Wireless LAN & OFDM

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Topics

- Link Considerations
- Wireless LAN Specifications and Modulations
- OFDM Signal Processing

Link Considerations

License Free Bands

- 2.4 GHz
  - 83.5 MHz
  - 1Watt
  - Spread Spectrum
    - FHSS
    - DSSS
  - Fair Usage
    - CCK
    - OFDM
  - Point to point 18dBi antenna – 14dBW EIRP
- 5.15 GHz
  - 100 MHz 2.5 mW/Hz
- 5.25 GHz
  - 100 MHz 12.5 mW/Hz
- 5.725 GHz
  - 100 MHz 50 mW/Hz
  - 1 Watt
  - Point to point - no reduction with antenna gain
- 60 GHz
  - 57 to 64 GHz

Line of Sight Propagation –LOS

- $Pr = PtGtGr\ \lambda^2/(4\pi d)^2$
- Path Loss = $\lambda^2/(4\pi d)^2$
- Path Loss Exponent = 2
- From experimental data at 5.8 GHz
  - Path Loss Exponent = 2
  - Standard deviation = 6.9 db
- Additional O_2 loss of 16 dB/km @ 60 GHz

Non Line of Sight -- NLOS

- Sum of reflections from many objects
- Rayleigh distributed
  - 10 % of time 10 dB below nominal level
  - 1% of time 20 dB below nominal level
- Form experimental data at 5.8 GHz
  - Path loss exponent = 3.5
  - Standard deviation = 9.5 dB
- Combated with antenna diversity

Bits per Hertz

- Baseband binary data
  - 2 bits/Hertz
  - Alpha α is filter factor 0.25 gives 1.6 bit/Hz
- Binary phase shift keying BPSK
  - 1 bit/Hertz
  - Upper and lower sidebands as baseband
- Quadrature phase shift keying QPSK
  - 2 bits/Hertz

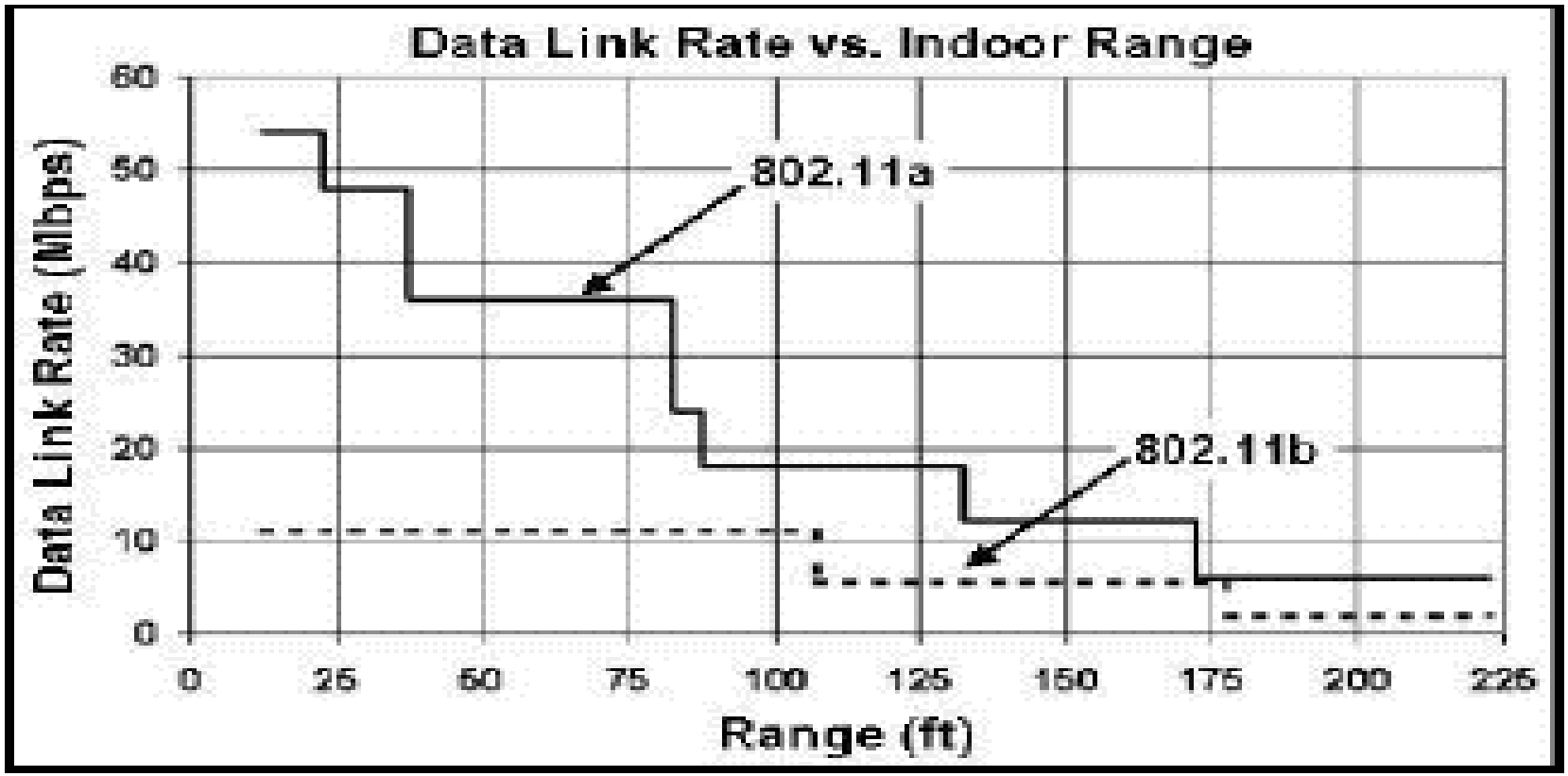
More bits per Hertz

- 16 Quadrature Amplitude Modulation
  - 16 QAM
  - 4 bits/Hertz
- 64 Quadrature Amplitude Modulation
  - 64 QAM
  - 6 bits/Hertz
- In practice with FEC, protocol, shaping and guard 2/3 of the available bits/Hertz is good

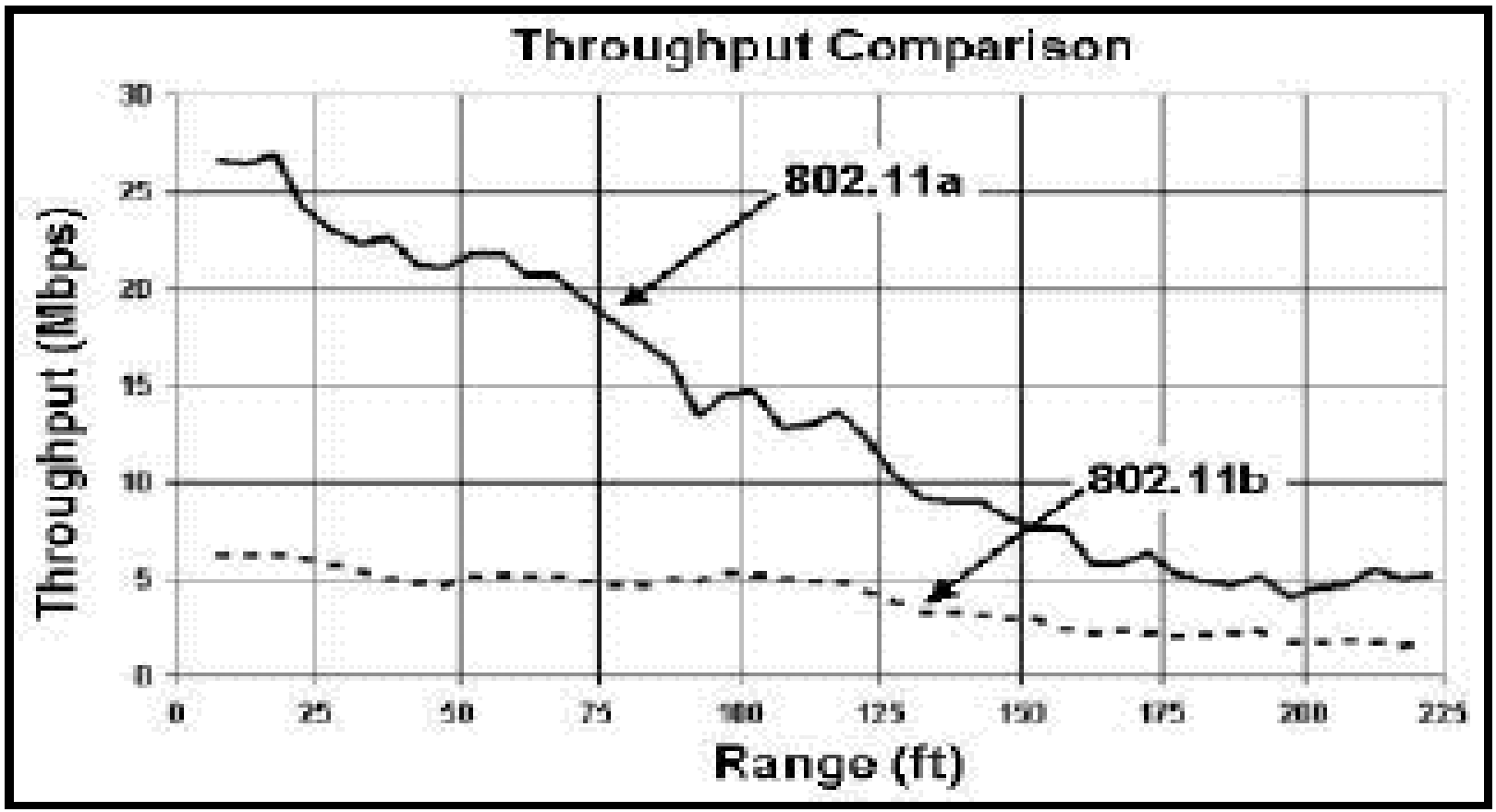
Energy per Bit / Noise Density

- E/N0 = Energy per bit / Noise density
- Additive White Gaussian Noise AWGN
- Un-coded error rate 10^{-4}
- BPSK or QPSK 8.5 dB
- 16 QAM 15.5 dB
- 64 QAM 21.7 dB

