A Real-Time Coded OFDM Acoustic Modem in Very Shallow Underwater Communications

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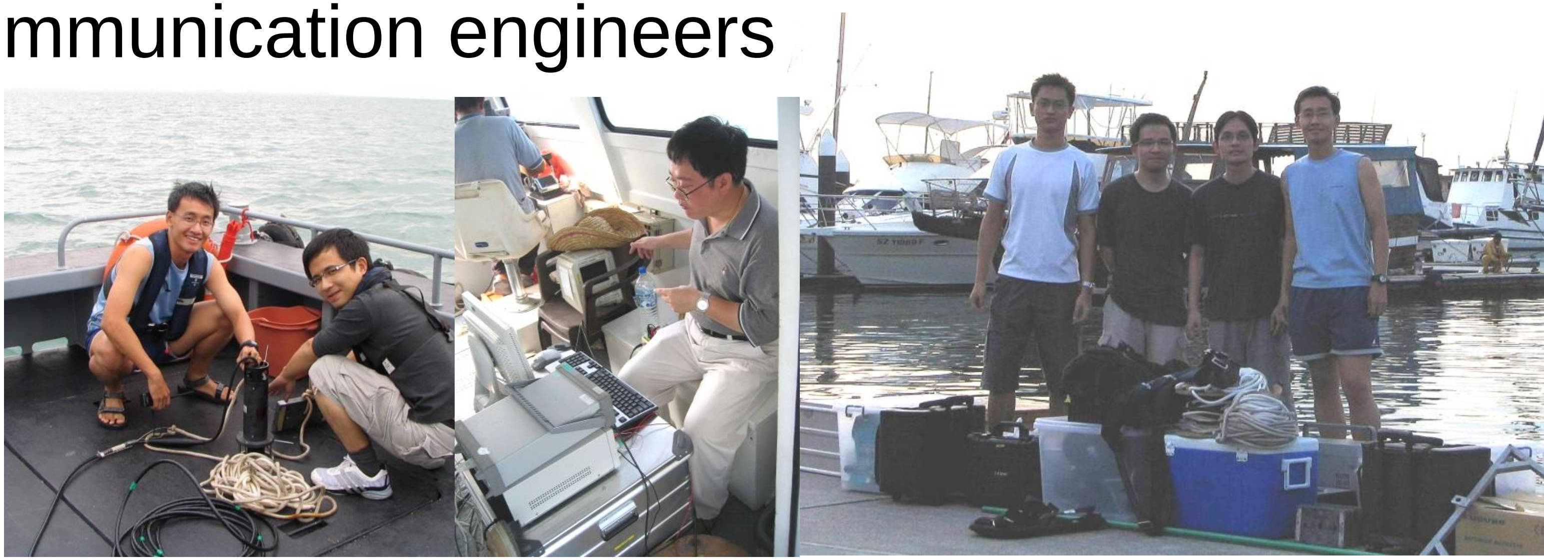
INTRODUCTION

- Typical COTS modems performed at 200-300bps @ BER ~ 10^{-7} - 10^{-6} for distances up to 2400m (Actual shallow water performance evaluated by DSO)
- July 2004 – assembled a team of acoustics and communication engineers

