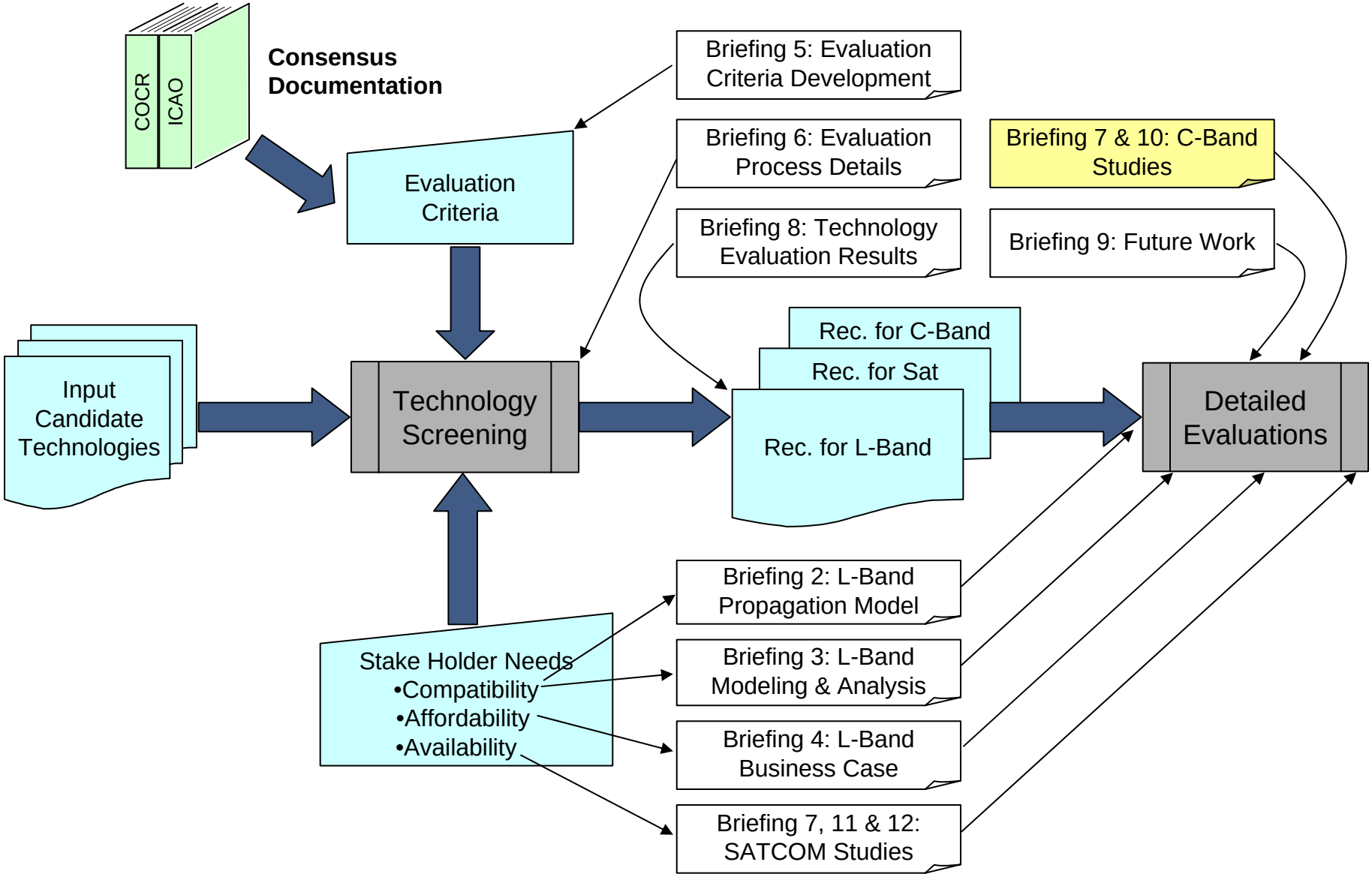
Briefing #10 - C-Band Studies

Future Communications Study

Phase II End of Task Briefing

June 22, 2006

Structure and Content of the Presentations



Briefing Outline

- Task Overview and Motivation
- 802-16 Overview
  - The 802-16 Standard
  - Relationship to WiMAX
- 802-16 Modeling
  - Transmitter Validation
  - Receiver Validation
- C-Band Channel Model
- Modeling Results and Suggested Further Research

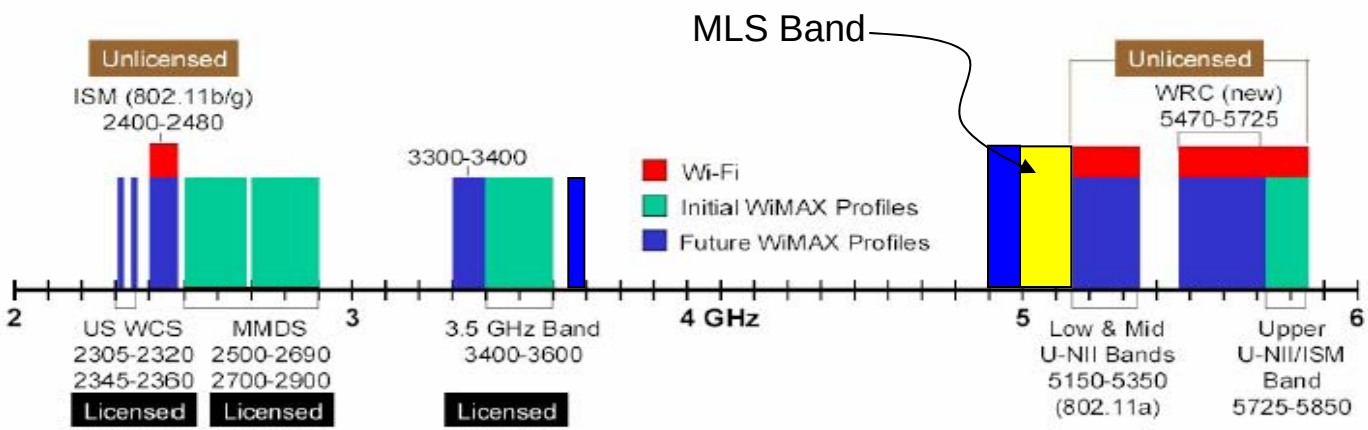
Task Overview and Motivation

Task Overview and Motivation

- What we did
  - We developed a high fidelity model of 802.16e and assessed its performance in the airport surface mobile propagation environment
- Why we did it
  - The first phase of the technology pre-screening suggested that the use of 802.16e might have some utility in the airport surface operational environment
  - There is increasing motivation for the aeronautical community to protect the current allocation of 5000 – 5250 MHz for ARNS
    - The MLS Band is underutilized
      - 11 civil systems and 29 military systems in the 5030 – 5091 MHz band
    - Commercial technologies, already contiguous to the band, are poised for explosive growth and are actively seeking new spectrum

Mounting Spectrum Pressure

- Potential Encroachment of Spectrum
  - Currently a lack of licensed spectrum for roll out of wireless broadband services in the U.S. using 802.16.
  - WiFi (802.11) has been highly successful, and analysts are predicting that with 802.16 (which allows handoffs from 802.11 LANS and provides for subscriber mobility as well as NLOS coverage) an explosion of usage
  - Additional bands are being considered today by different regions
    - 4.9 GHz – 5.0 GHz will be use after 2007 in Japan. The 5.47 GHz – 5.725 GHz band is being considered for future use.
    - 4.9 GHz public-safety band is being discussed in North America
    - As this technology is deployed, increased need/desire for spectrum might lead to pressure on the MLS band



Pre-Requisites to Deploying New Aviation Systems in the Band

- To protect aviation spectrum, aviation standardized systems will have to be deployed that use that spectrum; however, prior to deployment, these systems must be standardized
  - ANC/11 recommendation 7/5 on standardization requires that systems be <u>proven</u> to meet needs of ATN <u>before</u> standardization can commence
    - 802.16, perhaps coupled with 802.11, is a system that could meet the needs of aviation, especially on the airport surface, if not the entire TMA
      - Efforts to validate utility of standard up to and including flight tests would produce recommended standards changes for use in aviation. This could help to build a convincing case for ICAO standardization.
- Additionally, the proper allocations to the band will be required
  - The ICAO draft position for WRC-07 supports global allocations to AM(R)S in portions of the ARNS bands for ICAO standardized systems

Alignment of Need and Function

- 802.16e standard provides many features and modes that seem applicable to ATS & AOC communications
  - Applicable modes include
    - Metropolitan-area network, supporting both Point-to-Multipoint and Mesh topologies
      - Point to Multipoint would be the base topology for ATS & AOC comm.
      - Mesh features to extend range or provide utility at un-manned facilities
    - Backhaul connections (dedicated point-to-point links) could replace conventional telecommunications functions
      - Tower Data Link System communications link, ASDE-X multilateration ground station links, or other dedicated backhaul functions
  - Applicable 802.16e features include
    - Designed for mobility (802.16e should support mobility through 120 km/hr)
    - Air interface supports non-line of sight communications
    - Provides robust and guaranteed quality of service

802-16 Overview

802.16 Overview

- 802.16 is the IEEE developed standard for Wireless Metropolitan Area Networks (MAN)
  - Originally defined as fixed access only (mobility added with 802.16e)
  - Provides very efficient use of spectrum
  - Provides high bandwidth, with hundreds of users per channel
  - Flexible QoS offerings
    - Unsolicited Grant Services for constant bit-rate service flows (SFs)
    - Real-time Polling Services for real time Variable Bit Rate SFs
    - Non-real-time Polling Services
    - Best Effort
  - Wide range of applicable frequencies (up to 66 GHz)
  - High data rates for uplink and downlink
  - Supports multiple physical interfaces

IEEE 802-16e

- Provides enhancements to IEEE Std 802.16 to support subscriber stations moving at vehicular speeds
  - Specifies a system for combined fixed and mobile broadband wireless access.
  - Operation is limited to licensed bands suitable for mobility **below 6 GHz**
  - Fixed IEEE Std 802.16-2004 subscriber capabilities are not compromised

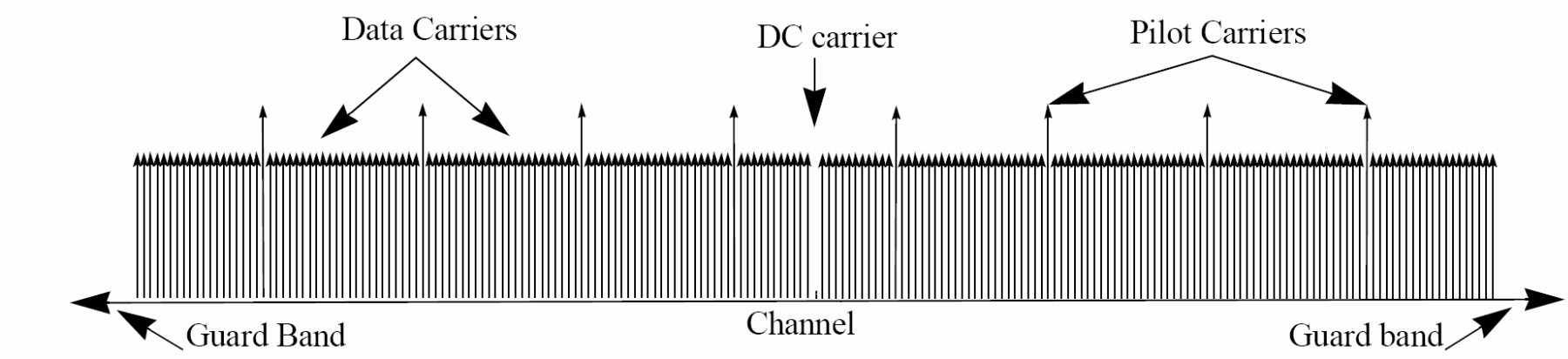
Designation	Applicability	PHY specification	Options	Duplexing alternative
WirelessMAN-SC™	10-66 GHz	8.1	—	TDD FDD
WirelessMAN-SCa™	below 11 GHz licensed bands	8.2	AAS (6.3.7.6) ARQ (6.3.4) STC (8.2.1.4.3) mobile	TDD FDD
WirelessMAN-OFDM™	below 11 GHz licensed bands	8.3	AAS (6.3.7.6) ARQ (6.3.4) Mesh (6.3.6.6) STC (8.3.8) mobile	TDD FDD
WirelessMAN-OFDMA	below 11 GHz licensed bands	8.4	AAS (6.3.7.6, 8.4.4.6) ARQ (6.3.4) HARQ(6.3.17) STC (8.4.8) mobile	TDD FDD
WirelessHUMAN™	below 11 GHz license-exempt bands	[8.2, 8.3 or 8.4] and 8.5	AAS (6.3.7.6) ARQ (6.3.4) Mesh (6.3.6.6) (with 8.3 only) STC (8.2.1.4.3/ 8.3.8/8.4.8)	TDD

Physical Layers that have mobility provisions in IEEE P802.16e

Physical Layer Descriptions

- WirelessMAN-SC™
  - This is an adaptive-modulation (QPSK, 16-QAM and 64-QAM) scheme on a single carrier that is designed for line-of-sight (LOS) channels in the frequency band 10-66 GHz. It is not applicable and does not support mobility
- WirelessMAN-SCa™
  - Defined for the 2-11 GHz band, the WirelessMAN-SCa™ (or SC2 as it is alternatively known) is also a single-carrier modulation. It is designed for non-LOS (NLOS) channels and also uses adaptive modulation.
    - Supported modulations include “spread BPSK”, BPSK, QPSK, 16-QAM, 64-QAM, and 256-QAM
    - Both Time- and Frequency-Division Duplex modes are defined
    - Uplink is TDMA, and downlink is either TDM or TDMA
    - While the 802.16e includes this PHY, and defines a new field in the Uplink Map message for fast-ranging of mobile stations, the PHY in general does not seem applicable

Physical Layer Descriptions - WirelessMAN-OFDM™

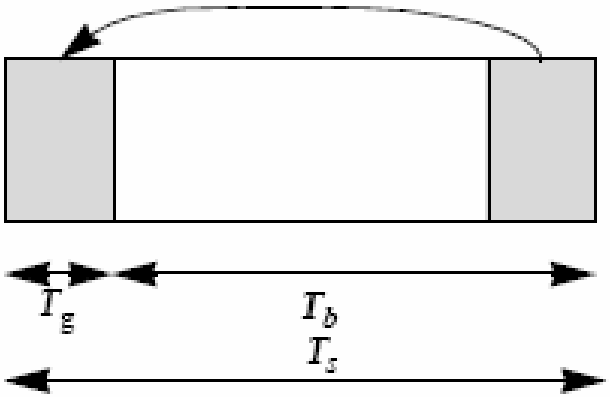


- Designed for NLOS operation
- Fixed FFT size (256 carriers), variable subcarrier spacing to support multiple defined bandwidths
- Adaptive modulation with BPSK, QPSK, 16-QAM and 64-QAM defined
- Coding includes concatenated Reed-Solomon-convolutional code (mandatory), Block Turbo coding (optional) or convolutional turbo codes (optional)

Physical Layer Descriptions - WirelessMAN-OFDM™ (2)

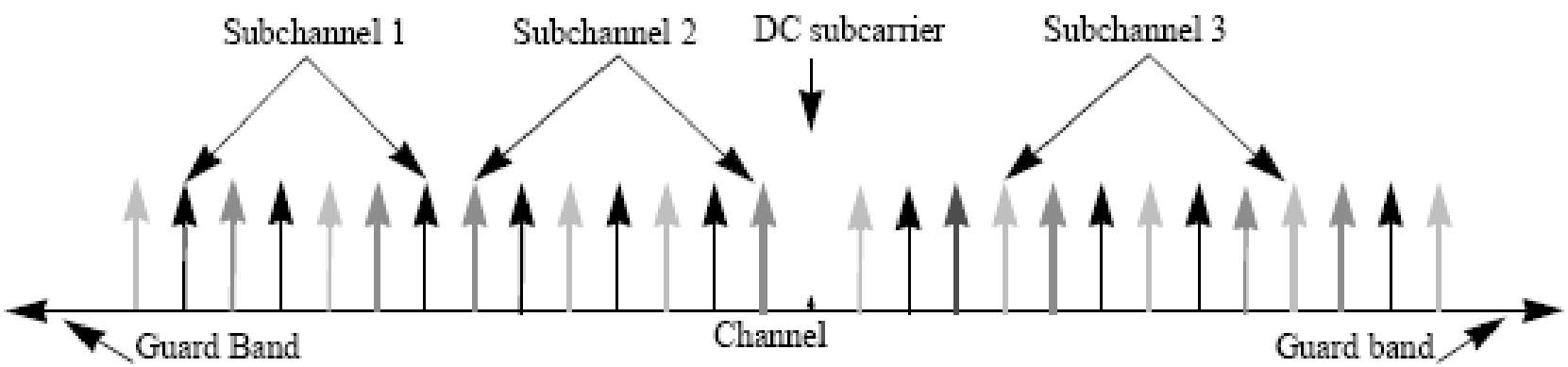
- Inverse-Fourier-transforming creates the OFDM waveform; this time duration is referred to as the useful symbol time *Tb*.
- A copy of the last *Tg* of the useful symbol period, termed CP, is used to collect multipath, while maintaining the orthogonality of the tones.
- Changes to the OFDM PHY in 802.16e include DL sub-channelization, fast ranging, fast tracking (for power, time and frequency corrections), and introduction of an open loop power control mode

Parameter	Value
N_{FFT}	256
N_{used}	200
n	For channel bandwidths that are a multiple of 1.75 MHz then n = 8/7 else for channel bandwidths that are a multiple of 1.5 MHz then n = 86/75 else for channel bandwidths that are a multiple of 1.25 MHz then n = 144/125 else for channel bandwidths that are a multiple of 2.75 MHz then n = 316/275 else for channel bandwidths that are a multiple of 2.0 MHz then n = 57/50 else for channel bandwidths not otherwise specified then n = 8/7
G	1/4, 1/8, 1/16, 1/32
Number of lower frequency guard subcarriers	28
Number of higher frequency guard subcarriers	27



