

# Long Range Acoustic Communications Experiment 2010

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## Objectives

Experimentally confirm that robust coherent synthetic aperture communications (SAC) is feasible between a source and a receiving array at speed and depth at long ranges in deep water with separations of at least 1,000 km.

## Background

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. By treating the tomography signals (m-sequence transmissions) as BPSK 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 and other experimental data, see the Appendix.

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

## Location and Participating Ships

The long range acoustic communications (LRAC) experiment will be carried out 8-21 September 2010 off the southern California coast. Two SIO (Scripps Institution of Oceanography) ships will participate – the R/V New Horizon will be the source ship and the R/V Melville will be the receiving array ship (<http://shipsked.ucsd.edu>).

It is anticipated that for marine mammal mitigation purposes, the source ship will need to transit ~900 km (~485 nmi) west or west-southwest for an appropriate operational area. The source ship will tow the sound source at relatively low speed (2-5 knots) within its operational area.

The receiving array ship will tow a horizontal line array (HLA) at distances 1000-2000 km (540-1080 nmi) from the source. The HLA will be towed at relatively low speed (2-5 knots) during this period. Although some of the towed array operation will be carried out with the array broadside to the source, most of the tow time will be spent in an endfire configuration with the HLA traversing roughly a radial path with respect to the source position.

In both cases, the source and receiving array ships will traverse tracks roughly aligned with the prevailing wind and seas.

### **Hardware**

The source will be a J15-3 (plus a spare). The source has a maximum depth of 100 m and the typical tow depth will be 75 m. The frequency transmitting current response (TCR) roughly is flat 50-300 Hz and gradually rolls off to 600 Hz. The maximum source level is ~180 dB re  $\mu\text{Pa}$  @ 1 m.

The towed HLA is the Five Octave Research Array (FORA) that is maintained by ARL/PSU. The FORA will be deployed to a depth of ~200 m with the ULF aperture (64 elements spaced at 3 m) being well-matched to the frequencies of interest in this experiment,

### **Acoustic Transmissions**

The acoustic transmissions primarily will be continuous transmissions of a phase modulated carrier (PSK) with center frequencies in the 100-300 Hz range and various bandwidths between 25-200 Hz. The transmissions all will be within the band 50-400 Hz although the majority of them will be in the 100-300 Hz band. Some linear frequency modulated (LFM) chirps also will be transmitted in the same band.

The source transmissions will be at a depth of 75 m with the source being towed slowly at a speed of 2-5 knots. If possible, it would be desirable to transmit at the maximum source level of 180 dB although it is unlikely the source could sustain such a level for extended periods. Thus, lowering the source level to 174 dB would be a reasonable level for extended operation considering just source operation.

During the data collection period (8 days total), it would be desirable to transmit continuously at the 174 dB level and sequence through a number of different communication transmissions. If this is not possible due to marine mammal exposure concerns, then using a 50% duty cycle would be reasonable where the continuous transmissions would be carried out roughly for 1 hour period with then an equal period where no transmissions were done (i.e. 1 hour on and 1 hour off) A shorter duty cycle period could be investigated if necessary where the minimum length of continuous transmissions would need to be roughly 10 min (i.e. 10 min on and 10 min off).

## Schedule

The experiment period is 8-21 September 2010 (14 days) for the R/V New Horizon and 8-19 September 2010 (12 days) for the R/V Melville. The experiment schedule somewhat is driven by the source ship transit to its operational area. The assumption is that 8 days will be devoted to data collection, 1 day to hardware testing, and 3-5 days devoted to transit to/from the deep water operational area of both ships.

