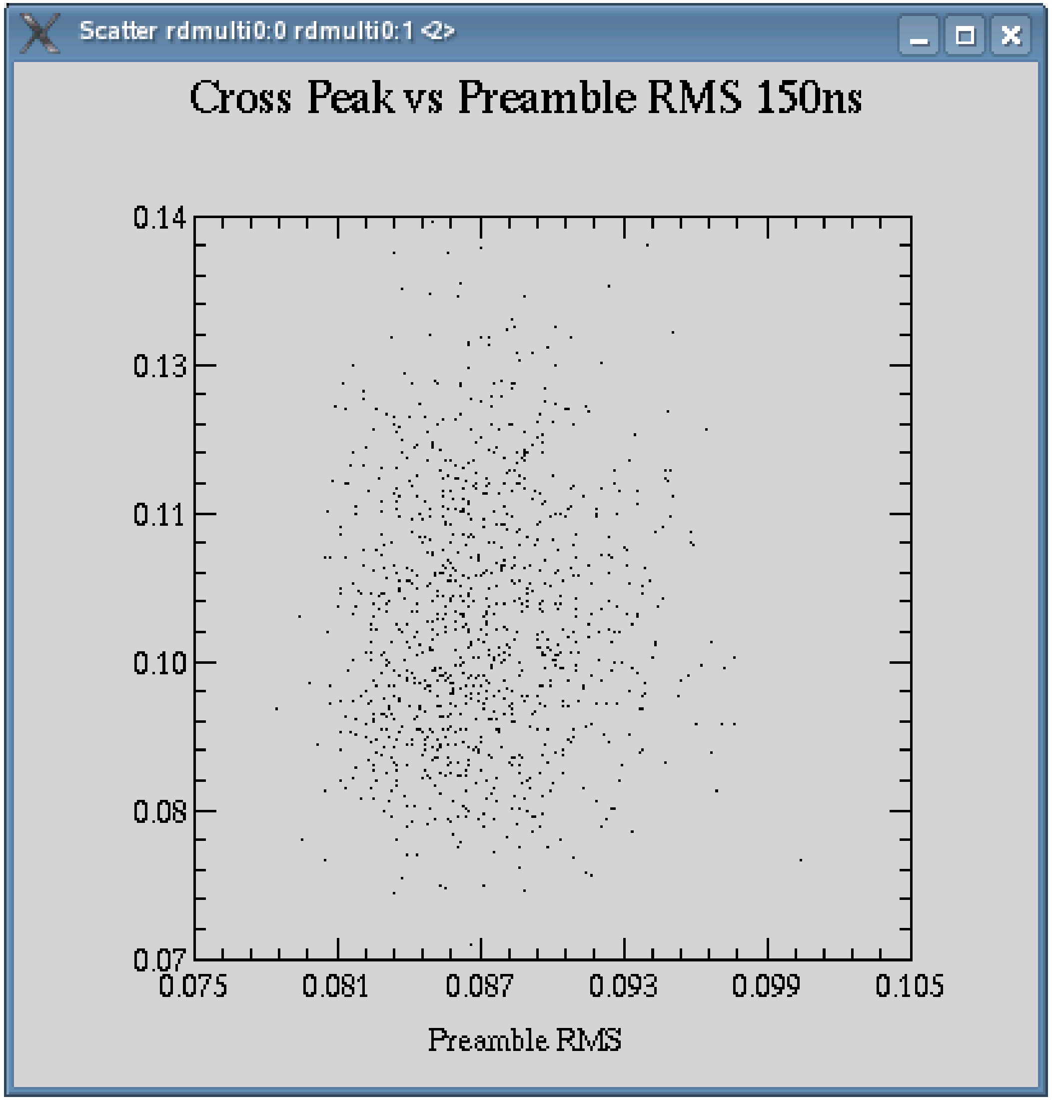




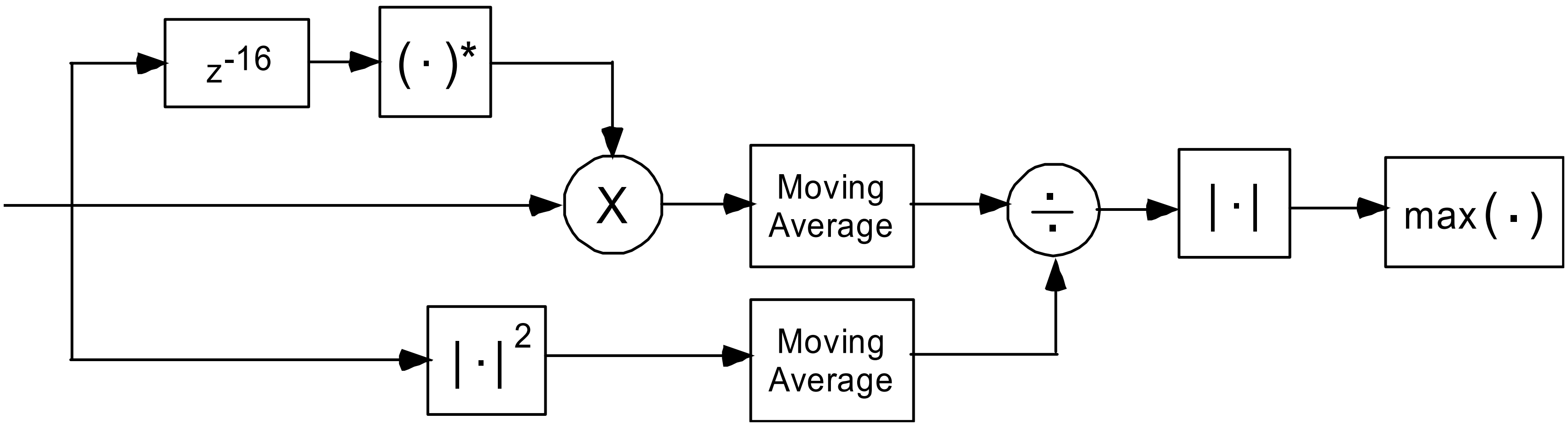


Scatter rdmulti0:0 rdmulti0:1 <2>
Cross Peak vs Preamble RMS 5ns
0.15
0.14
0.13
0.12
0.11
0.09
0.079
0.081
0.082
0.084
0.085
0.087
Preamble RMS


Scatter rdmulti0:0 rdmulti0:1 <4>
Cross Peak vs Preamble RMS 50ns
0.15
0.13
0.12
0.10
0.09
0.07
0.078
0.081
0.084
0.088
0.091
0.094
Preamble RMS