Atheros Measured Range



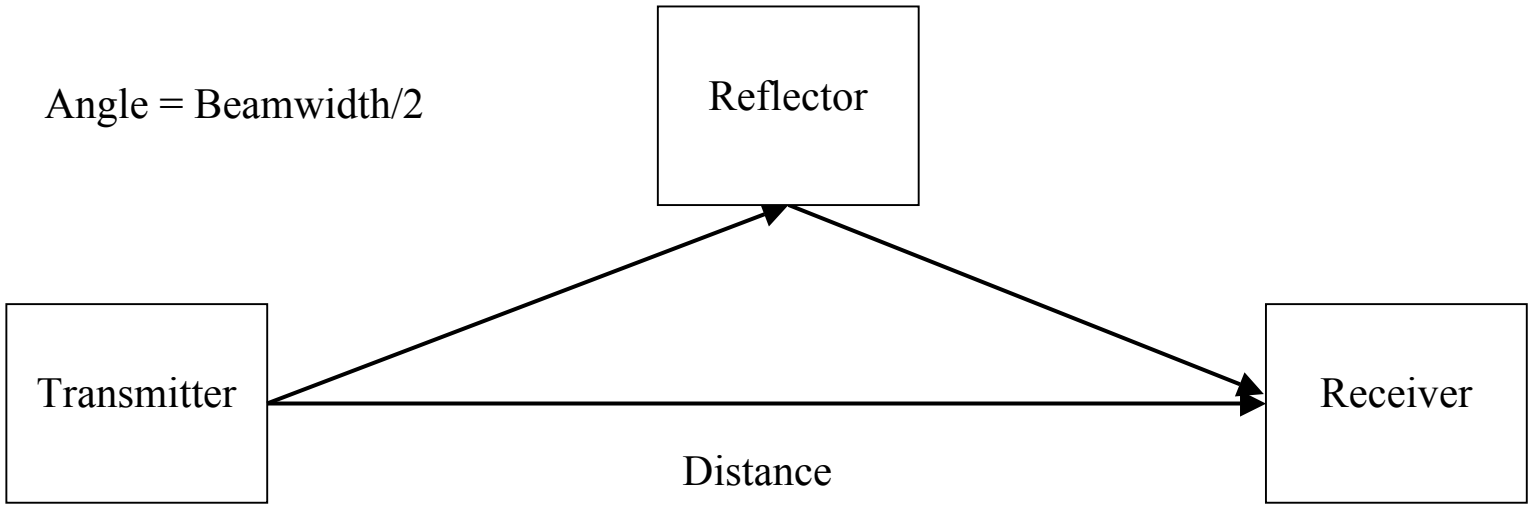
Atheros Measured Range



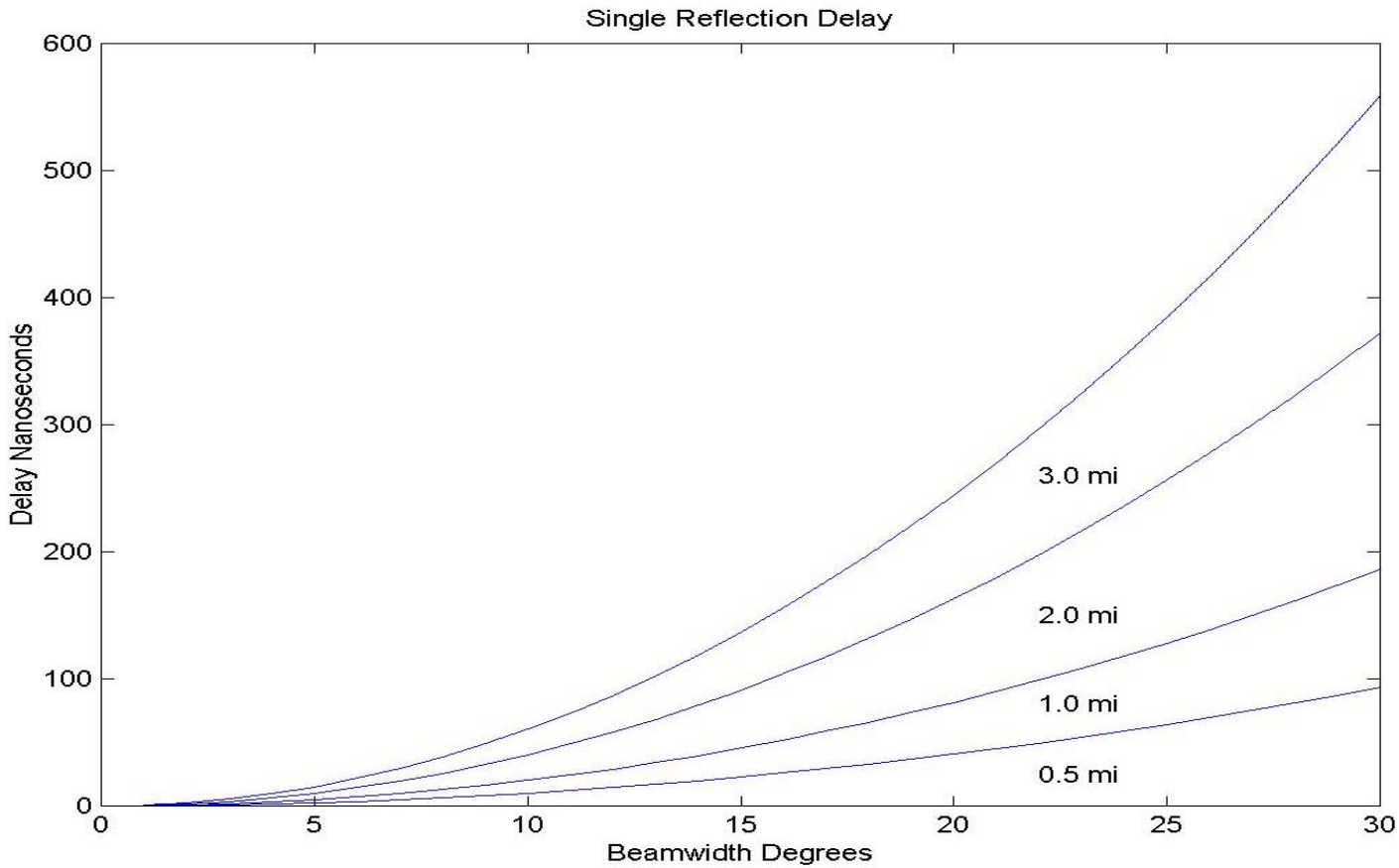
An Example of Range

- 5.8 GHz U-NII band transceiver
- 70 MHz bandwidth, 64 QAM, 280 Mbps
- Power out RMS 13 dBm
- Line of sight
  - 1ft. Tr and Rx 20 dB gain antenna 3 miles
  - Omi Tr and 20 dB rx 0.5 miles
  - Omi Tr and Rx 0.1 miles
- Non line of sight 50 ft
  - 1ft. Tr and Rx 20 dB gain antenna 50 feet

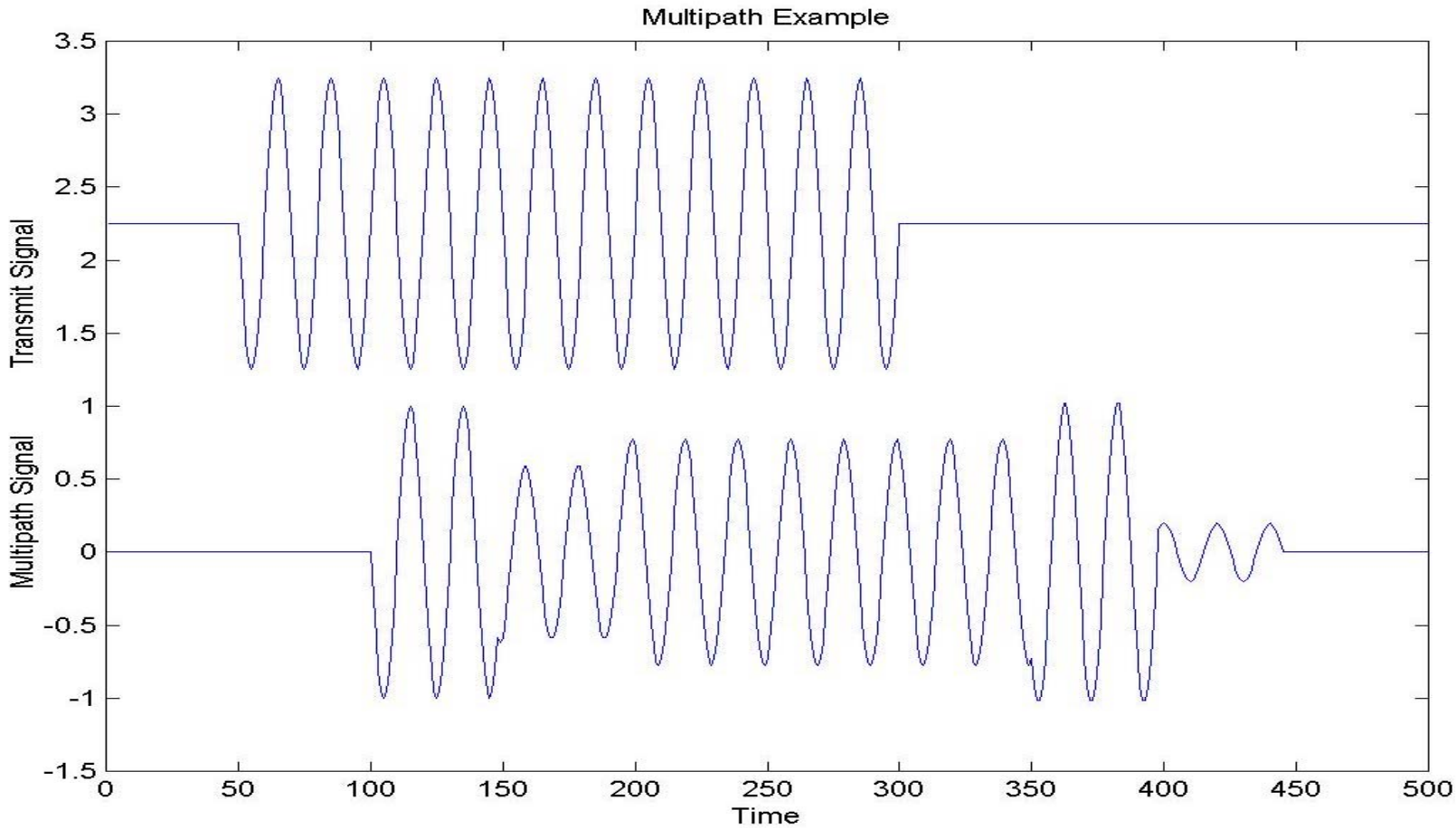
Multipath Geometry



Multipath Delay



Multipath Example



Link Considerations Summary

- Bandwidth is limited.
- Bandwidth efficient modulations require high S/N
- NLOS propagation is brutal giving low S/N.
  - High data rate LAN's are short range
- Multipath distorts waveforms.
  - Equalization
  - OFDM

Wireless LAN & OFDM
Part 2

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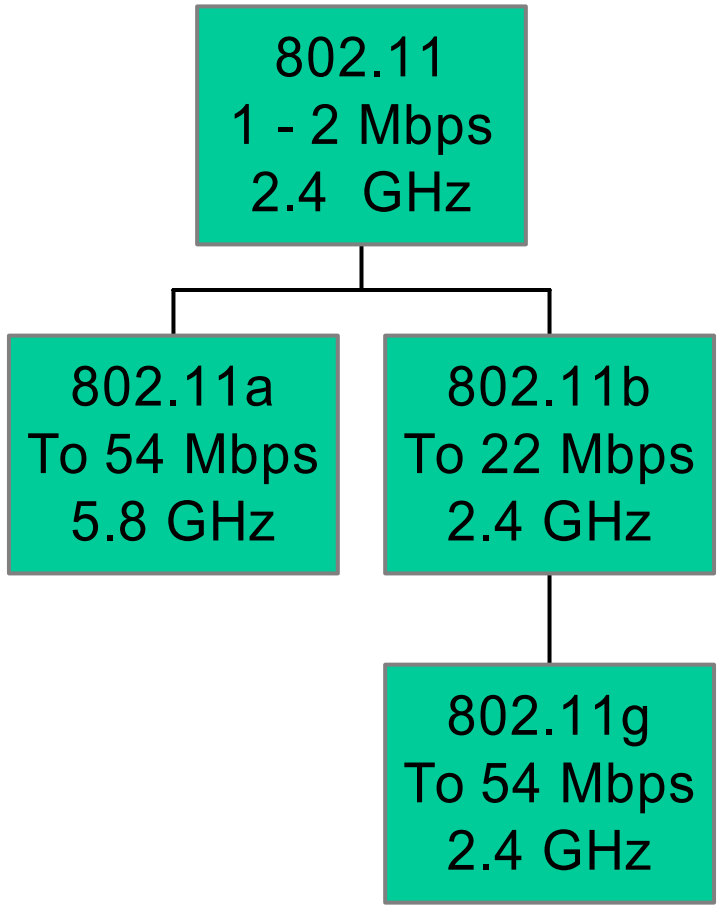
Wireless LAN Specifications and Modulations

802.11 Specifications



802.11 Characteristics

Standard	802.11a	802.11b	802.11
Standard Approved	September 1999	September 1999	July 1997
Available Bandwidth	300MHz	83.5MHz	83.5MHz
Unlicensed Frequencies of Operation	5.15-5.35GHz, 5.725-5.825GHz	2.4-2.4835GHz	2.4-2.4835GHz
Number of Non-Overlapping Channels	4 (Indoor) 4 (Indoor/Outdoor) 4 (Indoor/Outdoor)	3 (Indoor/Outdoor)	3 (Indoor/Outdoor)
Data Rate per Channel	6, 9, 12, 18, 24, 36, 48, 54 Mbps	1, 2, 5.5, 11 Mbps	1, 2 Mbps
Modulation Type	OFDM	CCK	FHSS, DSSS

802.11 FHSS Frequency Hopping Spread Spectrum

- Center frequency is selected from a large number of frequencies
- Processing gain is number of hopping frequencies.
- Slow hopper – symbol rate is much higher than hopping frequency
- Effective against large narrow band interference

802.11 FHSS PMD Physical Medium Dependent

- Hopping set 79 in US
- 3 sets of 26 Hopping frequencies
- Separation 1MHz
- 1 Mbit/s two-level GFSK BWE = 1/80
- 2 Mbit/s four-level GFSK BWE = 1/40

802.11 DSSS Direct Sequence Spread Spectrum

- Carrier directly modulated by a code sequence.
  - Symbol rate is rate of data symbol 1MHz
  - Chip rate is rate of code sequence 11 MHz
- Processing gain Symbol rate/Chip rate 10 dB
- Effective against moderate interference levels.

802.11 DSSS PMD Physical Medium Dependent

- 11 MHz chip rate --11 chip symbols
- 1Mbps Differential binary phase shift keying BWE = 1/11
- 2 Mbps Differential quadrature phase shift keying BWE = 2/11
- Spreading uses a 11chip Barker code
  - +1,-1,+1,+1,-1,+1,+1,+1,-1,-1.-1
  - Nearly impulsive autocorrelation

802.11b CCK Complimentary Code Keying

- Complementary codes are symbols having desirable correlation functions
- Symbol rate 11/8 = 1.375 MHz
  - Chip rate 11MHz
  - 8 chips per symbol
  - QPSK modulation
- 5.5 Mbps 4 bits or 16 codes per symbol
- 11 Mbps 8 bits or 256 codes per symbol

802.11b CCK PMD
Physical Medium Dependent

- 11 MHz chip rate -- 8 chip symbols
- 5.5 Mbps data rate BWE = 0.5
  - Four 8 chip codes
  - QPSK modulated
- 11 Mbps data rate BWE = 1.0
  - Sixty Four 8 chip codes
  - QPSK modulated

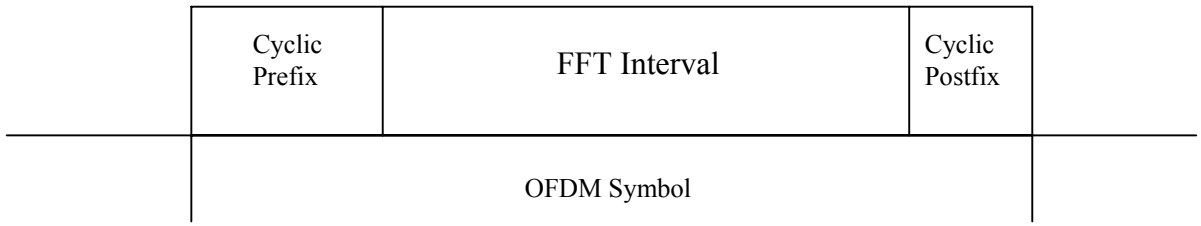
802.11b PBCC Packet Binary Convolutional Coding

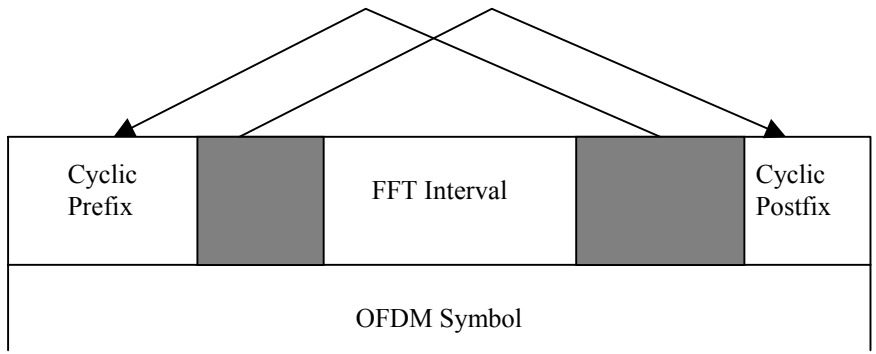
- Data is 1/2 rate convolutional coded
- 64 state convolutional coding -- 4 dB coding gain
- Data modulates carrier using pseudorandom cover sequence
  - At 11 Mbps data is QPSK BWE = 1.0
  - At 5.5 Mbps data is BPSK BWE = 0.5

