SFOMC - Acoustic Gateway

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LONG-TERM GOALS

Our long-term objectives are the study of the ocean environment and its impact on high-speed acoustic communication (acoustic noise, bottom type, surface wave activity, velocity profiles, bubbles), the comparison between predicted and measured communication performance through modeling, and to identify the impact of large scale spatial diversity on acoustic communications using multiple sources located at different locations.

OBJECTIVES

The overall objective of this research is to achieve reliable high-speed acoustic telemetry from a Buried Object Scan Sonar (BOSS) mounted on a BlueFin Unmanned Underwater Vehicle (UUV) during Mine Counter Measure (MCM) operations. To do so, the FAU Mills-Cross, connected to the FAU node (MUX), is to be used as a high-speed acoustic gateway to relay data back to shore. The source mounted on the BOSS payload will be an FAU Dual-Purpose Acoustic Modem (FAU-DPAM). The targeted peak data rate will be of 15,000 bits per second (bps) at a maximum range of 2,000 meters.

APPROACH

To achieve such goal, a preliminary study of the environment and its impact on high-speed acoustic communication has been performed. The two most influent factors impacting acoustic communications are known to be background noise and non-stationary multipath. The second factor is dominated by the influence of surface wave activity, presence of macro and micro-structures (thermal and chemical) and bubbles. Furthermore, seasonal change and adverse weather can cause significant changes in performance of the communication system. The major parameters to monitor in the ocean environment are: background acoustic noise, bottom type, surface wave activity, temperature and salinity profile, sound velocity profile and presence of bubbles. It is also essential to compare measured the communication performance with a set of reliable, well-established acoustic and communication models. Acoustic models such as the RAM PE model and SWAT can either generate artificial data transmissions or be combined with communication models (such as Nakagami's model) to achieve statistical estimates of communications performance. Environmental data of good quality are imperative to run such models. Finally, the presence of multiple sources located at different locations allows for the measurement of large-scale spatial diversity. This is a fundamental element in predicting the performance of a communication system mounted on a UUV, as this vehicle changes location during transmission. Indeed, the presence of only one source in space at a given time could lead to erroneous conclusions on the overall communication performance of the system.

WORK COMPLETED

- 3 FAU Modem Pingers built and operational. 2 Pingers were operating for 6 months underwater. 1 pinger is still in the water.
- The Range Dependent Acoustic Model now takes into account the surface dynamics and is compatible with modem signals. The model is currently limited to MFSK modulation. PSK simulation is under development.
- 8 weeks worth of acoustic data have been recorded.
- Control from shore of the Mills-Cross using FAU/SFTF fiber-optics junction box achieved.
- Reliable communication has been achieved up 16,000 bps using PSK modulation. Marginal performance is noted at 24,000 bps.

1) Experimental Setup. The precise deployment location for instrumentation is documented in the following Figure 1 and Table 1.

