User Guide for

In-Band Full-Duplex Underwater Acoustic Communication Measurements: Self-interference

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Abstract: In-band full-duplex (IBFD) refers to two-way communications at the same frequency and at the same time. To characterize self-interference in underwater acoustic IBFD communications, the joint research team from the University of Alabama and the University Delaware conducted a field experiment in the Lake of Tuscaloosa in July 2019. A single transmission-receiving line was deployed off a boat that was moored in the center of the lake. The transmission-receiving line had one acoustic transmitter and eight hydrophone receivers. Two types of signals, binary phase-shift keying (BPSK) and orthogonal frequency-division multiplexing (OFDM), were transmitted at the center frequency of 28 kHz. The receptions were recorded in .wav audio files by eighter high-precision digital hydrophones. In addition to the acoustic data, a complete set of source information, environmental measurements, and processed impulse responses are included in the data package. Matlab programs are also provided to retrieve the data and facilitate further analysis.

Keywords: Self-interference, In-band full-duplex, underwater acoustic communications

1. Time and Location.

The experiment was conducted in Lake Tuscaloosa in Alabama on July 9, 2019. Lake Tuscaloosa is a large lake in Tuscaloosa. The experimental site is marked with a red triangle in Fig. 1. The water depth at the experiment site was 17 m. A small vessel traveled to the site and was anchored at the experiment site.

Fig. 1. Experiment location at Lake Tuscaloosa.

2. Instruments.

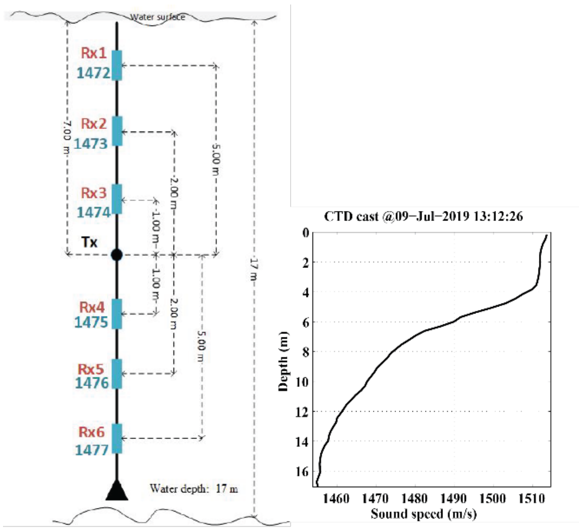
2.1. CTD. The CastAway-CTD (Conductivity, Temperature, and Depth) is a profiling instrument that measures conductivity, temperature, and pressure.

2.2. Acoustic transmitter. One high-frequency transducer, BTech BT-2RCL-OS, was used in this experiment. The resonance frequency of this transducer is at 28 kHz. The transducer was driven by a laptop, a National Instruments D/A board, and a power amplifier/matching network.

2.3. Acoustic Receiver. Six units of OceanSonics icListen Digital Hydrophones were used. The icListen digital hydrophones are compact, high-precision autonomous recording devices. The icListen units (shown in Fig. 2) had a sampling frequency of 512 kHz. These devices used 24 bits in the A/D conversion.

Fig. 2. Six OceanSonic icListen units were used in this experiment. The icListen series numbers are 1472, 1473, 1474, 1475, 1476, and 1477.

3. Experimental configuration and environmental data.



(a) (b)

Fig. 3. (a) Experimental configuration at Lake Tuscaloosa. The water depth was 17 m. The transducer was installed at 7 m below the water surface. Six digital hydrophones were distributed along the mooring line. (b) Sound speed profile.

The experimental configuration is shown in Fig. 3(a). One instrument line was deployed off the boat at the experiment site. The transducer was mounted 7 meters below the water surface. Six hydrophones were mounted at the same transmission line. Three of the hydrophones were mounted above the transducer. The first hydrophone (#1472) was mounted 5 meters above the transducer. The second hydrophone (#1473) was mounted 2 meters above the transducer. The third hydrophone (#1474) was mounted 1 meter above the transducer. Three hydrophones (#1475, #1476, #1477) were symmetrically mounted on the transmission line, but below the transducer.