802.11a OFDM Characteristics

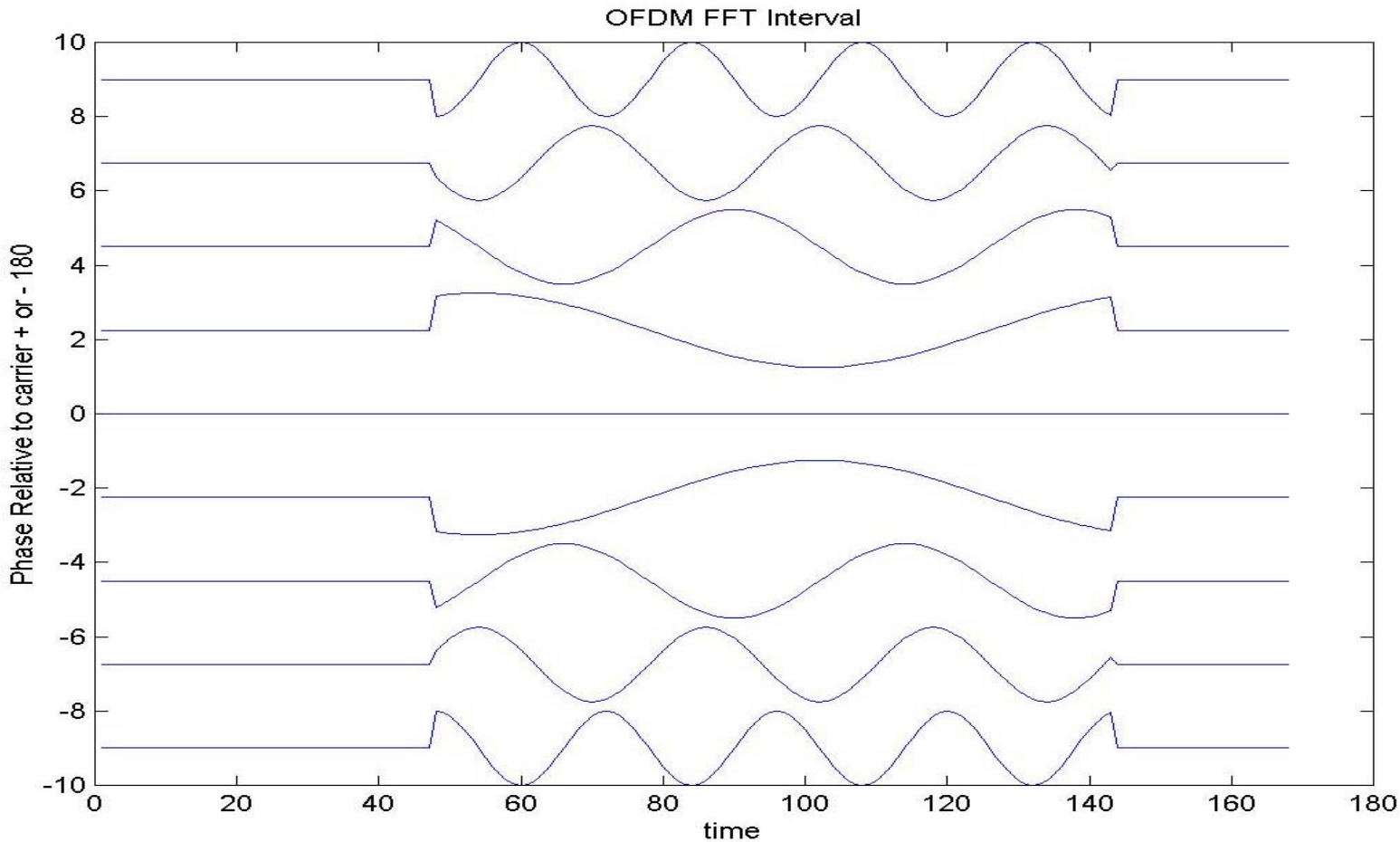
- Split high data rate stream into a number of lower data rate streams that are transmitted over subcarriers
- Combats multipath - Robust Equalization
- Forgiving to hardware frequency characteristics
- Flexible data rates
- Requires linear amplification

OFDM Symbol

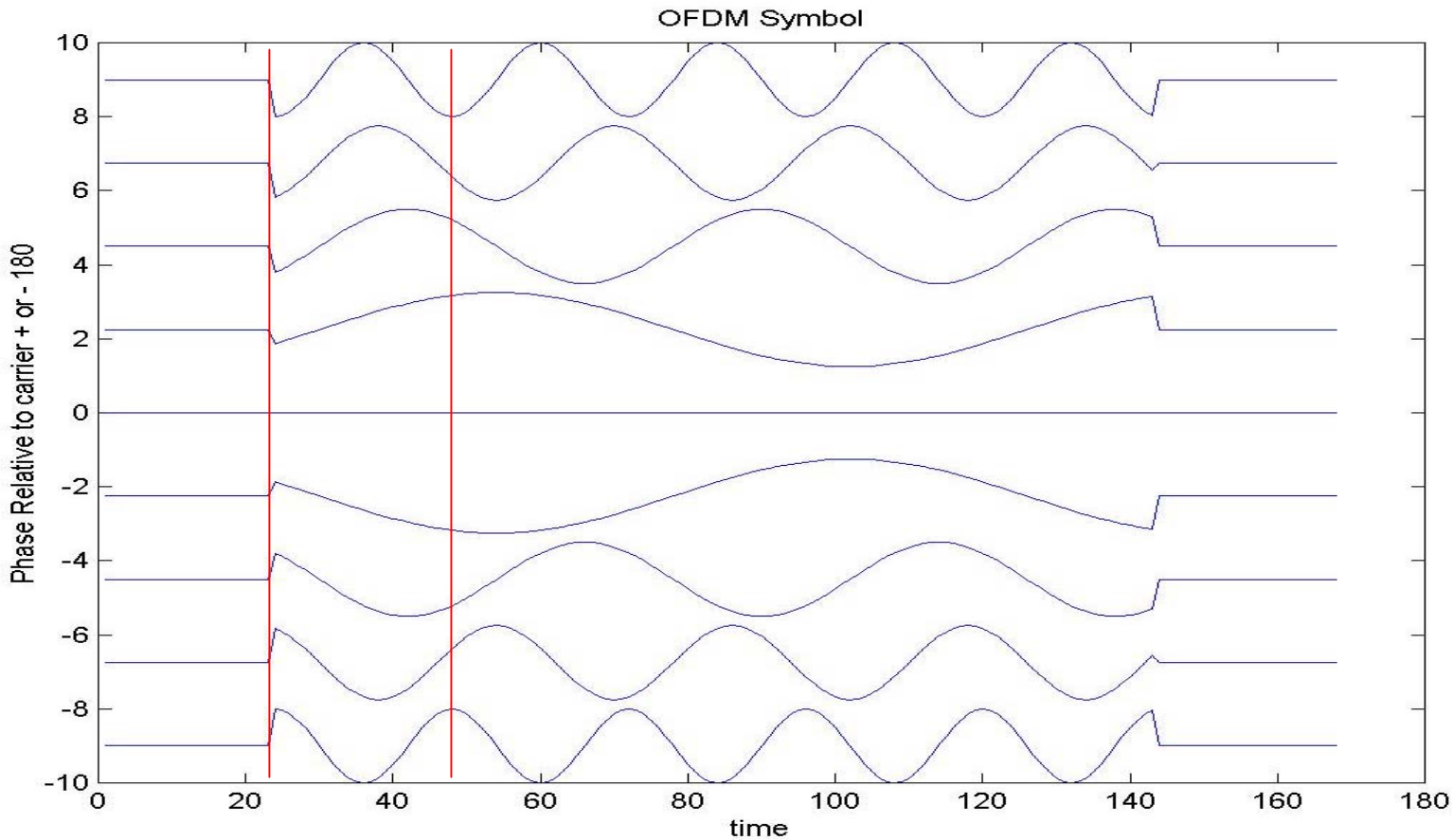

Cyclic
Prefix
FFT Interval
Cyclic
Postfix
OFDM Symbol


Cyclic
Prefix
FFT Interval
Cyclic
Postfix
OFDM Symbol

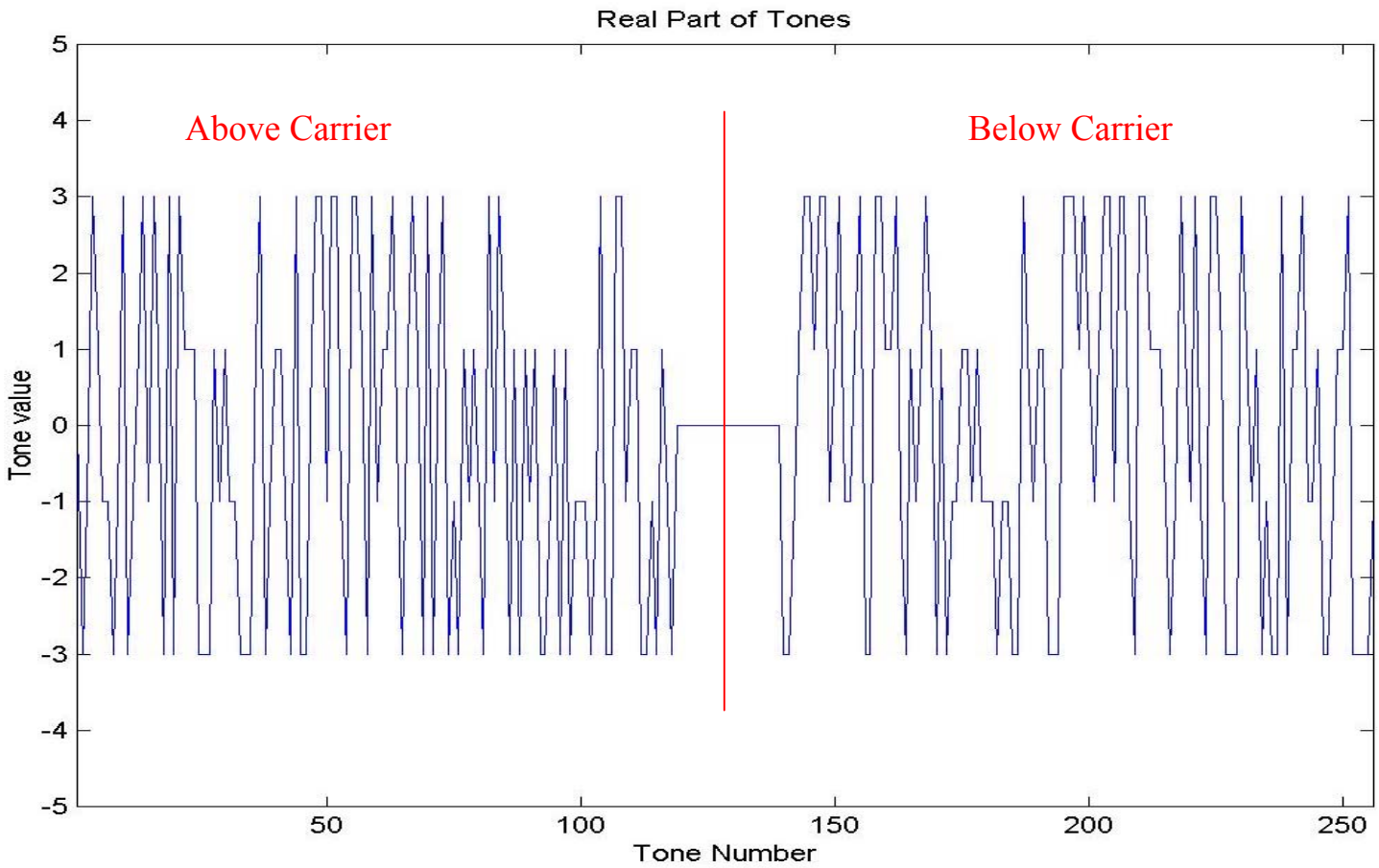
OFDM FFT Interval



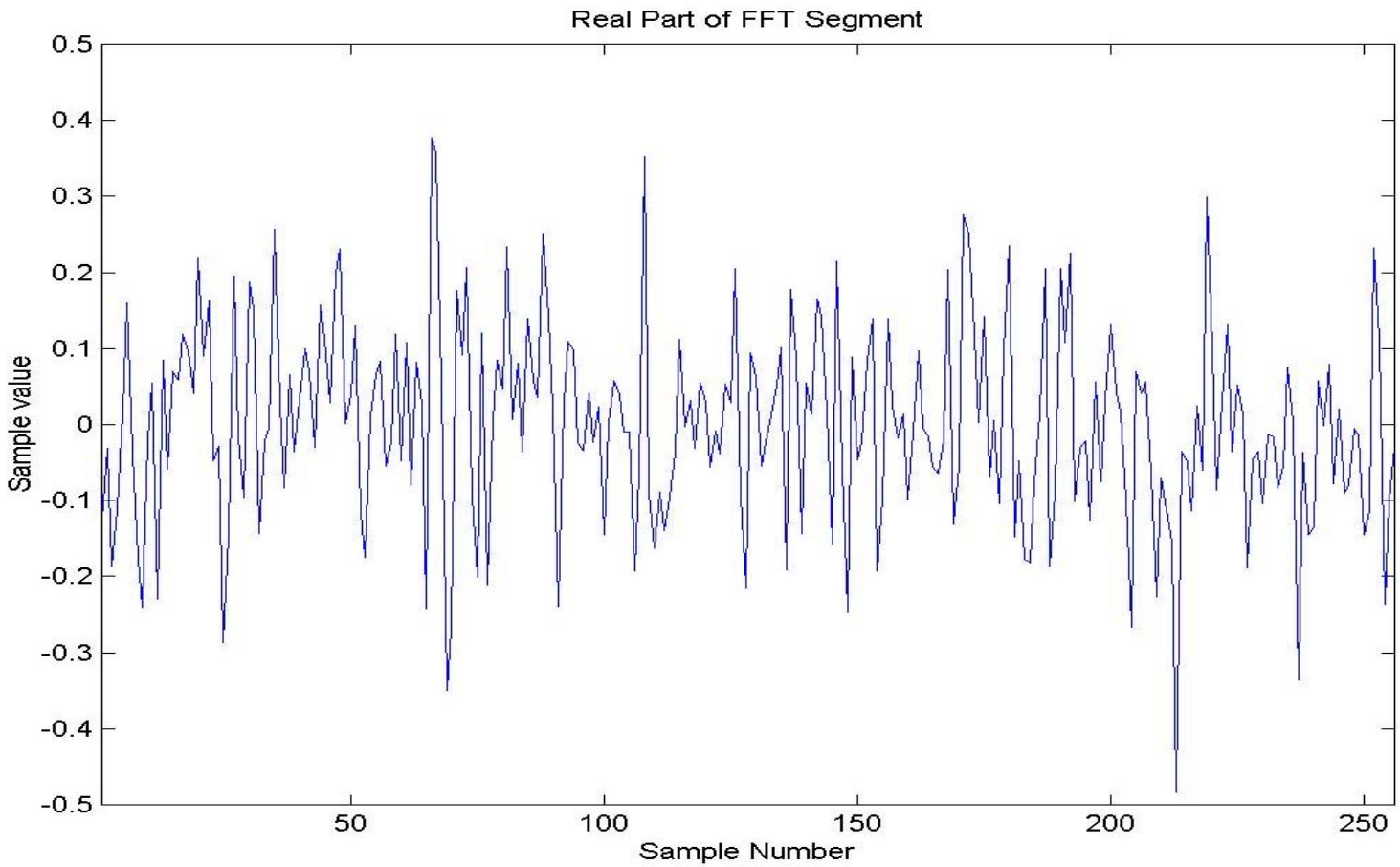
OFDM Symbol


OFDM Symbol
Phase Relative to carrier + or - 180
time
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
20
40
60
80
100
120
140
160
180