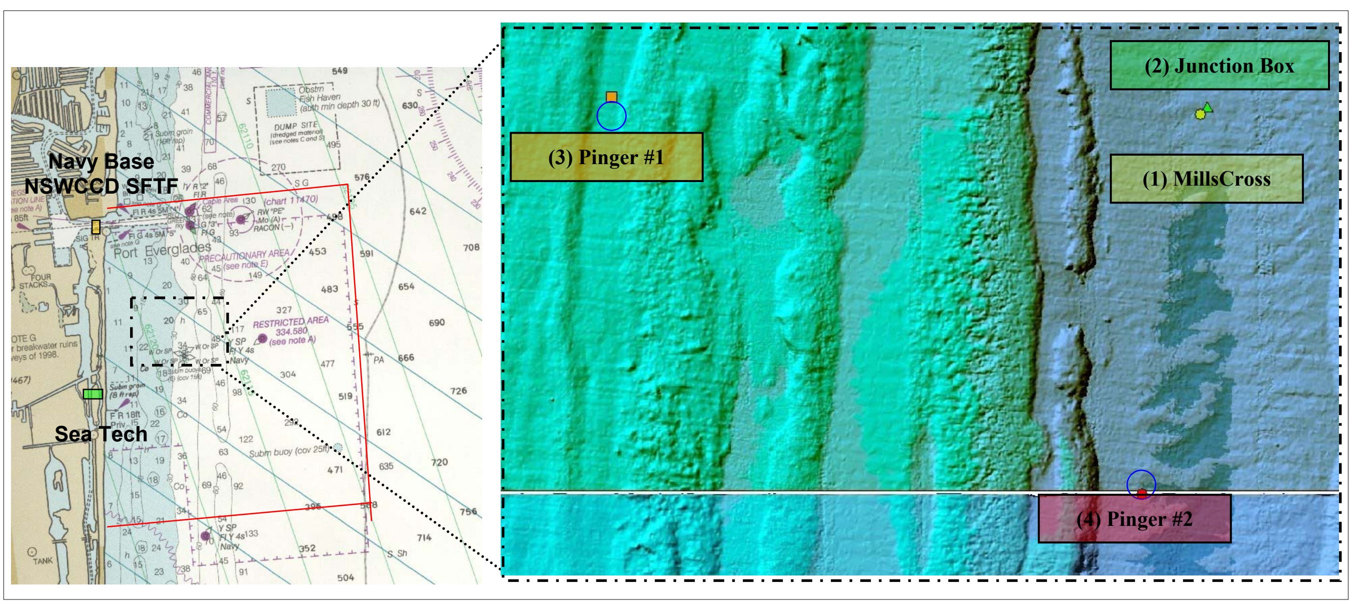

Figure 1. Sources and Receiver Location Map, SFTF Range

Table 1 also provides the platform details. In order to simulate the BOSS dynamic platform, high-speed acoustic transmissions were performed from a small boat: this is listed as "boat operation" in table 1. The FAU HPAL was located on an eight-foot tall tripod. Each pinger was located on an 8 foot-tall stand.

Table 1. Sources and Receiver Location

	Instrument	Location		Depth	Deployment
		Latitude	Longitude		
1	**FAU MillsCross Receiver Array**	26° 04.1990 N	80° 05.996 W	65 [ft]	▪ Fixed Platform
2	**FAU/SFTF Junction Box**	26° 04.1680 N	80° 05.358 W	65 [ft]	▪ Bottom Mount
3	**Pinger # 1 – West Source**	26° 04.1990 N	80° 05.996 W	30 [ft]	▪ Fixed Platform ▪ Boat operation
4	**Pinger # 2 – South Source**	26° 03.7950 N	80° 05.428 W	65 [ft]	▪ Fixed Platform ▪ Boat operation
5	**FAU-DPAM – Long Range Source**	26° 03.2010 N	80° 05.424 W	68 [ft]	▪ Boat operation

2) <u>Equipment</u>. Figure 2 and 3 show the two key pieces of equipment required for this experiment:

- The FAU High-Performance Acoustic Link (HPAL), also know as Mills-Cross receiver.
- The FAU Dual-Purpose Acoustic Modem (DPAM), programmed as a high-speed data source and equipped with a timer board and alkaline batteries.

Figure 5 shows the modem configuration when acoustic communication is performed from a small vessel.

Figure 2. FAU HPAL (Mills-Cross Receiver) before Deployment

Figure 3. Details of the DPAM Pinger Electronics

Figure 4. DPAM Topside Configuration

3) Data Collection. The principal study and collection of data pertinent to this investigation was conducted over the duration of approximately 8 weeks from July 14th, 2003 until September 5th, 2003. This continuous study of the acoustic channel and the governing environmental parameters in the South Florida Ocean Measurement Center's acoustic observatory was designed to identify specific environmental characteristics unique to the observatory that affect acoustic communication within it. While an eight weeks oceanographic experiment cannot be considered a long term study, the time period was selected as a compromise between statistical accuracy and the ability to process the nearly 200 GB of data in a timely fashion. Table 2 shows an abridged tabulation of transmitted acoustic communications recorded by the MillsCross receiver array and transmitted to shore, via the FAU/SFTF junction box, at the NSWCCD SFTF range house as the principal study. Figure 5 provides a diagram of the overall acoustic communications experiment. Table 3 provides the details of the pinger transmission schedule. Note that a transmission contains 9 messages in PSK mode, and 12

messages in MFSK mode. A "recorded transmission" typically requires 2 to 4 Gbytes of storage space when using the FAU HPAL.

