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High-Resolution Calibration of a Multibeam Echo Sounder

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Abstract—Calibration can greatly increase the utility of collecting seafloor backscattering strength with multibeam echo sounders (MBES). A calibration procedure to determine high resolution, three dimensional transmit and receive beam patterns of a Reson SeaBat 7125 MBES was performed using the fresh water calibration tank at the University of New Hampshire. The measurements employed an omni-directional Reson TC4034 projector/hydrophone as a reference transducer at an acoustic distance of 13 m. The multibeam sonar system was configured for 256 beams equi-angle mode and operating frequency of 396 kHz. The transmit beam pattern was computed for across-track angular range between $\pm 90^\circ$ in 0.1° increments and along-track angular range between $\pm 2.55^\circ$ in 0.09° increments. Receive directional characteristics were measured for the across-track range of $\pm 120^\circ$ in 0.1° increments with along-track angular range of $\pm 1.23^\circ$ in 0.18° increments. With these measurements, a three-dimensional plot of the transmit beam pattern was computed for the entire range of angles, although for the receive beam pattern it was only determined for the 0° along-track angle. The reduced angular coverage of the receive beam pattern was due to discrepancies in the off-axis results that are thought to be related to receiver saturation. Measurements for the transmit beam pattern show a -3 dB beamwidth of 0.99° for across-track angle of 0° with side lobes below -17 dB. The results show an unexplained curvature in the transmit beam pattern that would have gone un-noticed during a two dimensional beam pattern measurement. An interference effect causing ripples and attenuation of the transmit beam pattern was also observed. This effect is thought to be caused by a second 200 kHz projector mounted parallel to the 396 kHz projector. This interference occurs at an across-track angular region between $+30^\circ$ and $+75^\circ$ with gradual decrease in amplitude of about 3 dB. The receive beam pattern measurements show a -3 dB beamwidth of approximately 0.62° for the most inner beams (beams 128 and 129) and of approximately 1.40° for the most outer beams (beams 1 and 256) at along-track angular position of 0° with side-lobes below -26 dB for the most inner beams and below -17 dB for the most outer beams.

I. INTRODUCTION

Calibration under a controlled environment is essential to achieve better performance of multibeam echo sounders (MBES) [1]. A high-resolution calibration procedure to determine three dimensional transmit and receive beam patterns of a Reson SeaBat7125 MBES was conducted in the acoustic tank of Chase Ocean Engineering Laboratory at the University of New Hampshire.

The Acoustic Tank

The dimensions of the acoustic tank used to perform the measurements are 18 m long, 12 m wide and 6 m deep. The tank has a main bridge (powered) and a secondary bridge (non-powered) on a rail system with variable positioning along the 18 m length of the tank. On the top of the main bridge there is a cart (also powered) which can move along the 12 m width of the tank. A Yuasa rotator (with a programmable controller) is installed on the main bridge cart and can control the angular position of a carbon fiber pole attached to it. Designed to hold mounted transducers, this pole can slide into the rotator chucks and allow the vertical positioning of these transducers inside water. The secondary bridge is used for mounting reference transducers.

Beam Pattern Measurement Setup in the Acoustic Tank

A SeaBat 7125 mounting bracket supplied by Reson was used to mount the transducers and then fixed to a mounting support. This support was attached to the rotating pole, as illustrated by fig. 1. As seen from this figure, the MBES has two projector arrays and one hydrophone array. One projector array is designed to operate at the frequency of 400 kHz, while the other is to operate at the frequency of 200 kHz. The gravity center of the submerged mounted MBES transducers was determined and it was aligned with the rotating pole center. This alignment procedure was performed to avoid bending the pole with the weight of the mounting, minimizing errors on the angular position during the measurements.