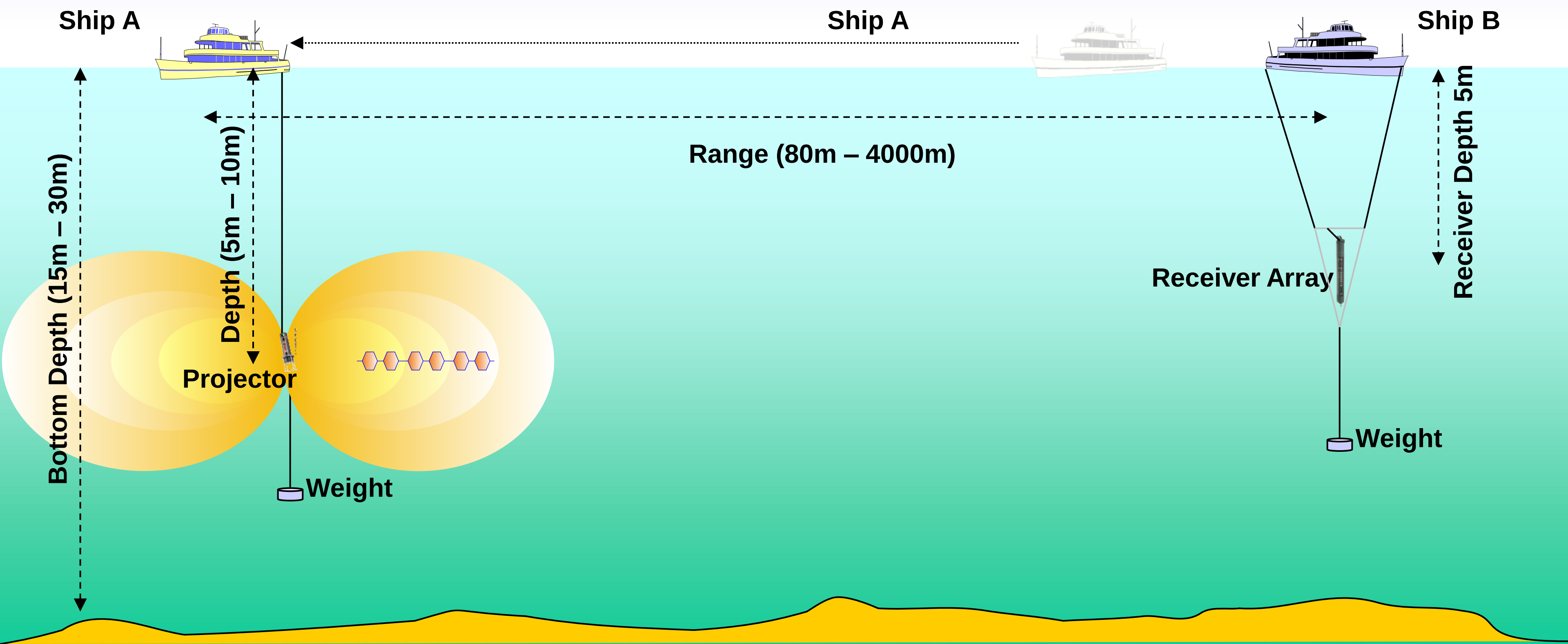


OBJECTIVES

- Study of local shallow waters
  - Measurements / Develop channel model
- Developed a versatile and reconfigurable underwater acoustic communications test bed
- Investigate and evaluate communications processing techniques
  - OFDM
  - Turbo Product Codes

