Long Range, Coherent Synthetic Aperture Communications

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LONG TERM GOALS

The central effort of this research will be the development of robust and reliable algorithms for coherent acoustic communications at very long ranges in deep water.

OBJECTIVE

We will study coherent synthetic aperture communications (SAC) between a source and a receiver at speed and depth that exploits the relative motion between the two.

APPROACH

Analysis of deep-water data collected as part of the ONR Acoustic Thermometry of Ocean Climate (ATOC) program has suggested that coherent acoustic communications is feasible at long ranges [1,2]. By treating the tomography signals (m-sequence transmissions) as BPSK

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **Long Range, Coherent Synthetic Aperture Communications**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, San Diego,Scripps Institution of Oceanography,Marine Physical Laboratory,La Jolla,CA,92093-0238**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

communication signals, successful recovery of the sequence of bits has been demonstrated. One example is from the ATOC Acoustic Engineering Test (AET) in November 1994 where 1023-digit m-sequences were transmitted at a 75 Hz center frequency to a 20-element (700 m aperture) vertical array at approximately 3250 km range in the NE Pacific Ocean. An information rate of 37.5 bits/s was achieved. For additional details about this test, refer to [1].

While initial feasibility of long-range acoustic communications has been demonstrated as discussed above, the transmissions in the September 2010 experiment were carried out at a higher center frequency (~100-300 Hz) and explored larger bandwidths and higher order constellations (QPSK and 8-PSK) with signals designed appropriate for deep-water, long-range synthetic aperture communications, rather than for acoustic tomography experiments. Thus, our intent was to understand the limiting characteristics of long-range acoustic communications in deep water.

WORK COMPLETED

The long range acoustic communications (LRAC) experiment was carried out 8-20 September 2010 off the southern California coast. Two SIO (Scripps Institution of Oceanography) ships were involved – the R/V New Horizon was the source ship and the R/V Melville was the receiving array ship. For marine mammal mitigation purposes, the source ship had to transit ~1100 km (~600 nmi) west of San Diego for an appropriate operational area. The source ship towed the sound source at relatively low speed (2-3 knots) around the starting point (34° N and 129° W).

The R/V New Horizon was the source ship. The acoustic transmissions primarily were continuous transmissions of a phase modulated single carrier (PSK) as well as multicarrier (OFDM) transmissions in the 100-300 Hz band. Some linear frequency modulated (LFM) chirps also were transmitted in the same band and various m-sequences were transmitted for either channel probing purposes or multiuser communications. The source was a J15-3. The transmitting current response (TCR) roughly was flat 100-300 Hz. Although the maximum source level was ~180 dB re μPa @ 1 m, the actual source level was estimated at 172~175 dB at the source depth. The source transmissions were done at a depth of 75 m with the source being towed slowly at a speed of 2-3 knots.

The R/V Melville towed the horizontal line array (HLA) during the experiment. The towed HLA was the ~280-m aperture, Five Octave Research Array (FORA) operated by ARL/PSU [3]. The FORA was deployed to a depth of ~200 m with both the LF aperture (64 elements spaced at 1.5 m) and ULF aperture (64 elements spaced at 3 m) being well-matched to the frequencies of interest in this experiment. The HLA was towed mostly at ~3.5 knots (~84 nmi/day or ~156 km/day).

The receive ship needed only be in deep water with no specific operational area restrictions. So after initial successful testing at a very close range (~2 miles), we towed away from the acoustic sound source with a minimum range of ~55 nmi and maximum range of ~460 nmi (i.e., 100-850 km). Early in the experiment, the HLS was in an endfire configuration with the HLA array traversing roughly a radial path with respect to the source position. However, at ~500 km range we collected data with the towed array broadside to the source (crosstrack) as shown below with each track ~12 mile long (3.5 hour at 3.5 kts). During one of those legs, the FORA was towed at ~100 m depth as opposed to the normal 200-m depth for most of data collection. In addition, starting from ~500-km range we ran a zig-zag path with each leg 15 miles in length so that the source ship was not always exactly in the endfire beam.