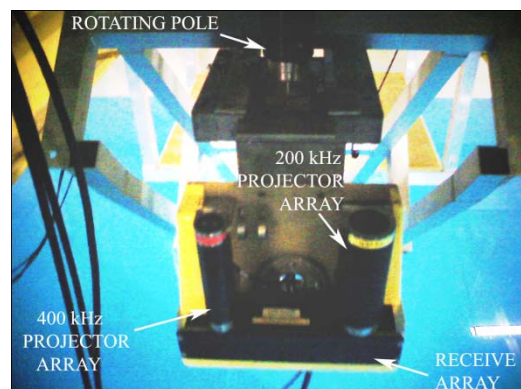


Figure 1. Mounting bracket with the 7125 transducers attached to the rotating pole.

The multibeam sonar system was configured for 256 beams operating in equi-angle mode and at a frequency of 396 kHz. An omni-directional Reson TC4034 hydrophone/projector was used as a reference transducer in the measurements. The setup in the acoustic tank is depicted by fig. 2 (top view) and fig. 3 (side view). As defined in these figures, the across-track direction of the MBES is on the y-axis, while its along-track direction is on the z-axis. The across-track angular position is determined by the Yuasa rotator, while the along-track angular position is determined by the depth of the TC4034 transducer. The 7125 transducers and the TC4034 hydrophone/projector were positioned inside the tank in such a way to avoid multi-path signals in the measurements from the tank walls, as well as from the tank bottom and the water surface.

The distance between the 7125 projector and the reference transducer was fixed at 13 meters. The TC4034 transducer was positioned at a distance of 3 meters from the tank wall behind it while the 7125 transducers were at a distance of 2 meters from the wall behind them. Using this configuration, the first reflected signals to arrive at the reference transducer are the ones from the bottom of the tank and from the water surface. They arrive approximately 880 μ s after the direct path signal arrival at the reference transducer, providing the time separation required in order to uniquely identify the direct path arrival.

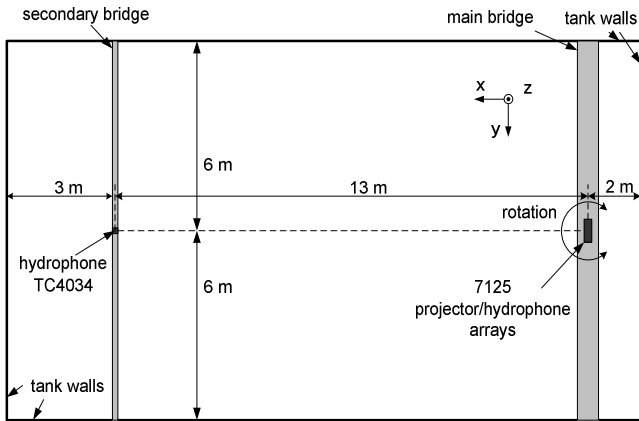


Figure 2. Beam pattern measurement setup – top view.

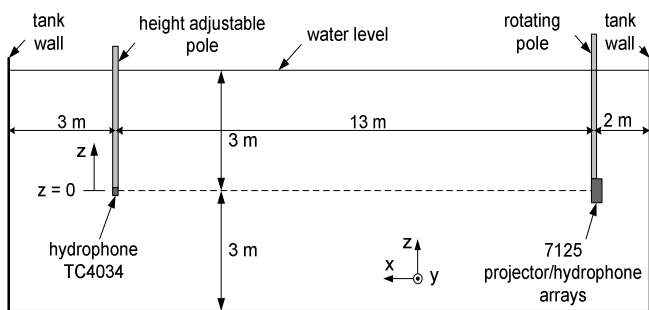


Figure 3. Beam pattern measurement setup – side view.