Table 2. Summary of Acoustic Transmissions Recorded

	Experimental Operation		
	Pinger Recording	Boat Operation	
	MPSK Modulation	MPSK Modulation	FH-MFSK Modulation
Number of Recorded Transmissions	38	7	10
Total Number FH-MFSK Transmission Recordings	10 Records		
Total Number MPSK Transmission Recordings	45 Records		
Total Number of Acoustic Communications Recorded	55 Records		

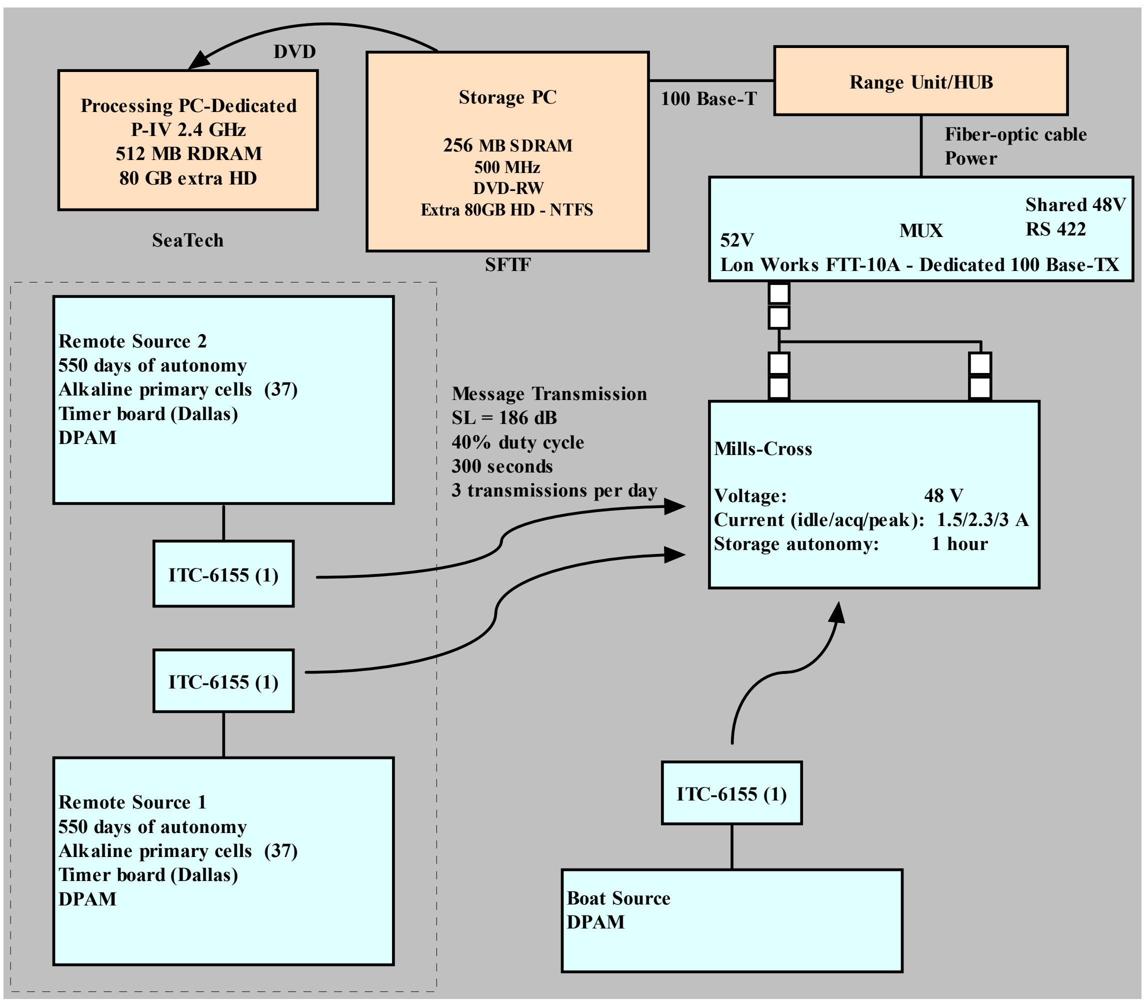

Figure 5. Overview of the Current Experimental Setup

Table 3. Daily Transmission Schedule for the FAU DPAM Pingers.