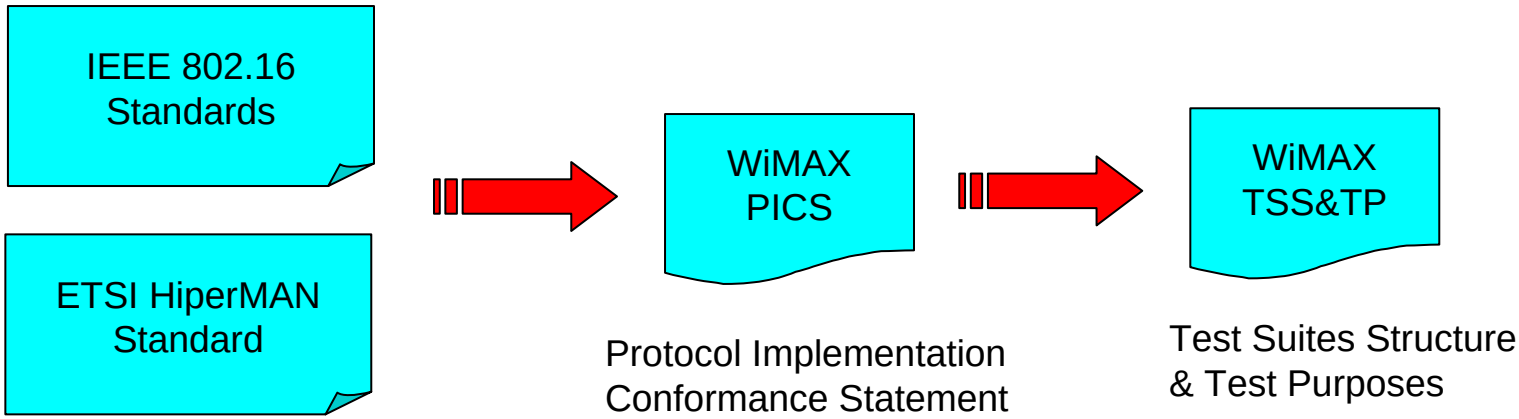
Physical Layer Descriptions - WirelessMAN-OFDMA™

- Like the OFDM waveform, this also uses OFDM modulation; however, subsets of carriers are mapped to sub-channels to support multiple access and other features
  - Designed for NLOS operation
  - Supports Mobility
  - Supports variable bandwidths by changing the FFT definition
    - At least one of the FFT sizes (2048, 1024, 512 or 128) shall be supported (802.16e)
  - Adaptive modulation with QPSK, 16-QAM and 64-QAM defined
  - Coding includes tail-biting convolutional coding (mandatory), Block Turbo coding (optional) or convolutional turbo codes (optional)



Relationship of WiMAX and IEEE, ETSI

- The WiMAX Forum scope is to
  - Ensure interoperability of IEEE 802.16 and other interoperable (ETSI HiperMAN) systems
  - Based upon market requirements, reduce the breadth of the IEEE 802.16 standard so that interoperability can be achieved
  - Host interoperability events
  - Enable certification on a worldwide basis
- The WiMAX Forum has been defining Protocol Implementation Conformance Statements (PICS) to which commercial equipment will be developed



"Fixed" WiMAX System Profiles

- The Initial WiMAX system profile was for Fixed Broadband Access
  - Uses 256 point FFT OFDM Physical layer

Freq Band	Duplexing	Channelisation (MHz)
3400 – 3600	TDD	3.5
		7.0
	FDD	3.5
		7.0
5725 – 5850	TDD	10

  - Additional profiles were defined for the 2500 – 2690 MHz band using 5 or 5.5 MHz channelisation. All defined profiles are OFDM for fixed broadband access

"Mobile" WiMAX System Profiles

- Release-1 Mobile WiMAX profiles will be completed in 2006
  - All will be based on Scaleable-OFDMA
  - Only Time-Division-Duplexing will be supported (FDD is tailored out)

Parameters	Values			
System Channel Bandwidth (MHz)	1.25	5	10	20
Sampling Frequency (F_p in MHz)	1.4	5.6	11.2	22.4
FFT Size (N_{FFT})	128	512	1024	2048
Number of Sub-Channels	2	8	16	32
Sub-Carrier Frequency Spacing	10.94 kHz			
Useful Symbol Time ($T_b = 1/f$)	91.4 microseconds			
Guard Time ($T_g = T_b/8$)	11.4 microseconds			
OFDMA Symbol Duration ($T_s = T_b + T_g$)	102.9 microseconds			
Number of OFDMA Symbols (5 ms Frame)	48			

Note: The highlighted text (yellow) represents the expected Mobile WiMAX profiles. Channel bandwidths of 7 and 8.75 MHz are also planned profiles. The 1.25 and 20 MHz bandwidths shown in the chart are IEEE 802.16e specified elements that will **not** be included

Differences Between OFDM and OFDMA Physical Layers

- Note the following
  - While the IEEE standard is quite flexible, the WiMAX Forum PICS (by design) are not
  - The aviation community will be free to use whatever elements of the standard make sense for aviation; however, the commercial implementations available will be
    - OFDM for “Fixed” WiMAX
    - OFDMA for “Mobile” WiMAX
- The differences between the two that impact performance include:
  - Use of HARQ
    - Standard indicates that this is an OFDMA option only (paragraph 6.3.17)
    - Provides a time-diversity element that is effective mitigator to mobility induced fading
  - Use of Fast Feedback Channel (CQICH)
    - Standard indicates this is an OFDMA option only (paragraph 6.3.17.4)
    - Use of Fast Feedback, when combined with adaptive modulation and coding, is an effective mitigator to mobility induced fading
  - Use of Diversity Sub-carrier permutations to form Sub-channels in OFDMA provides a frequency diversity advantage to the OFDM PHY

  ⇨Better mobile performance is expected with OFDMA than OFDM

802-16 Modeling

Selection of a Physical Layer for Modeling

- It is expected that the OFDM derivatives will have superior performance to the single frequency physical layer

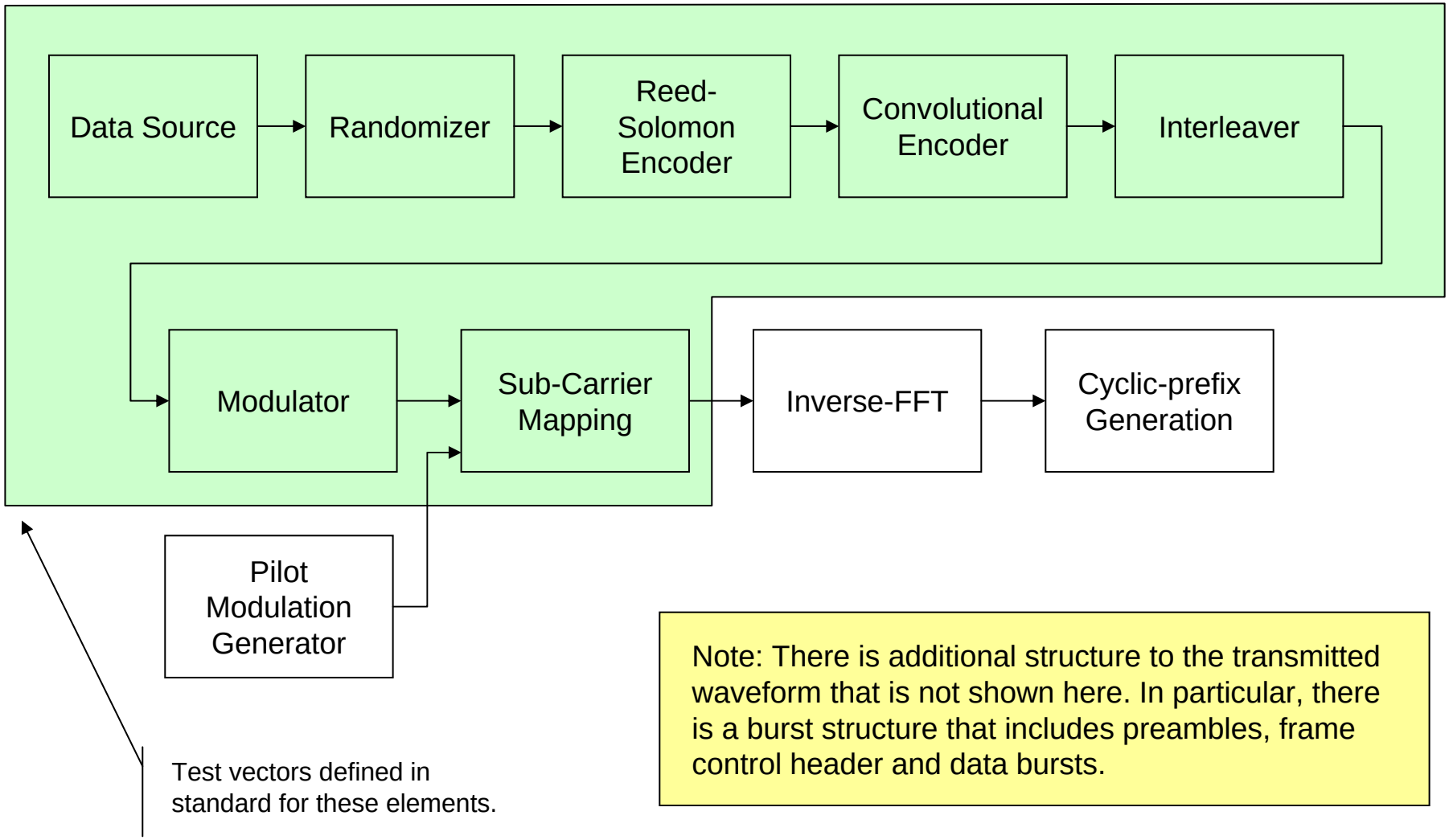
- Better mobile performance is expected with OFDMA than OFDM (additional features of OFDMA including HARQ, fast feedback channel and diversity sub-carrier permutations)

- Initial modeling will focus on OFDM physical layer
  - This mode of 802-16 is exactly analogous to ETSI HiperMAN
  - Results should be extensible to European implementations
  - Acceptable performance using OFDM allows inference of acceptable performance using OFDMA; the inverse is not necessarily true

802.16 Modeling Approach

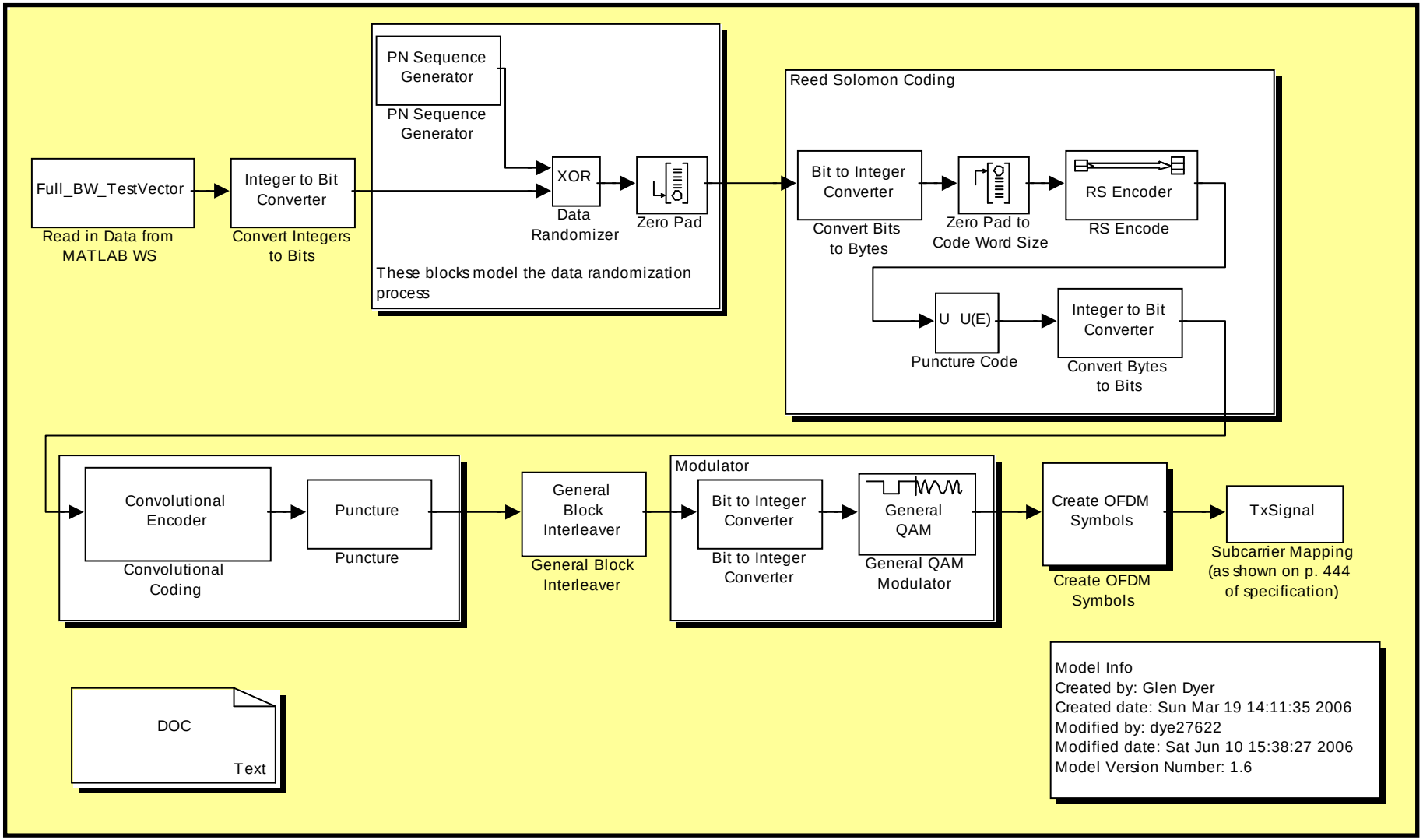
- Transmitter Modeling
  - The 802.16 standard provides test vectors for specific instantiation of the physical layer
    - A set of test vectors (input data, after randomization, after coding, after modulation) for the Rate ¾ (concatenated Reed Solomon and Convolutional Coding) QPSK OFDM implementation are provided
  - To ensure proper transmitter implementation, the transmitter was modeled in accord with the standard for this specific configuration, and the model output was checked against the published test vectors
  - Additional elements are required for proper transmitter modeling
    - OFDM carriers must be inverse-Fourier Transformed
    - Cyclic prefix is then appended
    - Burst structure must be created using appropriate preamble and data sequences
- Subsequent slides show the transmitter modeling steps

Transmitter Modeling – Replicate Test Vectors

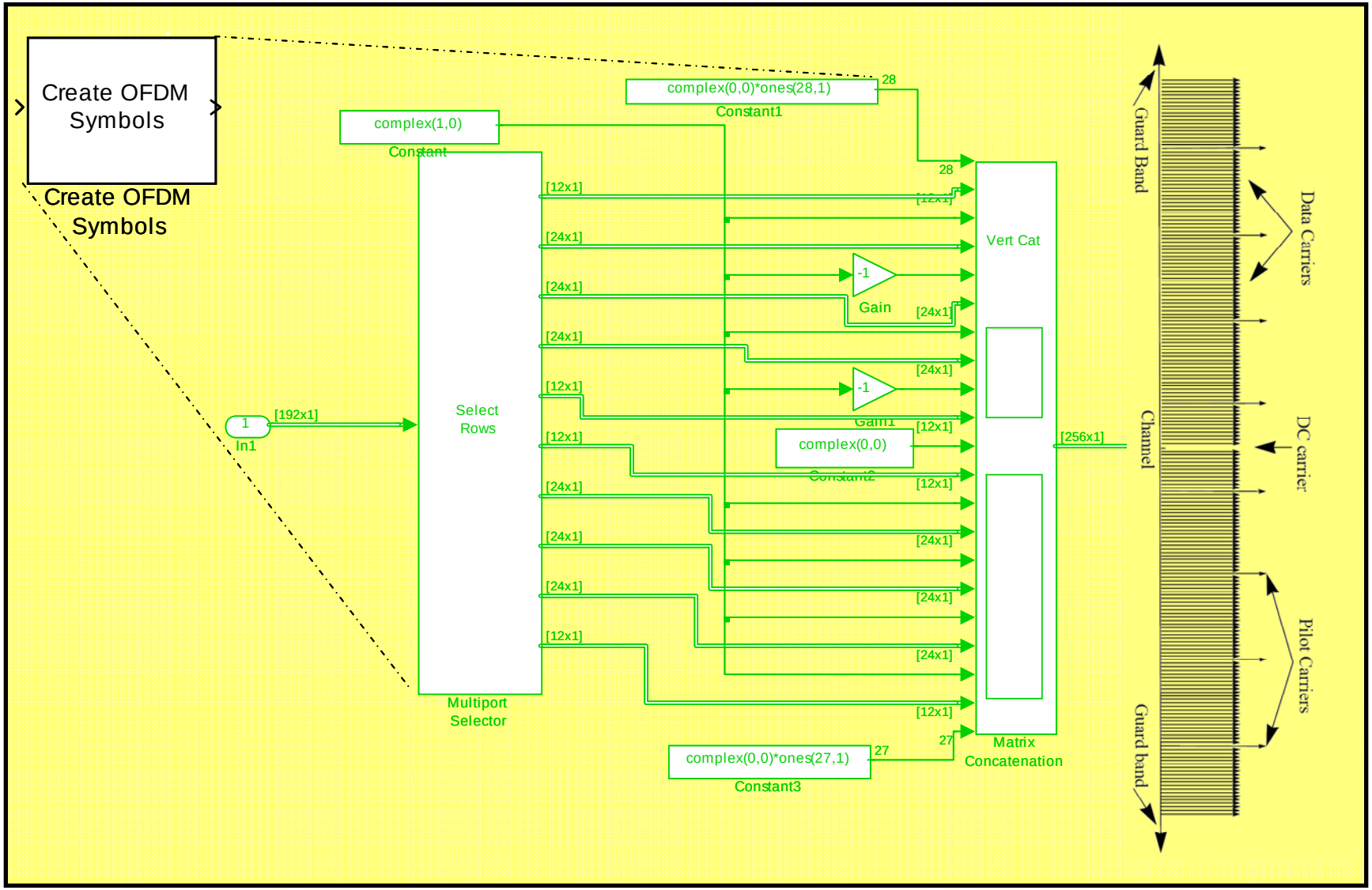


Note: There is additional structure to the transmitted waveform that is not shown here. In particular, there is a burst structure that includes preambles, frame control header and data bursts.