II. TRANSMIT BEAM PATTERN MEASUREMENTS

The transmit beam pattern measurement procedure was performed using a program code written in LabVIEW running in a personal computer with an installed data acquisition board. This code was used for acquiring the received signal from the TC4034 transducer while changing automatically the across-track angular position of the 7125 transducers after the desired number of pings for each position. The current date and time from a GPS device was recorded for each across-track angular position during the signal acquisition by the LabVIEW code, along with the raw waveforms and processed rms values of the received signal. Recording time data from the GPS device allowed synchronization between data recorded by the MBES computer and by the LabVIEW code. Fig. 4 shows the block diagram for the transmit beam pattern measurements.

A function generator, triggered by the MBES trigger signal, was used to generate a copy of the signal transmitted by the 7125 projector. The generated copy of the signal was used by the LabVIEW code to trigger the data acquisition process and to calculate the rms values of the acquired waveforms. A pre-amplifier was used to filter and amplify the signal from the TC4034 transducer to a proper level.

Transmit Beam Pattern Measurements Procedure

After positioning the transducers in the tank, it was necessary to perform the across-track and the along-track alignments to find the maximum response axis of the 7125 transducers. The across-track alignment was performed by setting the MBES to transmit and observing the response on the MBES screen for the two most inner beams (beams 128 and 129). The LabVIEW code was used to rotate the 7125 transducers while observing the response of beams 128 and 129. When these two beams had the same response intensity for the point corresponding to the TC4034 transducer, the across-track angular position was set to zero degrees by resetting the rotator controller. Fig. 5 illustrates this setup.

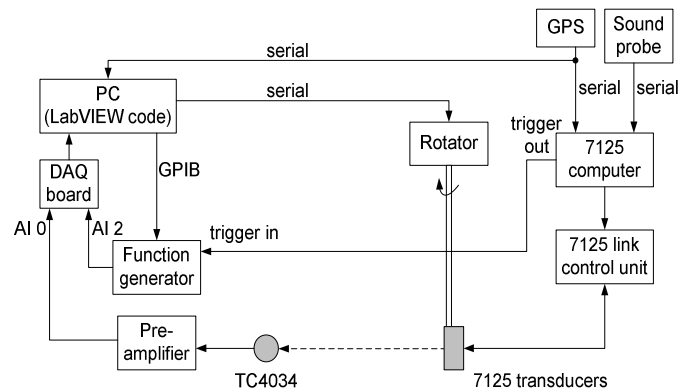


Figure 4. Transmit Beam Pattern – block diagram.

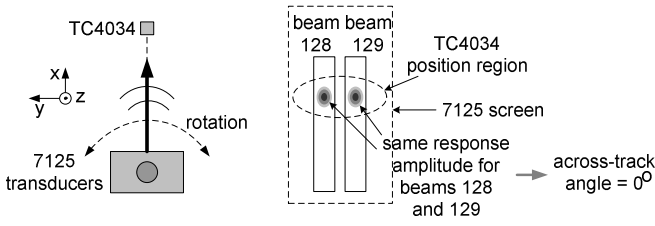


Figure 5. Across-track alignment.

The along-track alignment was done by setting the MBES to transmit and observing the amplitude value of the received signal from the TC4034 transducer with an oscilloscope as the pole height (where the TC4034 transducer is attached to) varied. When the signal amplitude was at a maximum level, the position was set at zero meters on the z-axis, corresponding to the along-track angle of zero degree (central acoustic axis). After the across-track alignment procedure, the along-track alignment was performed again to verify the position of maximum response after changing the across-track angular position of the 7125 transducers. Fig. 6 depicts the along-track alignment procedure. According to the geometry from fig. 7, the along-track angles were calculated using the vertical displacement of the TC4034 transducer (Δz) and the horizontal distance between the 7125 transducers and the TC4034 (13 m). The values for the along-track angles are given by

$$\text{along-track angle} = \tan^{-1}(\Delta z \text{ (in meters)}/13 \text{ meters}). \quad (1)$$

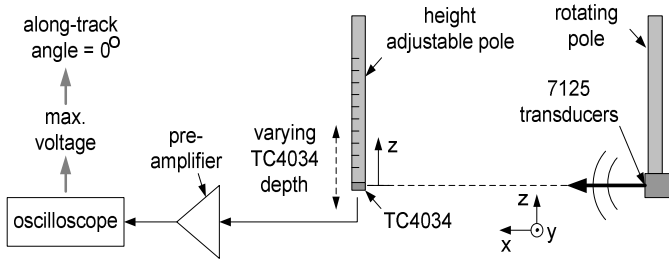


Figure 6. Along-track alignment.