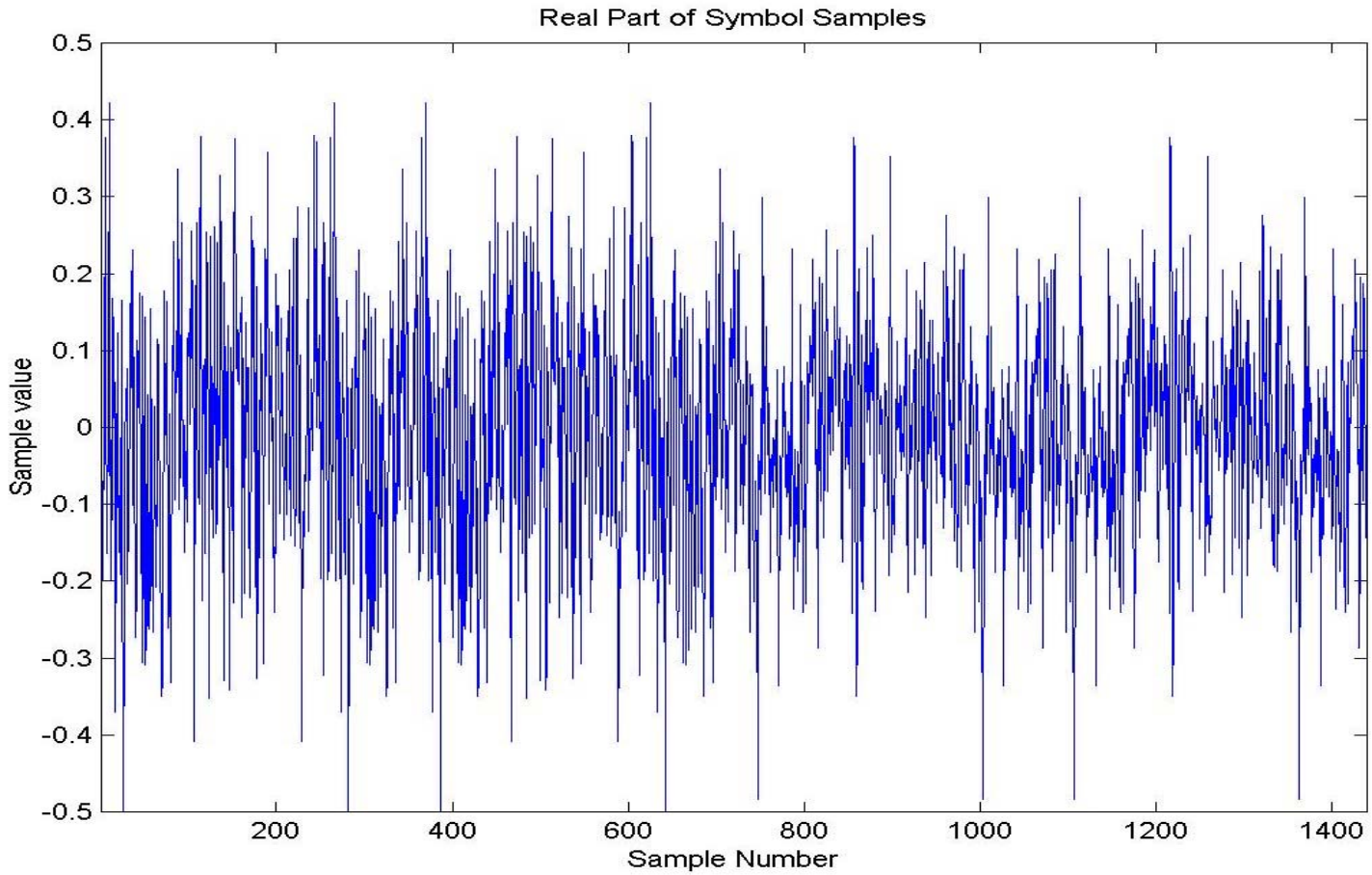
I Tone Values



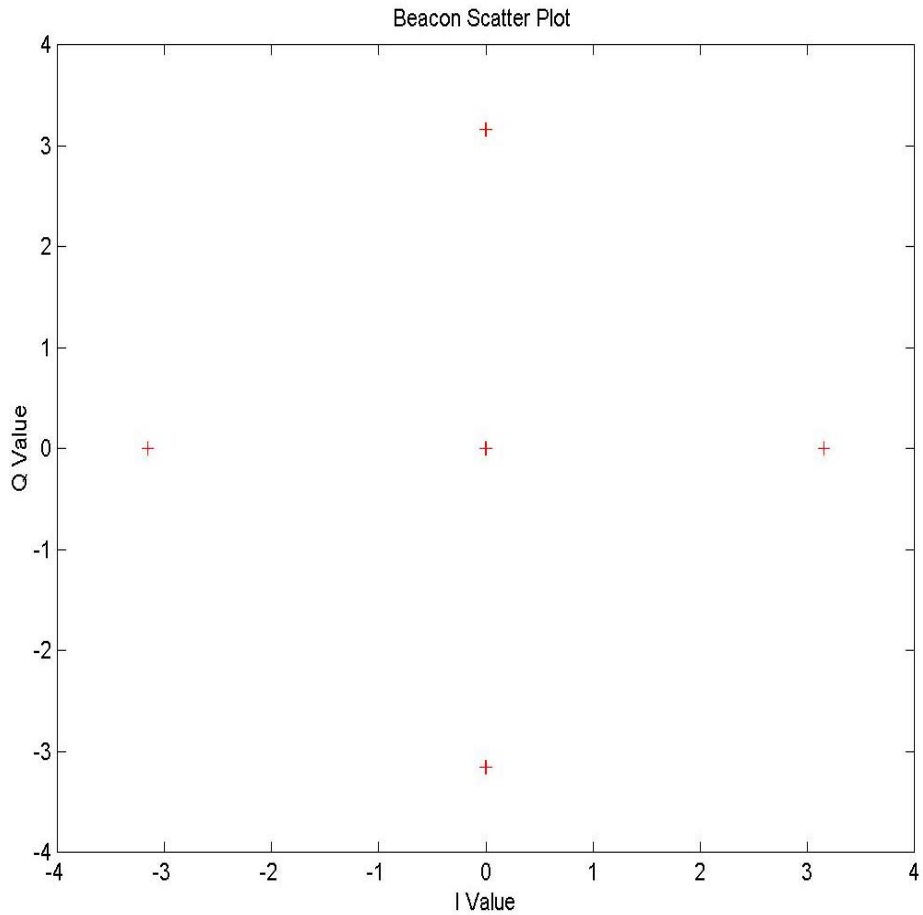
I Component of FFT Interval



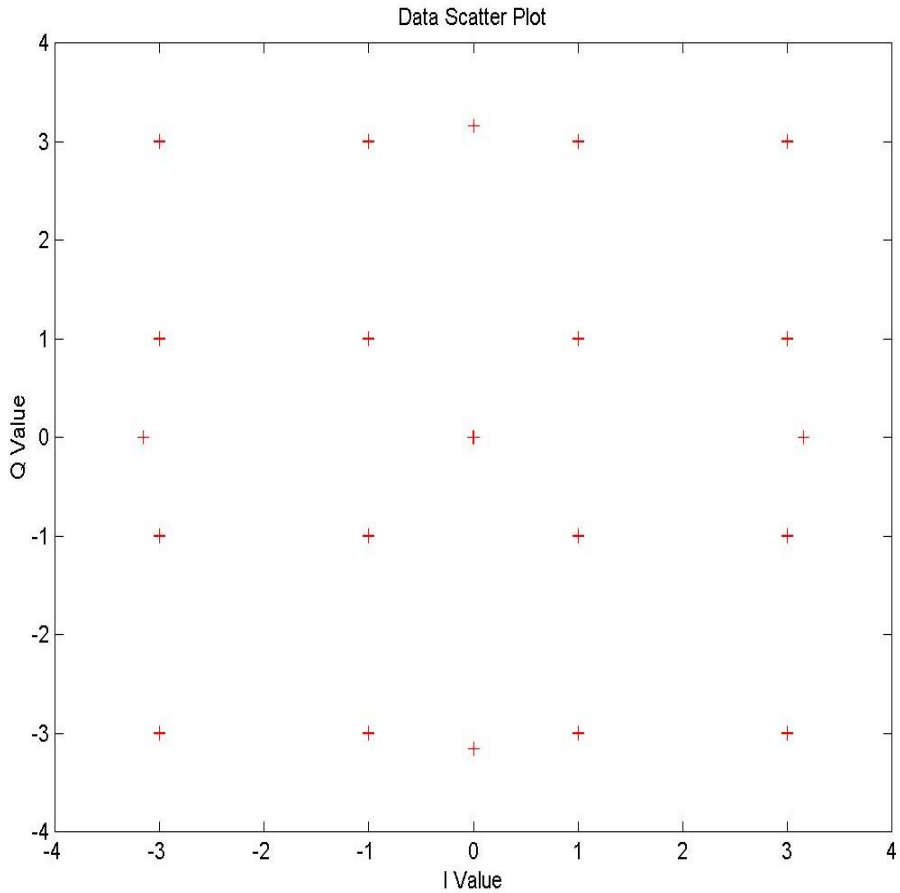
I Component of Four Symbols



QPSK Scatter Plot



16 QAM Scatter Plot



Motivation for OFDM

- Desired 54 Mbs in 20 MHz bandwidth in a 400 millisecond multipath enviroment
- Single carrier
  - Symbol length 50 nsec
  - 64 QAM
- OFDM
  - 64 Carriers
  - Symbol length 4 usec
  - 64 QAM

802.11a OFDM Parameters

- Total Number of Frequencies 64
- Number of Subcarriers Used 52
- Number of Pilots 4
- Number of Data Subcarriers 48
- Subcarrier Spacing 312.5 kHz
- -3 dB bandwidth 16.56 MHz
- Channel spacing 20 MHz

802.11a OFDM Parameters

- OFDM Signal Duration 4 usec
- Cyclic Prefix 800 nsec
- Complex sample rate 20 Msps
- Data Samples 64
- Guard Samples 16
- FFT Complex Tones 64

802.11a OFDM Parameters

- Data Rate 6,9,12,18,24,36,48,54 Mbps
- Modulation BPSK,QPSK,16QAM,64QAM
- Coding Rate 1/2, 2/3, 3/4
- Number of Data Subcarriers 48
- Max Data Rate 48*6*(3/4)/4 = 54 Mbps
  BWE = 2.7
- Min Data Rate 48*1*(1/2)/4 = 6 Mbps
  BWE = 0.3

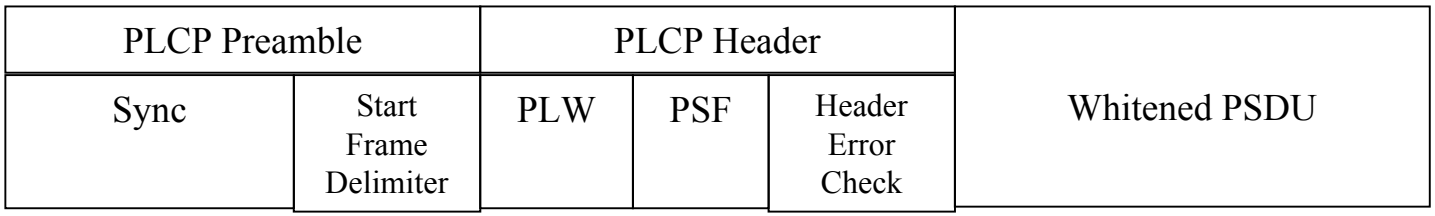
802.11g Unapproved

- Higher data rates for 2.4 GHz
- Mandatory OFDM as 802.11a
- Mandatory backward compatible with 802.11b
- Optional CCK/PBCC and CCK/OFDM
- Step towards dual band

PBCC 802.11g Packet Binary Convolutional Coding

- Data is 2/3 rate convolutional coded
- Coded data is modulates carrier with 8 PSK
- Throughput of 2 information bits per symbol

PLCP Physical Layer Convergence Protocol



Sync	80 bit Alternating one zero
Start of frame	0x0CBD
PSDU	PLCP service data unit
PLW	PSDU length word 12 bits
PSF	PLCP signaling field 4 bits – data rate
Header Error Check	16 bits

802.11g CCK/PBCC CCK/OFDM Hybrid CCK and PBCC or OFDM

- Uses the CCK to transmit the header/ preamble portion of each packet
- PBCC to transmit the payload. PBCC supports data rates up to 33 Mbps.
- OFDM to transmit the payload. OFDM supports data rates up to 54 Mbps.

