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Characteristics of Sounds Emitted During High-Resolution Marine Geophysical Surveys

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NEWPORT

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PREFACE

This report was prepared under Interagency Agreement No. M15PG00005, "Propagation Characteristics of High-Frequency Sounds Emitted During High-Resolution Geophysical Surveys" and Interagency Agreement No. G16P00011, "Airgun and Sparker Geophysical Survey Sources: Analysis and Reporting," principal investigator Steven E. Crocker (Code 1531). The sponsoring activities are the Bureau of Ocean Energy Management, Environmental Assessment Division and the United States Geological Survey.

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14. ABSTRACT

Scientific questions regarding the impact of noise in the marine environment have resulted in an increasing number of regulatory requirements and precautionary mitigation strategies to reduce the risk associated with high-resolution marine geophysical surveys performed in U.S. waters. However, data to estimate the ecological risk associated with the operation of a given high-resolution survey system are frequently lacking. The Naval Undersea Warfare Center Division Newport (NUWCDIVNPT) conducted a study to quantity characteristics of sounds radiated by a variety of commercial marine geophysical survey systems including boomers, sparkers, airguns, chirp profilers, side-scan sonars, and multibeam bathymetric echosounders. Calibrated acoustic data including source levels, intensity spectra, and beam patterns were acquired for a total of 18 different marine survey systems. This report presents the analysis of a calibrated acoustic dataset collected to support future permit applications and *in-situ* measurements in coastal U.S. waters.

15. SUBJECT TERMS

Geophysical Survey Systems Boomers Sparkers Airguns Chirp Profilers Side-Scan Sonars Multibeam Bathymetric Echosounders
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LIST OF ABBREVIATIONS AND ACRONYMS

1-D	One-dimensional
3-D	Three-dimensional
AA, AAE	Applied Acoustic Engineering Limited
ANSI	American National Standards Institute
ASA	Acoustical Society of America
BIPM	Bureau International des Poids et Mesures
BOEM	Bureau of Ocean Energy Management
CMGP	Coastal and Marine Geology Program
EMI	Electromagnetic interference
FFT	Fast Fourier transform
FFVS	Free-field voltage sensitivity
FIR	Finite impulse response
FM	Frequency-modulated
FSI	Falmouth Scientific, Inc.
GI/Mini-GI	Sercel Mini-Generator-Injector
GUM	Guide to the Expression of Uncertainty in Measurement
HF	High-frequency
IA	Interagency agreement
ICS	Inner continental shelf
LEFAC	Leesburg acoustic test facility
LF	Low-frequency
MRA	Main response axis
NAVSEA	Naval Sea Systems Command
NIST	National Institute of Standards and Technology
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

NSF	National Science Foundation
NUWC	Naval Undersea Warfare Center
NUWCDIVNPT	Naval Undersea Warfare Center Division Newport
OCS	Outer continental shelf
OTF	Open tank facility
Pk	Peak
PSD	Pressure spectral density
PZT	Lead zirconate titanate
rms	Root-mean-squared
S/N	Serial number
SEL	Sound exposure level
SI	International System of Units
SL	Source level
SPL	Sound pressure level
TCR	Transmit current response
TVR	Transmit voltage response
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
USN	United States Navy
USRD	Underwater Sound Reference Division
WHOI	Woods Hole Oceanographic Institution

LIST OF MATHEMATICAL SYMBOLS AND UNITS

a	Largest radius of a piston source or half the length of a line source
d	Distance between an acoustic source and receiver
dB	Decibel
e_{ref}	Open circuit voltage output by a reference standard hydrophone
e_p	Signal voltage applied to a projector's electrical input terminals
f	Frequency
i_p	Signal current applied to a projector's electrical input terminals
J	Joule

LIST OF MATHEMATICAL SYMBOLS AND UNITS (Cont'd)

L	Horizontal distance
SL_{pk}	Source level, peak
SL_{pp}	Source level, peak-to-peak
SL_{rms}	Source level, effective
SL_{SEL}	Sound exposure level referred to a distance of one meter
λ	Acoustic wavelength
m	Meter
ms	Millisecond
μPa	Micro-Pascal
μs	Microsecond
$(M_e)_{ref}$	Free-field voltage sensitivity of a reference standard hydrophone
$\hat{n}$	Outward normal vector at a point on a surface
p	Acoustic pressure
P_{ref}	Reference acoustic pressure (i.e., 1 μ❍Pa)
Pa	Pascal
r	Distance from an axis of rotation and the acoustic center of a source
s	Second
t	Time
T	Measurement period
S_e	Transmit voltage response
θ	Angle between the main response axis and a point in the acoustic field
V	Volt
Z	Vertical distance

CHARACTERISTICS OF SOUNDS EMITTED DURING HIGH-RESOLUTION GEOPHYSICAL SURVEYS

1. INTRODUCTION

Marine geophysical acoustic survey systems are critical to the mission of several federal agencies including the Bureau of Ocean Energy Management (BOEM), U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), U.S. Navy (USN), and the National Science Foundation (NSF). Geophysical survey systems are used by these agencies (and commercial interests) to support exploration and development on the outer continental shelf (OCS) including marine transportation, oil and gas, marine mineral, and renewable energy projects. In particular, geophysical surveys support infrastructure siting, sand resource delineation, geomorphic characterization, environmental monitoring, archaeological resource identification, and mapping of shallow hazards. The USGS Coastal and Marine Geology Program (CMGP), USACE Civil Works, and NOAA National Ocean Service (NOS) Office of Coast Surveys use the same technology for similar purposes on the shallower inner continental shelf (ICS).