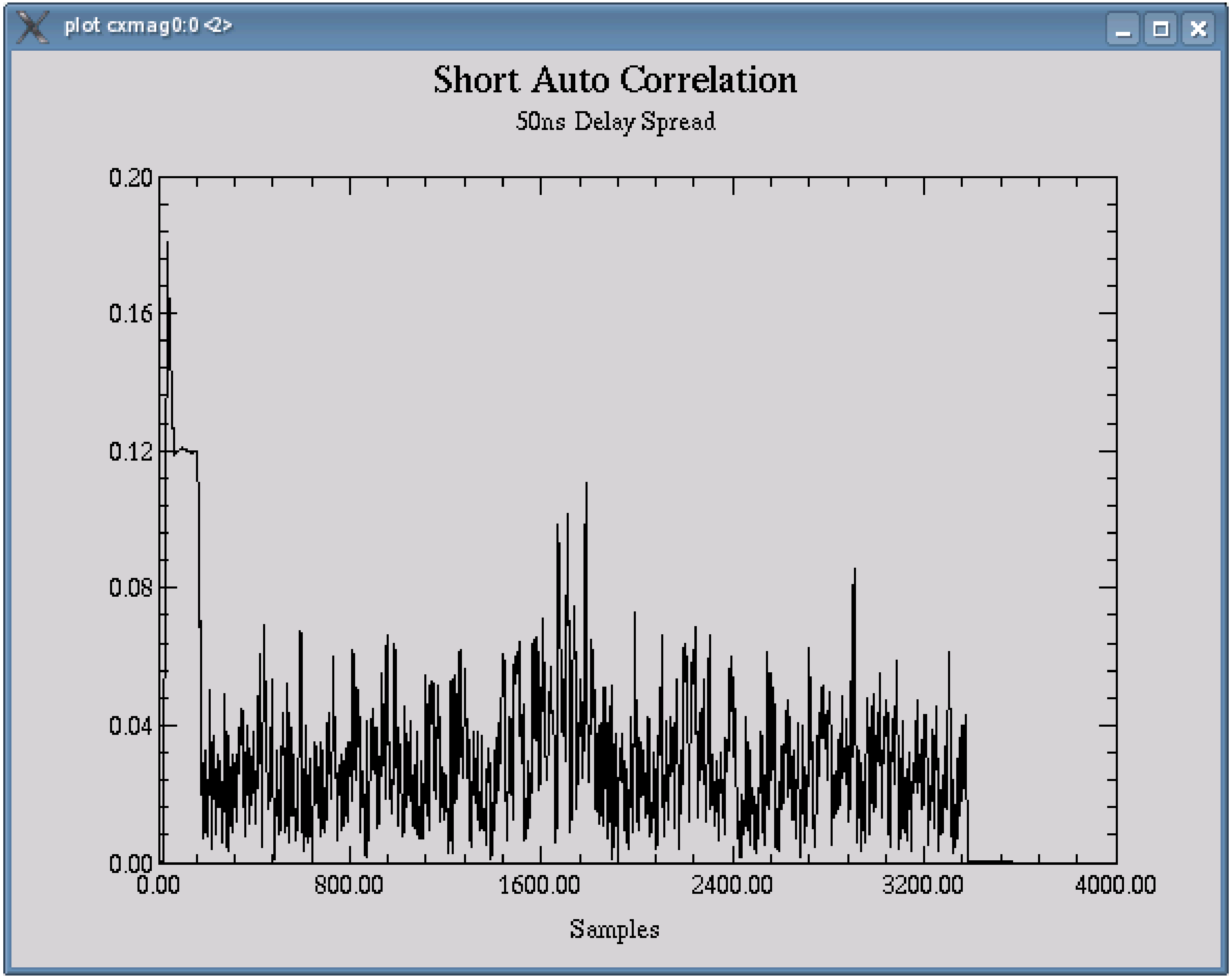
Scatter rdmulti0:0 rdmulti0:1 <2>
Cross Peak vs Preamble RMS 150ns
0.14
0.13
0.11
0.10
0.08
0.07
0.075
0.081
0.087
0.093
0.099
0.105
Preamble RMS