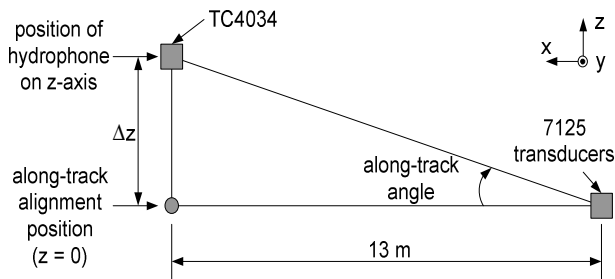


Figure 7. Along-track angle calculation.

Transmit beam pattern measurements were taken for reference transducer positions (Δz) between ± 0.58 meters in 0.02 meters increments, corresponding to along-track angles ranging between $\pm 2.55^\circ$ in 0.09° increments in a total of 59 measurements. Each of these measurements was taken for across-track angles ranging between $\pm 90^\circ$ in 0.1° increments, with 20 pings per across-track angular position at a rate of 4 pings per second, using a 396 kHz transmitted signal with a pulse length of 300 μs . The time spent for each measurement was about 50 minutes. With these measurements, it was possible to obtain a three-dimensional plot of the transmit beam pattern for those angular ranges. Table I shows the sonar settings used for the measurements.

TABLE I
7125 SETTINGS FOR TRANSMIT BEAM PATTERN MEASUREMENTS

Power (dB)	Pulse Length (μs)	Rate (pings/s)	Gain (dB)	Range (m)
200	300	4	20	30

III. RECEIVE BEAM PATTERN MEASUREMENTS

The receive beam pattern measurements were performed using a similar LabVIEW program code as the one used in the transmit beam pattern measurements. This code was used for controlling the generation of the transmitted signal sent to the TC4034 transducer while changing automatically the across-track angular position of the 7125 transducers after the desired number of pings per angle. The current date and time was also recorded from the GPS device. Since the across-track angular position was only recorded in the computer running the LabVIEW code, the time data were used to reference the recorded data from the MBES to the across-track angle data recorded by the LabVIEW code. Fig. 8 shows the block diagram for the receive beam pattern measurements.

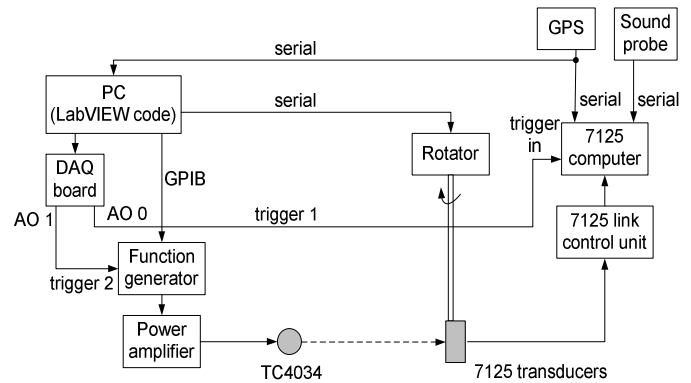


Figure 8. Receive Beam Pattern – block diagram.