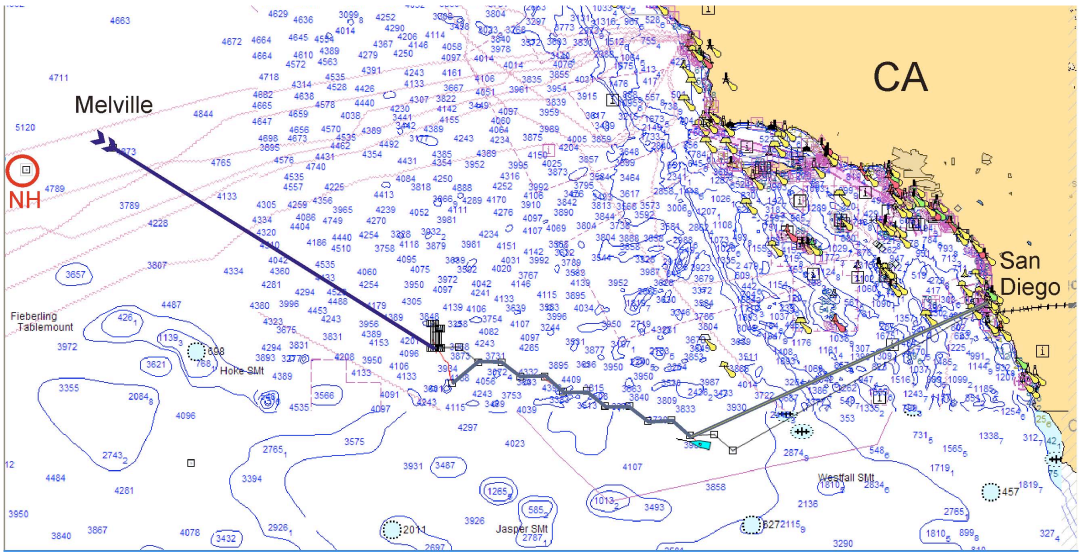

Figure 1. The ship track of R/V Melville with respect to the source location (R/V New Horizon) during the LRAC experiment.

RESULTS

Due to the source level being modest (the actual source level at 75 m depth was ~174 dB), beamforming of the data has been critical to provide adequate SNR. Fig. 2 shows an example of beamforming results for a narrowband signal (CW) around 250 Hz (248-252 Hz) during the crosstrack run at ~500-km range using the LF aperture array [4]. The source signal is shown at -22° from the broadside while the R/V Melville noise, persistent throughout the experiment, is distributed around $60^\circ - 70^\circ$. Apparently, the two arrivals at -42° and 30° come from transiting ships although we did not keep track of ships in the area. The CW tone also provided an estimate of the Doppler shift. The output of the beamformer steered to the source direction (-22°) is a single channel time-series to be processed for decoding.

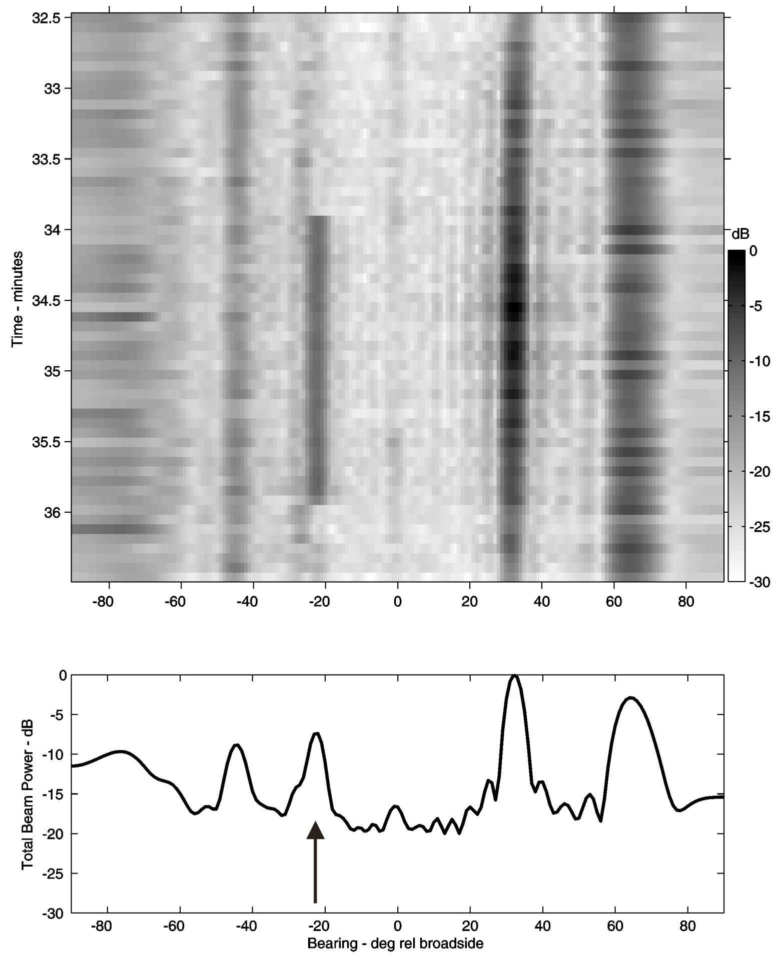

Figure 2. Beamforming results of the narrowband signal from the source (248-252 Hz) during the crosstrack run at ~550-km range. The signal is shown at -22 degrees from broadside while the towship noise is visible at ~ 65 degrees.