802.16e Transmitter
(as Modeled in Simulink)



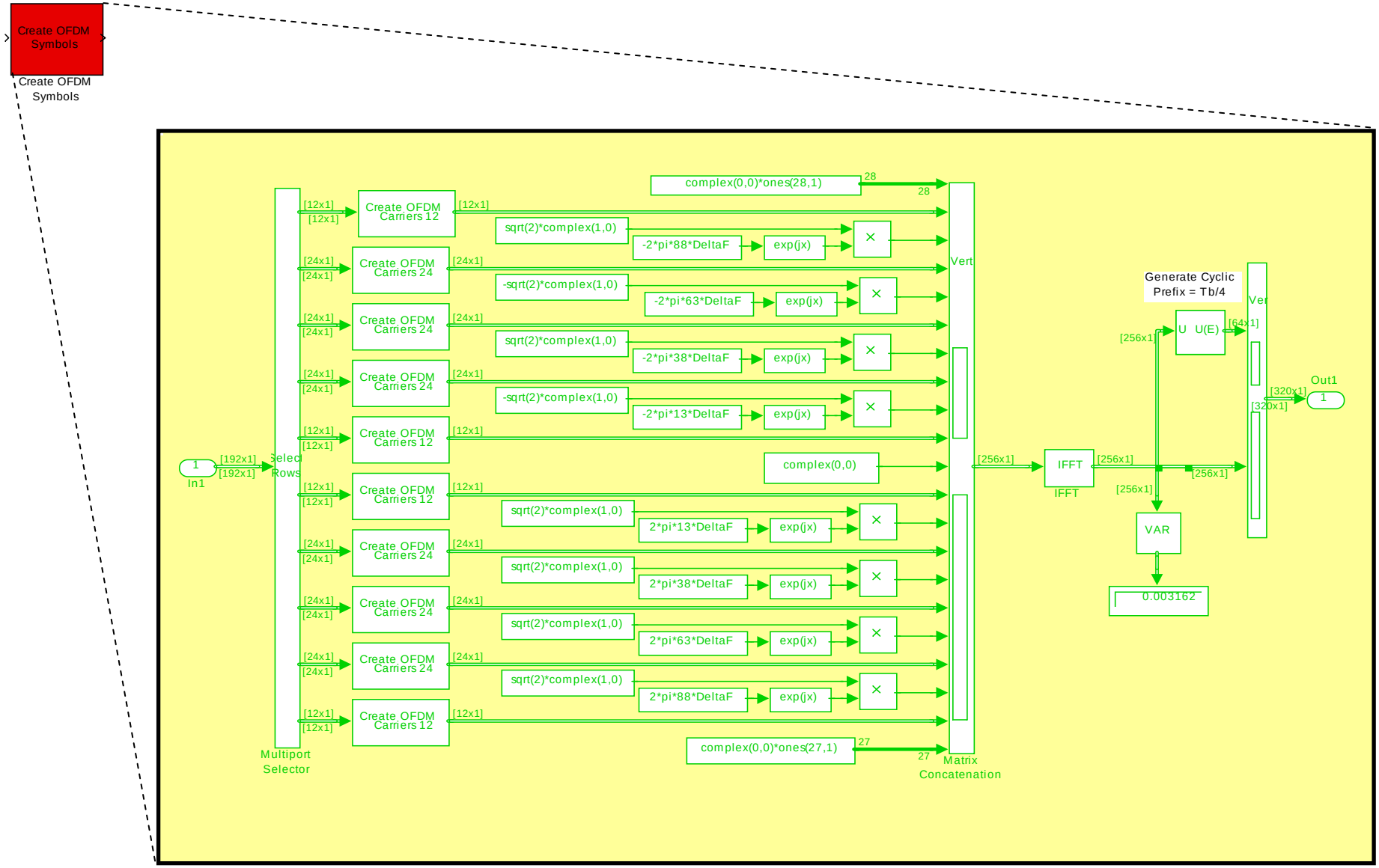
Mapping Data to OFDM Carriers



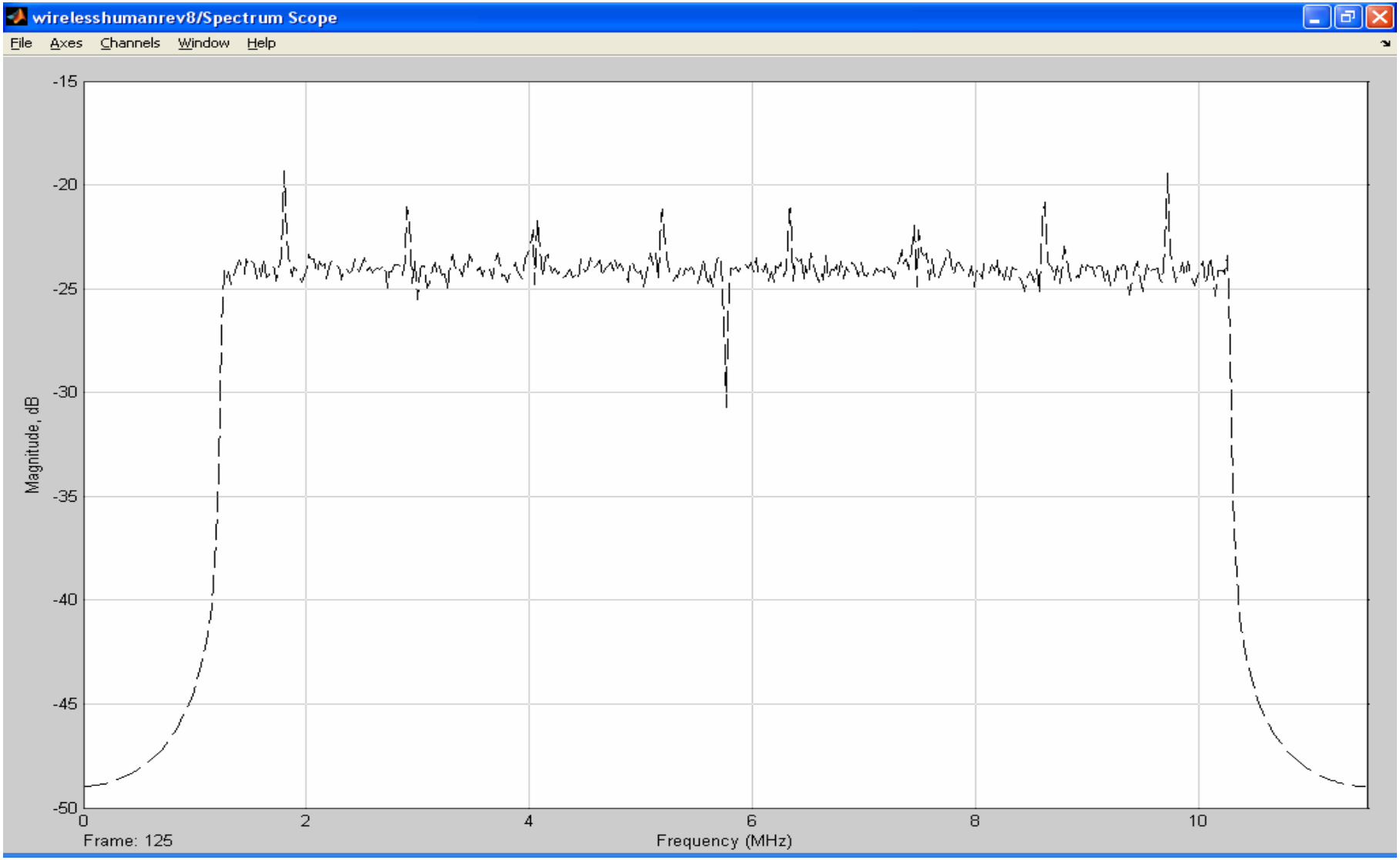
Validating the Model

- Output of the Subcarrier Mapping is shown on pages 444 through 445 of the 802.16-2004 standard
- From the standard, the MATLAB code required to generate the output test vector is:
  - pilot = sqrt(2);
  - ofdm_data= sqrt(0.5)*[-100 1 -1; -99 -1 -1; -98 1 -1; -97 -1 -1; -96 -1 -1; -95 -1 -1; -94 -1 1; -93 -1 1; -92 1 -1; -91 1 1; …
  - ofdm_symbol= complex(ofdm_data(:,2),ofdm_data(:,3));
- The output of our model is MATLAB variable “TxSignal”
- The test for correctness is:
  - >> all(abs(ofdm_symbol-TxSignal(29:229))<sqrt(eps))
  - This returns “ans = 1” (for non-MATLAB users, this means that the test passed)

Transmitter Modeling – Adding Additional Fidelity



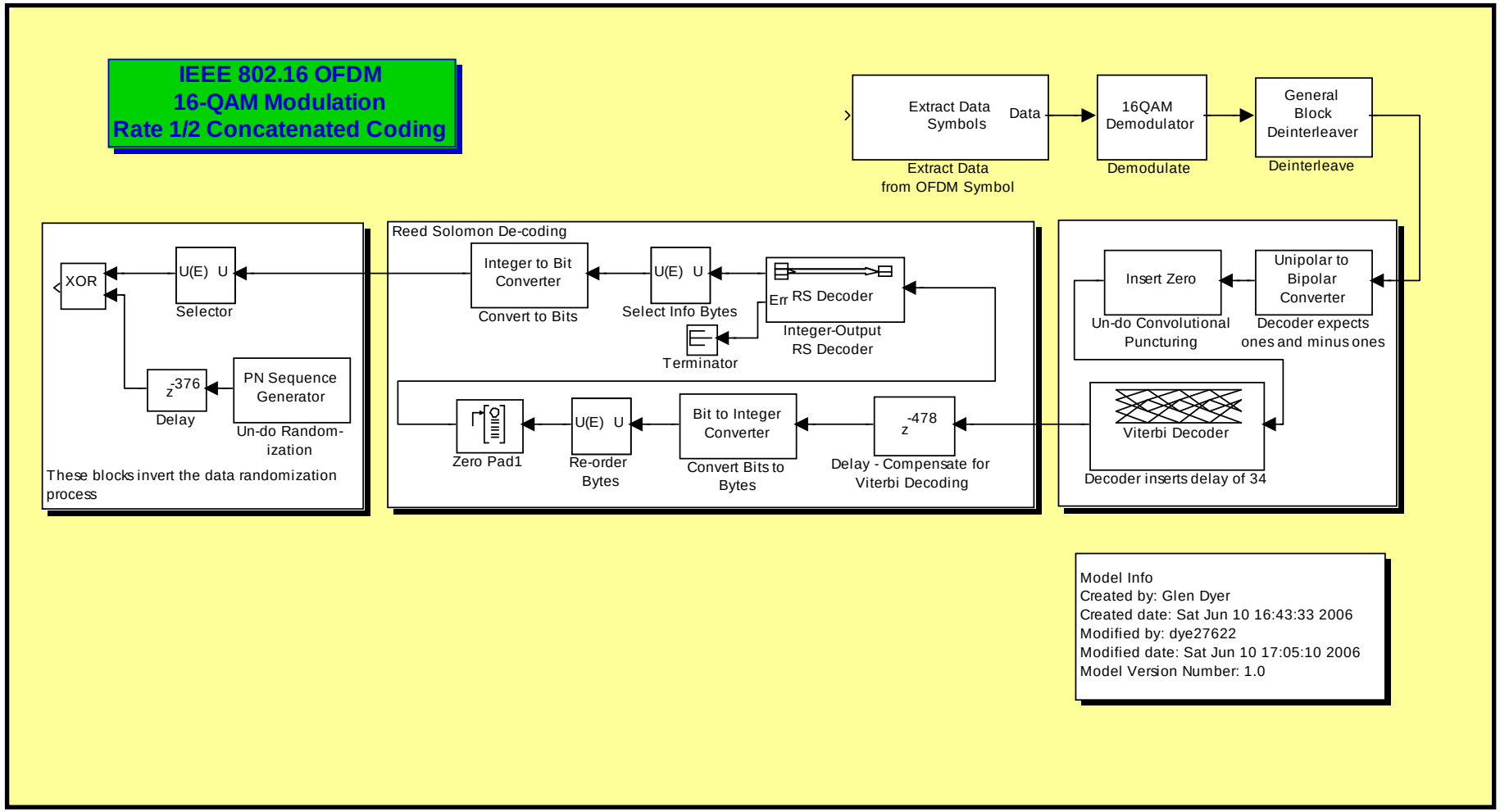
Output of Transmitter Model - 802.16 Emission Spectrum



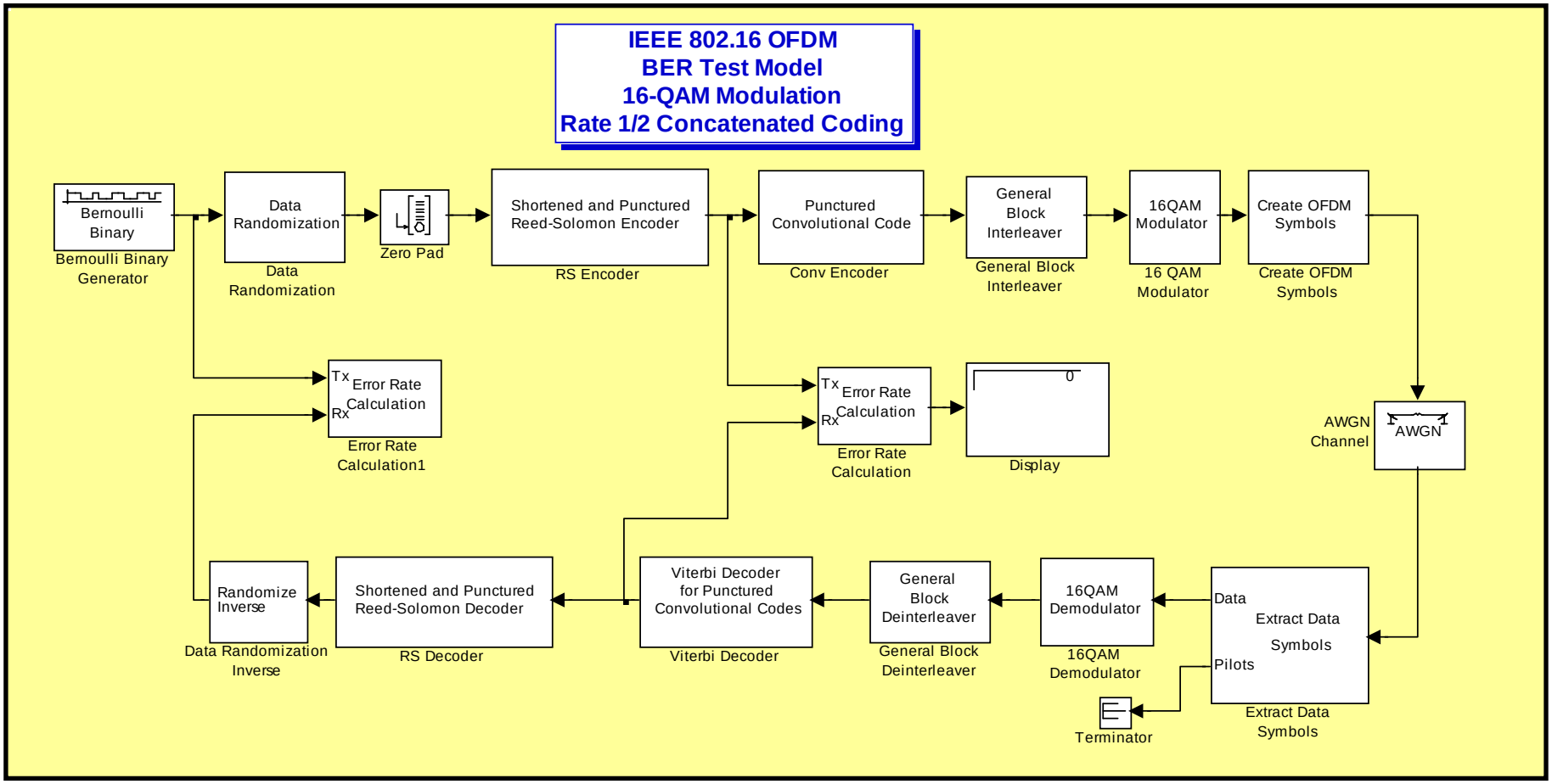
802.16 Receiver Modeling

- The 802.16 receiver modeling was performed in a sequential fashion
  - First, a receiver model was constructed that reverses all of the elements of the transmitter
    - This is useful for assessing performance in AWGN
  - Second, a known channel model (the “SUI 1”) was introduced
    - Stanford University Interim, or SUI, models were used for evaluation of suggested 802.16 physical layer modifications
    - Obtaining good results with the SUI channel requires implementation of a receiver channel equalization function
  - Once good results for known impairments were achieved, the model was considered satisfactory for use in evaluation of unknown impairments, i.e., the Ohio University Airport Surface Channel model

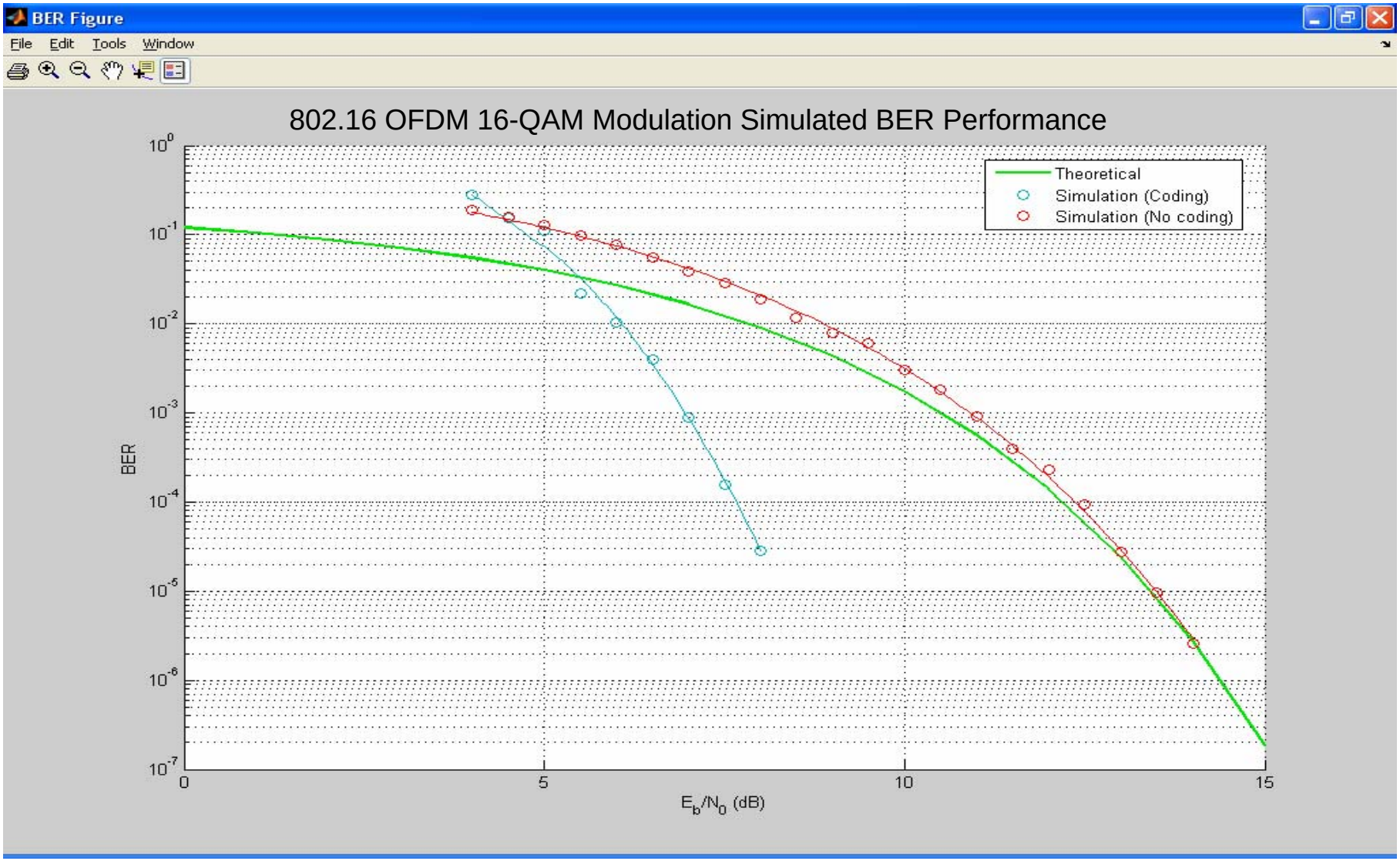
802.16e Receiver
(as Modeled in Simulink)