		SOURCE SPECS						
	Timer ID	Drift	Start1	Stop1	Start2	Stop2	Start3	Stop3
W Source (1)	4	0.85 min/180 days	8:00:00 AM	8:03:00 AM	1:00:00 PM	1:03:00 PM	6:30:00 PM	6:33:00 PM
S Source (2)	5	1.7 min/180 days	8:03:00 AM	8:06:00 AM	1:03:00 PM	1:06:00 PM	6:33:00 PM	6:36:00 PM

4) Data Processing. The space-time signal processing method [1-6] utilizes a beamformer optimization strategy, so that spatial array processing and time signal equalization are performed independently. The time-domain signal is subject to variations in phase that require rapid filter update whereas the directional characteristics of the signal do not vary appreciably over the message length and do not require a rapid adaptation response. The method allows for high-speed underwater acoustic communication in very shallow water using coherent modulation techniques. There are several advantages to this method. First, a significant reduction of the signal-to-noise and interference ratio (SNIR) is achieved. The SNIR is defined as the combination of the signal-to-noise ratio (SNR) and signal-to-multipath ratio (SMR). Second, significant stability improvement of the multi-channel Decision Feedback Equalizer (DFE) is achieved by using zero-th order Doppler-compensated data inputs, optimized initial conditions, accurate synchronization and reliable decision information available through the entire message. Next, the bandwidth efficiency is improved by reducing the forward-error coding redundancy level. Finally, the *BL* product and channel stability estimates are evaluated, taking advantage of ability to track multiple coherent paths. These estimates are computed to demonstrate that the communication bandwidth depends strongly on time and frequency spreading.

5) Data Modeling. A non-linear acoustic wave propagation model has been developed to determine the effects of ocean variations in the acoustic field, and to determine the signal measured by a receiver at any distance from an omni-directional source [7][8]. The model accounts for environmental conditions that include bathymetry, bottom properties, sound velocity profile and sea surface characteristics. First, a stationary estimate of the complex sound attenuation is computed as a function of frequency and location, using the parabolic equation numerical technique. For a given range, the vertical profile of the attenuation frequency spectrum is decomposed in the wave number domain. A specific Doppler shift is associated with each wave number. The space-frequency attenuation filter obtained is applied to the transmitted signal to create time-frequency selective fading. So far, the non-linear acoustic wave propagation model has been specifically applied to the area of Port Everglades, Florida, to simulate the performance of the FAU General Purpose Acoustic Modem (FAU-GPAM). The modem operates in the 15.6 kHz to 31.9 kHz frequency band, with 192 dB of source level, and transmits Multi-Frequency-Shift-Key modulated sequences. The range of operation varied from 1 to 5 km, in 12 meters of water. The sea bottom is mainly composed of medium sand. Experimental data have been collected under sea-state 2 conditions. The performance of the acoustic communication system has been successfully predicted using the non-linear model, the Crepeau model and experimental data [9][10]. The model is currently being upgraded to simulate high-speed PSK communication.

RESULTS

Table 4 provides a summary of the data decoded on July 14th, 2003. So far, only 20% of the data have been processed, due to initial technical difficulties and the time requirements associated with backing up data. Message decoding is a near real-time process. Table 4 shows that reliable communication can be achieved up to 16,000 bps. Issues still remain when using 83 microseconds symbols (BPSK and QPSK, 12kHz). Table 5 shows examples of received image transmissions. In this case, a canned image from a high-resolution side-scan was used. The image was a 48,000 bits (6 kilobytes) JPEG image.