Summary of 802.11 Modulation and Specifications

- 802.11
  - 2.4 GHz 1 or 2 Mbps FHSS or DSSS
- 802.11b
  - 2.4 GHz up to 11 Mbps CCK
- 802.11a
  - 5.8 GHz up to 54 Mbps OFDM
- 802.11g
  - 2.4 GHz up to 54 Mbps OFDM

OFDM Signal Processing

Transceiver

- Point to point communications
- Full duplex 100+ Mbps payload
- License free 5.8 GHz
- Low cost using many WLAN components
- Software defined radio
- Robust OFDM modulation
- Time Division Duplexed

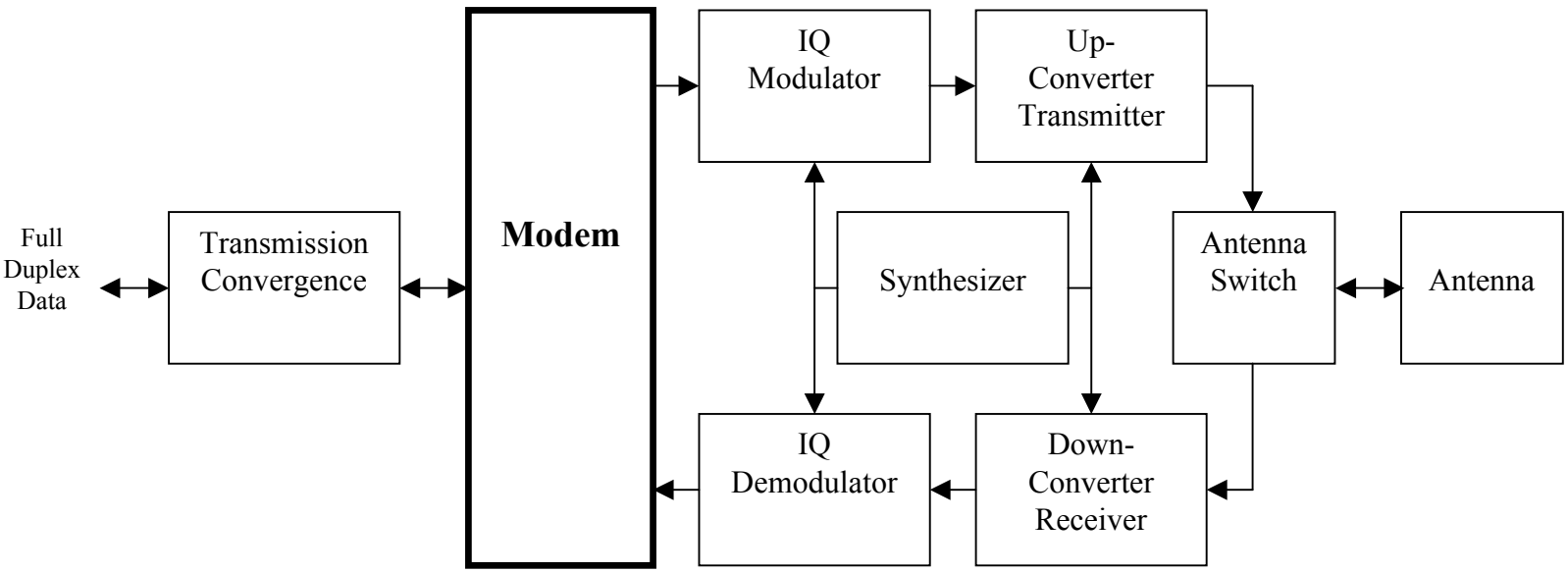
Software Defined Radio

- I and Q modulation
- Any modulation can be used
- Any data rate limited by complex sample rate of 75 MHz
- Programmable
  - High speed processing in FPGA
  - Control in DSP

TDD Characteristics

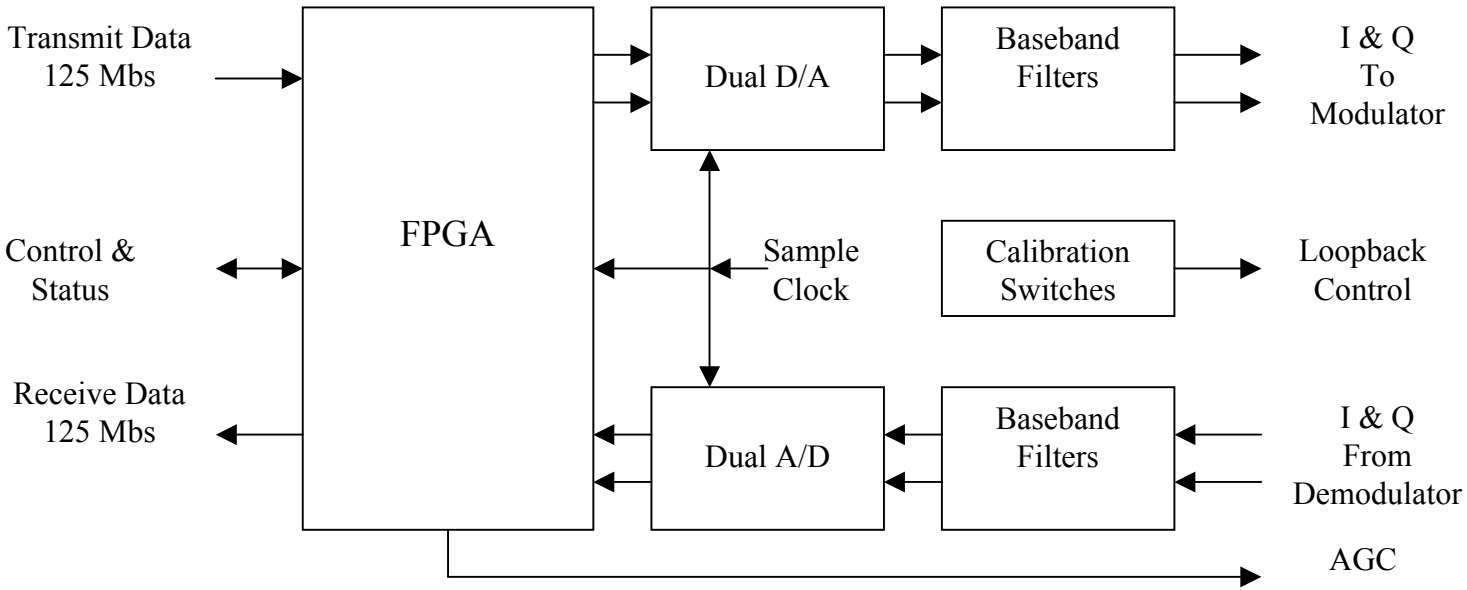
- Transmit and receive take turns on the same frequency.
- Adaptive asymmetrical service
- Simplifies RF hardware.
  - TR synthesizers have same frequency
  - No RF duplexer
  - No receive while transmit
- Reduces digital hardware. – Single FFT
- Introduces latency

TDD Transceiver



TDD Transceiver

Modem

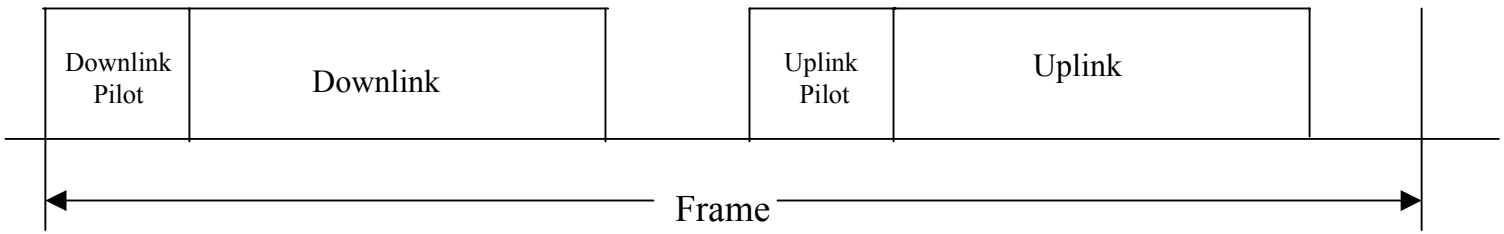

Transmit Data
125 Mbs
Control &
Status
Receive Data
125 Mbs
FPGA
Dual D/A
Baseband
Filters
I & Q
To
Modulator
Sample
Clock
Calibration
Switches
Loopback
Control
Dual A/D
Baseband
Filters
I & Q
From
Demodulator
AGC

Modem

OFDM Parameters

- Sample rate -- I and Q --75 Msps
- Symbol length 300 samples – 4 usec
- 256 FFT samples 30 preamble 14 postamble
- 210 data tones – 42 guard 2-pilot- 2 dc tones
- Frame 552 usec – 138 symbol slots per frame
- Frame 2 pilot 126 data 10 T/R Gap symbols
- 64 QAM modulation – 6 bits per symbol
- 0.92 Turbo product code
- Full duplex payload of 125 Mbs each direction
- RF Bandwidth 62 MHz – IQ 32 MHz

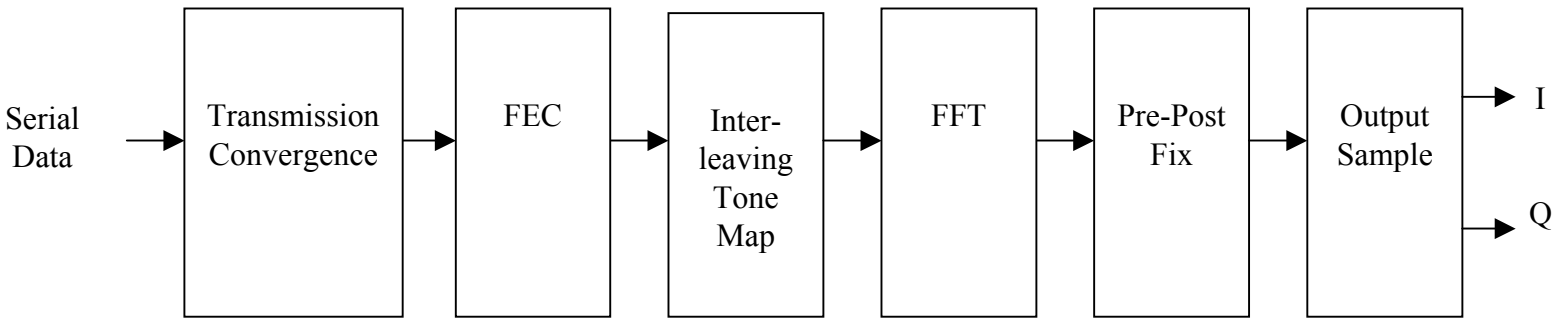
Frame Structure



Oscillator Considerations

- Oscillators 3 ppm @ 5.25 GHz 15.75 kHz.
  - Over 1 symbol 28 degrees of carrier shift.
  - Requires carrier correction during symbol.
- Oscillators 3 ppm @ 75 MHz 225 Hz.
  - Over 1 symbol 1/1000 of a sample shift
  - No time correction during symbol.
  - Over a frame 1/100 of a sample shift.
  - Requires time correction during frame.