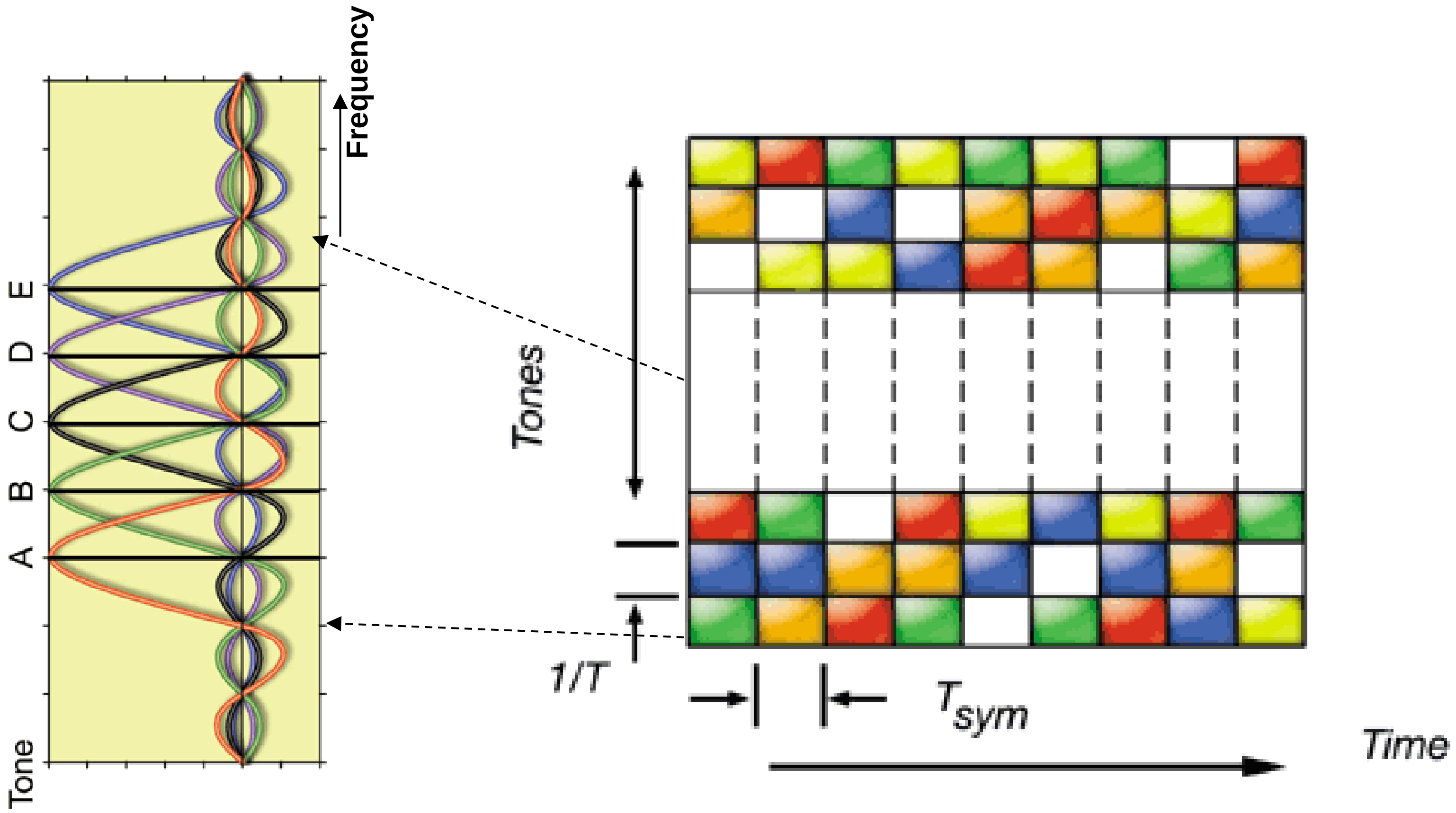
HARDWARE OVERVIEW

SEA TRIAL SETUP



COMMUNICATION SCHEME

- Orthogonal Frequency Division Multiplexing



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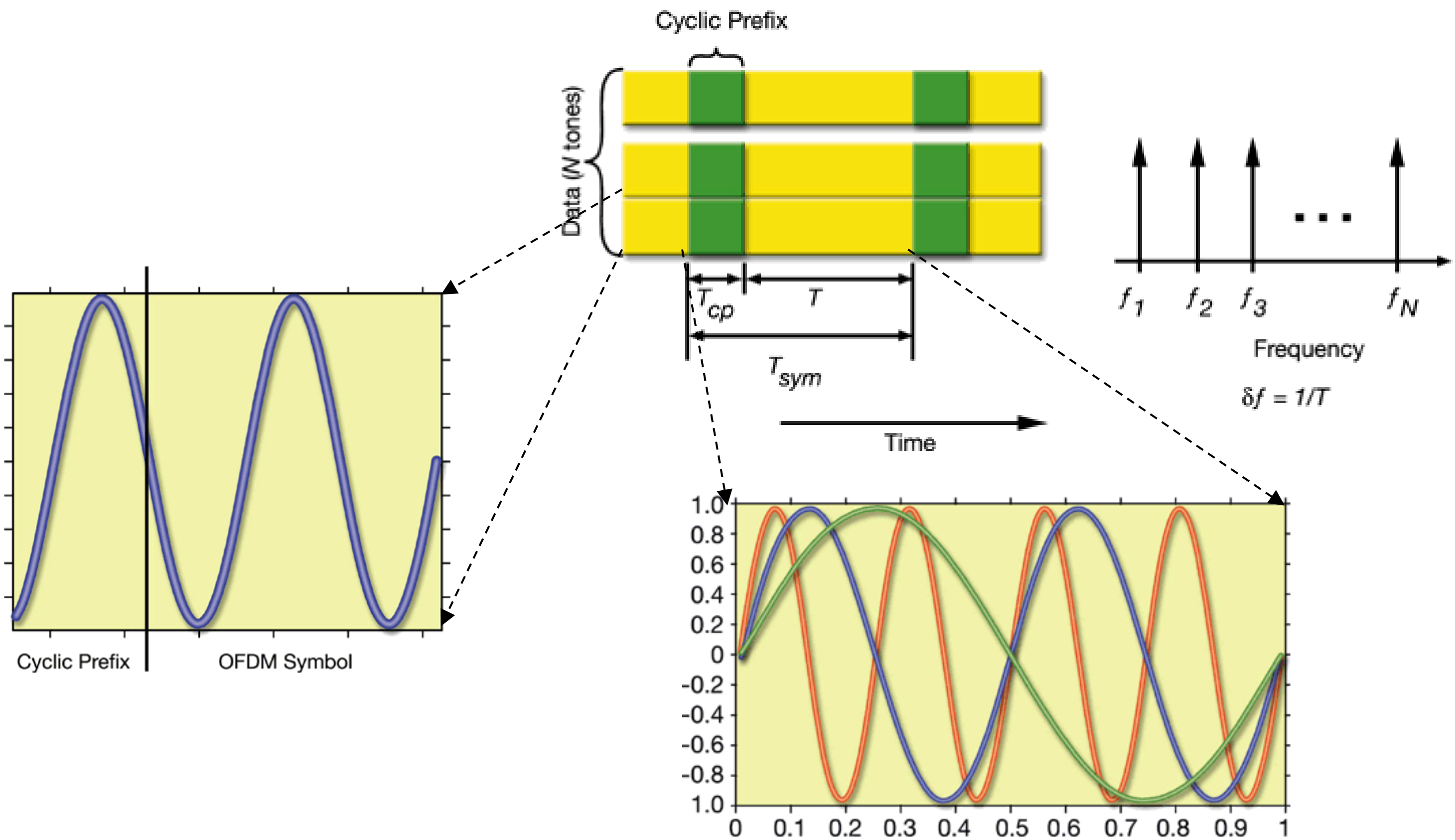


COMMUNICATION SCHEME

- Why OFDM?
  - Easy to combat multipaths by cyclic extension.
  - Robust against impulsive shrimp noise.
  - Mild channel Doppler spread – OFDM not suffer severe inter-carrier interference (ICI).
- Why DPSK on each sub-carrier
  - Slow channel fading allows time-domain DPSK.
  - Simplified receiver design – no channel estimation.

COMMUNICATION SCHEME

- Waveform Structure
  - Transmit in bursts, 12 frames in one burst, each burst starts with an Automatic Gain Control (AGC) preamble.

AGC	**OFDM Frame 1**	**OFDM Frame …**	**OFDM Frame 12**

COMMUNICATION SCHEME

- Waveform Structure (Cntd.)
  - Within one OFDM frame: 2 OFDM training symbols, 18 OFDM data symbols

Time Sync Preamble	**Guard Bits**	**OFDM Training Syms**	**OFDM Data Sym 1**	**OFDM Data Sym …**	**OFDM Data Sym 18**

Time Sync Preamble	Guard Bits	OFDM Training Syms	OFDM Data Sym 1	OFDM Data Sym …	OFDM Data Sym 18

- Single-carrier BPSK modulated time sync preamble
  - Easy to design time-domain binary sequence with good correlation property for receiver sync.
- Guard bits are actually cyclic extension of the time sync sequence
  - Sharper resolution of receiver sync correlator output

Time Sync Preamble	Guard Bits	OFDM Training Syms	OFDM Data Sym 1	OFDM Data Sym …	OFDM Data Sym 18

- Two identical OFDM training symbols for fine frequency offset estimation (FOE)
  - FOE using Moore's method.
  - Cyclic extensions surrounding the 2 training symbols and no cyclic extension between them.
  - No coarse frequency offset estimation because
    - channel Doppler effect is small
    - transducers introduce little FO
    - frequency up and down conversions are done all digitally with high precision (FO < 10 Hz)

Time Sync Preamble	Guard Bits	OFDM Training Syms	OFDM Data Sym 1	OFDM Data Sym …	OFDM Data Sym 18

- Each data symbol has both cyclic prefix and postfix.
- Why postfix?
  - Receiver designed to synchronize with the dominant path;
  - Dominant path need not be the first-arriving path when range is short;
  - In case that dominant path is not the first-arriving path, ISI will occur if no postfix!