Given the significant scientific questions and uncertainty about the potential impacts associated with noise in the marine environment, an increasing number of regulatory requirements and precautionary mitigation strategies are being applied to lower-energy geophysical surveys including those of short duration and limited geographic footprint. The BOEM is working to ensure that environmental mitigation requirements are scientifically supported, cost effective, operationally feasible, and impact reducing. BOEM is advancing this objective by characterizing the acoustic energy radiated by geophysical survey systems used on the continental shelf, and other shallow bodies of water under U.S. jurisdiction. Thus, characterizing the acoustic fields radiated by marine geophysical acoustic survey systems is a critical first step to understanding the potential for these surveys to impact marine ecosystems.

This report presents results of work performed under interagency agreements (IAs) between BOEM, USGS and the Naval Undersea Warfare Center Division Newport (NUWCDIVNPT) of the Naval Sea Systems Command (NAVSEA). The overall objective of this study was to acquire and analyze calibrated acoustic source data for a number of commonly used marine geophysical survey systems as required to support subsequent sound source verification of these systems *in situ* by future BOEM-USGS studies. This objective was satisfied by performing a series of acoustic measurements in an acoustic tank and in open bodies of water using methods and standards traceable to U.S. standards maintained by the Underwater Sound Reference Division (USRD).

2. SCOPE OF STUDY

2.1 GEOPHYSICAL SURVEY SYSTEMS

The characteristics of radiated sound were measured for 18 distinct geophysical survey systems through January to August of 2015. Table 1 provides a listing of the tested systems. Manufacturer's product information sheets for all of the systems included in this study are provided in the appendix. Where availability of equipment permitted, two systems of the same model were tested. In all cases, data were collected while the systems were functioning in operationally relevant modes and contexts. In certain cases, acoustic data were also collected in non-operational orientations to facilitate improved characterization of acoustic beam patterns.

The geophysical survey systems of table 1 are divided into two broad categories: sea floor mapping systems and sub-bottom profiling systems. The sub-bottom profiling systems were further divided by signal type: impulse and frequency-modulated (FM) chirp. While the FM chirp signals were all generated by piezoelectric transducers, the impulse signals were generated by a variety of mechanisms including accelerated water mass, release of high-pressure compressed air, and electrostatic discharge at high voltage.

Table 1. Geophysical Survey Systems Included in Study

Sea Floor Mapping		**Sub-Bottom Profiling**	
System	**Description**	**System**	**Signal**
Echotrac CV100	Single-Beam Echosounders	AA* 200	Impulse
Reson 7111	Multibeam Echosounders	AA* 251	Impulse
Reson T20-P	Multibeam Echosounders	AA* S-Boom	Impulse
Bathyswath SWATHPlus-M	Interferometer	FSI** Bubble Gun	Impulse
Klein 3000	Side-Scan Sonar	SIG ELC 820 Spark	Impulse
Klein 3900	Side-Scan Sonar	AA* Dura Spark	Impulse
EdgeTech 4200	Side-Scan Sonar	AA* Delta Spark	Impulse
		Sercel GI Airgun	Impulse
		EdgeTech 424	FM Chirp
		EdgeTech 512i	FM Chirp
		Knudsen 3202	FM Chirp
*Applied Acoustic Engineering, Ltd. **Falmouth Scientific, Inc.			

2.2 GEOPHYSICAL SURVEY SYSTEM ACOUSTIC SOURCES

2.2.1 Electromechanical Acoustic Sources

An electromechanical acoustic source generates a deterministic electrical signal to create a time-varying displacement in a mechanical device that results in the radiation of sound. Common electrical signals include impulsive and longer duration modulated waveforms with either broad or narrow frequency bandwidths. Piezoelectric transducers commonly found in commercial and naval sonar systems fit this description, as do less familiar acoustic sources such as boomer plates in which an actuator is used to displace a near-surface, downward-oriented metal disc to form a nearly ideal baffled piston source. An important distinction between electromechanical and other acoustic sources employed in geophysical survey systems is the determinism of the transmitted signal. Whereas electromechanical sources employ deterministic signals, non-electromechanical sources typically employ impulsive physical processes including the release of high-pressure air or electric field discharge at high voltage (i.e., airguns and sparkers) to generate high-intensity acoustic fields.

Electromechanical sources used in geophysical survey systems are subdivided into bottom mapping and sub-bottom profiling applications as shown in table 1. A representative selection of systems engaged in bottom mapping includes single, swath, and multibeam bathymetric echosounders, and side-scan sonar systems. Sub-bottom profilers include systems that transmit impulsive or FM acoustic signals (e.g., boomers and chirp profilers). Source levels generated by geophysical survey systems with electromechanical acoustic sources range from 170 to 240 dB re 1μPa@1m (peak-to-peak) at frequencies of about 300 Hz to several hundred kHz and transmit pulse widths ranging from less than one to tens of milliseconds.

Three examples of the geophysical survey systems included in this study are illustrated in figure 1. Figure 1a shows an Edgetech 512i sub-bottom profiling system. The system uses two transducers to generate FM acoustic signals across a broad frequency range. The larger, low-frequency transducer is located at the forward end of the tow body. A smaller, higher frequency transducer is located just aft of the low-frequency transducer. The figure also shows four receive arrays arranged parallel to the longitudinal axis and slightly recessed into the tow body. The white triangular and rectangular panels are skid plates to protect the tow body during handling and stowage aboard ship. The tow body can be operated near the water surface or closer to the bottom such that acoustic energy is transmitted vertically into the sea floor resulting in a received reflection sequence that is determined by the sub-bottom geology.