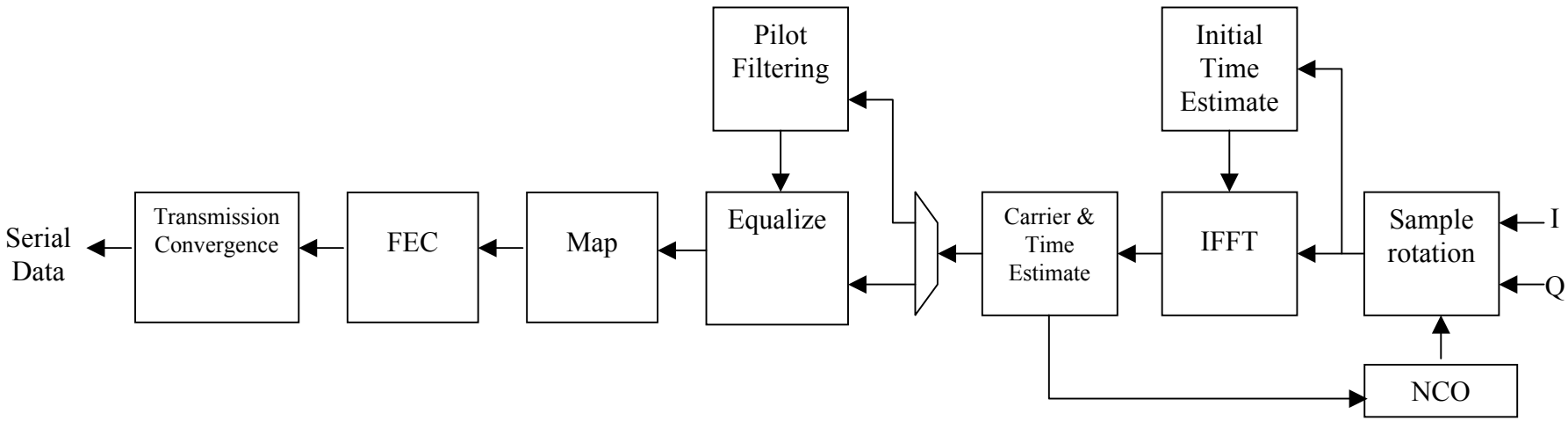
Transmit Signal Processing



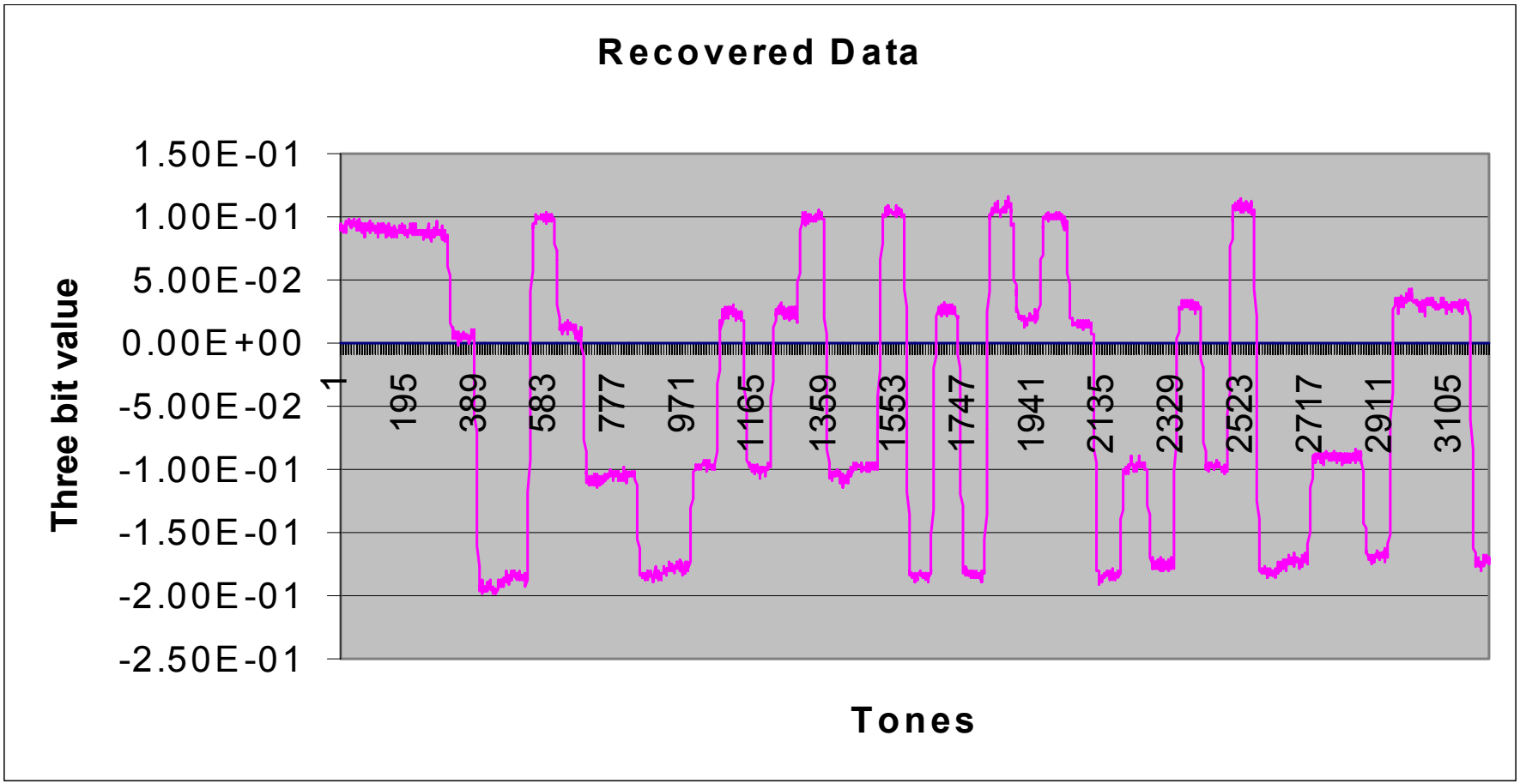
FFT

- 256 point FFT
- Fixed point
- Execution in 1 symbol time
- Radix 4 implementation
- 5 symbol latency

Receiver Signal Processing



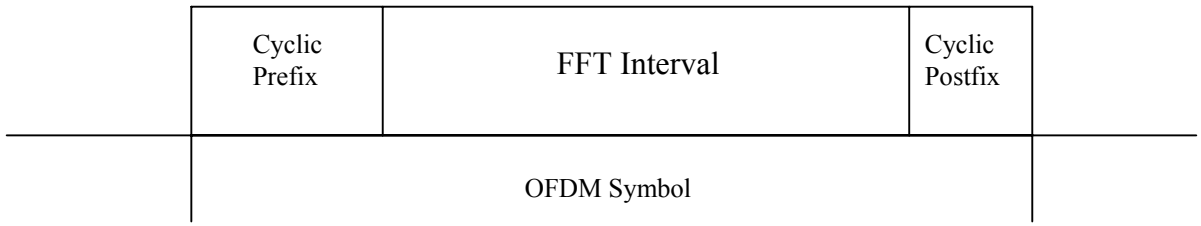
Hardware Recovered Data

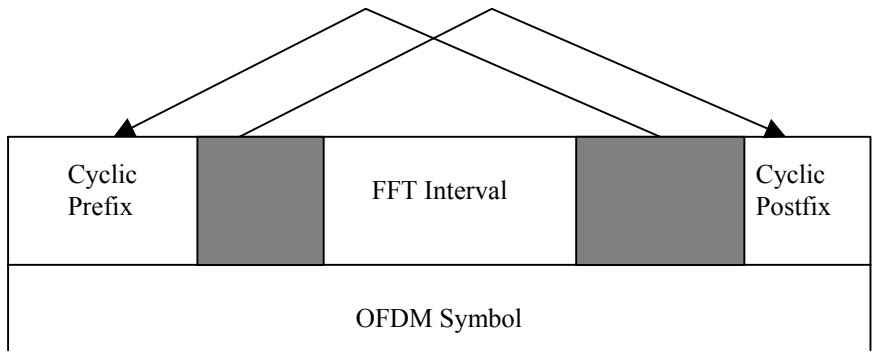


Initial Symbol Time Measurement

- Correlation measurement of pre and post fix
  - Maximum at signal time
  - Reliable detection of signal presence
- Minimum least squares difference measurement of pre and post fix
  - Minimum at signal time
  - Accurate measurement of signal time

OFDM Symbol


Cyclic
Prefix
FFT Interval
Cyclic
Postfix
OFDM Symbol


Cyclic
Prefix
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Cyclic
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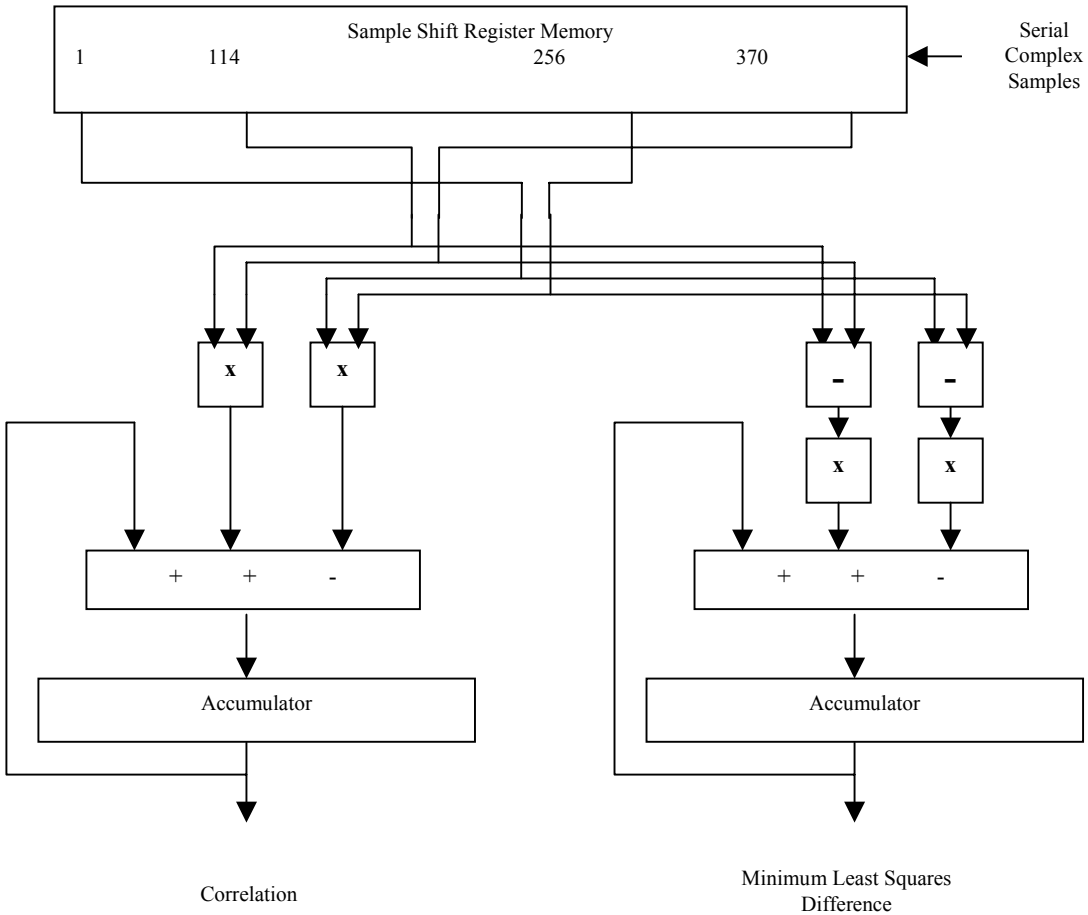
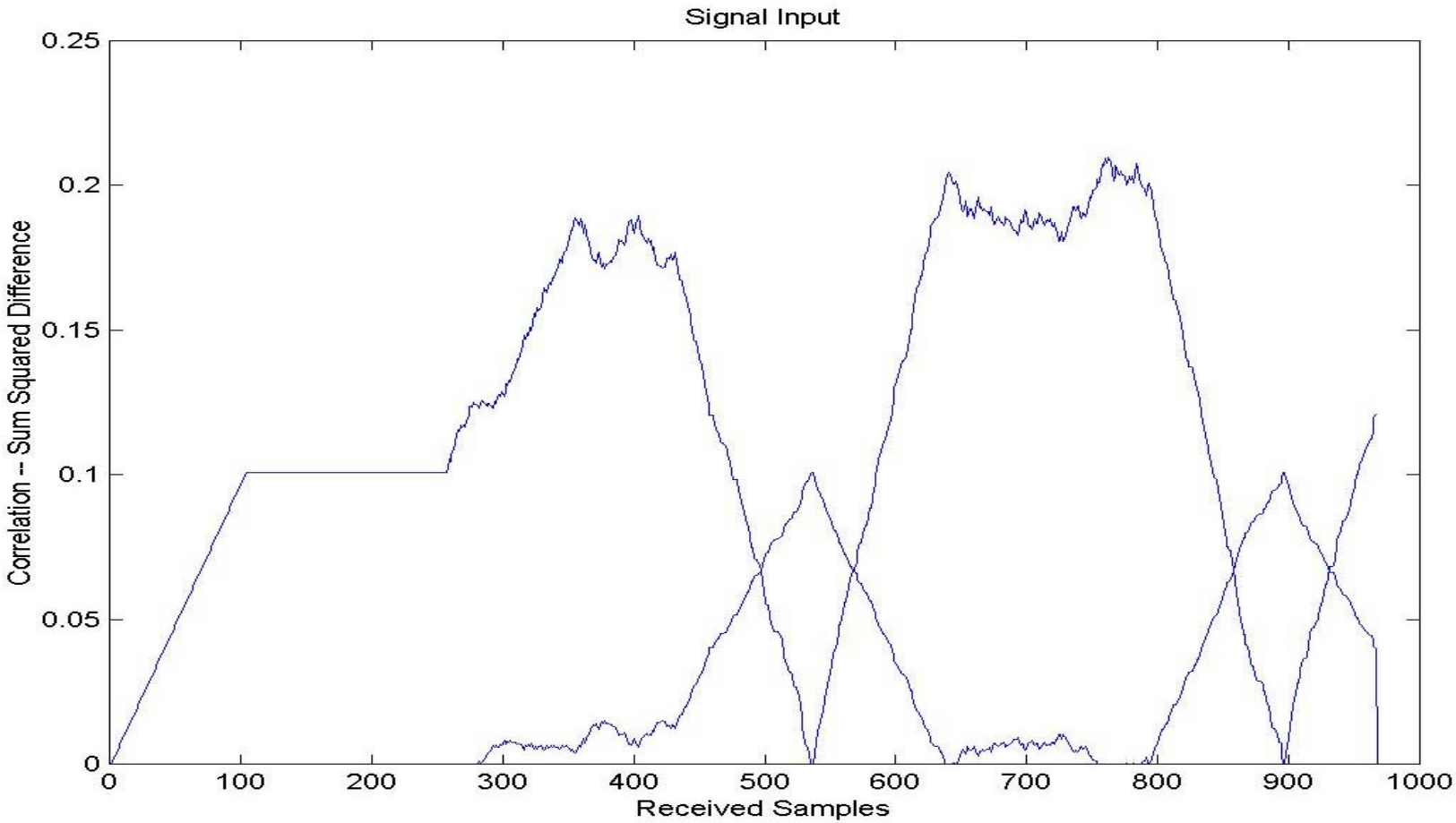
OFDM Symbol