Table 4. Preliminary Experimental Numerical Results for MPSK Transmission

Experimental Operation: Pinger Recording 07-14-03						
	MPSK Modulation Schemes		Results After Decoding			
	Type	Coding	Measured BER	Measured FER	Output Message	Image Status
1	BPSK 4 kHz	BCH (15,11,1)	0.094401%	1.5625%	Successfully Decoded	Recovered
2	QPSK 4 kHz	BCH (15,11,1)	0.023148%	0.0000%	Successfully Decoded	Recovered
3	BPSK 8 kHz	BCH (15,11,1)	0.009921%	0.0000%	Successfully Decoded	Recovered
4	QPSK 8 kHz	BCH (15,11,1)	0.145858%	0.0000%	Successfully Decoded	Recovered
5	BPSK 12 kHz	BCH (15,11,1)	1.277108%	56.0000%	Successfully Decoded	Corrupted
6	QPSK 12 kHz	BCH (15,11,1)	2.379975%	52.0000%	Message Contains Errors	Corrupted

Table 5. Preliminary Experimental Message Results for MPSK Transmission

Transmitted Images Recovered After Decoding			
BPSK 4 kHz	QPSK 4 kHz	BPSK 8 kHz	QPSK 8 kHz
Output0714_4kbpsk.jpg	Output0714_4kqpsk.jpg	Output0714_8kbpsk.jpg	Output0714_8kqpsk.jpg
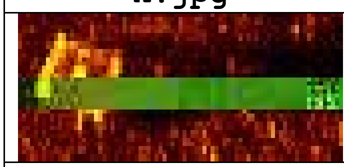	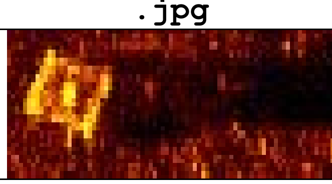	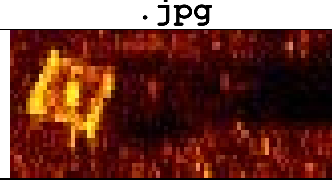	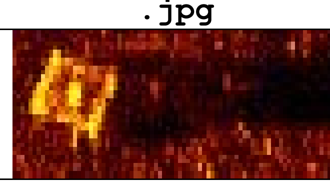
Image Partially Recovered	**Imaged Recovered**	**Image Recovered**	**Image Recovered**

IMPACT/APPLICATIONS

Experimental results are providing a new insight to the understanding of how shallow water propagation conditions affect the information capacity of digital data transmission for sonar operating in the frequency range of 25 kHz. Error rates, adaptation time constants, and the influence of the environment on the stability of the various modes of propagation are inferred.

RELATED PROJECTS

- "Development of a Synchronous High-Speed Acoustic Communication and Navigation System for Unmanned Underwater Vehicles", Dr. P-P. Beaujean (PI), Dr. Steven G. Schock (Co-PI) and Dr. A.

Folleco (Co-PI). Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-96-1-5031.

- "Smart Acoustic Network Using Combined Fsk-Psk, Adaptive Beamforming and Equalization", Dr. P-P. Beaujean (PI), Dr. Steven G. Schock (Co-PI). Sponsored by the Office of Naval Research (Dr. T. Swean). ONR award no. N00014-96-1-5031.

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[6] Jochen R. alleyne, "Digital Acoustic Communications using Decision Directed Learning", Ph.D. Dissertation, FAU, 2001.
[7] Pierre-Philippe J. Beaujean, Andres A. Folleco, Florent J. Boulanger, Stewart A.L. Glegg, "Non-Linear Modeling of Underwater Acoustic Waves Propagation for Multi-Receiver Channels", Proc. of MTS/IEEE Oceans'2003, September 2003, San Diego, CA.
[8] Florent J. Boulanger, "Time-Dependent Multipath Modeling for Underwater Acoustic Wave Propagation in Shallow Water", Masters' Thesis, FAU, May 2003.
[9] Cécile Boubli, "Design of a Frequency Shift Keying Array Receiver for the Acoustic Modem", Master Thesis, FAU, 2000.
[10] Emmanuel P. Bernault, "Array Processing Techniques for Frequency Hopping Multiple Frequency Shift Keying Long Range Communications", Master Thesis, FAU, 2001.

PUBLICATIONS

- Pierre-Philippe J. Beaujean, Andres A. Folleco, Florent J. Boulanger, Stewart A.L. Glegg, "Non-Linear Modeling of Underwater Acoustic Waves Propagation for Multi-Receiver Channels", Proc. of MTS/IEEE Oceans'2003, September 2003, San Diego, CA. [published]

- Florent J. Boulanger, "Time-Dependent Multipath Modeling for Underwater Acoustic Wave Propagation in Shallow Water", Masters' Thesis, FAU, May 2003. [published]