End-to-End Simulation (AWGN Only)



Simulation Results



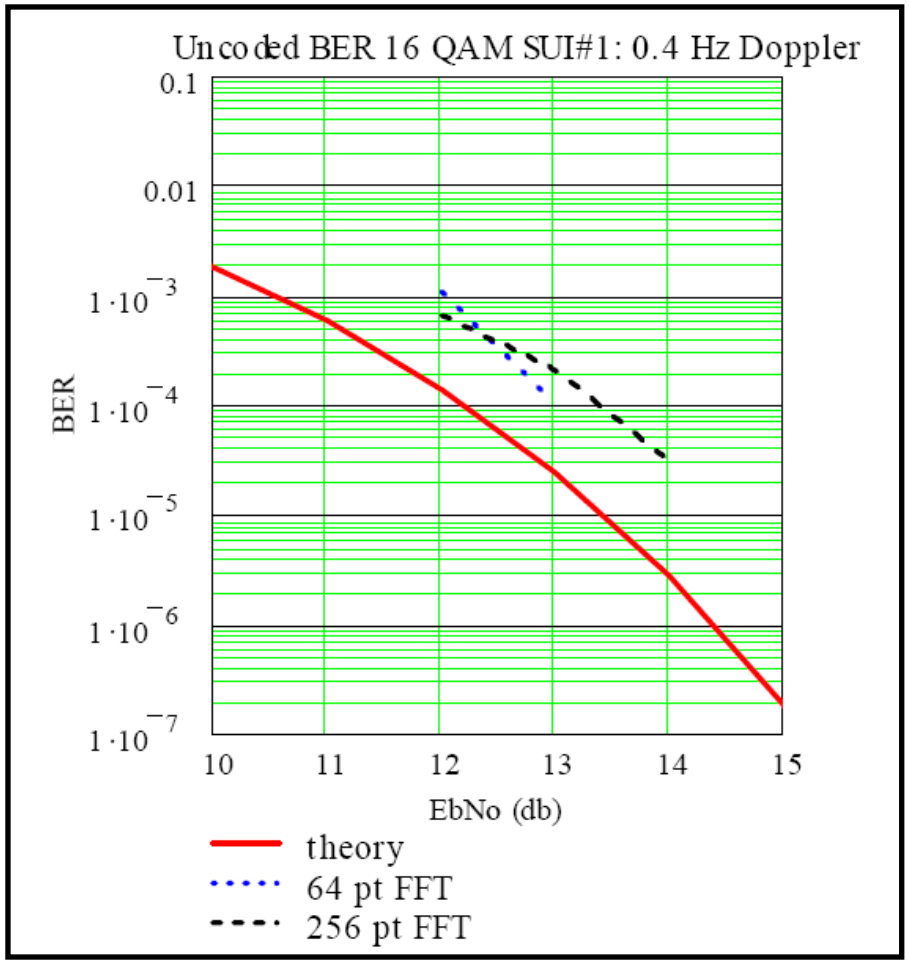
Stanford University Interim (SUI) Channel Models

- These are a set of channel models that were developed and specified for evaluation of the 802.16 physical layer
  - Channel Models for Fixed Wireless Applications, IEEE 802.16a-03/01
- A set of 6 typical channels was selected for the three terrain types that are typical of the continental US
  - Category A - Hilly terrain with moderate-to-heavy tree densities
  - Category C - Mostly flat terrain with light tree densities
  - Category B - Either mostly flat terrain with moderate-to-heavy tree densities, or hilly terrain with light tree densities
  - SUI Models are defined for all three terrain types

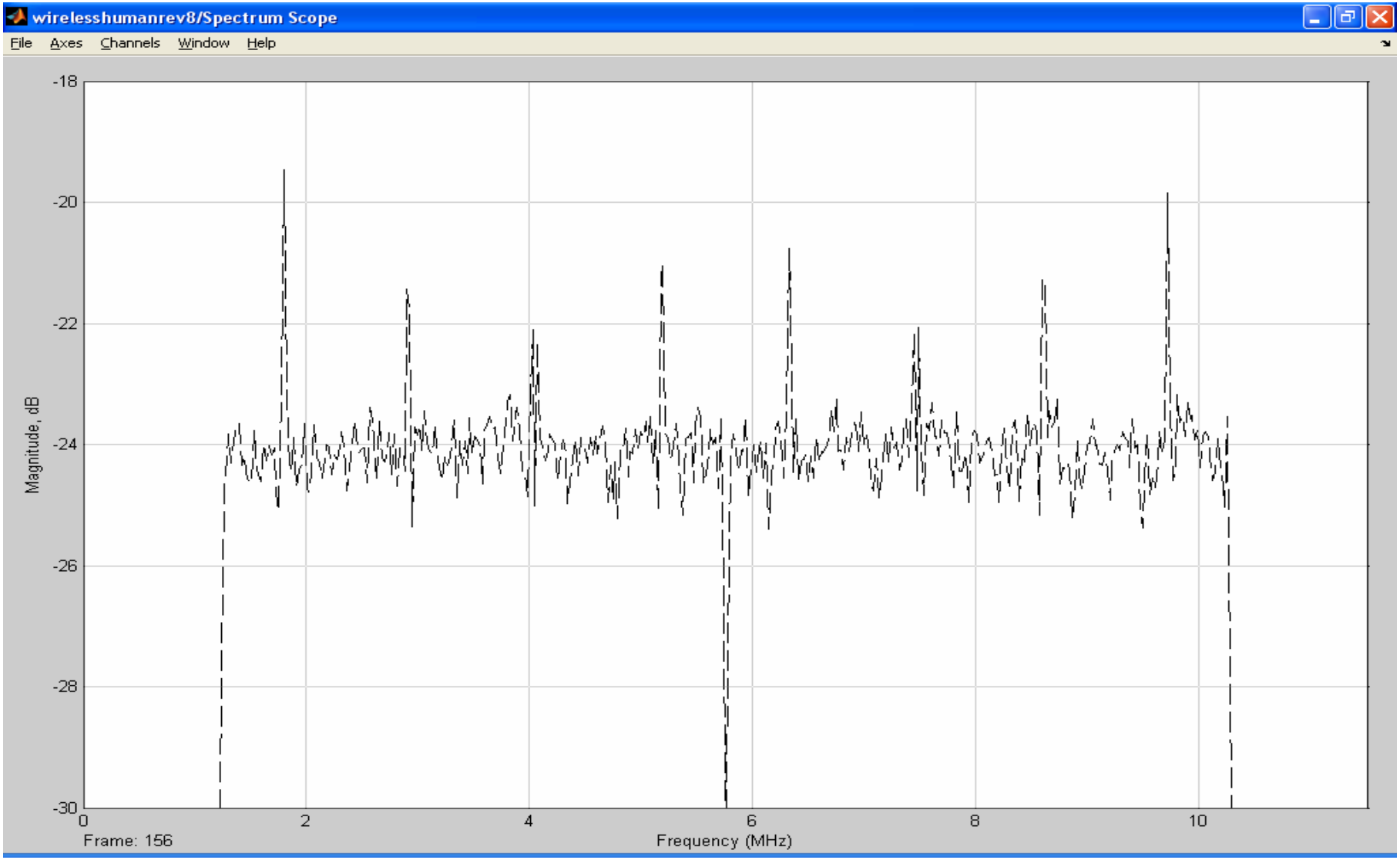
Terrain Type	SUI Channels
C	SUI-1, SUI-2
B	SUI-3, SUI-4
A	SUI-5, SUI-6

802.16 Simulated Performance on SUI Channels

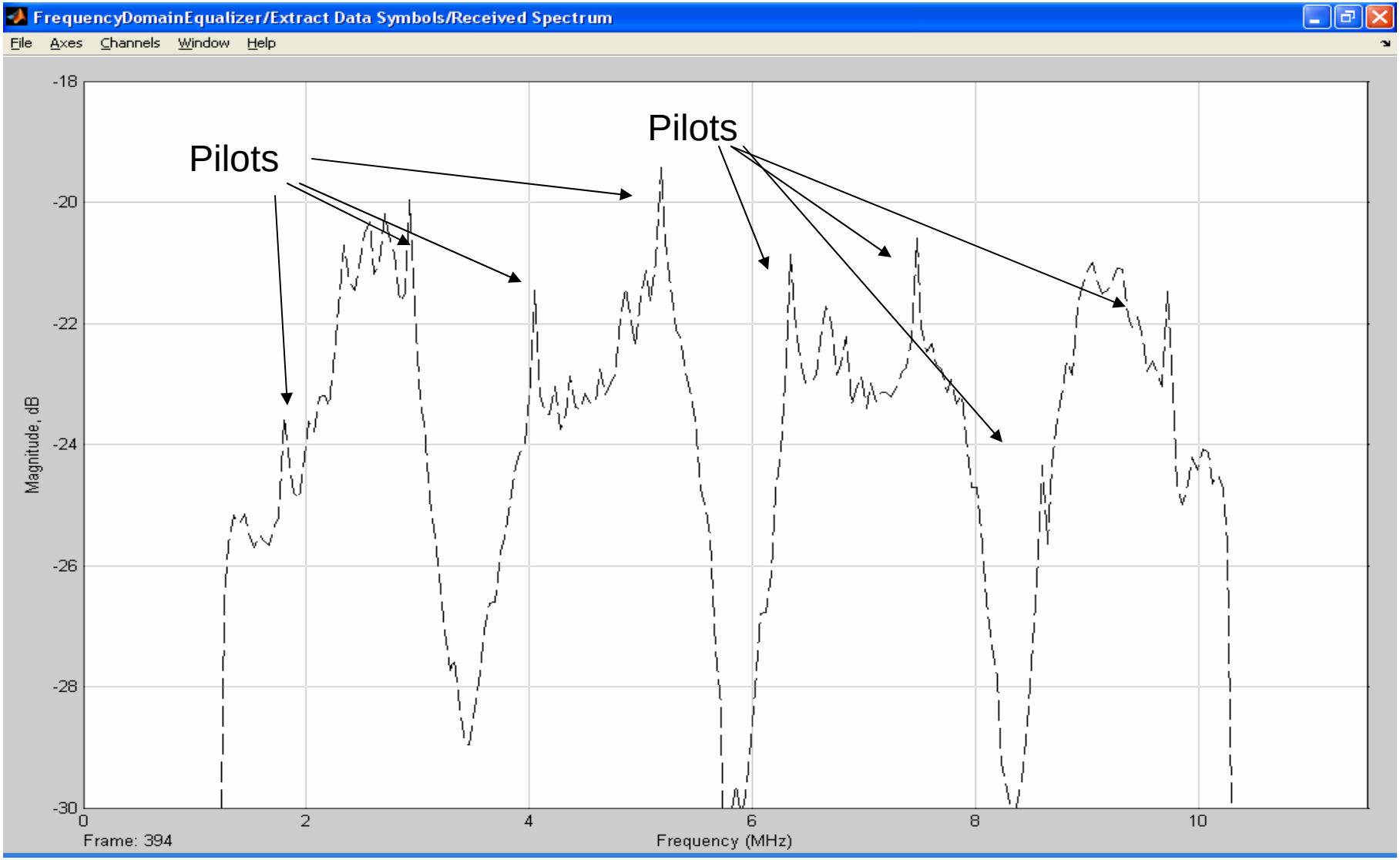
- Simulation results for 802.16 can be found in the referenced paper
  - Dr. Robert M. Ward Jr., SIMULATED BER RESULTS OF PROPOSED OFDM STRUCTURE IN MULTIPATH, IEEE 802.16.3c-01/48 1
- Paper presents results for 16 and 64 QAM (motivation for studying 16 QAM in this study)
- SUI 1 Channel Parameters
  - 3 taps, Dopper 0.4 Hz
    - Tap 1 – Ricean, K-factor of 4
    - Tap 2 – Rayleigh, 0.4 μs delay, -15 dB gain
    - Tap 3 - Rayleigh, 0.8 μs delay, -20 dB gain



802.16 Emission Spectrum (No impairments)

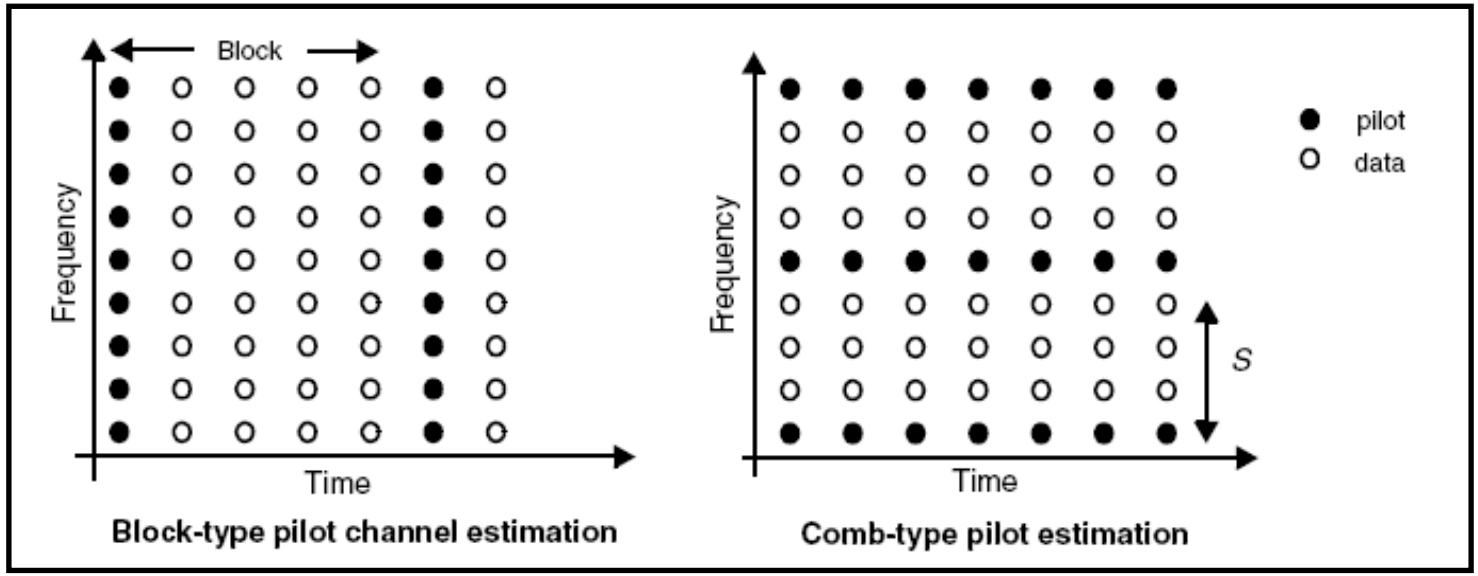


802.16 Emission Spectrum After SUI 1 Channel



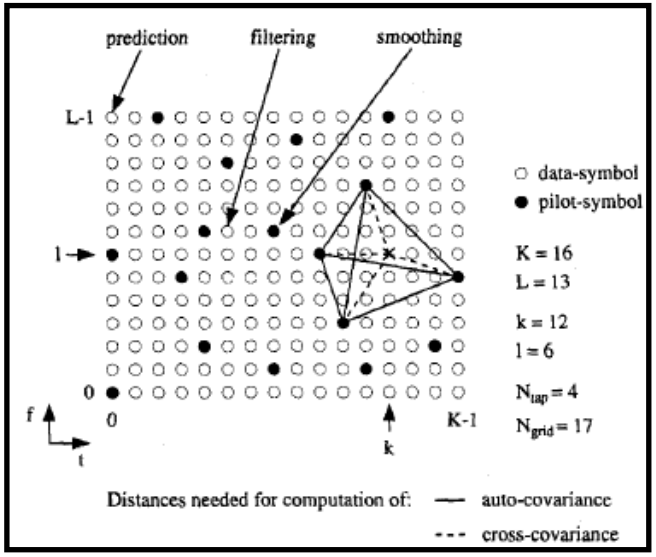
Channel Estimation in OFDM Systems

- Coherent demodulation (as is required for 16-QAM) requires estimation of the channel time and frequency response
- OFDM systems use both time and frequency pilot information to allow channel estimation
  - Both “Block Type” and “Comb Type” pilots are employed
  - 802.16 uses “Comb Type” pilots, but also uses a known synchronization sequence every (configurable) data blocks to frame the data bursts



Two-Dimensional Pilot-Symbol-Aided Channel Estimation

- The optimal algorithm is a 2-D Wiener filter
  - Computationally expensive
- Sub-optimal (but still good) algorithm is to separate the time and frequency estimation problem



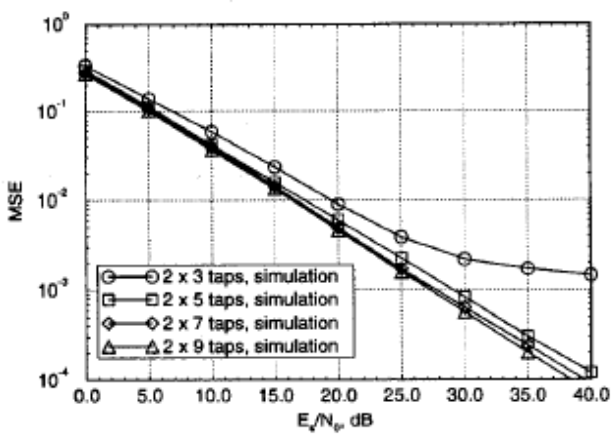


Figure 3: Average MSE versus SNR for 2× 1-D Wiener filtering given a rectangular grid.