Initial Time Measurement



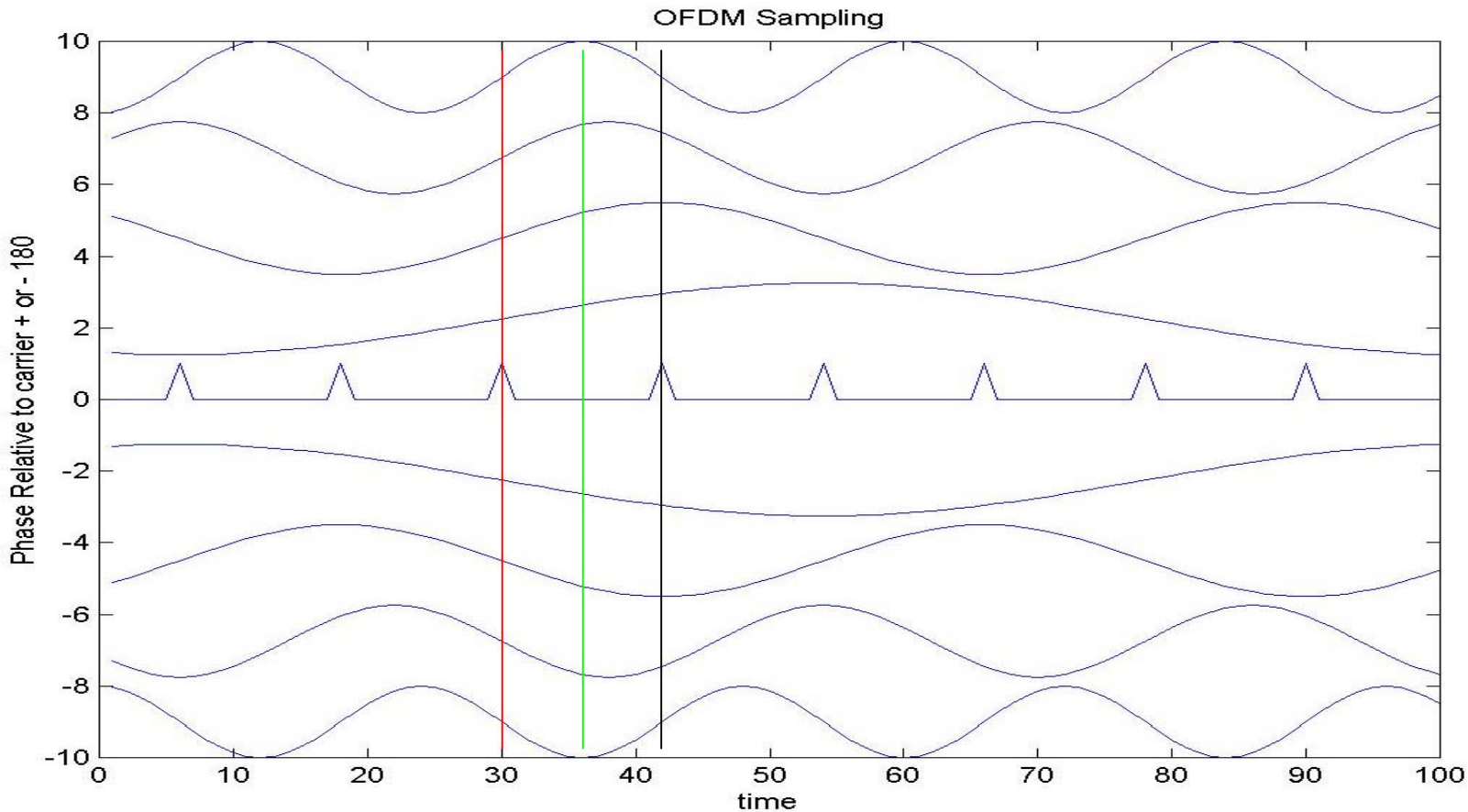
Initial Symbol Time Detection



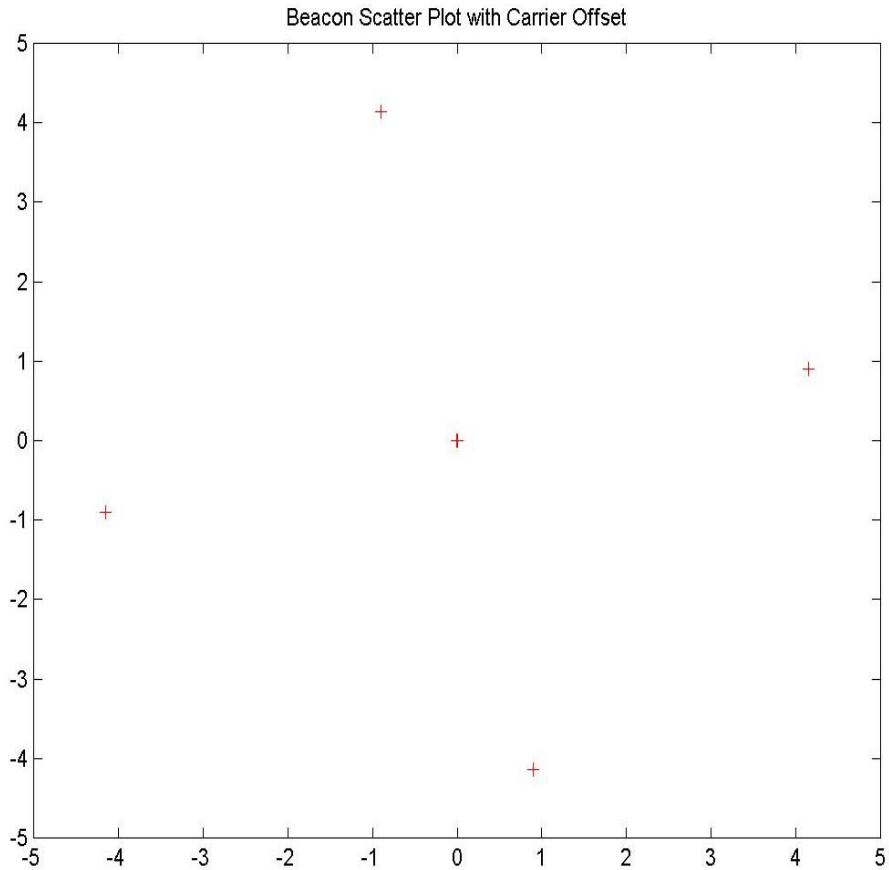
Received Signal Phase Estimation

- Received subcarrier phase is sum of nominal carrier phase, sample time and multipath.
  - Carrier phase adds to all subcarriers.
  - Time error adds phase of (n/N)*2pi.
  - Multipath is function of geometry.