Figure 1b shows an Applied Acoustic Engineering, Ltd., (AA/AAE) S-Boom sub-bottom profiling system as viewed from below. The system employs three boomer plates and an associated energy source to generate short transient signals. The frame mounted plates are installed in a catamaran that maintains the plates near the water surface and oriented for the vertical transmission of acoustic energy into the sea floor. The transmit pulse width ranges from 300 to 500 μs depending on the energy applied to the source array. The system can be driven with a maximum of 1,000 J for an estimated peak source level of 227 dB re 1μPa@1m.

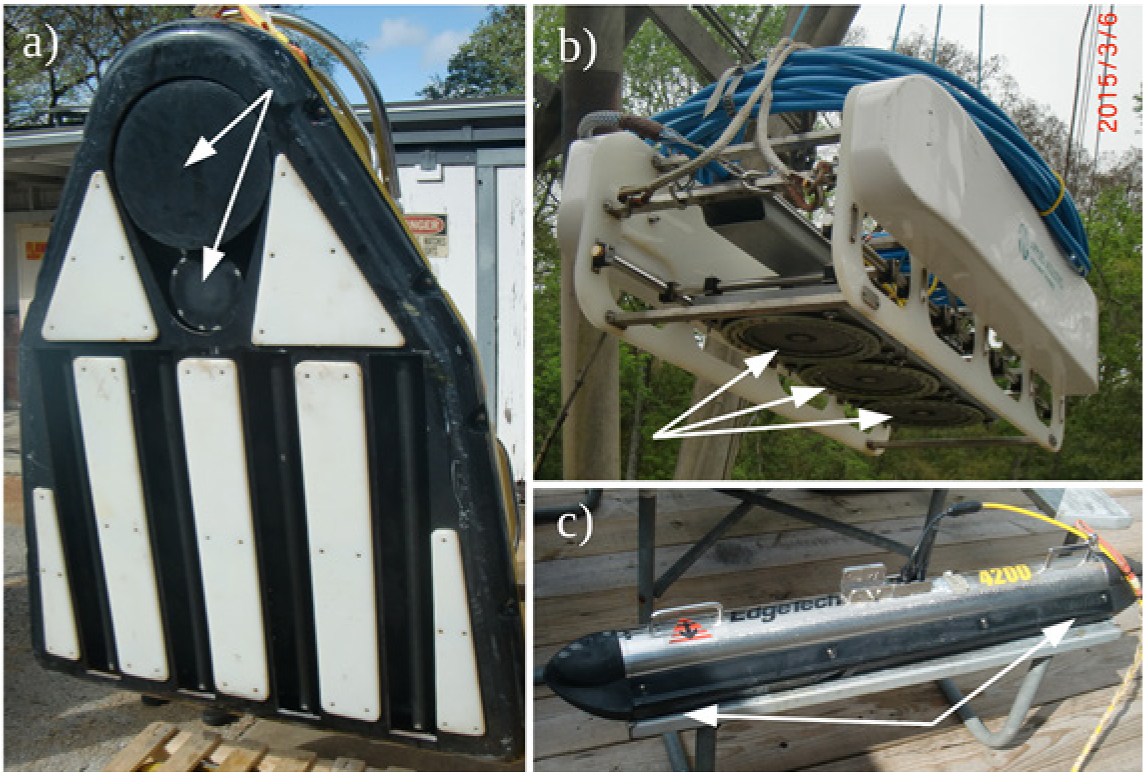


Figure 1. Electromechanical Acoustic Sources

An EdgeTech 4200 dual-frequency side-scan sonar is shown in figure 1c. An active transducer array is located on each side of the tow body. The transmit arrays produce acoustic beams with horizontal widths (i.e., along track) of less than one degree and vertical beamwidths (i.e., across track) of 40°. The transmit beams are angled toward the sea floor to scan the bottom on either side of the tow body. The tested system employed a dual-band transmitter operated at 100 and 400 kHz.

2.2.2 Electrostatic Discharge and Airgun Sources

Sparkers comprise a class of seismic sources used for high-resolution marine surveying. They function by the electric discharge of a high-voltage impulse across one or more electrode tips and a ground point on the sparker body. Resultant heating of the surrounding seawater generates a rapidly expanding steam bubble with a nearly ideal positive impulse. Continued expansion of the steam bubble beyond the equilibrium hydrostatic pressure results in collapse and the formation of a series of bubble pulse oscillations of diminishing amplitude until all of the energy is dissipated. Figure 2a shows the Applied Acoustics Dura-Spark employed in this study.