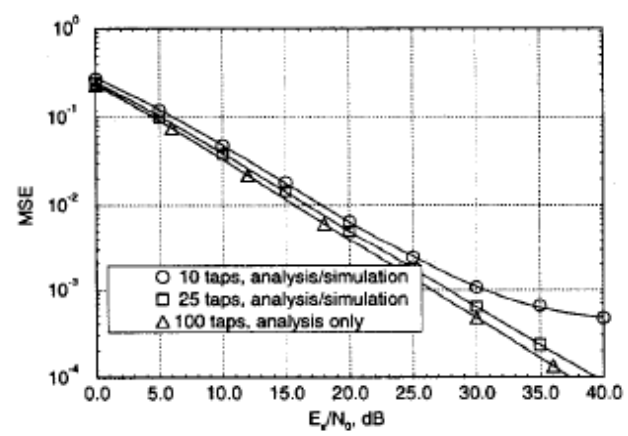


Figure 4: Average MSE versus SNR for 2-D Wiener filtering given a rectangular grid.

Channel Estimation for 802.16

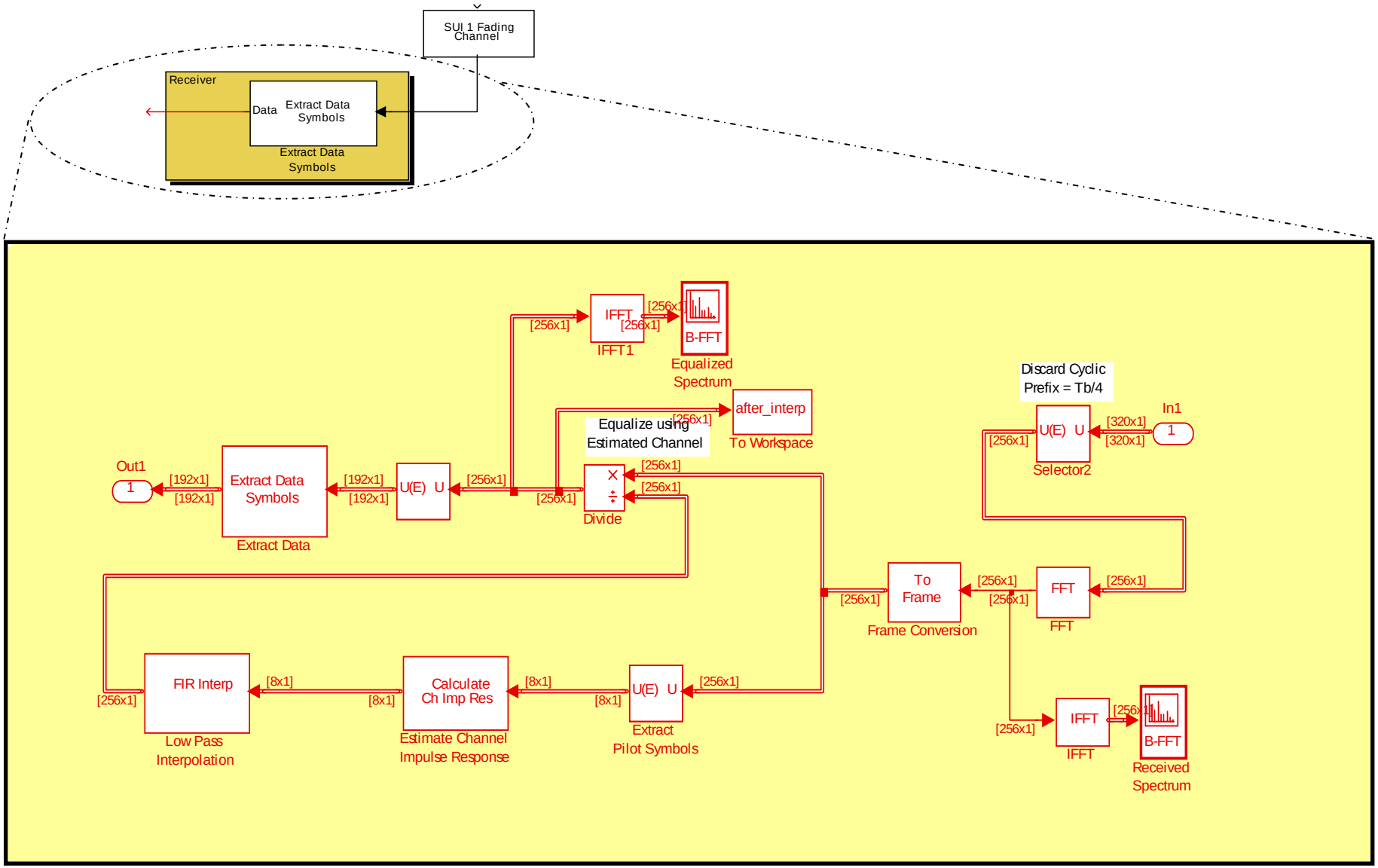
- The 802.16 Frame structure uses preambles; however, the preamble spacing is a bit far apart in time for a practical Wiener filter implementation
  - An approach was taken that first equalized in the frequency domain, then in the time domain
- Frequency domain channel estimation for a Comb-Type Pilot system has many implementations
  - Least Square estimation with 1-D interpolation (many types of interpolation are possible here - linear, low-pass, cubic spline)
  - Maximum likelihood estimation
  - Parametric Channel Modeling
- Low-pass interpolation is a good choice (see Figure)

Figure source: **Channel Estimation in OFDM Systems,** Yushi Shen and Ed Martinez

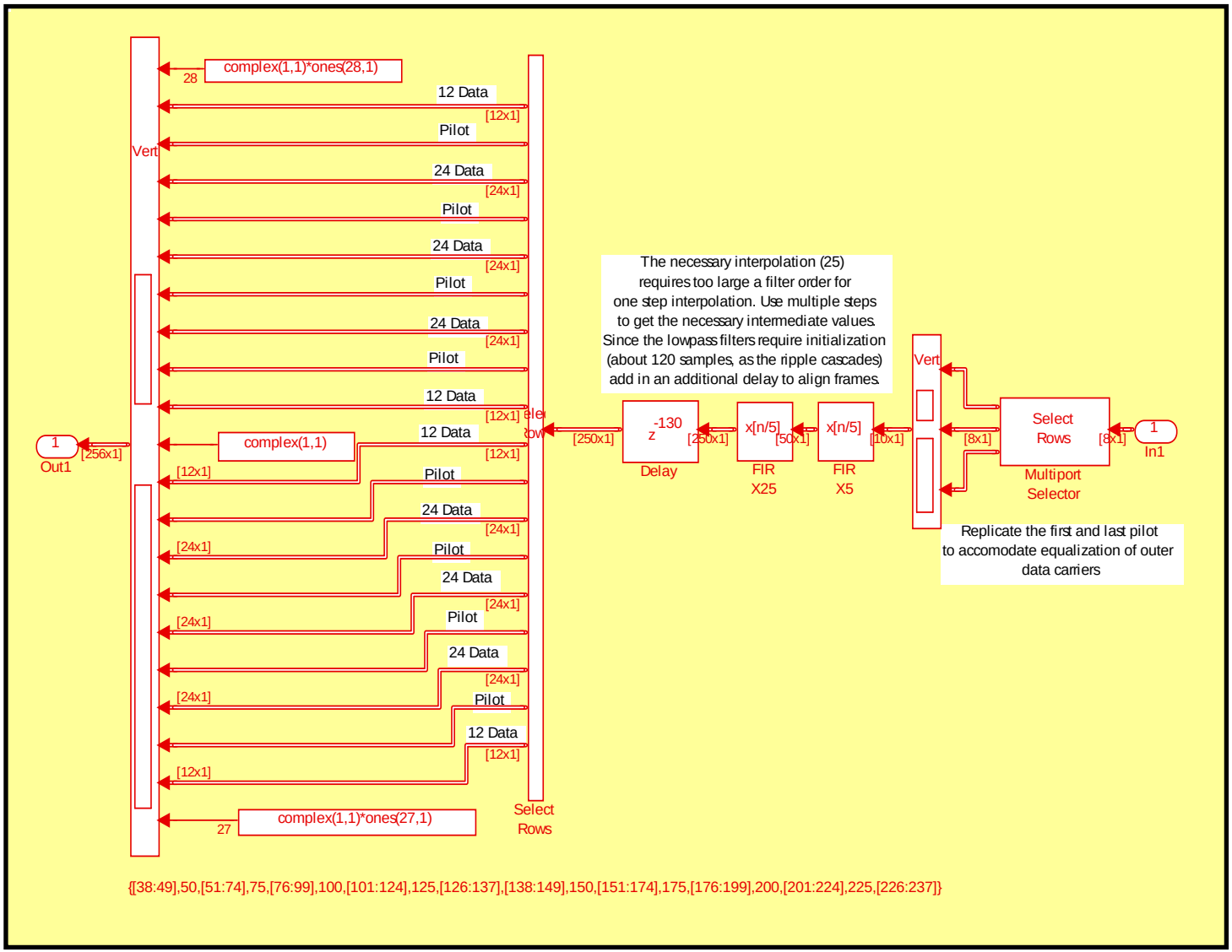
Table 3. Recommended OFDM System Channel Estimation Schemes for Different Scenarios and Requirements

Scheme	Scenario	Pilot	Complexity	2nd Order Statistics of Channel	Performance
OLR-MMSE	Slow fading channel	Block-type	Moderate	Needed	Good
LS with LPI	Middle and fast fading channel	Comb-type	Low	Not needed	Good
PCMB			High	Needed	Very good

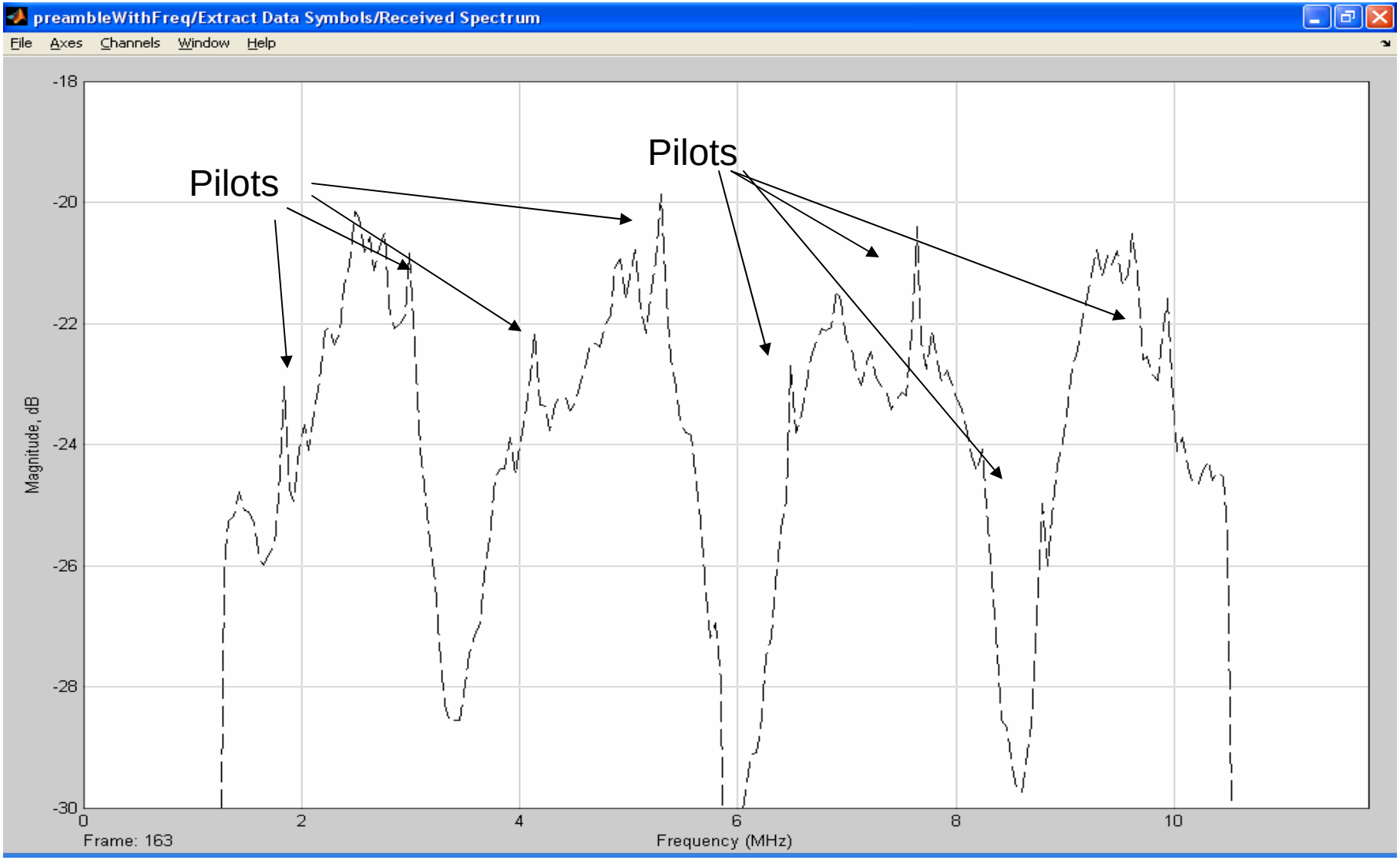
Frequency Domain Equalization Using Low-Pass Interpolation



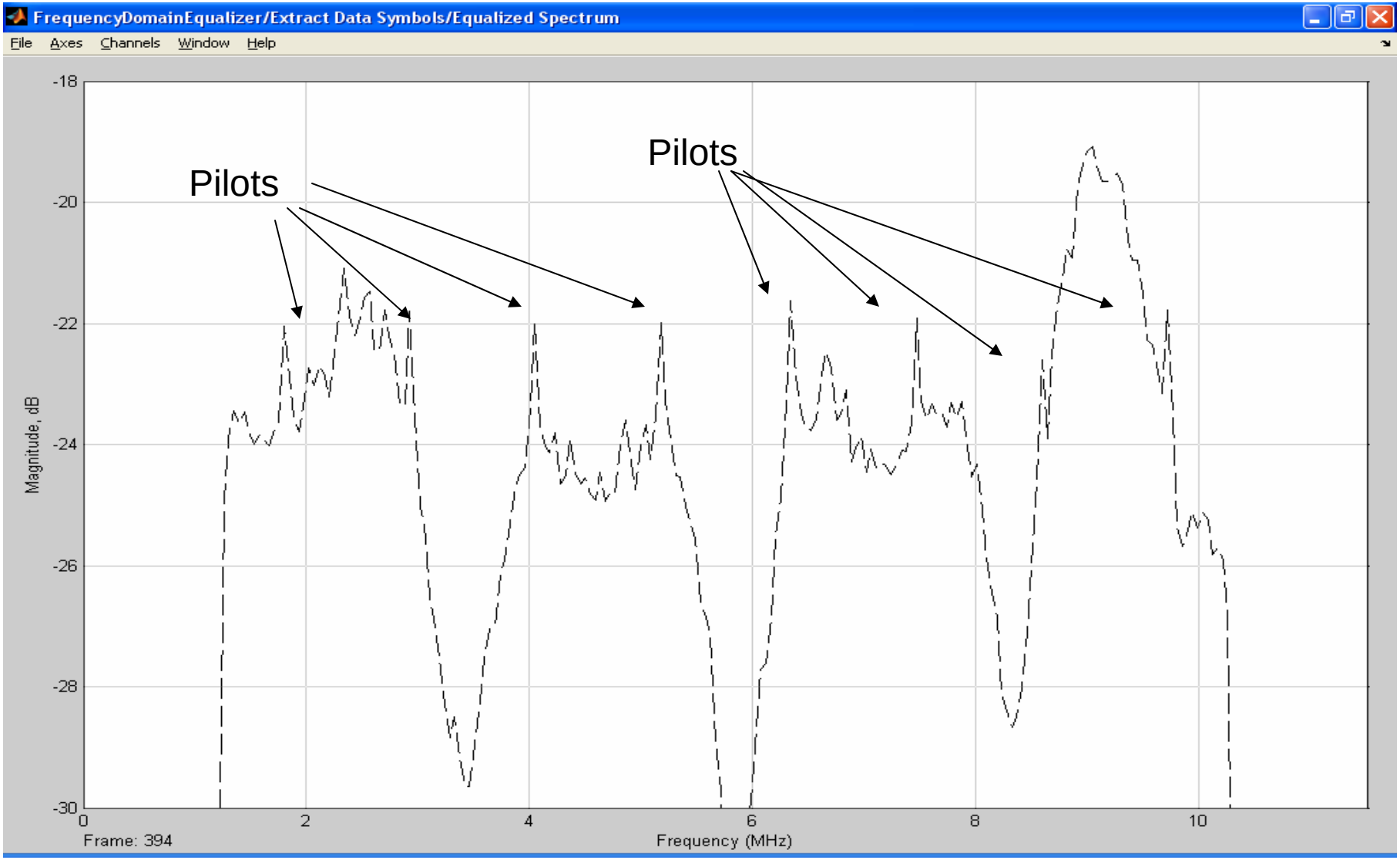
Frequency Domain Equalization Using Low-Pass Interpolation – Details of LPI



802.16 Spectrum After SUI1 Channel



After Freq Domain Equal



Using 802.16 Preamble to Enhance Channel Estimation

- From the standard:
  - The OFDM PHY supports a frame-based transmission.
  - A downlink PHY PDU starts with a long preamble, which is used for PHY synchronization.
  - All preambles are structured as either one of two OFDM symbols. The OFDM symbols are defined by the values of the composing subcarriers.
  - The first preamble in the downlink PHY PDU, as well as the initial ranging preamble, consists of two consecutive OFDM symbols.