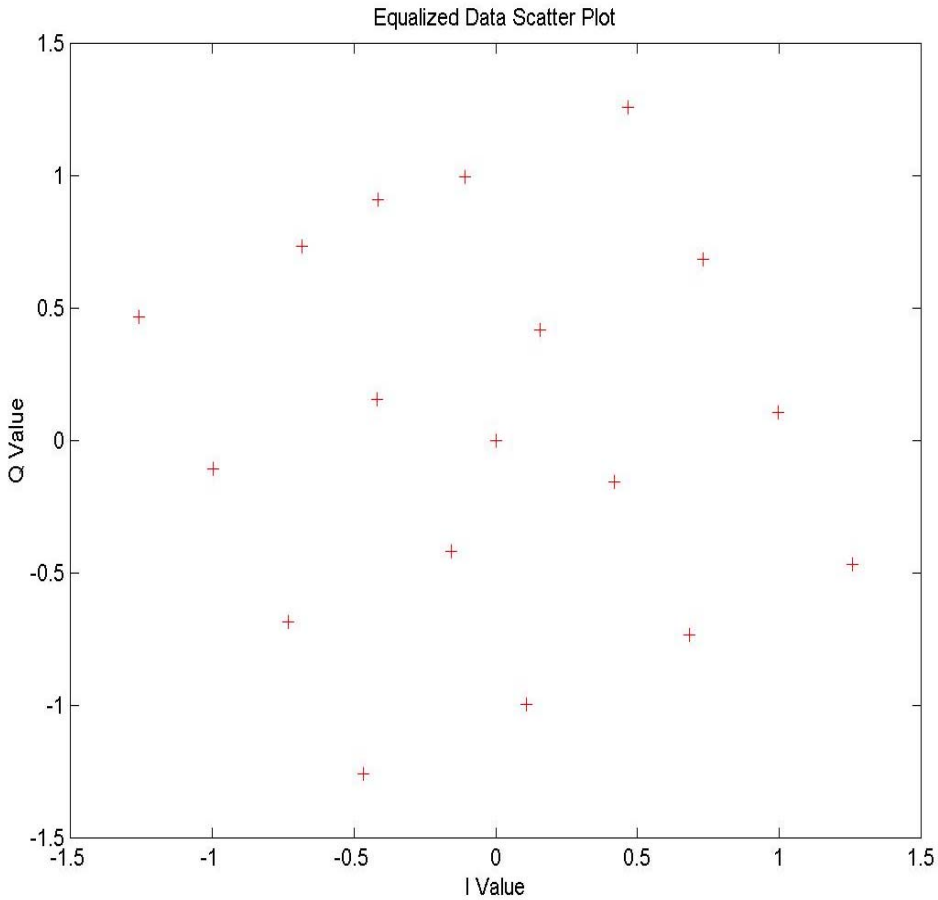
OFDM Sampling



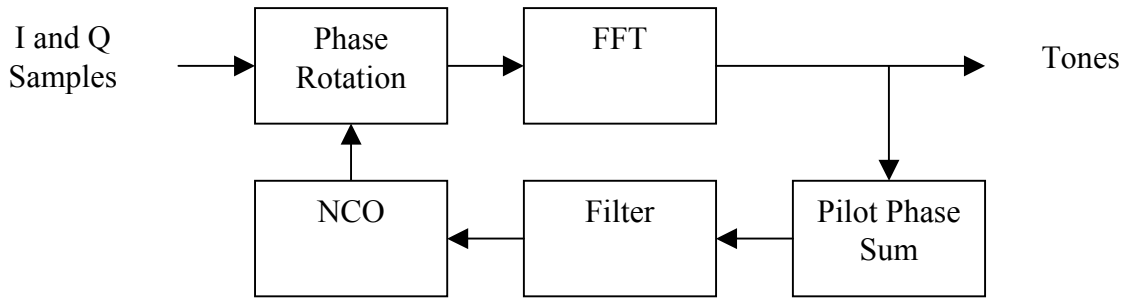
Pilot with Carrier Offset



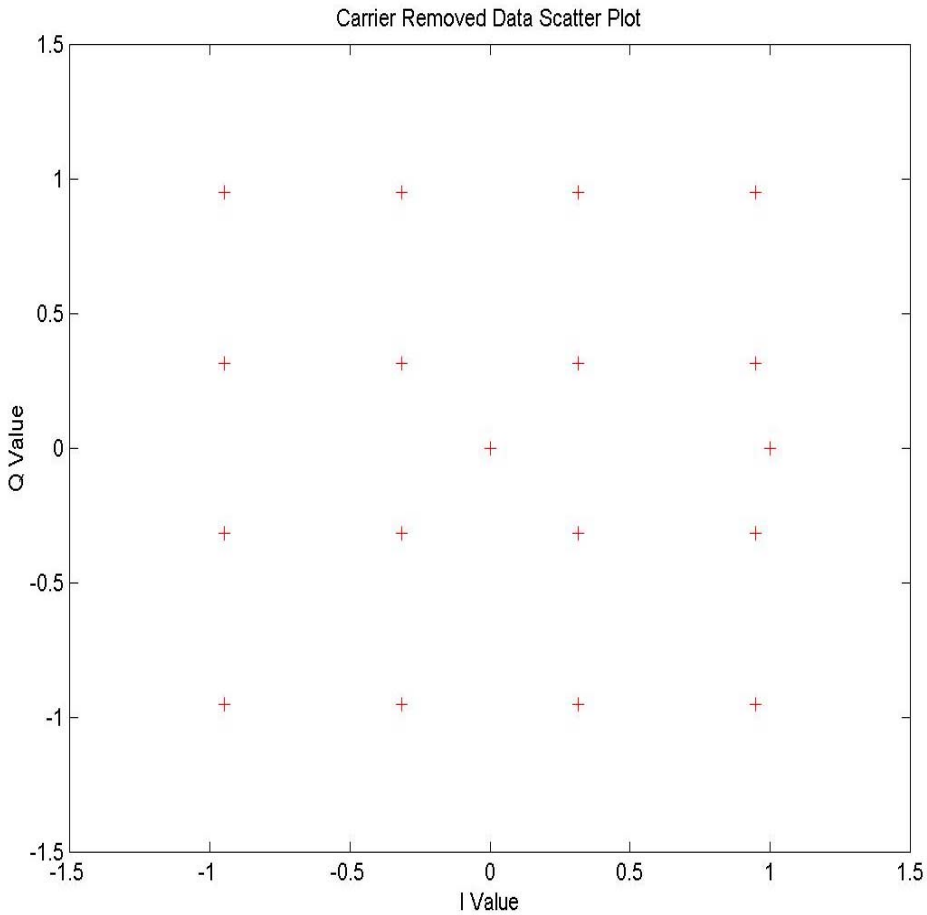
Data with Carrier Phase Offset



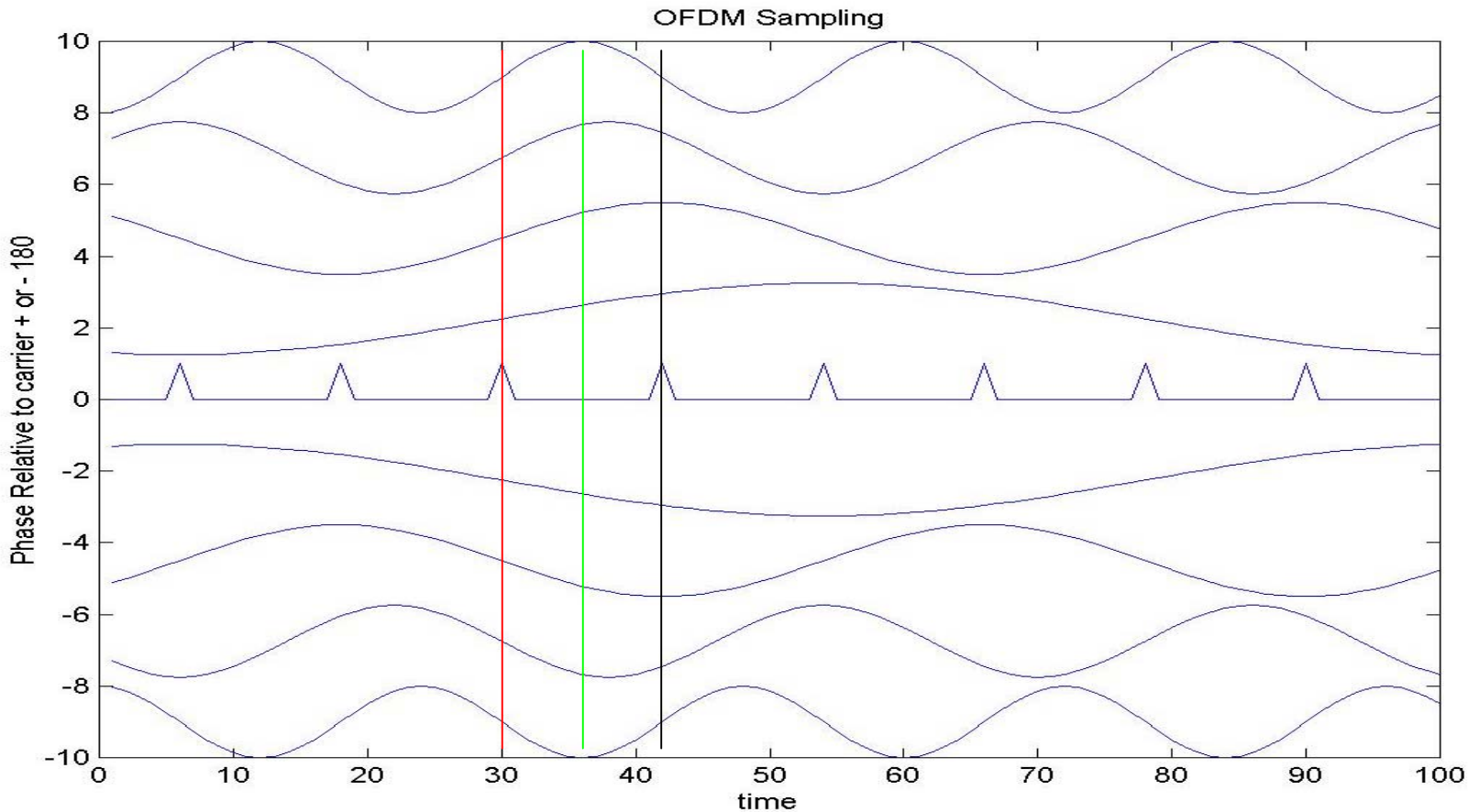
Carrier Tracking



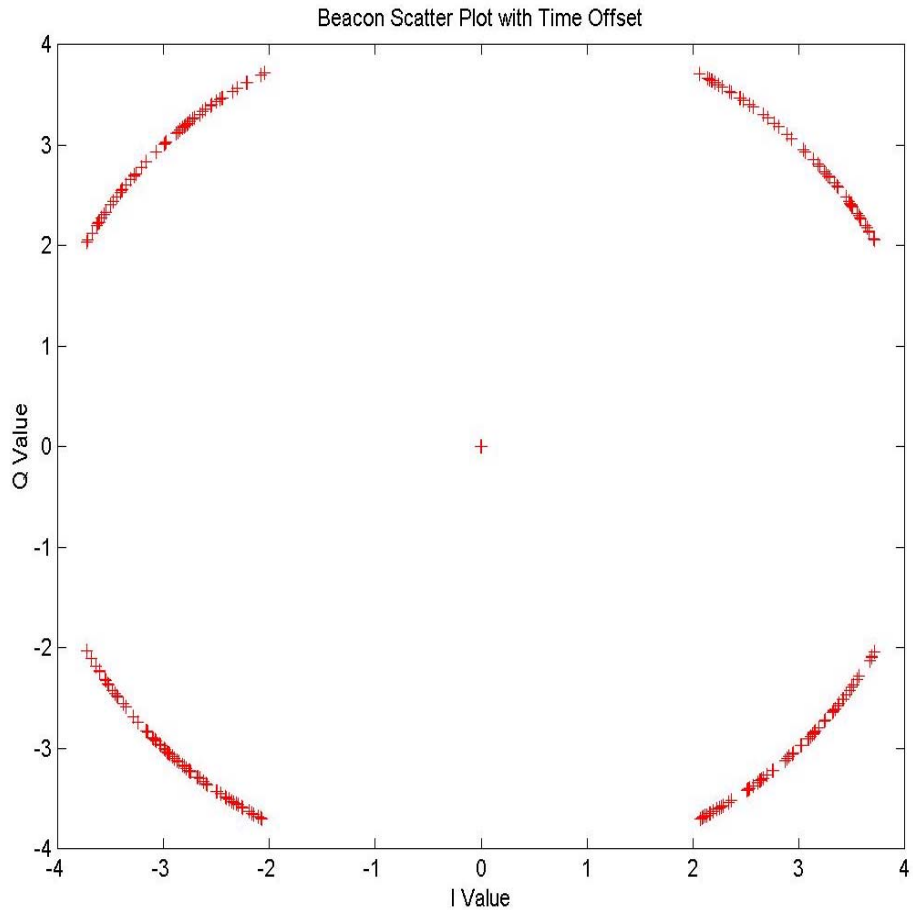
Data -- Carrier Offset Removed



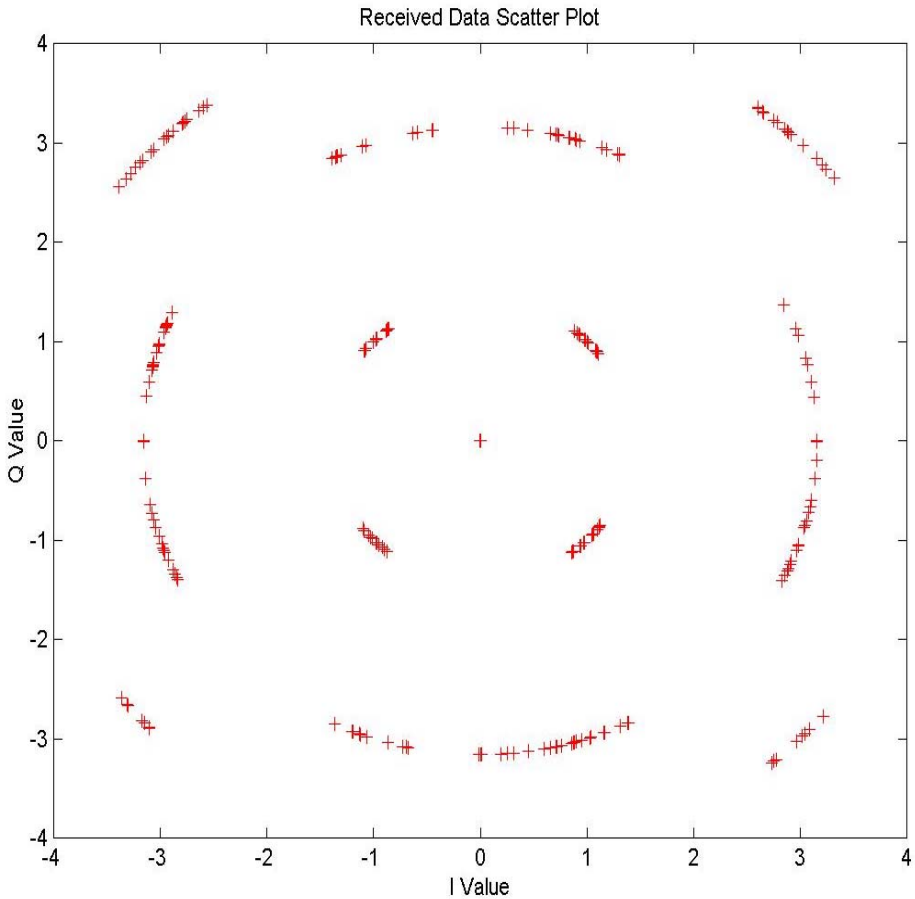
OFDM Sampling



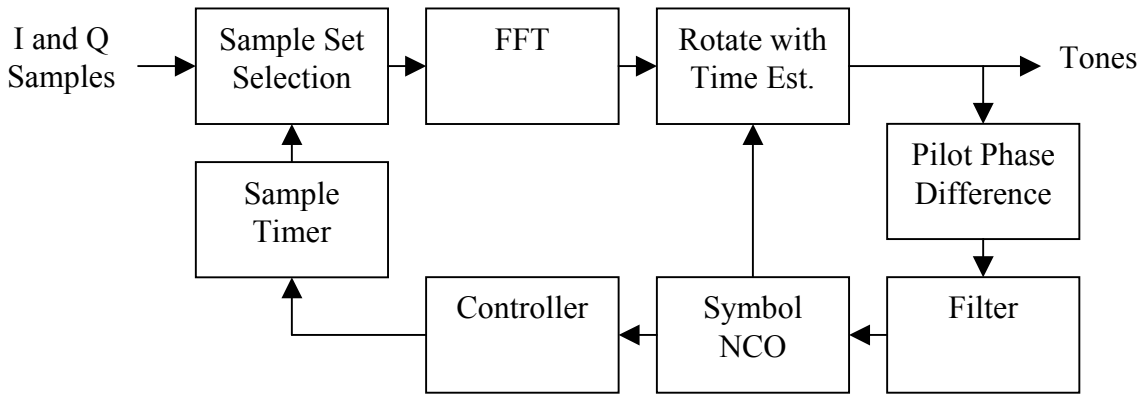
Pilot with Time Offset



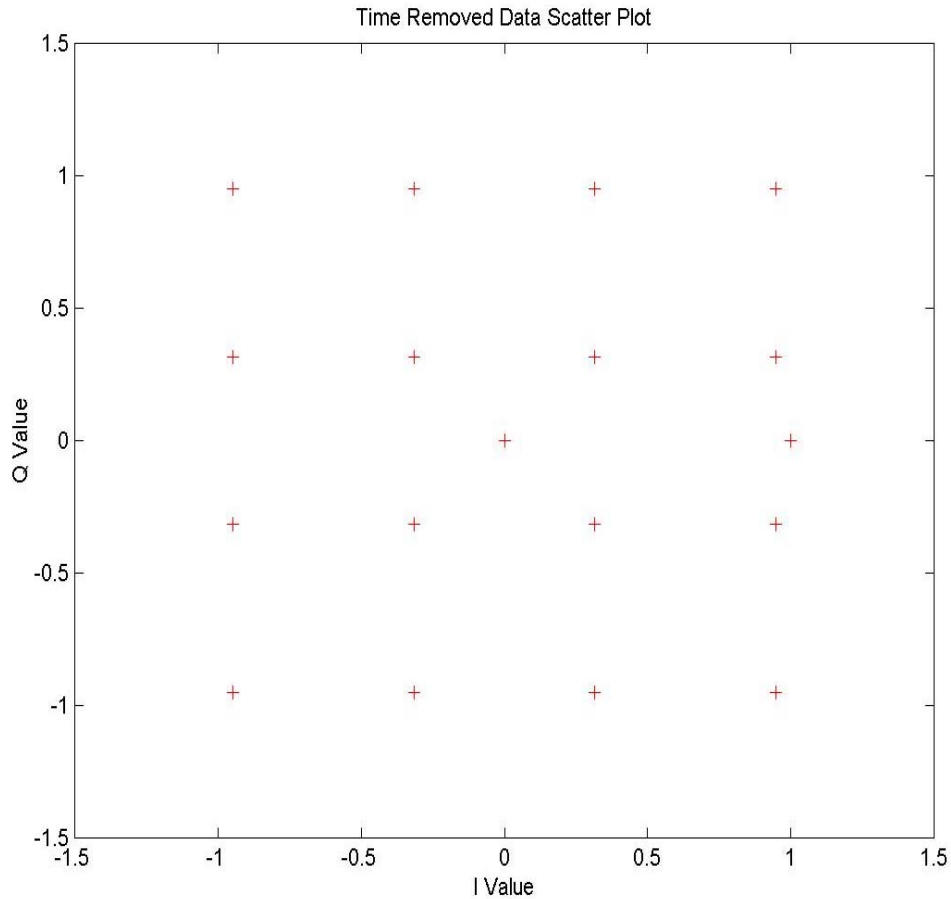
Data with Time Offset



Symbol Time Tracking



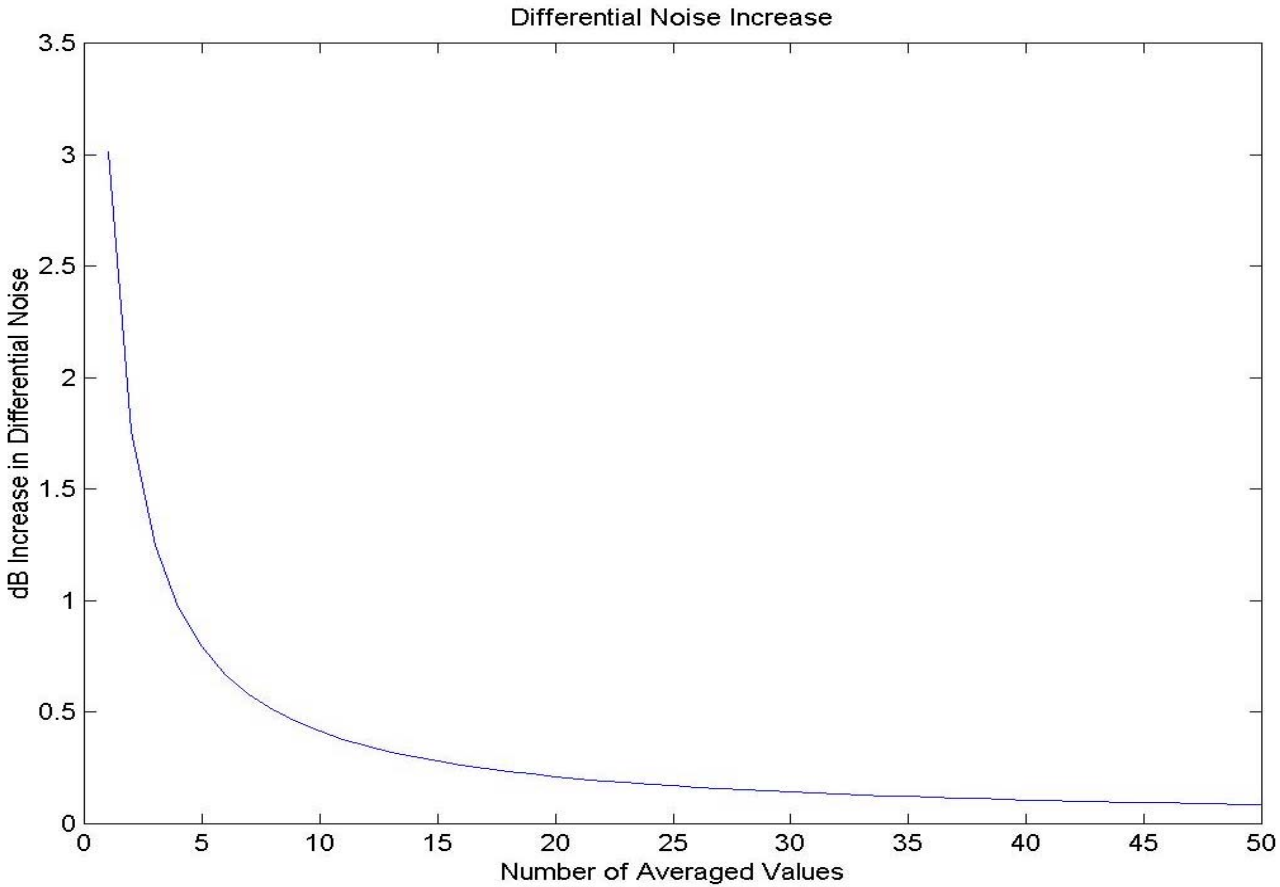
Data with Time Offset Removed



Equalization

- Pilot transmitted first in each burst
- Pilot components filtered over multiple frames
- Data normalized by pilot components
- Pilot designed for easy detection

Differential Loss



OFDM Signal Processing Summary

- FFT is an efficient method of recovering multiple subcarriers
- Coherent detection of subcarriers requires
  - Carrier recovery
  - Symbol time recovery
  - Equalization
- FPGA implementation to OC-3 speeds