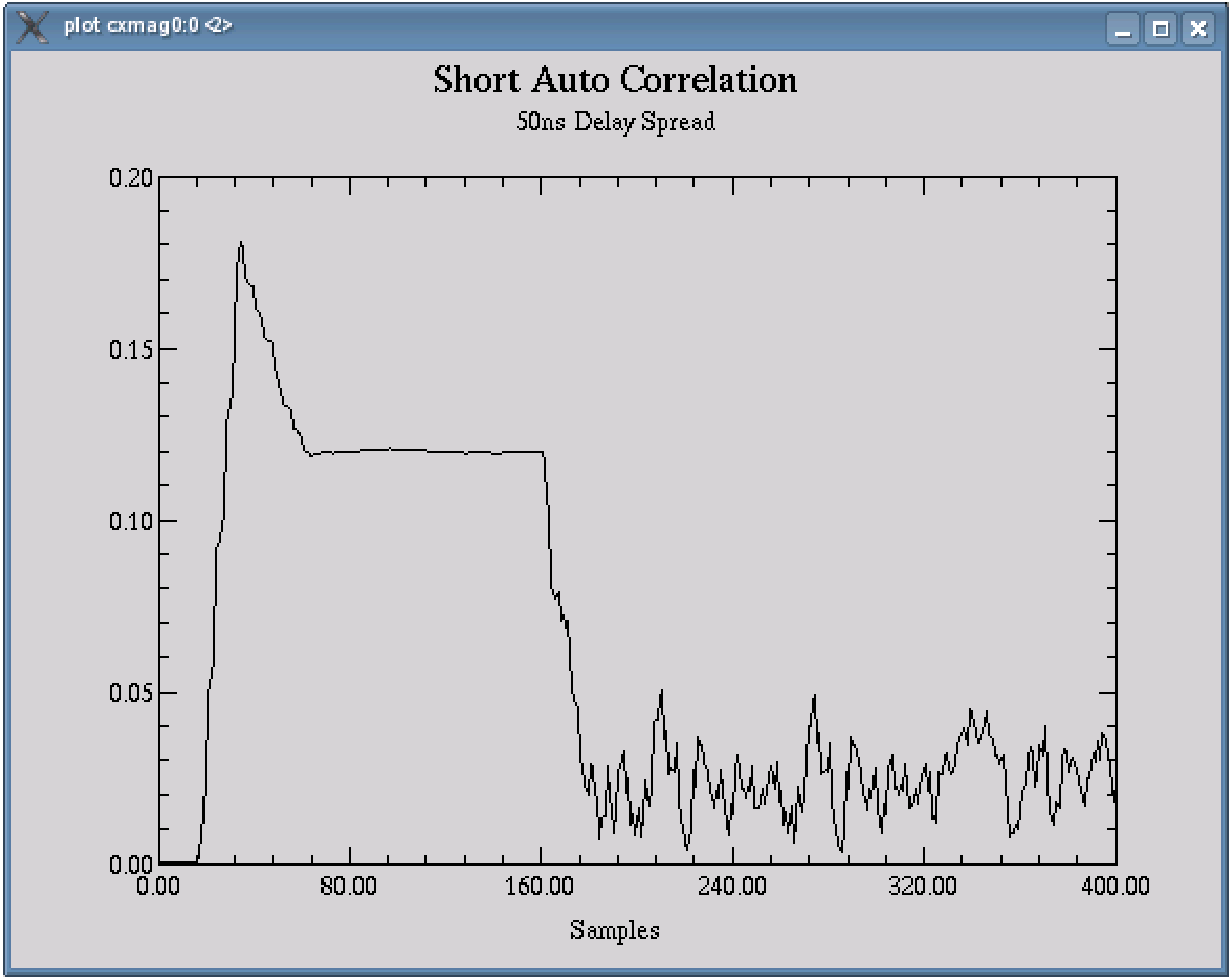


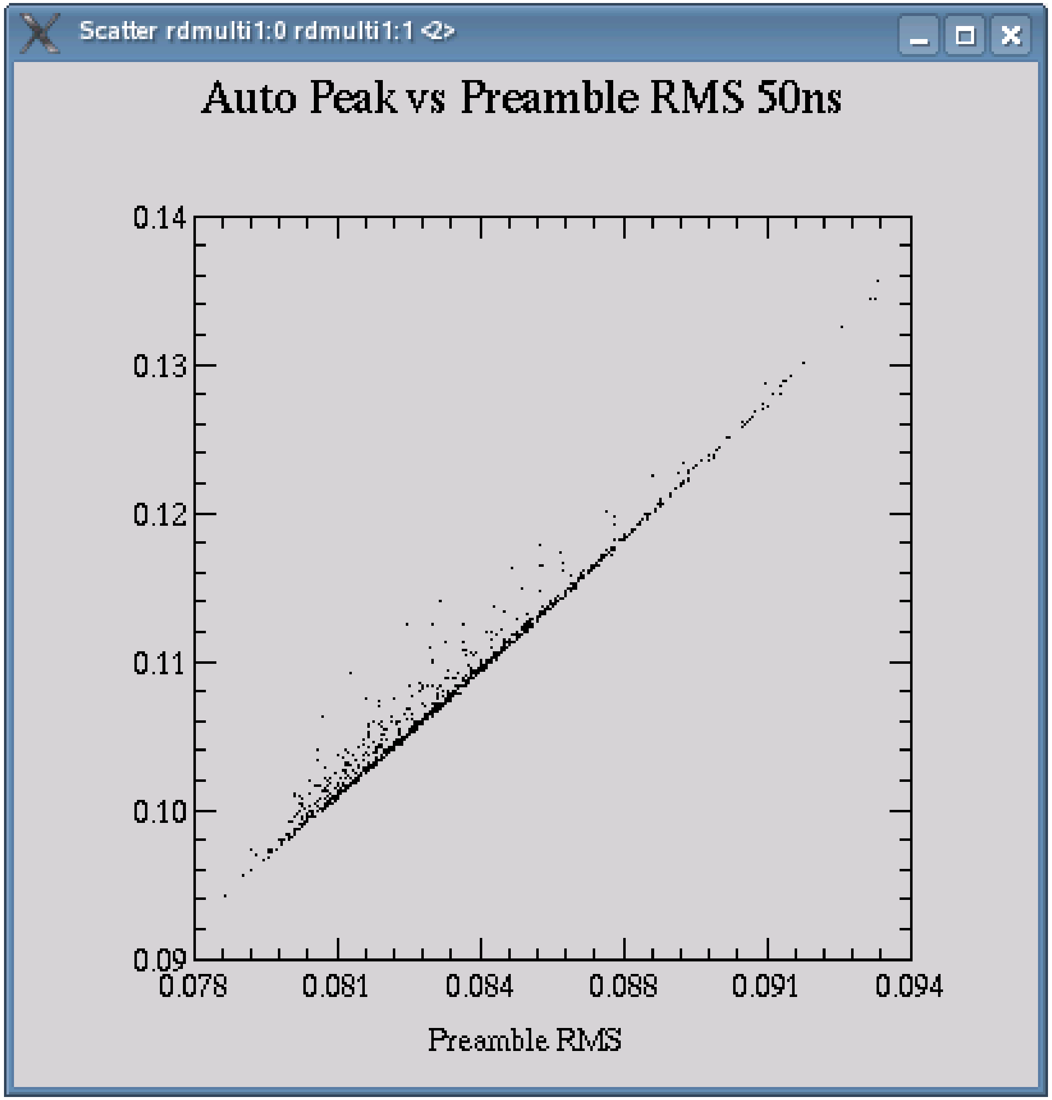
$$S(n) = \sum_{m=0}^{M-1} r^*(n+m-16)r(n+m)$$