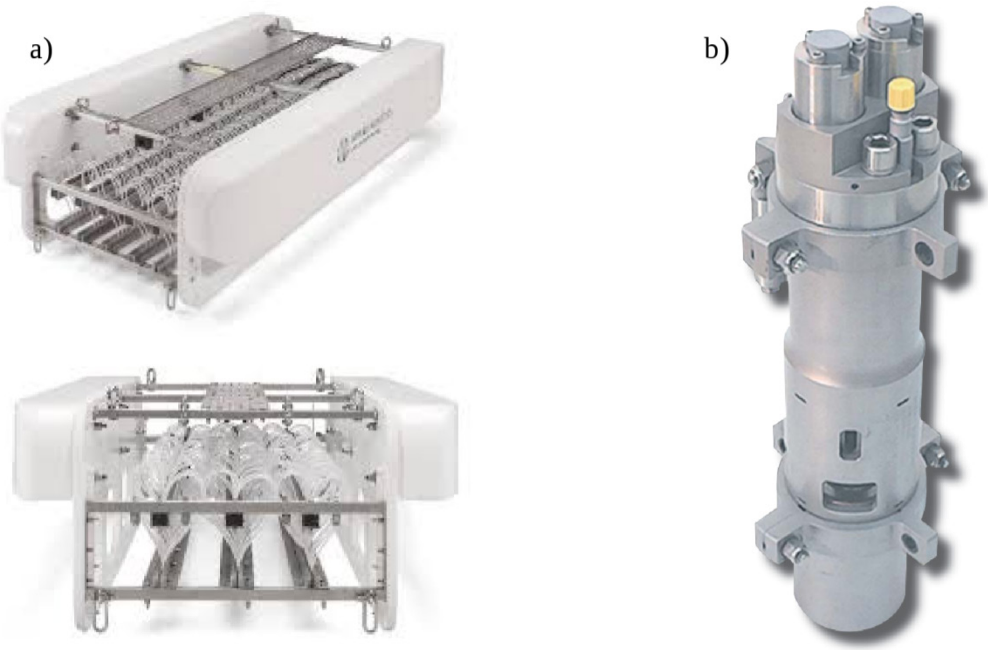


Photo credit: Applied Acoustic Engineering Ltd

Photo credit: Sercel

Figure 2. Applied Acoustics Dura-Spark and Sercel Mini-GI Airgun

Airguns function by the rapid release of compressed air into the surrounding water to create an impulsive acoustic waveform. The acoustic waveforms typically exhibit a prominent bubble pulse in the time history. The bubble pulse is a secondary source of sound generated by the oscillating expansion and collapse of air under hydrostatic pressure after it has been released and during its ascent to the surface. The energy contained in the bubble pulse can result in notches in the acoustic intensity spectrum where the frequencies affected depend on the bubble oscillation period. Sounds associated with the bubble pulse can create “multiples” in the seismic section that can complicate interpretation of the geology.[1]

The Sercel Mini-Generator-Injector (Mini-GI) airgun employed in this study (see figure 2b) is a small seismic source developed to reduce or suppress the bubble oscillations that are common to traditional seismic airguns. The GI airgun consists of a generator to create the acoustic impulse and an injector to reduce or suppress the bubble oscillations. The total airgun volume is 980 cm^3 (60 $in.^3$) divided equally between the generator and the injector. The GI airgun first generates the initial impulse and the associated air bubble. When the bubble reaches its maximum size, an additional volume of air is injected into it. Depending on the characteristics of the injection, the bubble oscillations can be significantly reduced.

2.3 MEASUREMENT AND ANALYSIS PROCEDURES

2.3.1 Acoustic Measurement Standards

ANSI/ASA S1.20-2012 [2] prescribes a set of procedures for the calibration of underwater electroacoustic transducers. Measurements performed as part of this study were in general accordance with reference 2, although some minor modifications were required to accommodate particulars of the individual geophysical survey systems. Detailed descriptions applicable to the measurement geometry, rigging, and data collection for each individual geophysical survey system are provided in sections 3 and 4.

Preparation of the acoustic transducers began by rigging the equipment for deployment in the water. While details of rigging were dependent on the equipment and the desired measurement, the acoustic output for nearly all systems was observed with the equipment in its operational orientation. In some cases, data were also collected with the equipment placed in a non-operational orientation to facilitate more detailed characterization. For example, the acoustic source levels of the EdgeTech sub-bottom profiling systems were measured with the tow bodies in a normal operating mode with the transducers oriented downward as shown in figure 3a. However, detailed measurement of the directional response, or beam patterns, required that the tow bodies be rigged to transmit sound in a horizontal direction to facilitate attachment and manipulation with the rotating equipment used at the measurement facilities as shown in figure 3b. Once rigged, the acoustic sources were submerged to depths that were consistent with their normal operating modes.

a) Source Levels b) Beampatterns

Figure 3. EdgeTech 512i Rigged for Acoustic Measurements

Acoustic beam pattern measurements were performed to provide information needed to assess the potential environmental impact associated with operation of a given geophysical survey system. While knowledge of the acoustic source level is required for environmental impact assessment, it is not sufficient for sources that do not radiate sound equally in all directions. Since many geophysical survey systems are designed to focus sound in a particular direction, the intensity of sound radiated in other directions can be greatly reduced. Therefore, the beam patterns of directional acoustic sources must be included in the analysis; otherwise, estimates of the impact to marine ecosystems will include significant errors.[3]

The acoustic fields radiated by the geophysical survey systems were observed using one or more calibrated reference standard hydrophones maintained by the USRD. All of the hydrophones used during this study were calibrated following completion of the survey system measurements to ensure the precision and accuracy of the results. In each case, the distance between the acoustic center of the projector and the reference hydrophone(s) was set to ensure the observations were performed in the farfield of the projector. American National Standard Institute ANSI/ASA S1.1-2013[4] defines the farfield as the spatial extent over which the acoustic field exhibits spherical divergence. Thus, the acoustic pressure within the farfield varies with the inverse of distance from the source, provided that correction is made for any attenuation due to absorption and scattering, if necessary.