Time Sync Preamble	Guard Bits	OFDM Training Syms	OFDM Data Sym 1	OFDM Data Sym …	OFDM Data Sym 18

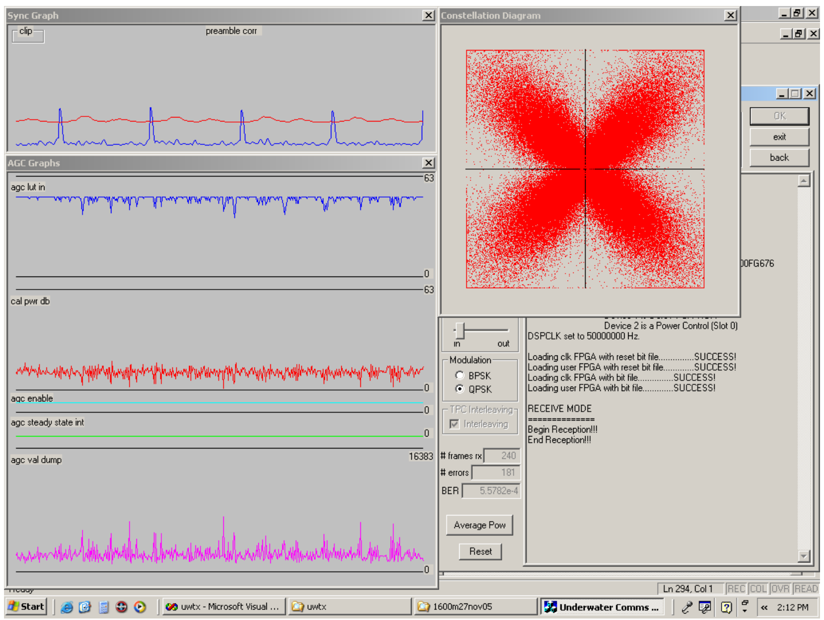
- Length of cyclic extensions varies according to channel multipath spread at different ranges, thus different data rate between 2 kbps to 10 kbps.

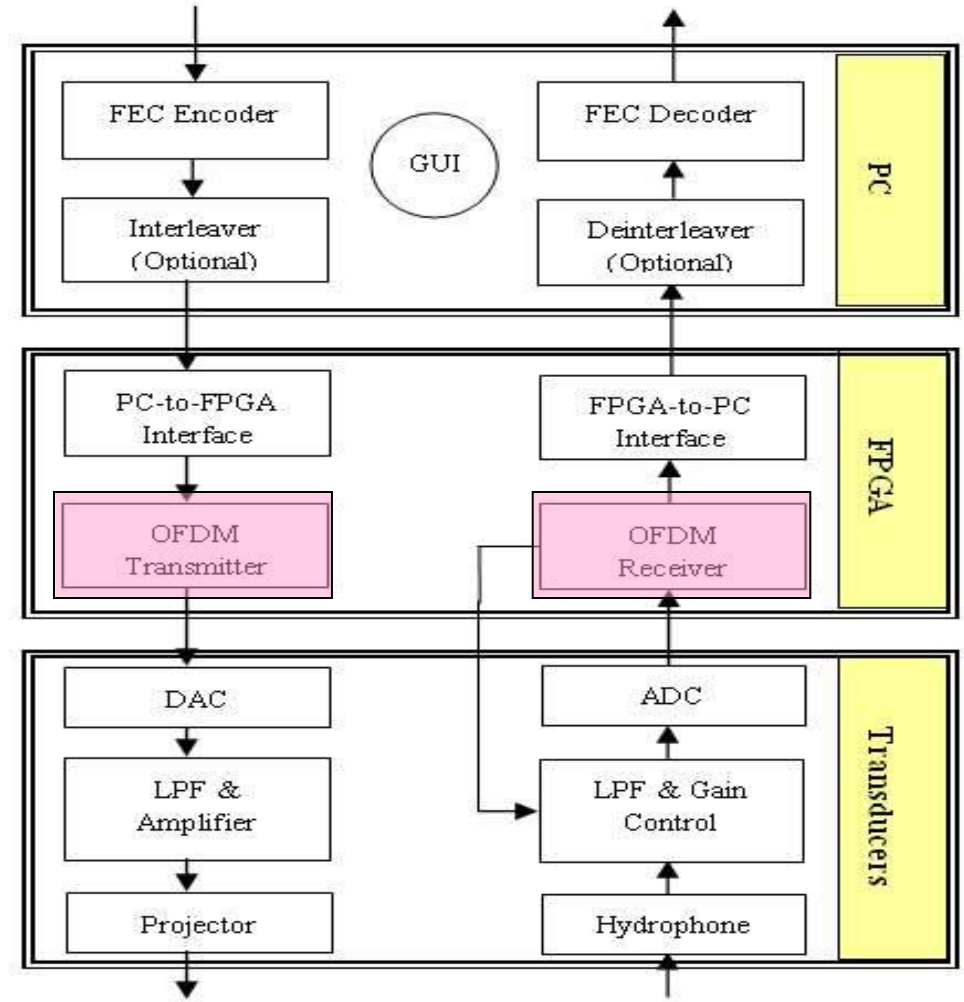
COMMUNICATION SCHEME

- Turbo Reed-Solomon Product Code
  - Encoder: Product code based on Reed-Solomon code.
  - Decoder: Soft-input soft-output iterative decoding, Chase algorithm, and algebraic Reed-Solomon harding decoding.
- Benefit
  - High code rate (0.75).
  - Easy to implement as compared to turbo convolutional code.
  - Better performance over multipath fading channels.