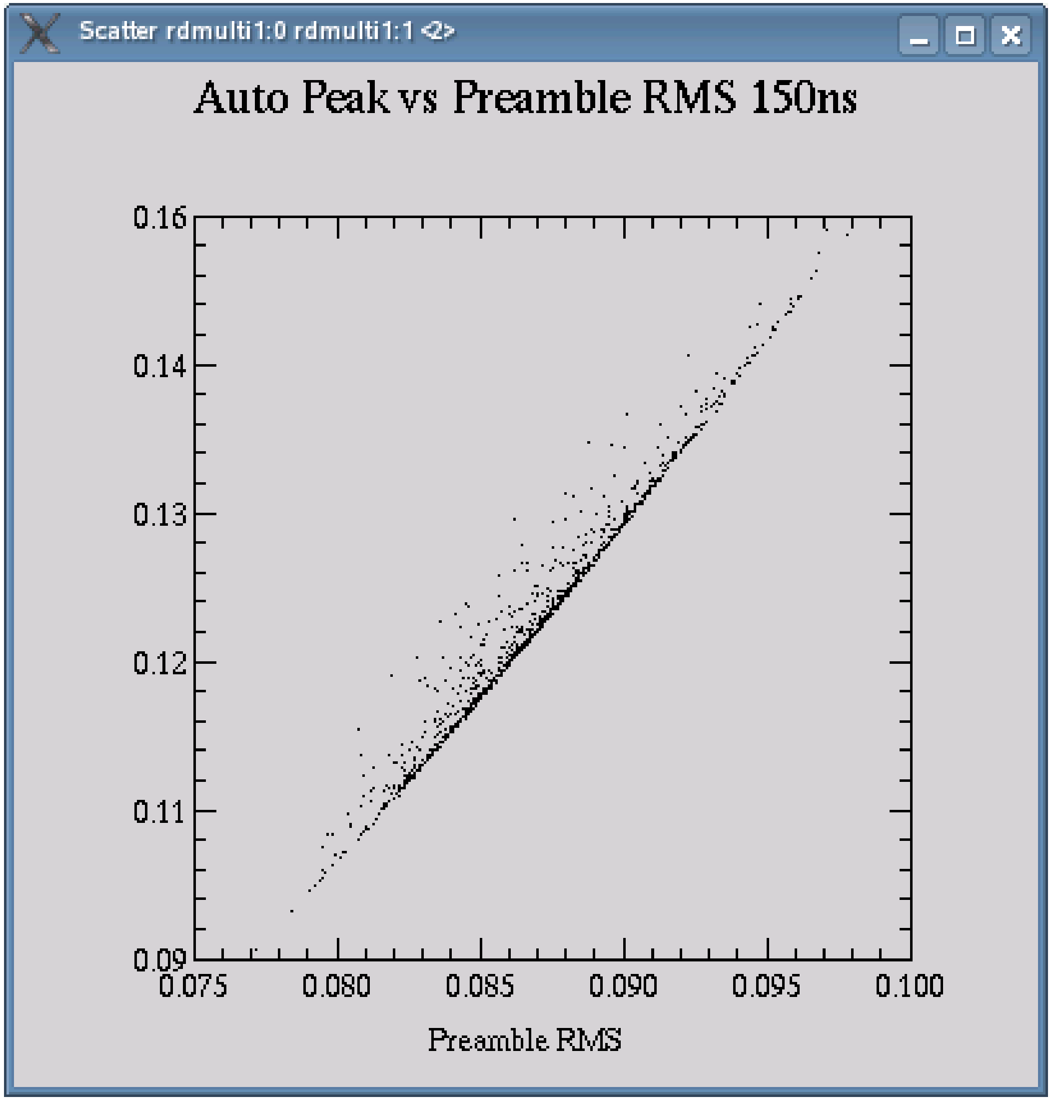
$$\hat{f}_o = \frac{arg\,(S(\hat{n}_{acmax}))}{2\pi(16T_s)}$$