The minimum distance, d , from the acoustic center of a projector to a point in the acoustic farfield was estimated as

$$d > \frac{\pi a^2}{\lambda} \text{ and } d > a, \qquad (1)$$

where

a is the largest radius of a piston source or half the length of a line source, and

λ is the acoustic wavelength.[1]

Physically, the criteria of equation (1) stipulates that the variation in distance from the point of observation to any place on the surface of the projector is small relative to an acoustic wavelength. While this criteria was usually satisfied, there were instances where measurement facility constraints precluded acoustic observations at distances greater than (or equal to) those prescribed by equation (1). This was found to be the case for certain high-frequency, high-resolution sea floor mapping systems where the transmit aperture dimensions were quite large relative to an acoustic wavelength. Measurement geometry details and potential measurement errors are presented in the detailed discussions for affected systems.

A significant difference between the measurements required by this study and those described in reference 2 is that the ANSI/ASA standard procedures for acoustic source characterization are confined to measurements performed with electroacoustic transducers independent of other system components such as amplifiers, waveform generators, and tow bodies. Thus, the ANSI/ASA standard describes procedures where the measurand is either transmit voltage response (TVR) or transmit current response (TCR) for a given acoustic source under steady state conditions.

Reference 2 defines the TVR measurand in the international system of units (SI) as

$$|S_e| \;=\; \left|\frac{p}{e_p}\right| d \;=\; \left|\frac{e_{ref}}{e_p (M_e)_{ref}}\right| d\,, \tag{2}$$

where

S_e	is the transmit voltage response of a projector (or source),
p	is the sound pressure realized by a projector,
e_p	is the signal voltage applied to a projector's input terminals,
e_{ref}	is the open circuit voltage output of a reference standard hydrophone,
$(M_e)_{ref}$	is the free-field voltage sensitivity of the reference standard hydrophone, and
d	is the ratio of the distance from the acoustic center of the projector to the reference standard hydrophone and the reference distance of one meter.

The SI derived unit of the TVR, S_e, is the pascal meter per volt, $1\,\mathrm{Pa\cdot m/V}$. The TVR is expressed in decibels relative to one micro-pascal meter per volt, $\mathrm{dB\ re\ 1\mu Pa\cdot m/V}$. This is frequently annotated as $\mathrm{dB\ re\ 1\mu Pa/V@1m}$ and read as *decibels referenced to one micro-pascal per volt at one meter*. The TCR is similarly defined, but with the transmit current, i_p, substituted in place of the transmit voltage, e_p, in equation (2). The TVR is traditionally used when specifying the performance of a piezoelectric transducer due to the high input electrical impedance of these devices. The TCR is frequently used for moving coil transducers due to their low input electrical impedance.

Since the objects of this study were complete geophysical survey systems, measurement of the TVR was neither practical nor relevant to the study's objectives. Measurement of the TVR was not practical since observation of the voltage signal at the input to the acoustic sources was not feasible without modifying the equipment. Nor was knowledge of the TVR relevant since the desired information pertained to the acoustic fields radiated by complete geophysical survey systems under normal operation. The engineering details describing internal system parameters (such as amplifier output voltage) were not required to characterize the radiated acoustic fields. Thus, it was both necessary and sufficient to operate complete geophysical survey systems as would occur during a survey and to observe the radiated acoustic fields.

2.3.2 Acoustic Measurands

Acoustic field parameters of interest for environment impact assessment include variations of the sound pressure level (SPL) for effective, peak and peak-to-peak acoustic pressure, and the sound exposure level (SEL). When used to describe the characteristics of an acoustic source, engineering convention is to reference these parameters to a distance of one meter from the acoustic center of the source. Thus, the acoustic field pressure referenced to one meter is given by equation (3)

$$p = \frac{e_{ref}}{\left(M_e\right)_{ref}} d, \tag{3}$$

where

e_{ref} is the voltage output by a reference standard hydrophone,

$\left(M_e\right)_{ref}$ is the free-field voltage sensitivity of the reference standard hydrophone, and

d is the distance from the source to the reference standard hydrophone.

The SPL referred to a distance of one meter from the source, or source level, SL_{rms} , is then defined in terms of the effective, or root-mean-squared (rms) pressure as

$$SL_{rms} = 10\log_{10}\left(\frac{\frac{1}{T}\int p^2(t)dt}{P_{ref}^2}\right) \mathrm{dB_{rms}} \mathrm{re}\, 1\mu\mathrm{Pa@1m}, \tag{4}$$

where

P_{ref} is a reference acoustic pressure (i.e., 1 μPa),

T is the measurement period, and

t is time.

Source levels for the maximum instantaneous peak, SL_{pk} , and peak-to-peak, SL_{pp} , pressure relevant for impulsive signals were computed as provided in equations (5) and (6) where

$$SL_{pk} = 10\log_{10}\left(\frac{p^2(t)_{max}}{P_{ref}^2}\right) \mathrm{dB_{pk}}\ \mathrm{re}\, 1\mu\mathrm{Pa@1m}, \text{and} \tag{5}$$

$$SL_{pp} = 10\log_{10}\left(\frac{\left(p(t)_{max} - p(t)_{min}\right)^2}{P_{ref}^2}\right) \text{ dB}_{\text{pp}} \text{ re } 1\mu\text{Pa@1m}. \quad (6)$$

The sound exposure level, SL_{SEL}, for a single acoustic transmission referenced to a distance of one meter was calculated as

$$SL_{SEL} = 10\log_{10}\left(\frac{\int p^2(t)dt}{P_{ref}^2}\right) \text{ dB}_{\text{SEL}} \text{ re } 1\mu\text{Pa}^2 \cdot \text{s@1m}. \quad (7)$$

The power spectral density, PSD, for the acoustic pressure field referenced to a distance of one meter is defined as

$$PSD(f) = 10\log_{10}\left(\frac{\frac{1}{T}\left|\int p(t)e^{j2\pi ft}dt\right|^2}{P_{ref}^2}\right) \text{ dB re } 1\mu\text{Pa}/\sqrt{\text{Hz}}\text{@1m}, \quad (8)$$

where, f is frequency. The PSD were computed using Welch's Method[5] for power spectrum estimation. The measurement period, T, of each acoustic signal was taken as the time centered period during which 90% of the signal energy was observed such that $0 < t < T$ in all cases.