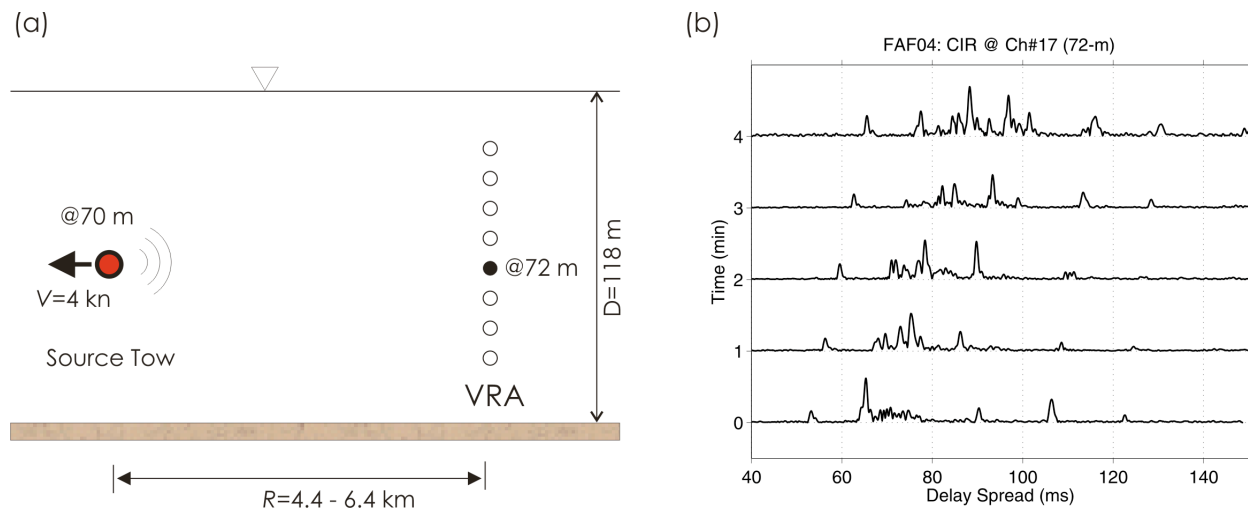
A notional schedule for the experiment follows.

<b>Date</b>	<b>Operation</b>
07Sep10	Mobilize
08-09Sep10	Transit to operational areas
10Sep10	Deploy source and FORA towed array – operational checks
11-18Sep10	Data collection
19Sep10	Transit to port (R/V Melville)
19-21Sep10	Transit to port (R/V New Horizon)
20Sep10	Demobilize – R/V Melville
22Sep10	Demobilize – R/V New Horizon

## Appendix

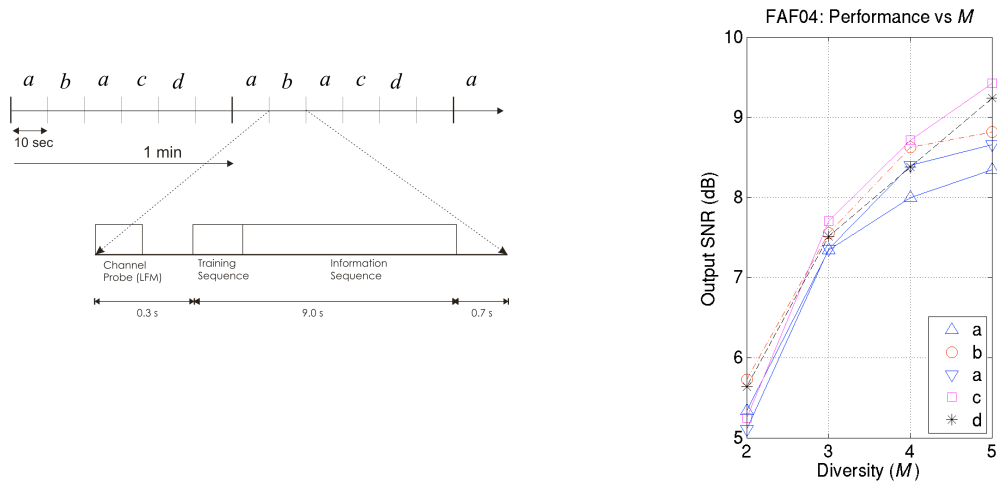
The MPL/NURC/ONR series of Time Reversal (TR) experiments in shallow water environments at frequencies from 400 Hz-15 kHz have demonstrated:

1. Spatial diversity enhances TR processes [1]
2. Active TR based acomms [2,3,4]
3. Passive TR based acomms [5,6]
4. Space-Time diversity further enables TR based processing [4,7]
5. Incoherent Synthetic Aperture TR based acomms [8]
6. TR combined with equalization and other communications algorithms yields best results [9,10]
7. Coherent synthetic aperture acomms based on the above and including Doppler processing [11]



**Fig. 1 (a) Schematic of synthetic aperture communications involving a source at 70-m depth moving away from a fixed receiver array at about 4 kts. (b) The channel impulse responses (envelope) experienced by a receiver at 72-m depth over 4 minutes, providing the diversity required for time reversal approach.**

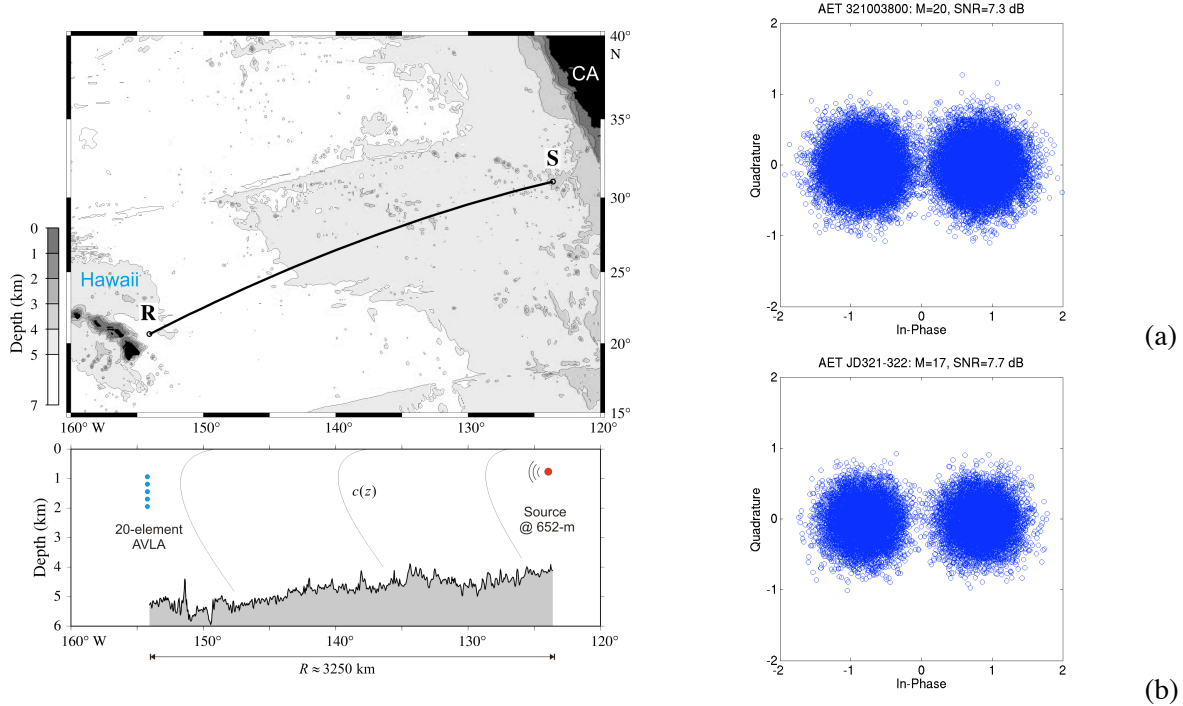
Figures 1 and 2 illustrate item 7. Multiple transmissions from a moving source were used to construct a synthetic source array. The process includes radial motion (significant Doppler), coherent BPSK modulation, interleaving appropriate for SAC, a state-of-the-art time reversal approach (TR+DFE), and channel updates to accommodate channel variations due to source motion. Four or five consecutive transmissions (Fig. 1(b)) were combined successfully confirming the feasibility of coherent synthetic aperture communications (Fig.2).