3.1. Environmental data. The environmental data was measured by the CTD. The recorded data are provided in the "env" folder, named "CC1603005_20190709_181226.mat". The environmental data can be read by the Matlab program "castaway_read.m". This program gives the measured sound speed profile (SSP) at the experimental location. The SSP from "CC1603005_20190709_181226.mat" is presented in Fig. 3(b).

4. BPSK Signaling and Reception.

4.1. BPSK transmission. The BPSK symbols were the pseudo-random (PN) sequences. The transmitted data are provided in the "tx" folder. The files containing the transmitted signal information are listed in Table 1. The symbol rate of the signal was 5 kHz. A total number of 75,000 symbols were transmitted, which converted to 15 seconds. These symbols were pulse shaped and then modulated by the carrier frequency of 30 kHz. The carrier-modulated signal was sampled at 800 kHz. This signal was then passed to the DAC (Digital-to-analog converter) then fed to an amplifier.

Table 1. Content of the "tx" folder.

Filename	**Description**
tx_sy_bpsk_30_5.mat	Transmitted symbols
tx_bb_bpsk_30_5.mat	Transmitted baseband symbols
tx_pb_bpsk_30_5.mat	Transmitted passband symbols

4.2. BPSK recordings. The data recorded by icListen units were stored in wav files. The received data are provided in the "rx" folder. Each wav file is named in the format of RBW(icListen #)_(year, month, date)_(hour, minute, second). The BPSK signal was recorded at UTC time 1610 on July 9, 2019. Thus for icListen 1472, the wav file was named "RBW1472_20190709_161000". The raw data in wav files were sampled at 512 kHz. The wav files can be read by the program "demo_reading.m", which is a Matlab program. To read different wav files, change the file name at this program. This program gives the passband as well as the baseband signal waveform. The files containing the received signal data are listed in Table 2. The received passband signal sample, from "RBW1472_20190709_161000.wav", is presented in Fig. 4.

Table 2. Content of the "rx" folder.

Filename	**Description**
RBW1472_20190709_161000.wav	Data recorded by icListen 1472
RBW1473_20190709_161000.wav	Data recorded by icListen 1473
RBW1474_20190709_161000.wav	Data recorded by icListen 1474
RBW1476_20190709_161000.wav	Data recorded by icListen 1475
RBW1476_20190709_161000.wav	Data recorded by icListen 1476
RBW1477_20190709_161000.wav	Data recorded by icListen 1477

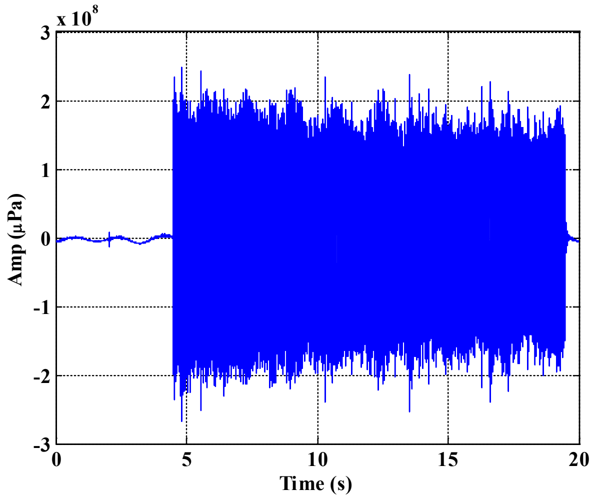


Fig. 4. The received passband BPSK signal from raw data “RBW1472_20190709_161000.wav”.

4.4. Channel impulse responses and channel coherence for the BPSK packet. The recorded data were used to extract the channel impulse response (CIR) of the self-interference transmission. The extracted CIRs and channel coherence data are provided in “cirmat” folder. The files containing the extracted CIRs are listed in Table 3. Based on the extracted CIRs, the channel coherence curves ware calculated. The variable named “cirmat” stores the extracted CIR, the variable named “corr_mat” stores the coherence curve of two group paths using the CIRs in the same file. The start and end time of the two group paths are indicated by the variable named “grpdef_mat”. The extracted CIR files can be read by the Matlab program "cirmat_read.m". This program presents the extracted CIRs in an image. The extracted CIR sample, from “CIR@1610#1472.mat”, is presented in Fig. 5.