Figure 4 and table 2 show the set of calculations described above. The acoustic signal radiated by an EdgeTech 512i sub-bottom profiling system referred to one meter is shown in figure 4a. As inspection of the pressure time series shows, the transmit signal was modulated in both amplitude and frequency with a nominal pulse width of 5 ms and 1 to 10 kHz bandwidth. Figure 4b shows the normalized energy in the received signal as required to identify and isolate that part of the acoustic waveform containing 90% of the total radiated energy as indicated by the red lines in the figure. Figure 4c illustrates the power density spectrum of the transmit waveform (90%) referred to a distance of one meter where the half power points (i.e., -3 dB) of the power spectrum were located at 4.3 and 7.2 kHz.

Figures 4d and 4e show the pressure and normalized energy for a Falmouth Scientific, Inc., (FSI) Bubble-Gun sub-bottom profiling system. While the peak amplitude is about the same as that realized by the EdgeTech 512i, other signal characteristics were quite distinct: the frequency bandwidth (see figure 4f) in particular where the half-power point was located at 1.4 kHz.

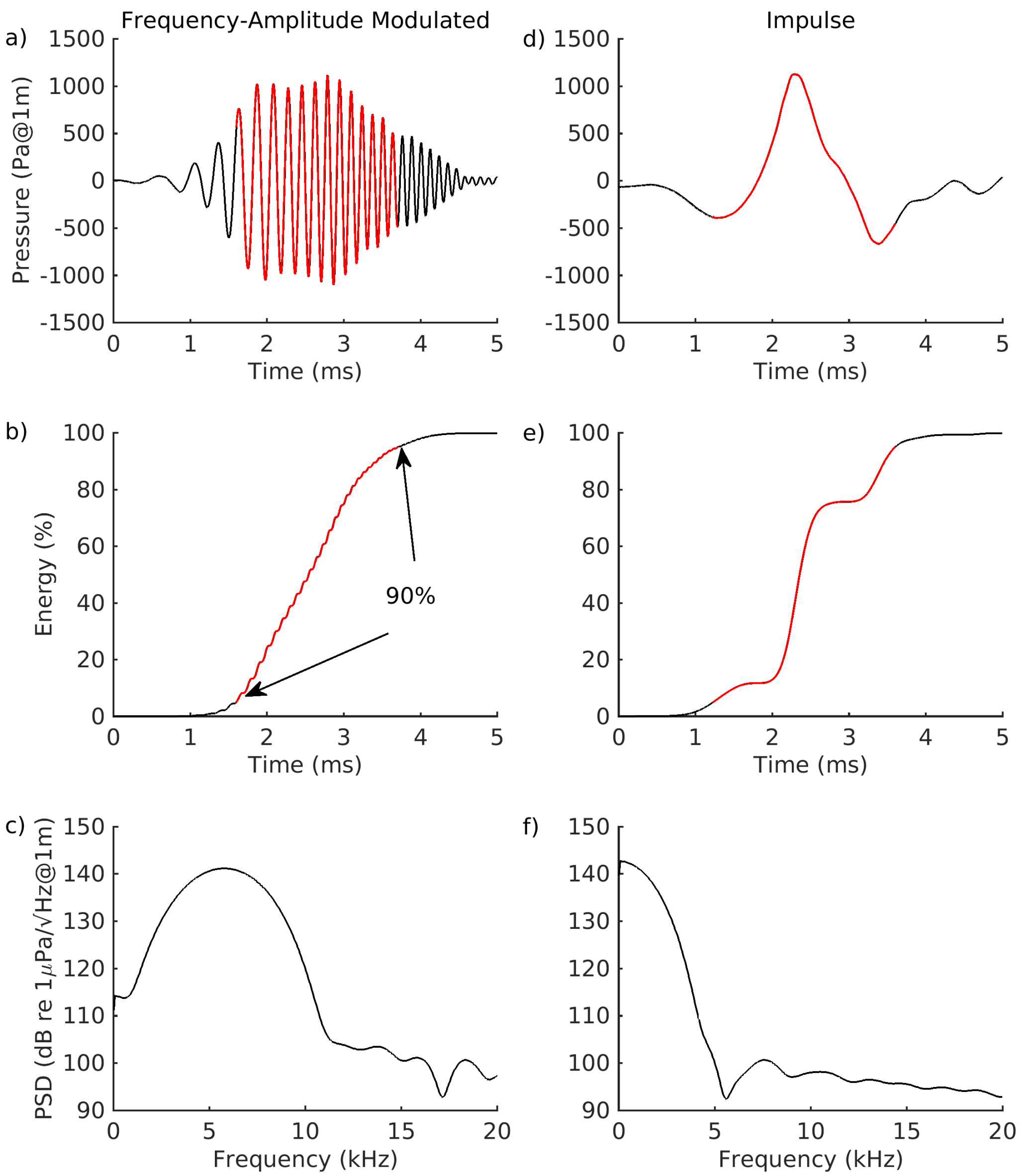


Figure 4. Acoustic Waveform Examples

Table 2. Example Calculated Acoustic Source Parameters

System	**T (ms)**	**Source SEL (dB re 1µPa^2·s@1m) Eq. (7)**	**Source Level (dB re 1µPa@1m)**		
			RMS Eq. (4)	**Peak Eq. (5)**	**Peak-Peak Eq. (6)**
EdgeTech 512i	2.1	115	176	181	187
FSI Bubble Gun	2.4	114	175	181	185