IV. RESULTS

The function generator was used to produce the 396 kHz pulses. This signal was applied to a power amplifier and sent to the TC4034 transducer, which worked as a projector to send the signal to the 7125 receive array. In preliminary tests, one trigger signal generated by the LabVIEW code (using one data acquisition board analog output channel) was used to trigger the function generator and the MBES computer at the same time. It was observed that the MBES was triggering with a delay of approximately 3 ms after the function generator was triggered. Therefore, it was necessary to generate two separated trigger signals: one to trigger the MBES computer, and another one to trigger the function generator after that delay. The generation of these trigger signals was implemented in the LabVIEW code using two analog outputs from the data acquisition board. The code allowed adjustment for the values of ping rate, number of pings per across-track angular position, time delay between the two trigger signals, and time between changes in across-track angular positions.

Receive Beam Pattern Measurements Procedure

Receive beam pattern measurements were first performed for an across-track angle range between $\pm 120^\circ$ in 0.1° increments for the along-track angle of 0° . The pulse length of the transmitted signal was set to $300 \mu\text{s}$ at a rate of 4 pings per second. These settings allowed one beam pattern measurement per along-track angular position in 4.5 hours for the specified across-track angular range. Table II shows the sonar settings used for these measurements. The along-track and across-track alignments for these measurements were performed using the same methodology described in the transmit beam pattern measurement procedure.

Measurements for the across-track angular range between $\pm 90^\circ$ in 0.1° increments and along-track angular positions in the range of $\pm 1.23^\circ$ in 0.18° increments were also performed. These measurements would allow the determination of the three dimensional receive beam pattern for the 256 beams. They were taken using the same settings for the signal transmitted to TC4034 transducer as used in the previously described measurements, providing the same sound pressure level of 154 dB at the 7125 hydrophone array. However, the MBES gain setting was adjusted to 50 dB (instead of the value of 20 dB used in the first receive beam pattern measurement), in an effort to increase the dynamic range. The amplitude of the receive beam pattern for the along-track angle of 0° was then amplified to align its main lobe amplitude to the main lobe amplitudes of the beam patterns for the adjacent along-track angles ($+0.18^\circ$ and -0.18°).

TABLE II
7125 SETTINGS FOR RECEIVE BEAM PATTERN MEASUREMENTS

Power (dB)	Pulse Length (μs)	Rate (pings/s)	Gain (dB)	Range (m)
0	300	4	20	25

Transmit Beam Pattern Results

Fig. 9 shows the three dimensional transmit beam pattern plot from the measurements performed for the 400 kHz projector array of the Reson 7125 MBES. The top view of the three dimensional plot is depicted by fig. 10.

It can be observed from fig. 10 that the 7125 transmit beam pattern looks curved. Ripples in the beam pattern can also be seen in an across-track angular region between $+30^\circ$ and $+75^\circ$. The two dimensional plot of the transmit beam pattern for the 0° along-track angle and across-track angular range between $\pm 90^\circ$ is shown in more detail in figure 11.

The two dimensional plot of fig. 11 shows that the beam pattern amplitude is above the -3 dB line for across-track angles between approximately $\pm 75^\circ$. Ripples can be observed in the beam pattern for the across-track angular region between $+30^\circ$ and $+75^\circ$, where the amplitude gradually decreases. This leads to the hypothesis that the 200 kHz projector installed parallel to the side of the 400 kHz projector could be interfering with the transmitted signal. To investigate this phenomenon, the transmit beam pattern for the 200 kHz projector was measured for a 0° along-track angle using the same setup for the 400 kHz projector. Fig. 12 shows the results for the 200 kHz transducer transmit beam pattern.

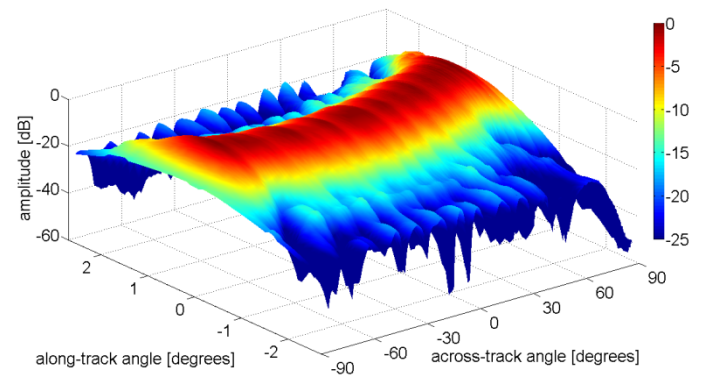


Figure 9. 3-D plot of Reson 7125 transmit beam pattern.