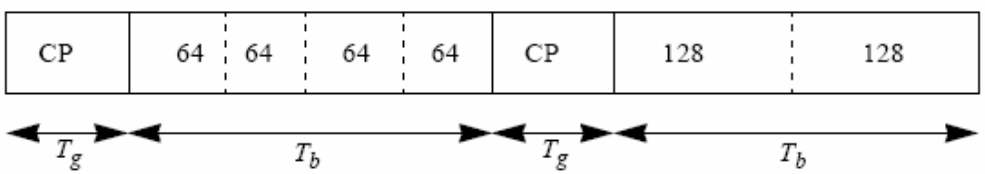
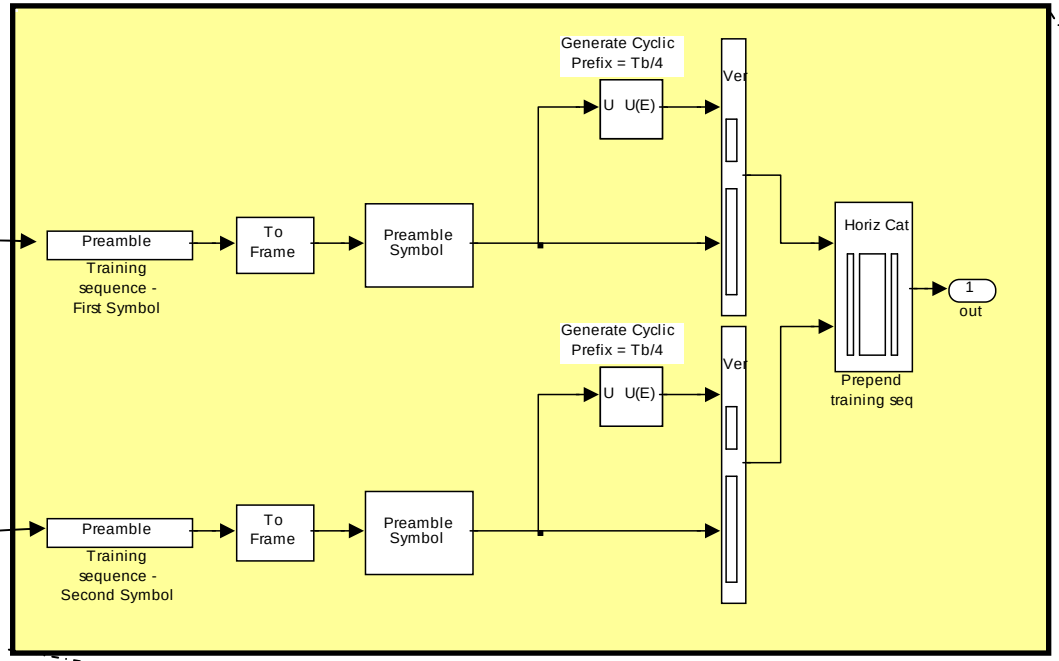


Figure 205—Downlink and network entry preamble structure

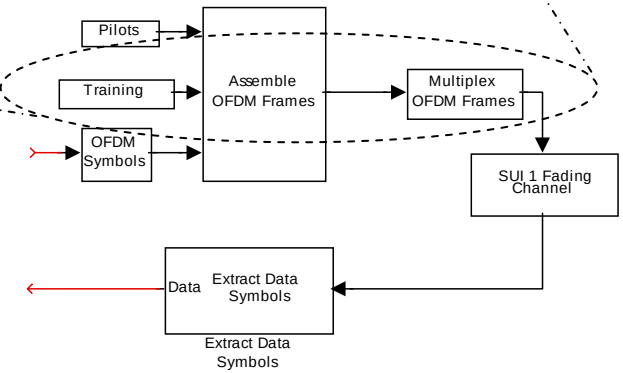
Table 232—OFDM frame duration (T_F ms) codes

Code	Frame duration (ms)	Frames per second
0	2.5	400
1	4	250
2	5	200
3	8	125
4	10	100
5	12.5	80
6	20	50
7–255	*reserved*	*reserved*

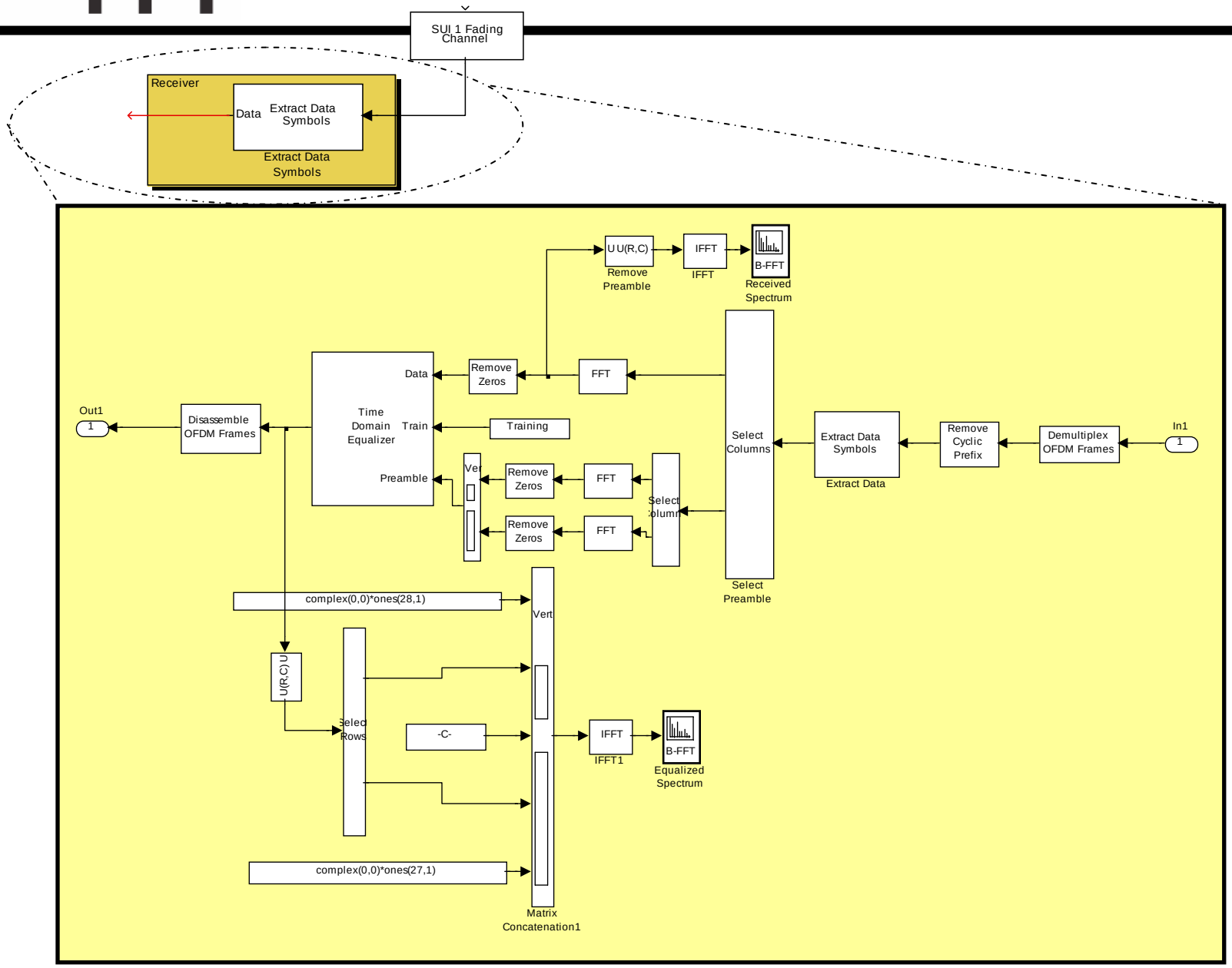
Generating Preamble



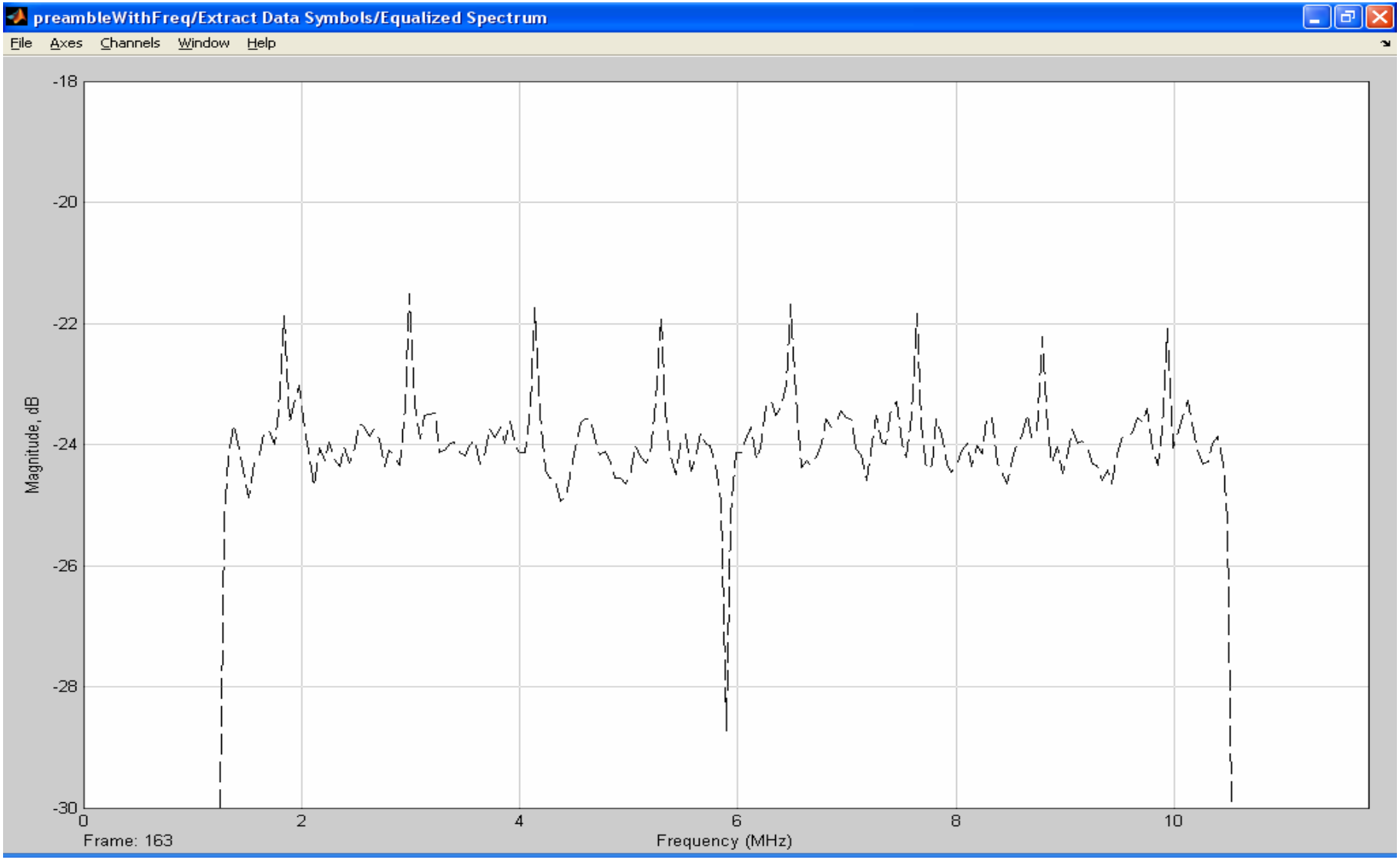
- Preamble =[1-i 1-i -1-i 1+i 1-i 1-i -1+i 1-i 1-i 1-i 1+i -1-i 1+i 1+i -1-i 1+i …];
- indexsym1=[4:4:201];
- Preamble_Sym1=Preamble(indexsym1);
- indexsym2=[2:2:201];
- Preamble_Sym2=Preamble(indexsym2);
- SymbolsPerFrame=90;



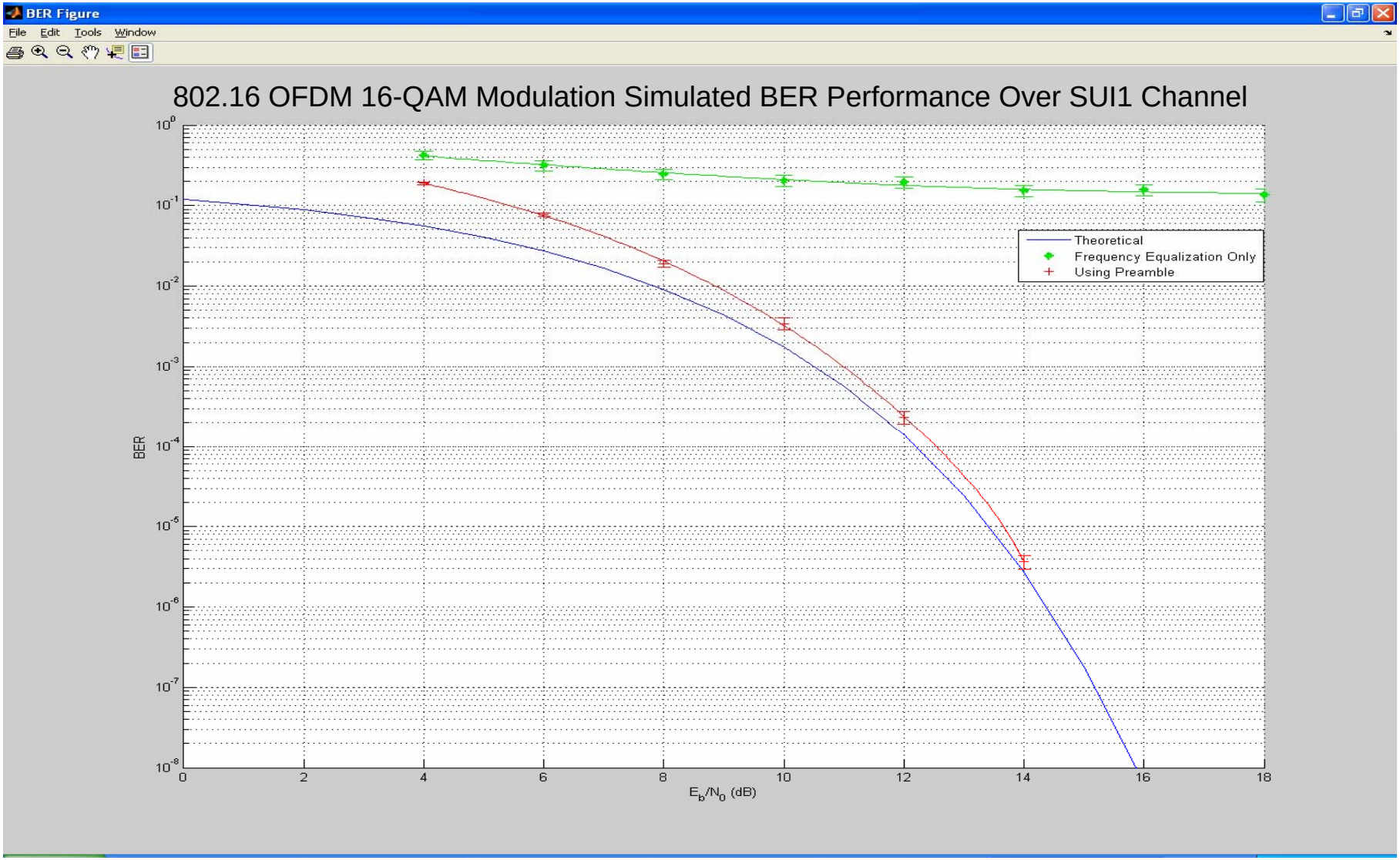
Using the Preamble



Equalized 802.16 Spectrum (After SUI1 Channel)



Simulated BER Performance (SUI1 Channel)



C-Band Channel Model

C-Band Channel Model - Overview

- In order to assess 802.16e performance in an airport environment, a realistic model of the communications channel is required
  - This model must accurately reflect the small-scale fading environment so that waveform performance can be assessed
    - Should accurately categorize delay spread (assess whether cyclic prefix is adequate)
    - Should accurately categorize Doppler Power spectrum (determines coherence time of channel and assesses adequacy of pilot symbol structure)
- Ohio University has conducted an airport surface measurement campaign for NASA Glenn Research Center
  - Results published in “Wireless Channel Characterization in the 5 GHz Microwave Landing System Extension Band for Airport Surface Areas”, David W. Matolak, March 2006
- Adapted channel model (as described in report and subsequent correspondence) was used for this evaluation

C-Band Channel Model – Ohio U. Measurements

- Ohio University has conducted wireless channel characterization of the MLS Extension band (5.091 – 5.150 GHz) for NASA Glenn
- Channel sounding has characterized
  - Type of channel (LOS, NLOS and NLOS Specular)
  - Type of airport (small, medium, large)
- Measurements included
  - Mobile
  - Point-to-point
  - Emulation of communication relay (both Tx & Rx on airport surface)
- Measurements included statistics on
  - Delay Spread
  - Coherence Bandwidth
  - Path loss
  - Tap amplitudes, # of taps and correlation between taps

C-Band Channel Model – Suggested Ohio U. Models

- The wireless channel characterization measurement report specifies different channel models by:
  - Airport type – models are specified for Small, Medium and Large Airports
    - The large airport model looks to be the most severe and was selected for analysis
  - Airport region – three distinct regions were specified in the measurement report – Line of Sight (LOS), Non-LOS (NLOS) and NLOS-Specular (NLOS-S)
    - The NLOS region is by far the most severe and was selected for analysis
  - Different fidelity models were defined as well
    - The *high-fidelity* model is directed towards academic applications and provides a comprehensive and highly accurate depiction of the channel (at the cost of implementation complexity)
    - The *sufficient-fidelity* model provides a practical emulation of the channel with moderate implementation complexity
    - Selected the sufficient fidelity model for simulation

Ohio U. Channel Model Suggested Parameters

- The suggested channel model parameters include the tap persistence, number of taps, fading processes and tap correlations.
  - The tap persistence accounts for the finite lifetime of propagation paths
  - Modeled as a random “switching” process, or Markov chain
  - Suggested persistence matrix shown below
- Not simulated – absence of taps is a good thing – omitting this is conservative

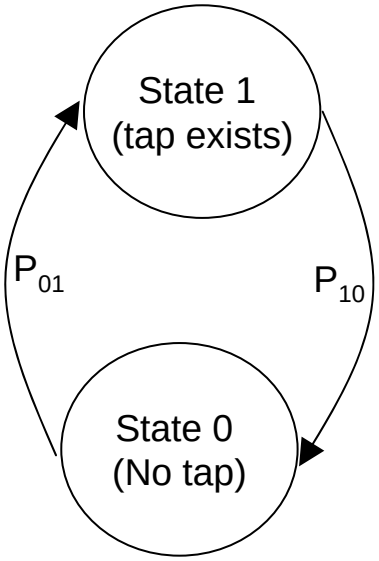


Table 1 Persistence Process for [Large Airport, NLOS, 10]