The communication sequence consisted of a 5-sec long LFM chirp (200-300 Hz) as a preamble for synchronization and channel estimation purposes. After resampling using the estimated Doppler shift, the 3-min long communication sequence was complex-basebanded at two samples per symbol [4]. The communication performance is shown in Fig. 3 as a scatter plot: (a) QPSK at 250-km range (40 bits/s) with a 40-Hz bandwidth (230-270 Hz) and (b) BPSK at ~550-km range achieving a data rate of 50 bits/sec with a 100-Hz bandwidth (200-300 Hz). A fractionally-spaced decision-feedback equalizer (DFE) with a second-order phase-locked loop was utilized.

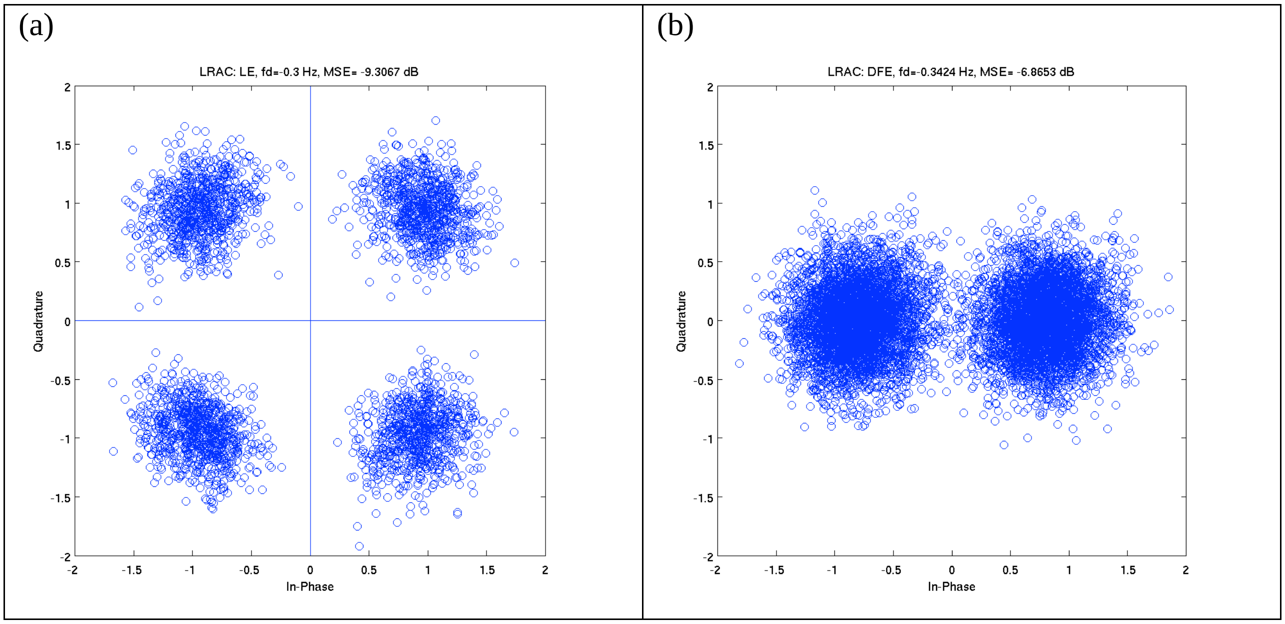

Figure 3. Scatter plots for single carrier communications: (a) QPSK at 250-km range (40 bits/s) with a 40-Hz bandwidth (230-270 Hz) and (b) BPSK at 500-km range achieving a data rate of 50 bits/s with a 100-Hz bandwidth (200-300 Hz).

IMPACT/APPLICATIONS

The LRAC10 experiment involved two mobile components in deep water at shallow depths: (1) a source at 75-m and (2) a horizontal line array towed at 3.5 knots at a depth of ~200-m. The implication is that maintaining communication at speed and depth is feasible for submarines at long ranges.

PUBLICATIONS

1. H.C. Song, W.A. Kuperman, and W.S. Hodgkiss, “Basin-scale time reversal communications,” *J. Acoust. Soc. Am*. 125, 212-217, 2009 [published, refereed].

2. H.C. Song and M. Dzieciuch, “Feasibility of global-scale synthetic aperture communications (L),” *J. Acoust. Soc. Am*. 125, 8-10, 2009 [published, refereed].

3. K. Becker and J. Preston, “The ONR five octave research array (FORA) at Penn,” in Proc. *IEEE OCEANS’03*, 2607-2610, 2003.

4. H.C. Song, S. Cho, T. Kang, W.S. Hodgkiss, and J. Preston, “Long-range acoustic communication in deep water using a towed array,” *JASA Express Letter* [submitted].