COMMUNICATION SCHEME

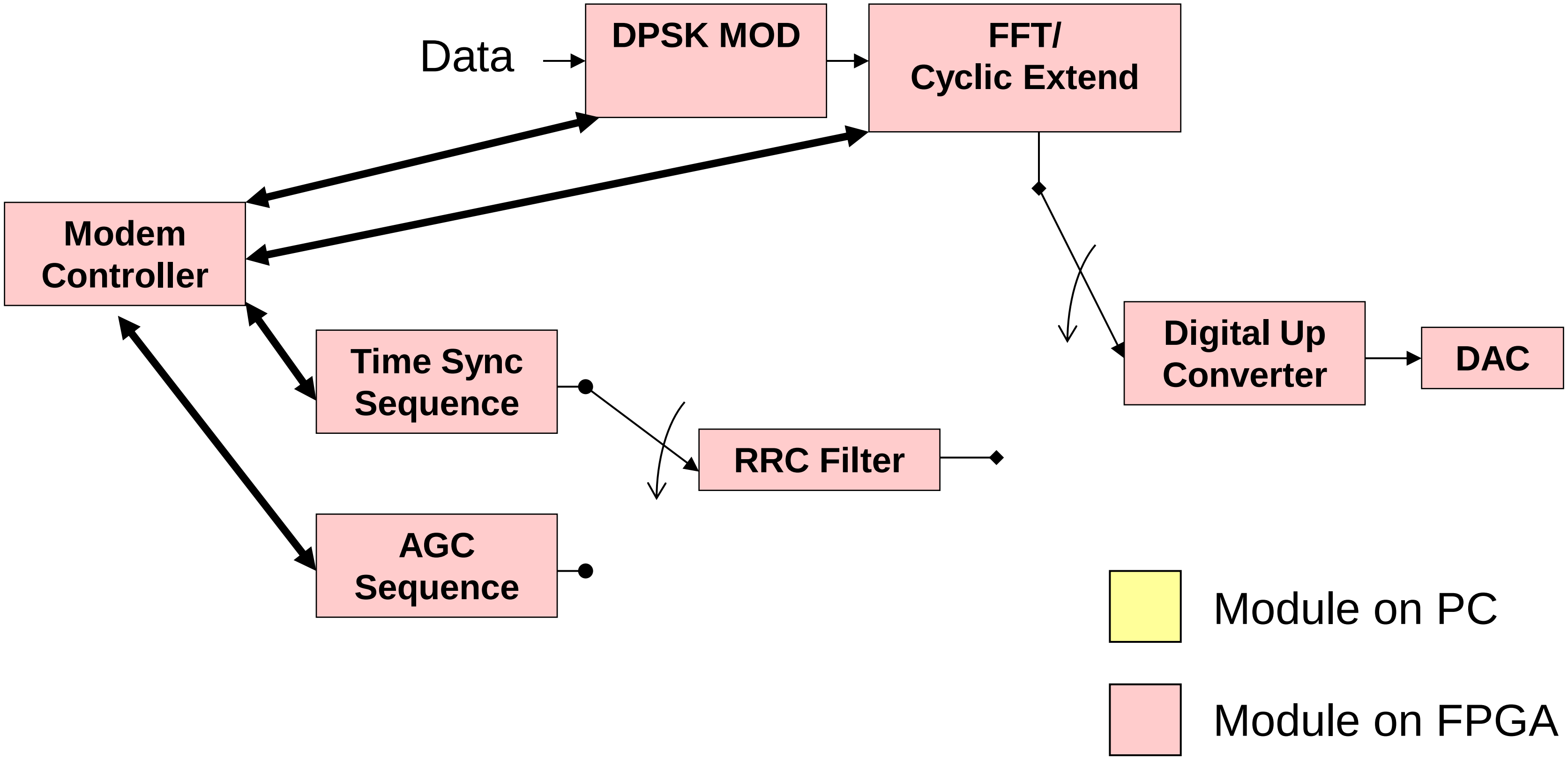
- Modem Architecture





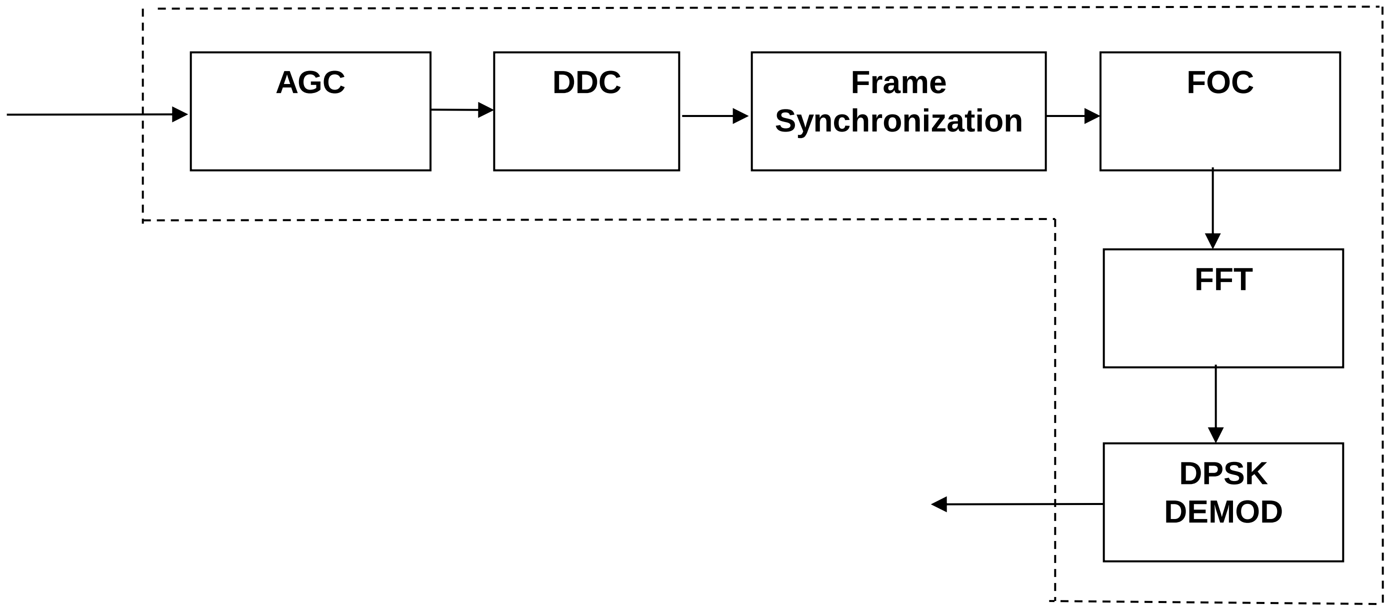
COMMUNICATION SCHEME

- OFDM Transmitter



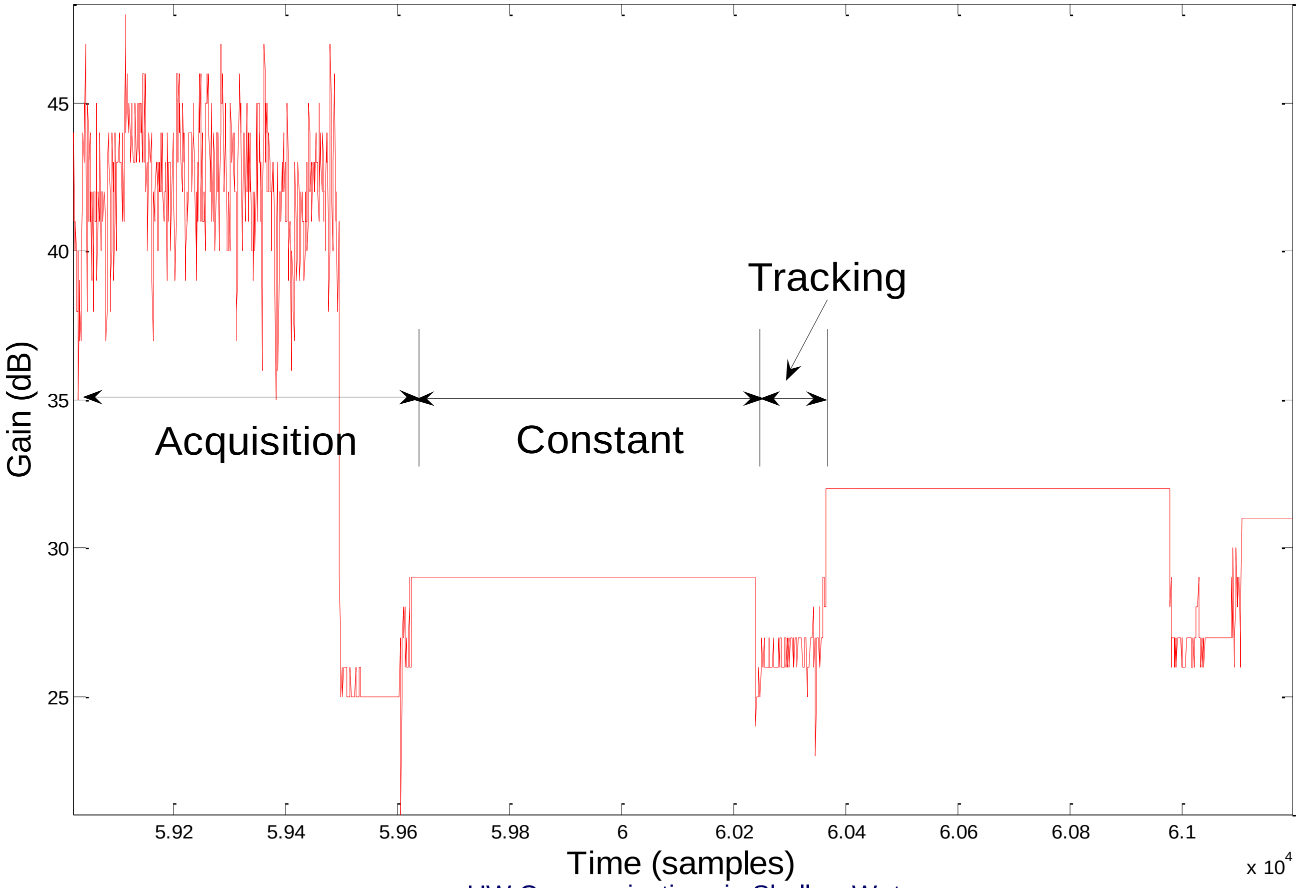
COMMUNICATION SCHEME

- OFDM Receiver



PERFORMANCE