Calibrated intensity spectra were measured to investigate the potential for certain acoustic sources to radiate sound at frequencies below the intended transmit frequency. A recently published account[6] has suggested that certain commercial multibeam sonar systems operating at 200 kHz also radiate sound at frequencies that were consistent with the first sub-harmonic, or half the design frequency. If present, such unintended acoustic emissions could present an unrecognized ecological risk if a system thought to operate above the auditory bandwidth of a particular species was to radiate sound at one or more sub-harmonic frequencies within the auditory bandwidth of that species. Therefore, calibrated intensity spectra and half-power bandwidths were calculated for all of the systems used in this study to explore, among other things, the propensity of these systems to radiate sound outside the design frequency band.

2.3.3 Beam Pattern Measurements

The acoustic sources included in this study do not radiate sound equally in all directions but were designed to focus acoustic energy either directly toward the sea floor or in a narrow swath across the survey track. Therefore, a comprehensive estimate of the risks posed by operation of these systems depends not only on the acoustic levels along the main response axis (MRA), but in all directions, most of which receive significantly lower intensity relative to that on the MRA.[2] Selection of an appropriate measurement method for the acoustic beam patterns generated by a given geophysical source was strongly influenced by each system's acoustic transmit aperture geometry, operating mode, and characteristics of the transmitted signals.

Beam patterns are typically measured in one or more planes that contain the outward normal vector, $\hat{n}$, having its origin at the geometric center of the acoustic projector. In the case of circular piston projectors, the radiated beam patterns are symmetric about the outward normal vector, thus measurement in a single plane is sufficient. However, an elongated projector such as that in figure 5, usually requires beam pattern measurements in two planes: one parallel to the elongated direction and one orthogonal to it.

The beam pattern for an elongated source is characterized by a wide acoustic beamwidth in the plane that contains both the outward normal vector, $\hat{n}$, and the minor axis of the rectangular aperture (see figure 5). In the case of a multibeam echosounder, this broad beamwidth extends in the across-track direction in order to survey a wide swath on either side of the ship's track. The beam pattern in the plane defined by the outward normal vector, $\hat{n}$, and the major axis of the acoustic aperture is characterized by a more narrow acoustic beamwidth and a greater number of acoustic sidelobes. This narrow beamwidth spans the along track direction such that each transmission of an acoustic waveform results in a narrow (or line) scan of the sea floor that is orthogonal to the track taken by the survey ship.