Table 3. The estimated CIRs in folder “cirmat”.

Filename	**Description**
CIR@1610#1472.mat	Extracted CIRs from icListen 1472
CIR@1610#1473.mat	Extracted CIRs from icListen 1473
CIR@1610#1474.mat	Extracted CIRs from icListen 1474
CIR@1610#1475.mat	Extracted CIRs from icListen 1475
CIR@1610#1476.mat	Extracted CIRs from icListen 1476
CIR@1610#1477.mat	Extracted CIRs from icListen 1477

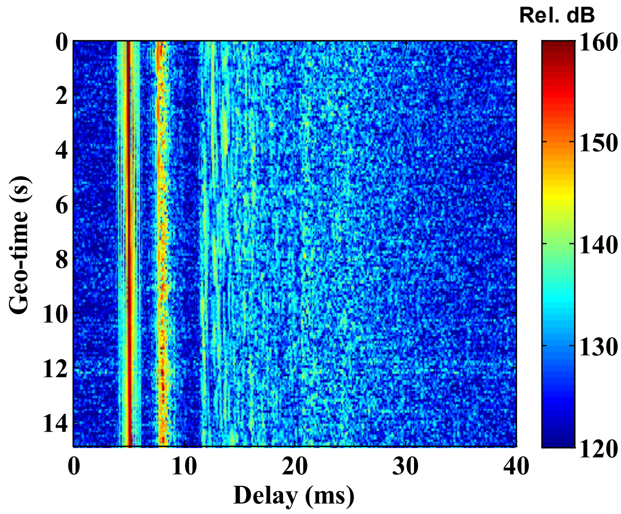


Fig. 5. The CIRs from “CIR@1610#1472.mat”.

5. OFDM Signaling and Reception.

Fig. 6 presents the transmission, reception and channel impulse response (CIR) estimation procedure used at the experiment, with OFDM signal.

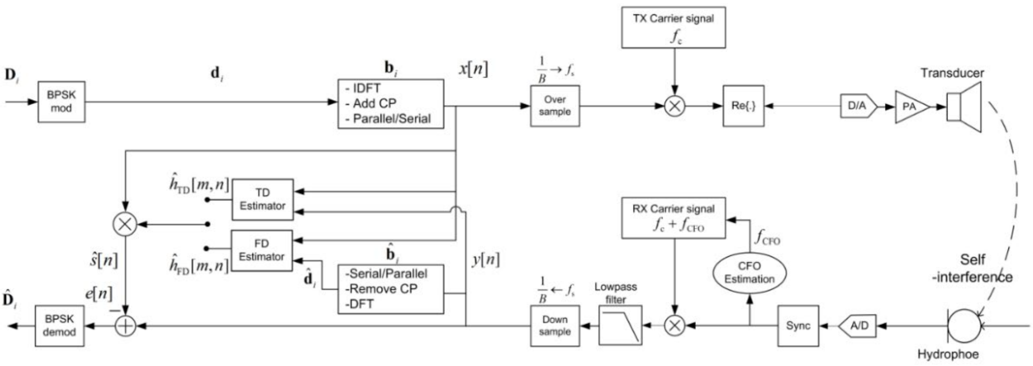


Fig. 6. UWA-IBFD transmission and reception procedure using OFDM signals.

5.1. OFDM Parameters: OFDM parameters utilized in the experiment can be found in ”OFDM_Parameters.mat” located in folder “OFDM_Par”.

5.2. OFDM Transmission. Previously generated OFDM blocks with symbol rate 5 kHz were fed into the transducers via an amplifier. A total number of 240 OFDM blocks were transmitted taking about 24.5 s. The carrier frequency of the transmitted signal was 28 kHz with sample rate 800 kHz. The transmitted signal data is provided in folder “tx” as presented in Table 4.

Table 4. Content of “tx” folder.

Filename	Description

tx_sy_bpsk_5kHz.mat	Transmitted symbols
tx_bb_OFDM_5KHz.mat	Transmitted baseband signal
tx_pb_OFDM_28kHz_800kHz.mat	Transmitted passband signal

5.3. OFDM Reception: The received signals for different hydrophones, with the sample time 512 kHz, are provided in “rx” folder. Table 5 presents the content of this folder. As an example, Fig. 7 shows the recorded passband signal in “RBW1472_20190709_162400.wav”.