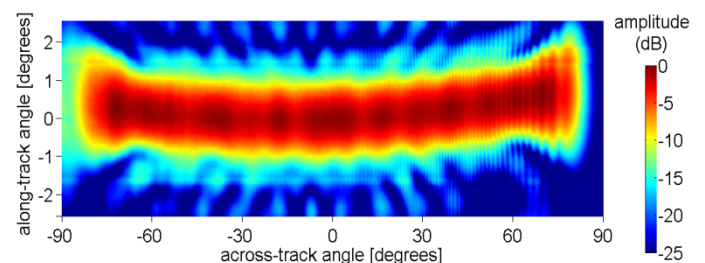


Figure 10. Top view of 3-D plot of Reson 7125 transmit beam pattern.

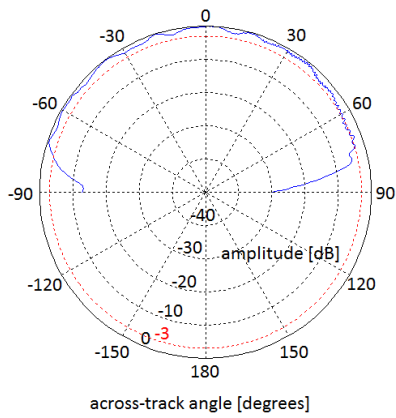


Figure 11. 2-D plot of 7125 transmit beam pattern (400 kHz projector) – along-track angle: 0°.

The plot of fig. 12 shows that the transmit beam pattern for the 200 kHz is very similar to the beam pattern obtained for the 400 kHz, except that the ripples appear in the region between -30° and -75° , approximately. This result supports the hypothesis that the unused projector interferes with the transmit beam pattern of the one in use.

Fig. 13 depicts the plots of the along-track transmit beam pattern for across-track angular positions of -60° , 0° , and $+60^\circ$.

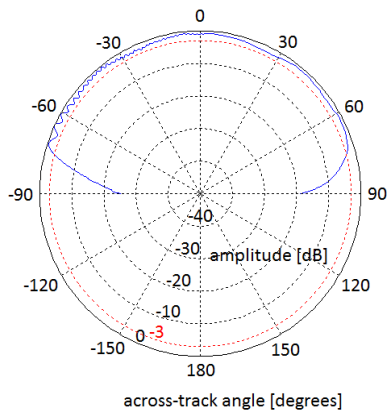


Figure 12. 2-D plot of 7125 transmit beam pattern (200 kHz projector) – along-track angle: 0°.

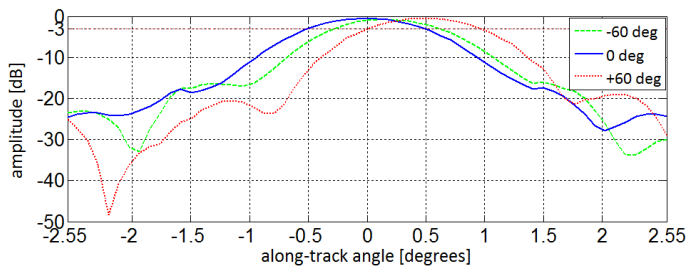


Figure 13. 7125 along-track transmit beam pattern – across-track angles: -60° , 0° , and $+60^\circ$.