Tap Index	Steady State Probability for State 1	Steady State Probability for State 0	Transition Probability (P_{00})	Transition Probability (P_{01})	Transition Probability (P_{10})	Transition Probability (P_{11})
1	1.0000	0	NaN	NaN	0	1.0000
2	0.8794	0.1206	0.1975	0.8025	0.1101	0.8899
3	0.7890	0.2110	0.3258	0.6742	0.1803	0.8197
4	0.7747	0.2253	0.3301	0.6699	0.1949	0.8051
5	0.7519	0.2481	0.3363	0.6637	0.2191	0.7809
6	0.7437	0.2563	0.3599	0.6401	0.2206	0.7794
7	0.7288	0.2712	0.3789	0.6211	0.2310	0.7690
8	0.7102	0.2898	0.4013	0.5987	0.2444	0.7556
9	0.7060	0.2940	0.4063	0.5938	0.2471	0.7529
10	0.6930	0.3070	0.4324	0.5676	0.2512	0.7488
11	0.7065	0.2935	0.4052	0.5948	0.2472	0.7528
12	0.7000	0.3000	0.3868	0.6132	0.2626	0.7374
13	0.6798	0.3202	0.4453	0.5547	0.2614	0.7386
14	0.6992	0.3008	0.4067	0.5933	0.2551	0.7449

Ohio U. Channel Model Suggested Parameters (2)

- The 802.16 OFDM signal being modeled has an emission bandwidth of 10 MHz
  - The sufficient-fidelity model for 10 MHz, Large Airport, NLOS has 14 taps with the fading process and energies as shown in the table

Table 2 Amplitude Statistics for [Large Airport, NLOS, 10]

Tap Index	Weibull Shape Factor (b)	Tap Energy	Alternative Distribution Parameter (Nakagami)
1	2.1	0.5273	$m = 1.2$
2	1.58	0.0605	$m = 0.72$
3	1.56	0.0382	$m = 0.72$
4	1.61	0.0346	$m = 0.74$
5	1.63	0.0315	$m = 0.76$
6	1.57	0.0310	$m = 0.73$
7	1.6	0.0302	$m = 0.74$
8	1.67	0.0276	$m = 0.79$
9	1.66	0.0266	$m = 0.78$
10	1.68	0.0248	$m = 0.8$
11	1.65	0.0262	$m = 0.77$
12	1.66	0.0260	$m = 0.78$
13	1.75	0.0234	$m = 0.84$
14	1.72	0.0230	$m = 0.83$

Ohio U. Channel Model Suggested Parameters (3)

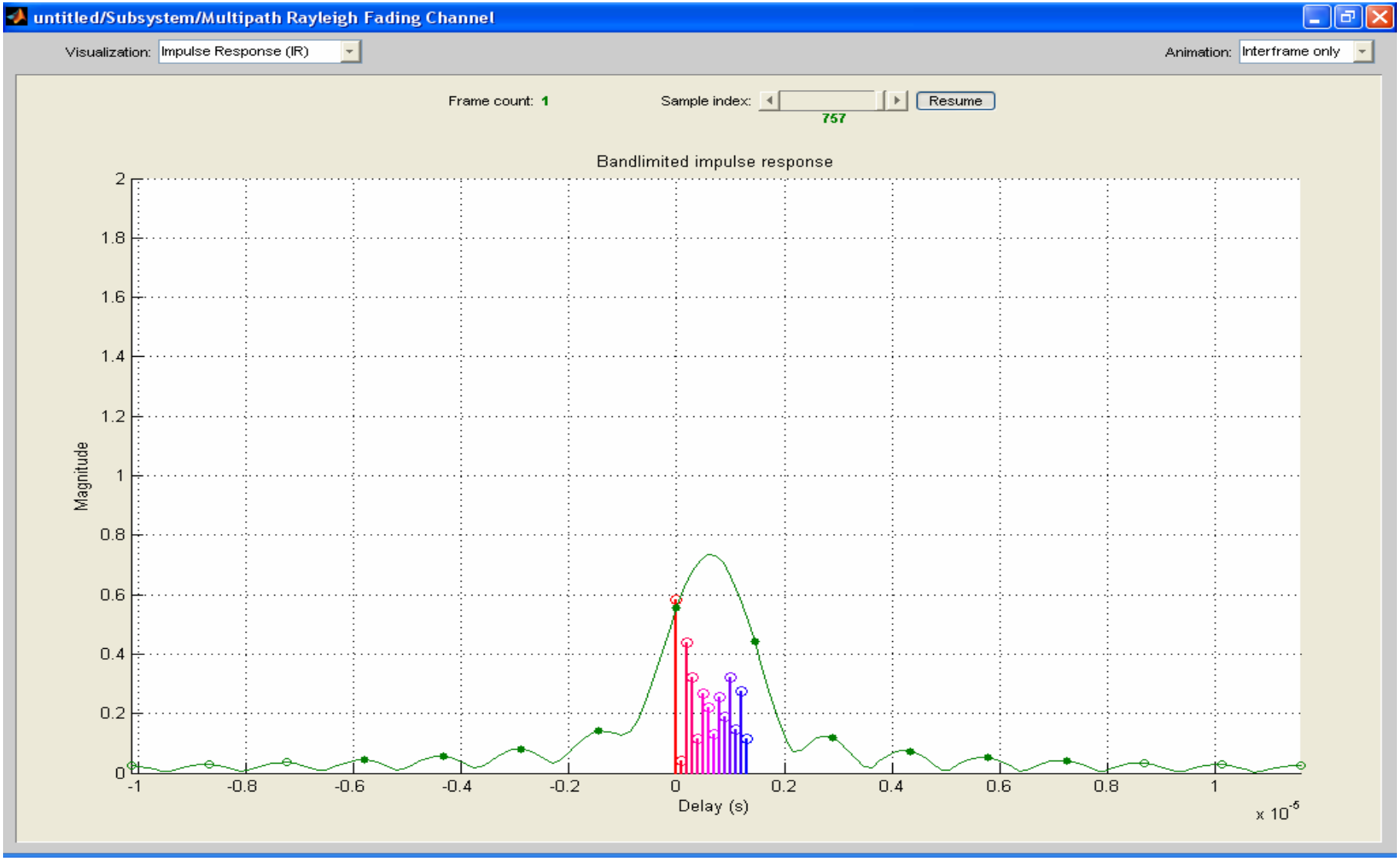
- The taps are expected to exhibit correlated fading
  - This reduces the amount of attainable time diversity, which is not a feature that our particular implementation of 802.16 is attempting to leverage
  - Did not model the correlated fading between taps

Suggested Tap Correlation Matrix for the Sufficient Fidelity, Large Airport, NLOS 10 MHz Model

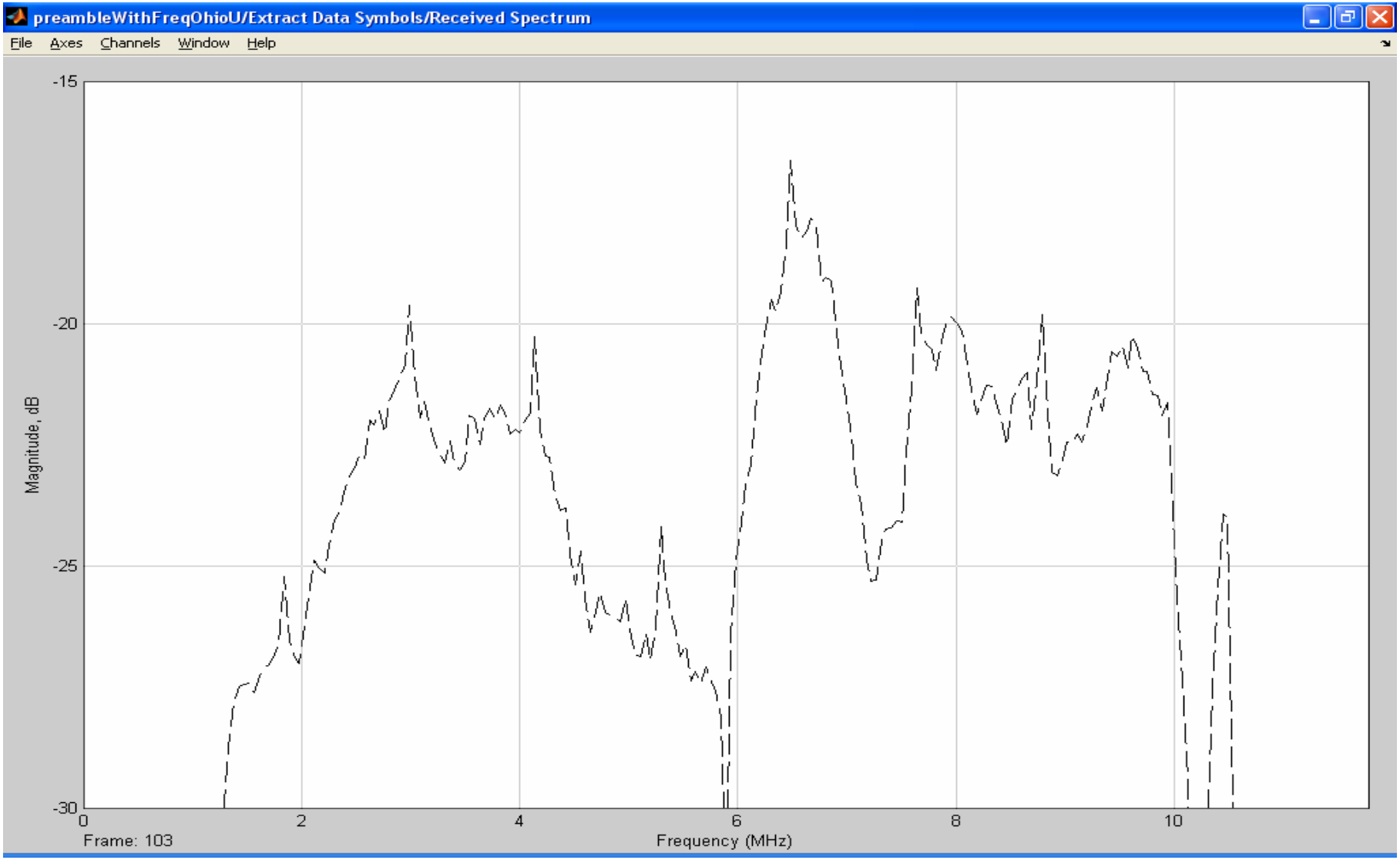
i,j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.0000	0.5918	0.6812	0.5749	0.6441	0.6502	0.8756	0.7405	0.7231	0.5870	0.7161	0.5807	0.5496	0.9924
2	0.5918	1.0000	0.4184	0.3755	0.5485	0.4209	0.4793	0.5451	0.6644	0.9408	0.7814	0.6817	0.8126	0.4801
3	0.6812	0.4184	1.0000	0.5666	0.7584	0.5592	0.4585	0.8646	0.5190	0.8350	0.7176	0.5476	0.5406	0.5982
4	0.5749	0.3755	0.5666	1.0000	0.9978	0.8270	0.5931	0.3813	0.5177	0.5171	0.3701	0.4382	0.9092	0.5384
5	0.6441	0.5485	0.7584	0.9978	1.0000	0.9321	0.7170	0.6391	0.8684	0.7690	0.8450	0.9917	0.8419	0.6710
6	0.6502	0.4209	0.5592	0.8270	0.9321	1.0000	0.7656	0.6292	0.3860	0.6396	0.7282	0.6136	0.5330	0.3691
7	0.8756	0.4793	0.4585	0.5931	0.7170	0.7656	1.0000	0.4566	0.6887	0.7423	0.4230	0.3845	0.4437	0.9722
8	0.7405	0.5451	0.8646	0.3813	0.6391	0.6292	0.4566	1.0000	0.3898	0.4199	0.7568	0.7600	0.7588	0.6000
9	0.7231	0.6644	0.5190	0.5177	0.8684	0.3860	0.6887	0.3898	1.0000	0.7998	0.6423	0.5593	0.6839	0.5689
10	0.5870	0.9408	0.8350	0.5171	0.7690	0.6396	0.7423	0.4199	0.7998	1.0000	0.5163	0.5457	0.6479	0.6471
11	0.7161	0.7814	0.7176	0.3701	0.8450	0.7282	0.4230	0.7568	0.6423	0.5163	1.0000	0.4338	0.5805	0.8398
12	0.5807	0.6817	0.5476	0.4382	0.9917	0.6136	0.3845	0.7600	0.5593	0.5457	0.4338	1.0000	0.6277	0.6282
13	0.5496	0.8126	0.5406	0.9092	0.8419	0.5330	0.4437	0.7588	0.6839	0.6479	0.5805	0.6277	1.0000	0.8564
14	0.9924	0.4801	0.5982	0.5384	0.6710	0.3691	0.9722	0.6000	0.5689	0.6471	0.8398	0.6282	0.8564	1.0000

Modeling Results and Suggested Further Research

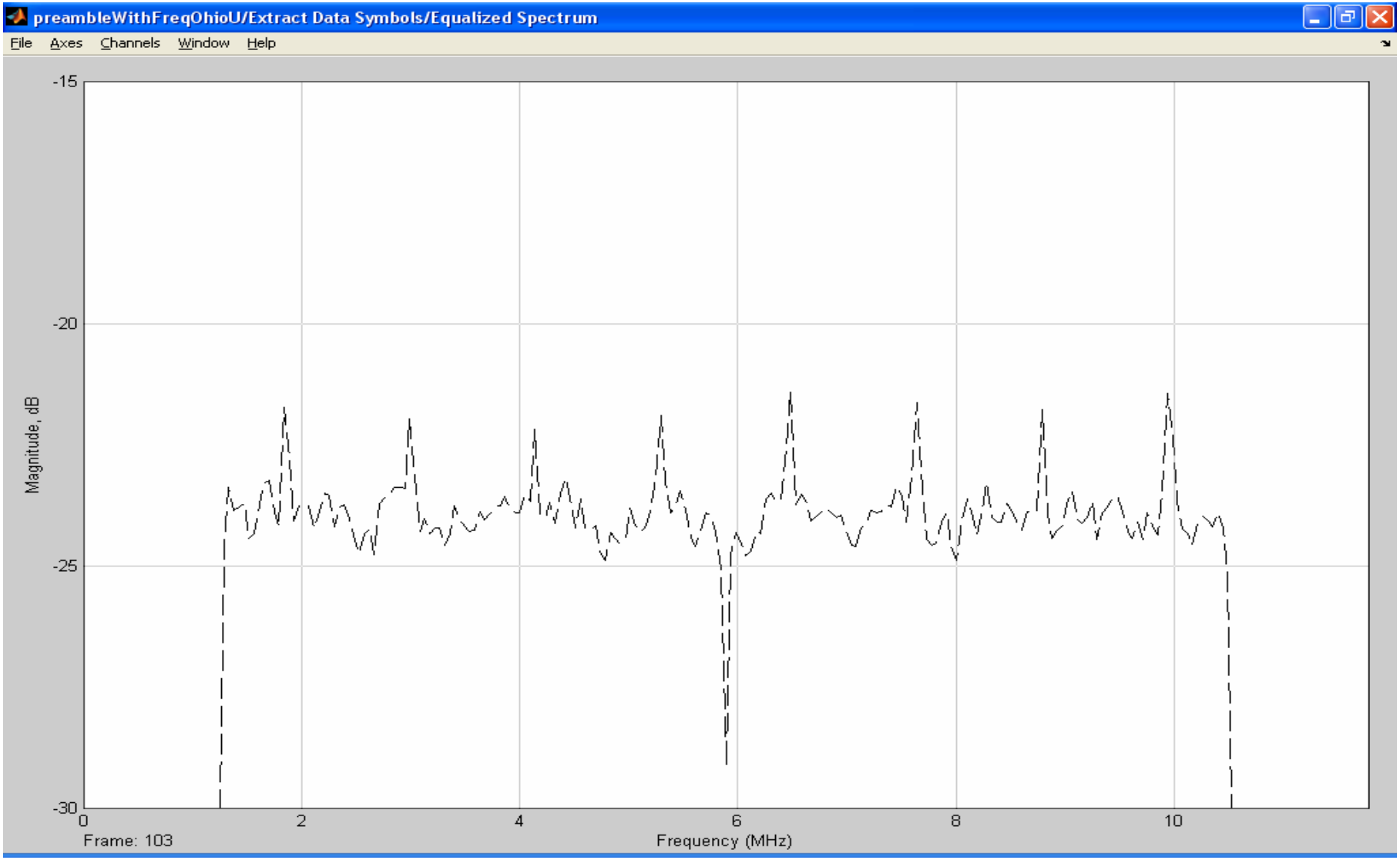
Ohio University Channel Model NLOS/Large/10MHz