Table 5. Content of “rx” folder.

Filename	**Description**
RBW1472_20190709_162400.wav	Data recorded by icListen 1472
RBW1473_20190709_162400.wav	Data recorded by icListen 1473
RBW1474_20190709_162400.wav	Data recorded by icListen 1474
RBW1476_20190709_162400.wav	Data recorded by icListen 1475
RBW1476_20190709_162400.wav	Data recorded by icListen 1476
RBW1477_20190709_162400.wav	Data recorded by icListen 1477

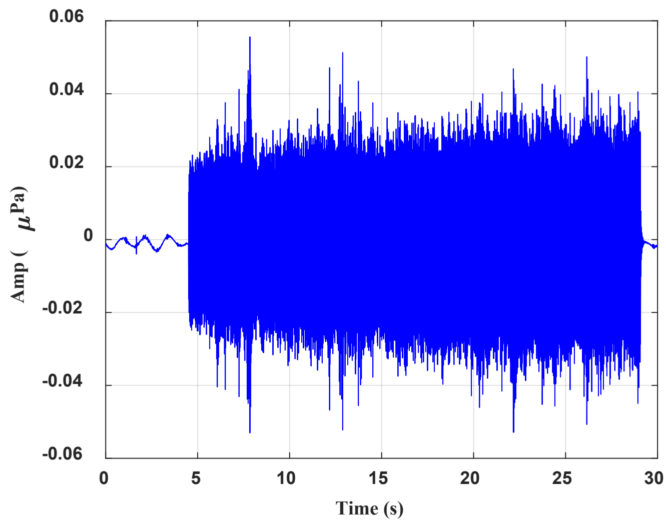


Fig. 7. The received passband OFDM signal from raw data “RBW1472_20190709_162400.wav”.

5.4. Channel impulse responses and channel coherence for the OFDM packet. The recorded signals from the transducers are used for CIR estimation and characterization. The results are provided in “cirmat” folder. The content of this folder are presented in Table 6. The estimated CIR files can be read by the Matlab program "OFDM_cirmat_read.m". This program presents the estimated CIRs versus the delay-time and geo-time. For example, the estimated CIRs in “CIR@1624#1472.mat” are plotted in Fig. 8.

Table 6. The estimated CIRs in folder "cirmat".

Filename	Description
CIR@1624#1472.mat	Extracted CIRs from icListen 1472
CIR@1624#1473.mat	Extracted CIRs from icListen 1473
CIR@1624#1474.mat	Extracted CIRs from icListen 1474
CIR@1624#1475.mat	Extracted CIRs from icListen 1475
CIR@1624#1476.mat	Extracted CIRs from icListen 1476
CIR@1624#1477.mat	Extracted CIRs from icListen 1477

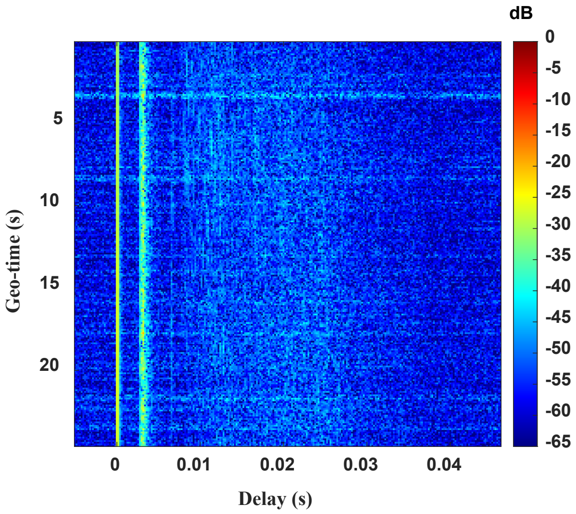


Fig. 8. The estimated CIRs in "CIR@1624#1472.mat".

6. Readme files.

Detailed instruction how to use the provided experimental data in readme.txt for BPSK and OFDM data.

7. Points of contact.

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