- AGC Performance



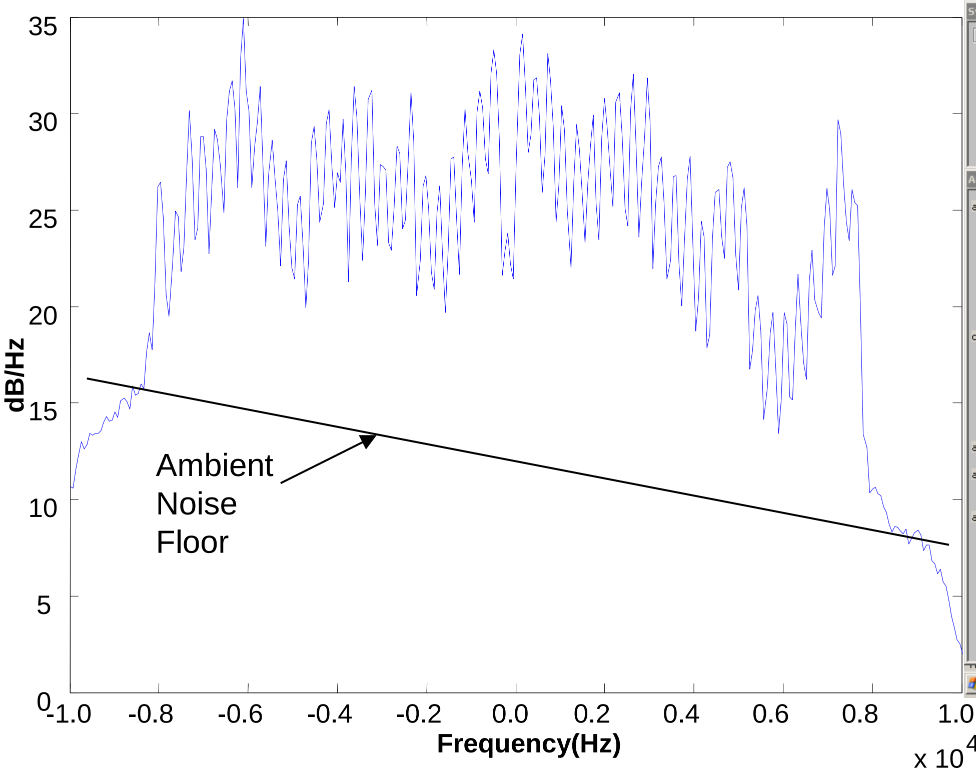
PERFORMANCE

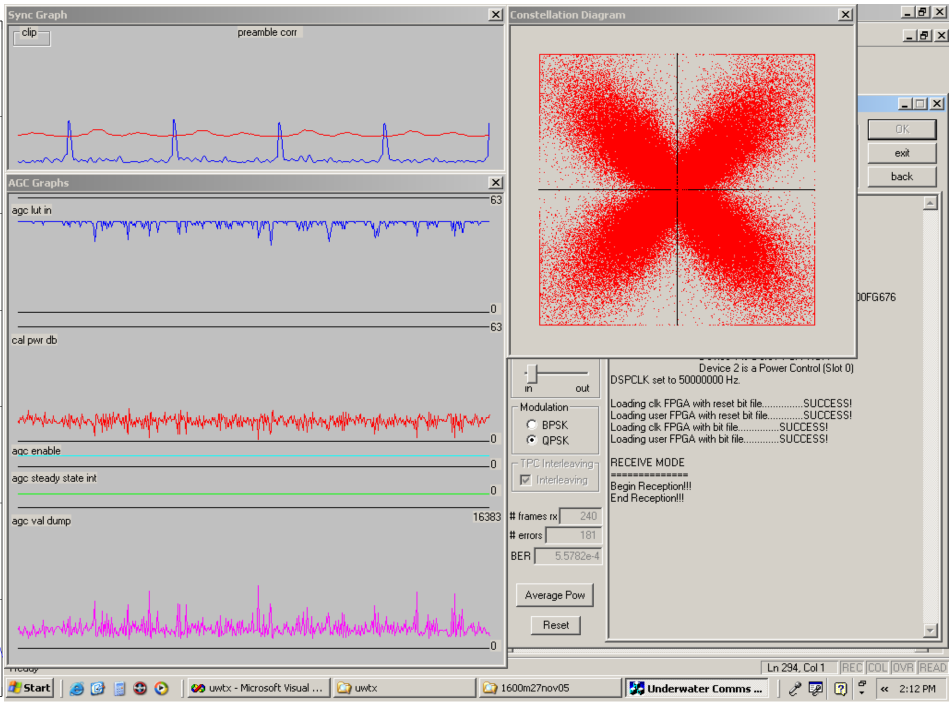
- OFDM Performance

Category	Dist (m)	Mod	FEC	# of Rx frames in error	BER
Short Range	80	DB/QPSK	**BER: 0.04 to 0.1 (Uncoded only: – conditions not good enough to switch on channel coding)**		
	140	DB/QPSK			
Medium Range	400	DBPSK (2.08kbps)	TRSPC	1	5e-5
	1000	DBPSK (2.08kbps)	TRSPC	0	<4e-6
	1000	DQPSK (4.16kbps)	TRSPC	0	<4e-6
	1700	DBPSK (4.77kbps)	TRSPC	0	<4e-6
	1700	DQPSK (9.54kbps)	TRSPC	0	<4e-6
Long Range	2500	DQ/BPSK	**BER:0.04 to 0.1**		