A Performance and Complexity Comparison of Auto-Correlation and Cross-Correlation and OFDM Burst Synchronization
Andrew Fort, Jan-Willem Weijers, Veerle Derudder, Wolfgang Eberle, Andre Bourdoux
IMEC, IEEE ICASSP 2003


plot cxmag0:0 <2>
Short Auto Correlation
50ns Delay Spread
0.20
0.16
0.12
0.08
0.04
0.00
0.00
800.00
1600.00
2400.00
3200.00
4000.00
Samples


plot cxmag0:0 <2>
Short Auto Correlation
50ns Delay Spread
0.20
0.15
0.10
0.05
0.00
0.00
80.00
160.00
240.00
320.00
400.00
Samples


Scatter rdmulti1:0 rdmulti1:1 <2>
Auto Peak vs Preamble RMS 50ns
0.14
0.13
0.12
0.11
0.10
0.09
0.078
0.081
0.084
0.088
0.091
0.094
Preamble RMS


Scatter rdmulti1:0 rdmulti1:1 <2>
Auto Peak vs Preamble RMS 150ns
0.16
0.14
0.13
0.12
0.11
0.09
0.075
0.080
0.085
0.090
0.095
0.100
Preamble RMS

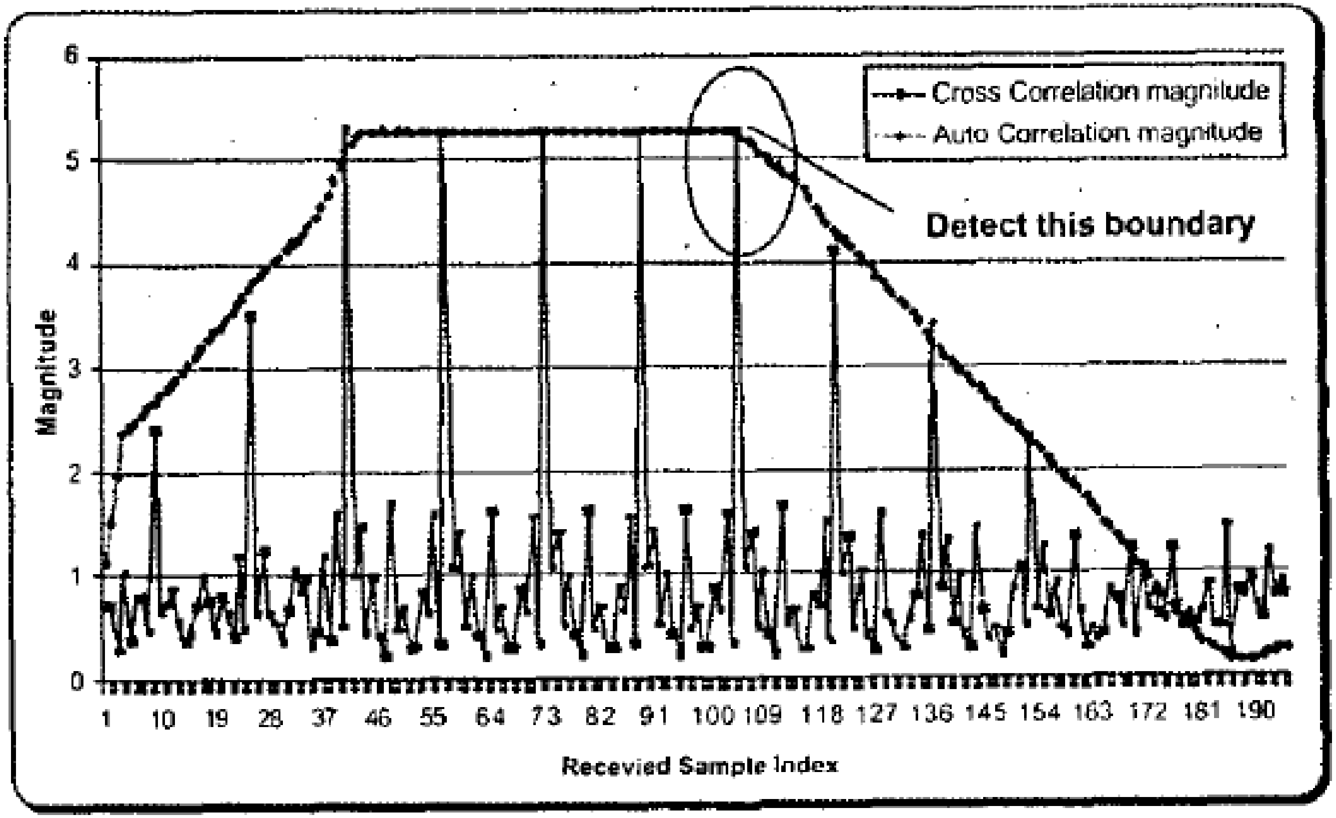


Figure 3. Auto-Correlation curve and Cross-Correlation peaks for ideal case (No noise, no multipath and no frequency offset)

$$C(n)=\sum_{l=0}^{M}\sum_{k=1}^{N} r(l*N+k+n)s^*(l*N+k)$$

ROBUST TIMING SYNCHRONIZATION FOR OFDM BASED WIRELESS LAN SYSTEM, Sridhar Nandula, K Giridhar,2003 IEEE

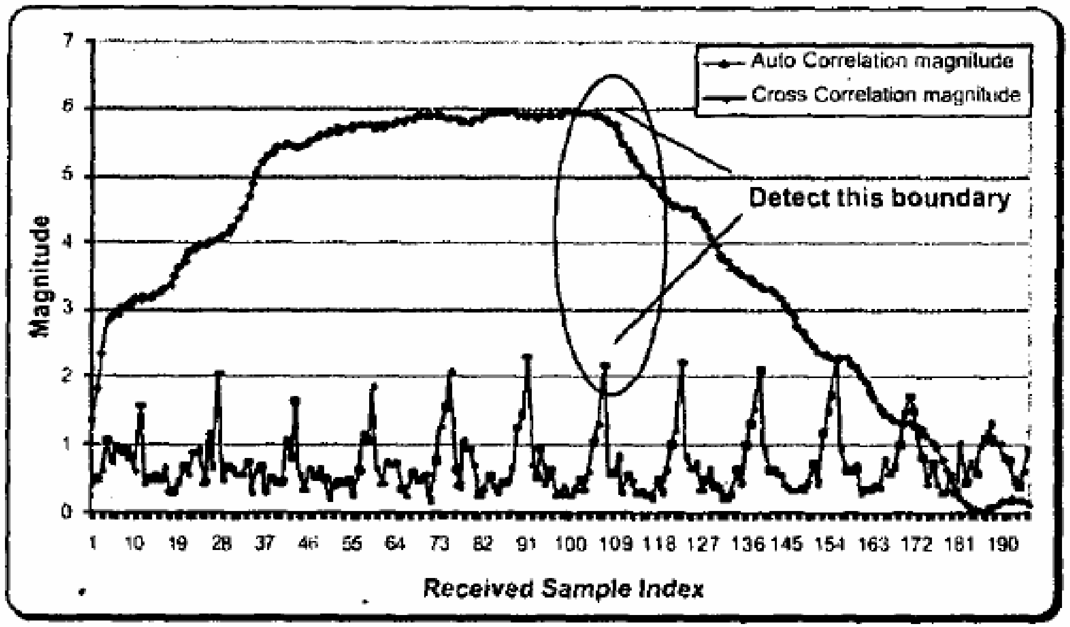


Figure 6. Auto-Correlation curve and Cross-Correlation peaks for SNR = 7dB, multipath delay spread = 100 ns and frequency offset = 200 kHz