**Fig. 2 (Left) Communications signal transmitted by a source during the synthetic aperture experiment (FAF-04): interleaving. (Right) Performance of synthetic aperture time reversal communications versus the number of transmissions combined ( $M$ ) spaced 1-min apart as shown in Fig. 1(b).**

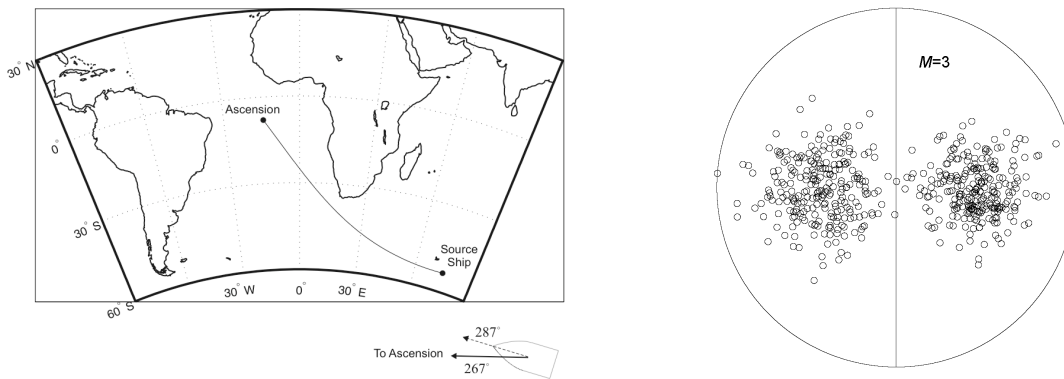
**Long-range communications:** Based on the research itemized above, we have performed a preliminary analysis of deep-water data taken by the ATOC/NPAL group. As a first step, we have investigated basin-scale time reversal communications using the data from the Acoustic Engineering Test (AET) of the Acoustic Thermometry of Ocean Climate (ATOC) program conducted in November 1994 [12]. The tomography signal (1023-digit m-sequence) was transmitted from a 75-Hz source to a 20-element, 700-m vertical array at approximately 3250 km range in the eastern North Pacific Ocean (Fig. 3). We can treat the AET tomography signal as a BPSK communication signal with an information rate of 37.5 bits/s. Figure 3(a) shows the resulting performance at basin-scale exploiting the **spatial diversity** of a vertical array for a single 20-min long transmission. It takes about 5-min on a conventional desktop workstation to process the data, confirming lower complexity due to a single channel equalizer after time reversal combining and a smaller number of taps required due to temporal compression of time reversal approach.

Furthermore, similar diversity can be obtained from temporal variations of the channel (temporal diversity) provided that the channel responses are sufficiently uncorrelated with each other. Note that the channel coherence time for the AET data is in the vicinity of 5-13 min. To examine the temporal diversity, a single element (Ch#1) is selected and a total of 17 transmissions made over 2-day period with transmissions separated by 2 or 4 hours are combined. The comparable performance of single receive element communications using multiple transmissions as shown in Fig. 3(b) indicates that **temporal diversity** is as effective as spatial diversity.



**Fig. 3** Acoustic path from a 75-Hz source S off San Diego to the vertical receive array R moored east of Hawaii. Performance: (a) Vertical array diversity from  $M=20$  elements for a single transmission and (b) Temporal diversity combined from  $M=17$  transmissions over a two-day period for a single element.

We also have an extreme example from the Heard Island Feasibility Test (HIFT) conducted in January 1991 (Fig. 4). Specifically, a reception at Ascension Island, about 9200 km from the source ship moving at 3 kts near Heard Island, is analyzed by treating the 57-Hz, 255-digit m-sequence tomography signal as a BPSK communication signal with an information rate of 11.4 bits/s. The performance of single receive element combining three consecutive receptions spaced 5.2-min (~470-m) apart indicates that synthetic aperture communications is feasible at global distances [13].



**Fig. 4 Geodesic from the nominal position of the source ship near Heard Island to Ascension Island in the southern Atlantic Ocean (about 9200 km distance). Performance of synthetic aperture communications combining three consecutive receptions spaced 5.2-min ( $\sim 470$ -m) apart after Doppler compensation. The output SNR is 6.6 dB with a bit error rate (BER) of 1/510.**

## References

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