PERFORMANCE

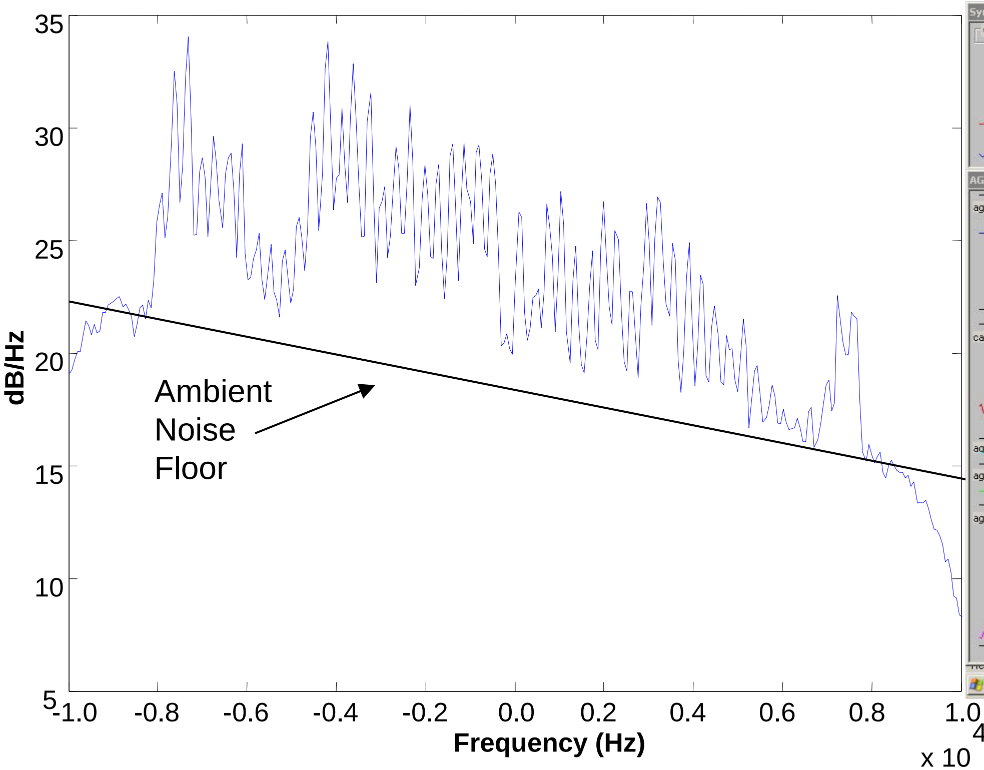
- “Medium Range” Performance

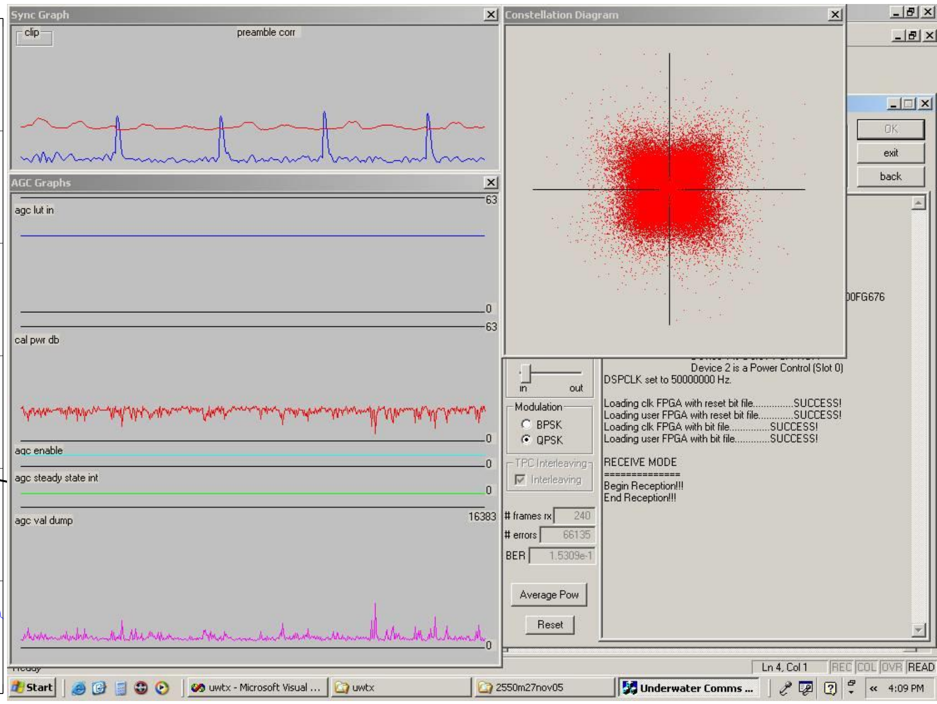




PERFORMANCE

- "Near/Far Range" Performance





FUTURE WORK

- Rectify "Near" Range Problems
  - Inter Channel Interference
    - Sub-Channel Equalization
  - Time Synchronization
    - Frame and Symbol Level Synchronisation
- Rectify "Far" Range Problem
  - Improve the Peak to Average Power Ratio (PAR≈1) of OFDM Signal

SUMMARY

- Developed a versatile and reconfigurable underwater acoustic communication test bed
- Accumulated at-sea data for communication channel characterizations and communication signals
- Implemented a real time OFDM communication modem in FPGA
- Successful application advanced channel coding methods (TRSPC) to underwater communications
- The OFDM DB/QPSK (2.08-9.54kbps) BER performance of< 4×10^{-6} was achieved at the ranges from 400m to 1700m.
- However, for ranges less than 400m and above 2500m, our OFDM modem did not perform well. We have identified the problems and recommendations were made to overcome them

THAT'S ALL FOLKS!

- Have a pleasant day ahead!