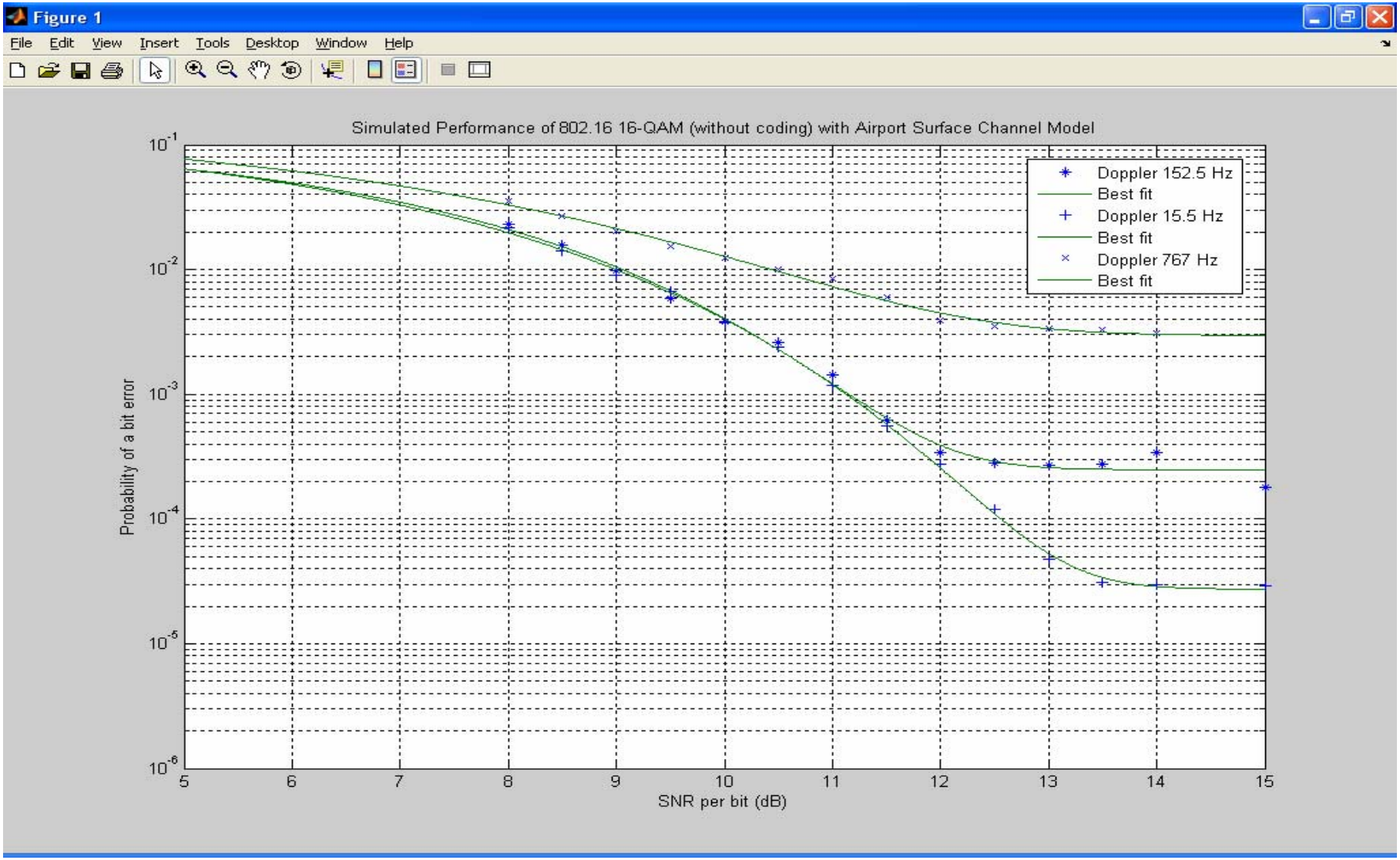
802.16 Signal After Ohio U Channel



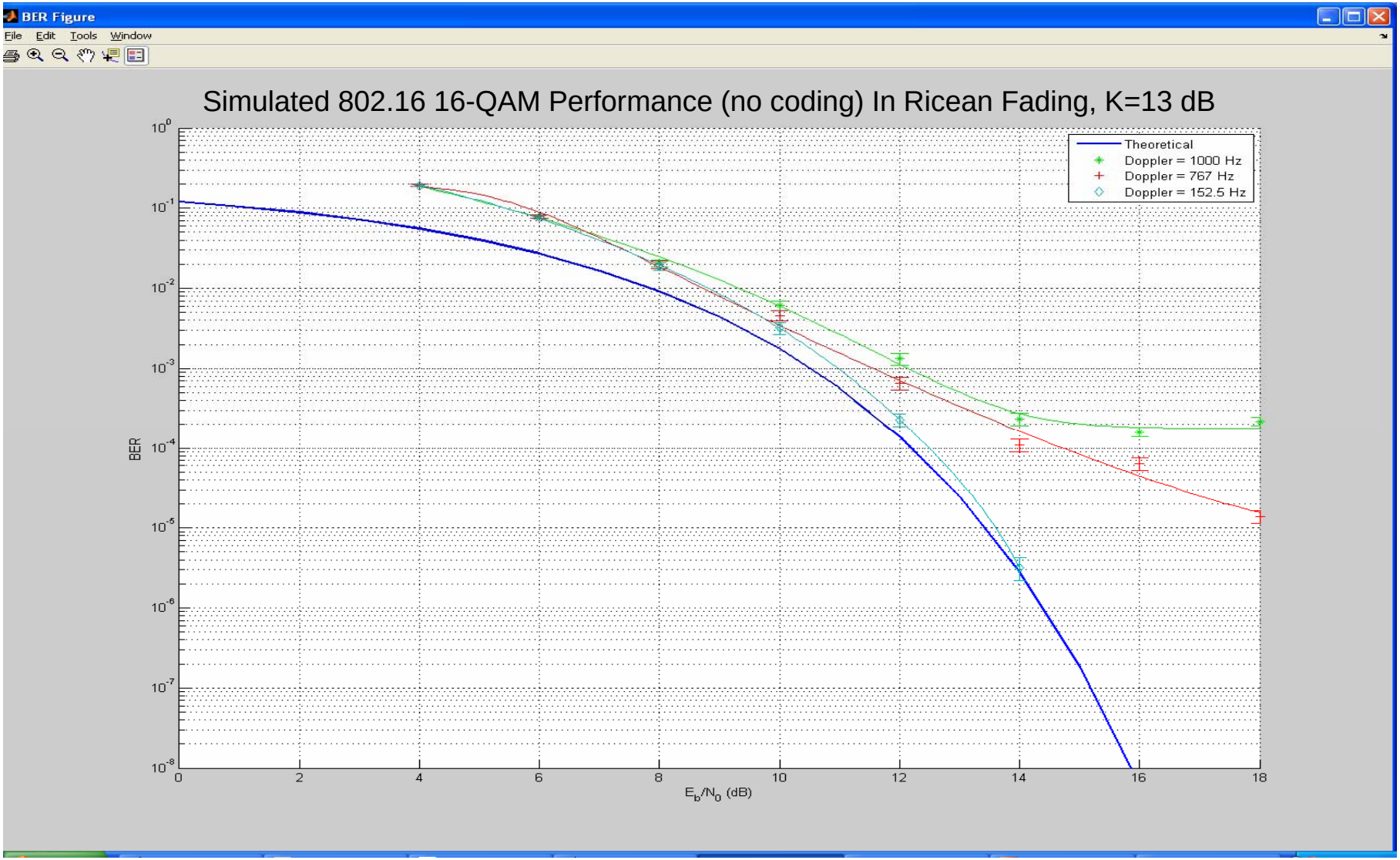
Equalized Spectrum



Simulated 802.16 16-QAM Performance



Simulated 802.16 16-QAM Performance – LOS Model



Conclusions and Recommendations

- The performance of 802.16 on an airport surface is expected to be quite good for most of the movement area

- Recommended topics for further analysis
  - The 802.16e OFDMA physical layer has several interesting features that should enhance system performance in the airport surface movement area. These features include:
    - HARQ
    - Fast feedback channel
    - Diversity sub-carrier permutations
    - Space-time coding
    - Use of MIMO and associated handover issues
    - Convolutional turbo codes
  - It is recommended that these techniques be modeled and studied in the context of the Ohio University airport surface channel models

Supplemental Slides

802.16 Data Randomizer

- Data is randomized using a PRBS generator
  - Preambles are not randomized
- Seed value used to calculate the randomization bits, which are combined in an XOR operation with serialized bits of each burst
  - Initialized in accord with validation data: UIUC: 7, BSID: 1, Frame: 1
- Simulink Implementation shown
  - Uses Shift Register connections as shown ($1 + X^{14} + X^{15}$)
  - The Zero Pad is required because on page 433 we read: "A single 0x00 tail byte is appended to the end of each burst. This tail byte shall be appended after randomization."

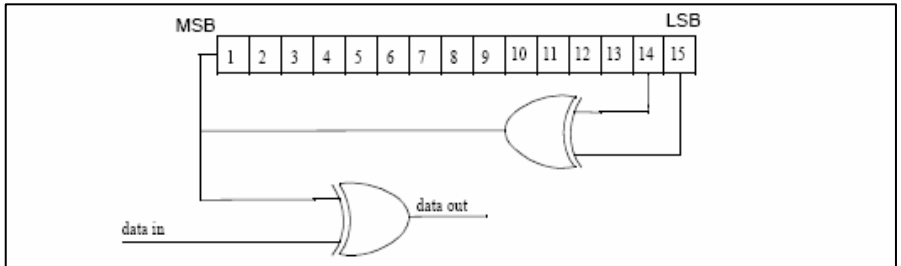
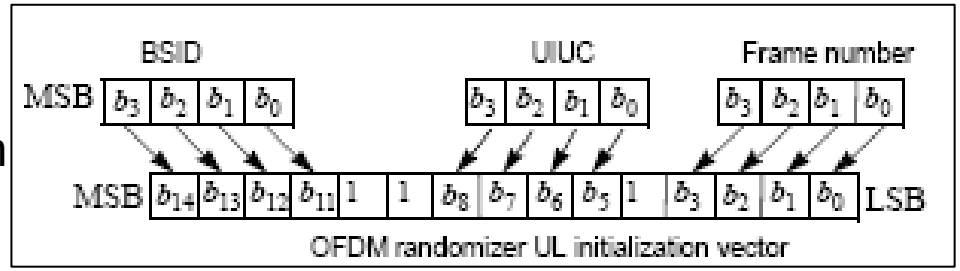
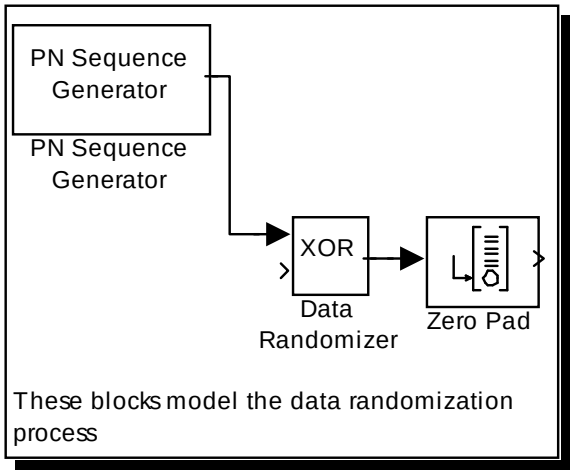


Figure 197—PRBS for data randomization





Reed-Solomon Coding

- The Reed–Solomon encoding shall be derived from a systematic RS (N = 255, K = 239, T = 8) code using GF(2^8)

Code Generator Polynomial: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots(x+\lambda^{2T-1}), \lambda = 02_{HEX}$

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

Table 215—Mandatory channel coding per modulation

Modulation	Uncoded block size (bytes)	Coded block size (bytes)	Overall coding rate	RS code	CC code rate
BPSK	12	24	1/2	(12,12,0)	1/2
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16-QAM	48	96	1/2	(64,48,8)	2/3
16-QAM	72	96	3/4	(80,72,4)	5/6
64-QAM	96	144	2/3	(108,96,6)	3/4
64-QAM	108	144	3/4	(120,108,6)	5/6

Full Bandwidth test case is specified using QPSK, rate 3/4

Convolutional Encoding

- Each RS block is encoded by the binary convolutional encoder, which shall have native rate of 1/2, a constraint length equal to 7, and shall use the generator polynomials codes

$$G_1 = 171_{OCT} \qquad FOR\ X$$
$$G_2 = 133_{OCT} \qquad FOR\ Y$$

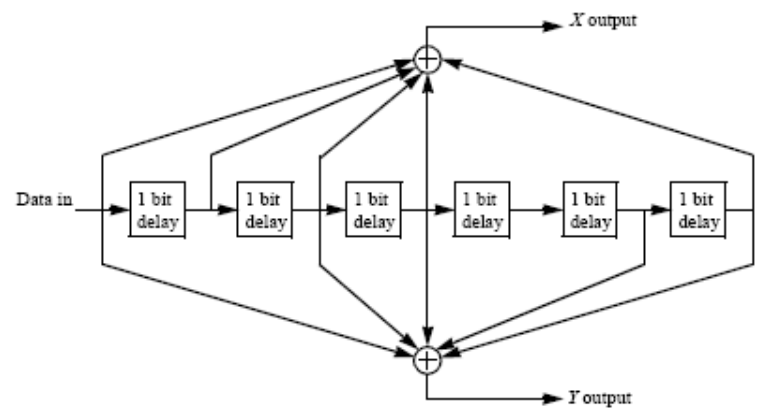


Figure 200—Convolutional encoder of rate 1/2

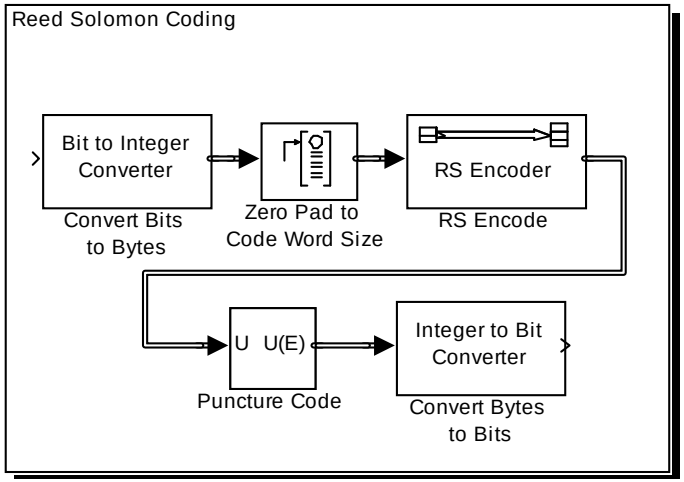
- Puncturing patterns and serialization order that shall be used to realize different code rates are defined in Table 214. In the table, “1” means a transmitted bit and “0” denotes a removed bit, whereas *X* and *Y* are in reference to Figure 200.

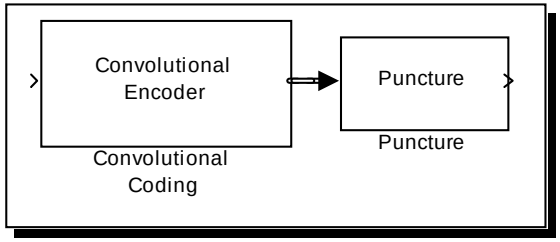
Table 214—The inner convolutional code with puncturing configuration

	Code rates			
Rate	1/2	2/3	3/4	5/6
d_{free}	10	6	5	4
X	1	10	101	10101
Y	1	11	110	11010
XY	X_1Y_1	$X_1Y_1Y_2$	$X_1Y_1Y_2X_3$	$X_1Y_1Y_2X_3Y_4X_5$

Simulink Models

- Reed Solomon Model
  - Convert to bytes (RS is a byte-operator coding scheme)
  - Zero pad the data block from 36 bytes (shortened code) to 239 bytes (native RS code)
  - After coding, puncture the 255 byte code word to recover information bytes and first 4 parity bytes
    - This gives the (40,36,2) code shown for QPSK rate ¾
- Convolutional Coding
  - Define the generator for the convolutional encoder as a constraint length 7, taps (octal) of 171 and 133
  - Puncture output by selecting *X*1*Y*1*Y*2*X*3*Y*4*X*5





Interleaving

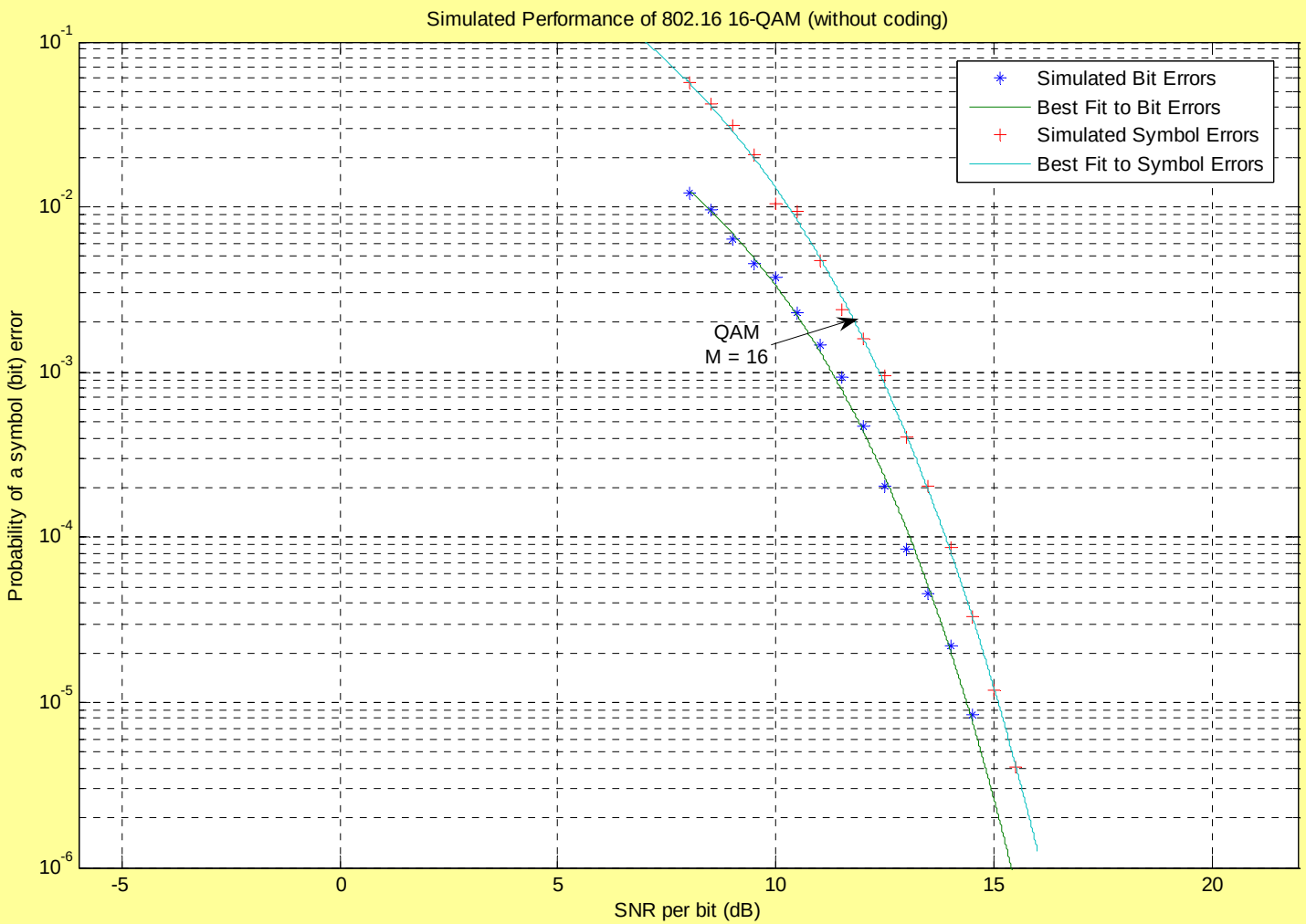
- All encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of coded bits per the allocated subchannels per OFDM symbol, *N*cbps.
  - The interleaver is defined by a two step permutation. The first ensures that adjacent coded bits are mapped onto nonadjacent subcarriers.
  - The second permutation insures that adjacent coded bits are mapped alternately onto less or more significant bits of the constellation, thus avoiding long runs of lowly reliable bits.

The first permutation is defined by Equation (71):

$$m_k = (N_{cbps}/12) \cdot k_{mod12} + floor(k/12) \qquad k = 0, 1, \ldots, N_{cbps} - 1$$

The second permutation is defined by Equation (72):

$$j_k = s \cdot floor(m_k/s) + (m_k + N_{cbps} - floor(12 \cdot m_k/N_{cbps}))_{mod(s)} \qquad k = 0, 1, \ldots, N_{cbps} - 1$$

- This is modeled using Matlab code to define an index vector that is the specified parameter to the Simulink general data interleaver block

Base Simulation Results – Comparison of SER and BER