According to fig. 13, the transmit beam pattern for the across-track angle of 0° has a -3 dB beamwidth of 0.99° and side lobes below -17 dB. The main lobe of the transmit beam pattern for the across-track angle of $+60^\circ$ is centered at approximately 0.5° , while for the -60° across-track angle it is centered at approximately 0.1° . The -3 dB beamwidth is 0.89° for the across-track angle of -60° , while for the $+60^\circ$ across-track angle it is 0.98° , approximately.

Receive Beam Pattern Results

The three dimensional receive beam pattern was computed using all the measurements for the across-track angular range between $\pm 90^\circ$ and along-track angular range between $\pm 2.55^\circ$. Fig. 14 shows the receive beam pattern for beam 128. The plot of this figure was obtained by aligning the main lobe of the beam pattern for the along-track angular position of 0° with the adjacent beam pattern main lobes, since it was used a lower gain setting for the first set of measurements.

After aligning the main lobe maximum levels, as shown by the 3-D plot of the receive beam pattern from fig. 14, it is possible to see the potential saturation effects (low side lobe amplitudes at along track angle of 0°).

The across-track receive beam pattern for the along-track angular position of 0° for beam numbers 128, 129, 1, and 256 (the two most inner and the two most outer beams) are depicted by figures 15, 16, 17, and 18. Table III shows the beamwidth for these beams.

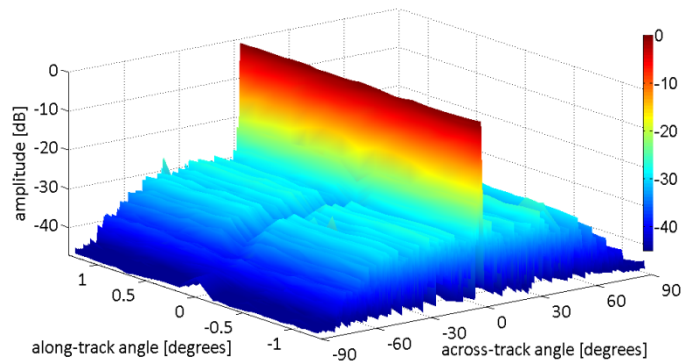


Figure 14. 3-D plot of 7125 receive beam pattern for beam 128.

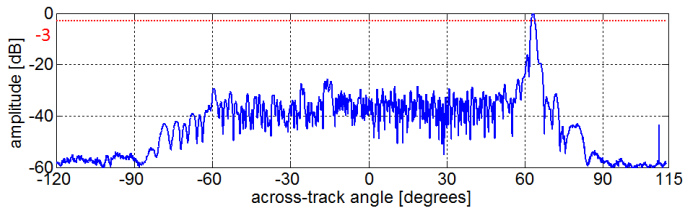


Figure 15. Receive beam pattern for along-track angle of 0° for beam 1.

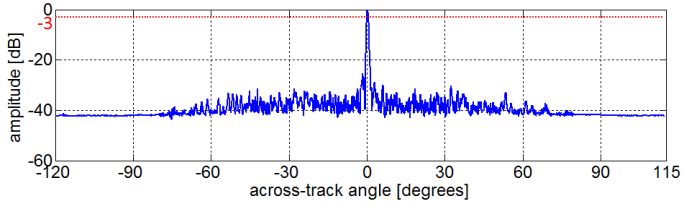


Figure 16. Receive beam pattern for along-track angle of 0° for beam 128.

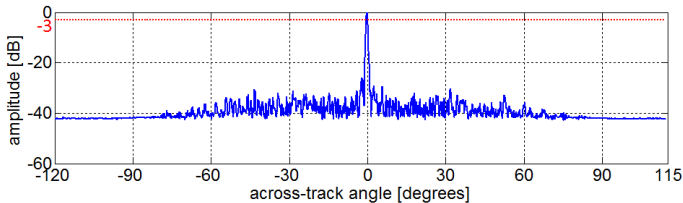


Figure 17. Receive beam pattern for along-track angle of 0° for beam 129.

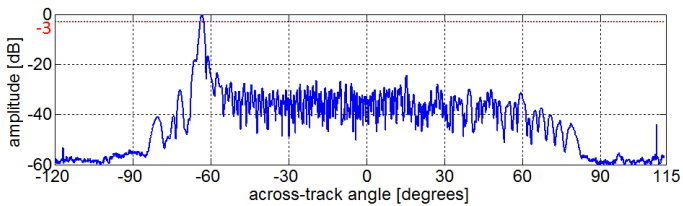


Figure 18. Receive beam pattern for along-track angle of 0° for beam 256.

TABLE III
RESON 7125 RECEIVE BEAM PATTERN: -3 dB BEAMWIDTH

	Beam 128	Beam 129	Beam 1	Beam 256
Beamwidth	0.614°	0.617°	1.395°	1.392°

V. CONCLUSION

A calibration procedure for the Reson 7125 MBES was performed for the operating frequency of 396 kHz and 256 beams/equi-angle mode at an acoustic distance of 13 m using the fresh water acoustic tank at the University of New Hampshire.

These measurements allowed the computation of a three dimensional plot of the transmit beam pattern for across-track angular range between $\pm 90^\circ$ in 0.1° increments and along-track angular range between $\pm 2.55^\circ$ in 0.09° increments.

The -3 dB beamwidth of the transmit beam pattern for across-track angle of 0° was observed to be approximately 0.99° , with side lobes below -17 dB. The transmit beam pattern plot appears to be curved. This curvature in the beam pattern would have gone un-noticed during a two dimensional beam pattern measurement.

Interferences from the transducer not in use (200 kHz projector) were observed in the transmit beam pattern of the 400 kHz projector array. Ripples and attenuation were observed in the transmit beam pattern measurements at the across-track angular region between $+30^\circ$ and $+75^\circ$ with gradual decrease in amplitude of about 3 dB. This suggests that the two projectors should be mounted farther apart to avoid undesirable interferences.

The receive beam pattern was measured for across-track angular range between $\pm 120^\circ$ in 0.1° increments and along-track angular position of 0° . From these measurements, the beam pattern revealed that the -3 dB beamwidth for the most inner beams (beams 128 and 129) was approximately 0.62° , with side-lobes below -26 dB. For the most outer beams (beams 0 and 256), the beamwidth was approximately 1.40° , with side-lobes below -17 dB.

Measurements to compute a three dimensional plot of the 7125 receive beam pattern were also performed. While measurements for along-track angle of 0° in increments of 0.1° were taken using a sonar gain setting of 20 dB, measurements for the along-track ranges from -1.23° to -0.18° and from $+0.18^\circ$ to $+1.23^\circ$ in 0.18° increments were performed with a sonar gain setting of 50 dB in an attempt to increase the dynamic range. However, after aligning the main lobe maximum levels for all the measurements, the three dimensional receive beam pattern shows lower side lobe amplitudes at along-track angle of 0° compared to other along-track angular values. This is an evidence of possible saturation effects, which limited the receive beam pattern main lobe amplitude for the measurements taken with higher sonar gain setting. This effect, which would not have been observed here without the three-dimensional measurements, would have caused large artifacts in the beam pattern measurements.

A single transmit beam pattern measurement set (one set for each along-track angular position) required an acquisition time of 50 minutes. Fifty nine sets of measurements were performed to compute the three dimensional plot of the transmit beam pattern for the described angular ranges, which is the equivalent of 50 hours of data acquisition time. For the receive beam pattern measurements, a single set of measurements required approximately 4.5 hours. Fifteen sets of measurements were taken to compute a three dimensional plot of the receive beam pattern for the described angular ranges, corresponding to approximately 68 hours of data acquisition time. Considering the set up time, the total time spent to perform the all the measurements for transmit and receive beam patterns for the described angular ranges required three weeks.

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