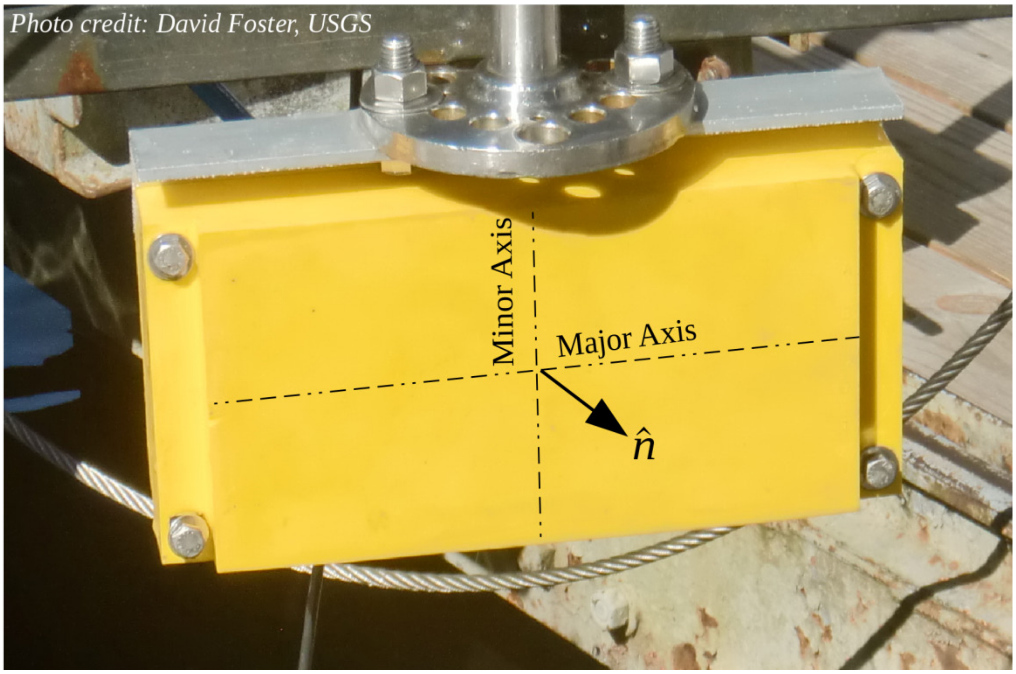
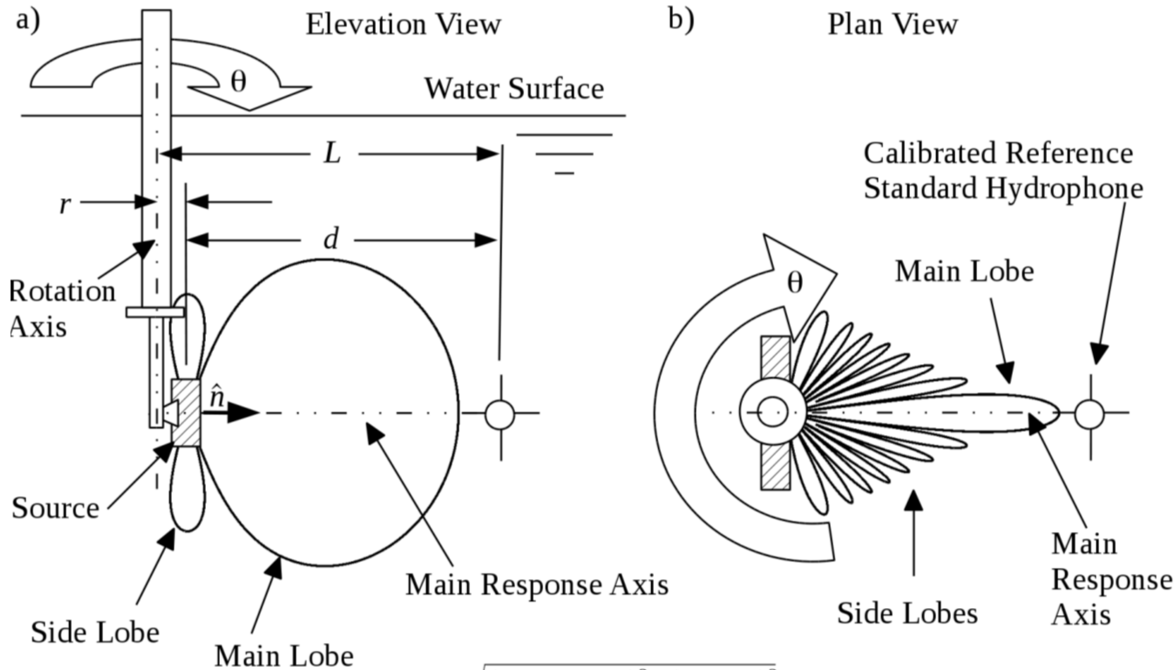


Figure 5. Elongated Acoustic Aperture Geometry

Figure 6 illustrates the geometry used to measure the acoustic beam pattern of an elongated acoustic projector. The elevation view of figure 6a depicts an acoustic projector mounted to a vertically oriented rotator shaft submerged in water. One or more calibrated reference hydrophones receive the acoustic signals where they are stored in a data acquisition system (not shown). In the ideal arrangement, the rotation axis passes through the acoustic center of the projector such that the distance, d, to the reference hydrophone remains constant during rotation. However, this arrangement is not feasible in some cases, and it is necessary to correct for varying distances to the reference hydrophones as is shown in figure 6a where the acoustic center of the projector is displaced from the axis of rotation by the distance, r.

Figure 6b depicts the plan view for the beam pattern measurement of an elongated source. As discussed above, characterizing the elongated source requires beam pattern measurements in two planes. In this example, measurement in the second plane requires mounting the projector such that the major axis (see figure 5) is oriented vertically and parallel to the axis of rotation. As suggested by consideration of figures 5 and 6, measurement of the acoustic beam pattern in the plane containing the minor axis of the aperture requires more precise control over the measurement geometry in order to keep the main beam oriented toward the reference standard.

Many of the sub-bottom profiling systems include sources composed of circular pistons that radiate sound vertically downward into the sea floor. The beam patterns produced by these sources tend to exhibit axial symmetry about the outward normal vector $\hat{n}$, which is collinear with the MRA of the radiated acoustic field pattern. The planning process for these measurements included a series of predictions for the radiated beam patterns as required to optimize the measurement geometry for each source.



$$d=\sqrt{(L-r\cos\theta)^2+(r\sin\theta)^2}$$

Figure 6. Beam Pattern Measurement Geometry

Figures 7a and 7b illustrate the beam pattern predicted for the circular piston source of the Applied Acoustics AA251 boomer plate when driven with a continuous harmonic signal at 5 kHz. The figure provides two equivalent depictions of the beam pattern. For example, figure 7a provides a Cartesian plot of gain versus angle for the AA251 boomer plate radiating sound at 5 kHz. Angle 0° corresponds to the MRA and is the direction of maximum sound intensity. Angle 40° corresponds to the first sidelobe, or the direction in which sound is radiated, but at significantly reduced intensity, in this case about 18 dB less than the MRA intensity. Located at angle 30° is a null, or the direction in which little to no sound is radiated. A second null and sidelobe are located at about 60° and 90°, respectively. Figures 7b and 7d present the same information but rendered as a three-dimensional surface depiction of the beam pattern colored with the gain realized in a particular direction. Note the mainlobe, two sidelobes, and two nulls are clearly depicted in the rendered shape.

Figures 7c and 7d illustrate the beam pattern for the same acoustic source when transmitting an acoustic impulse with significant bandwidth as is radiated by this system in practice. Note the predicted beam pattern varies smoothly with angle and lacks the sidelobe and null structure that results from radiation of a narrow band signal. Thus, the acoustic aperture geometry and radiated signal characteristics influence the choice of measurement method.

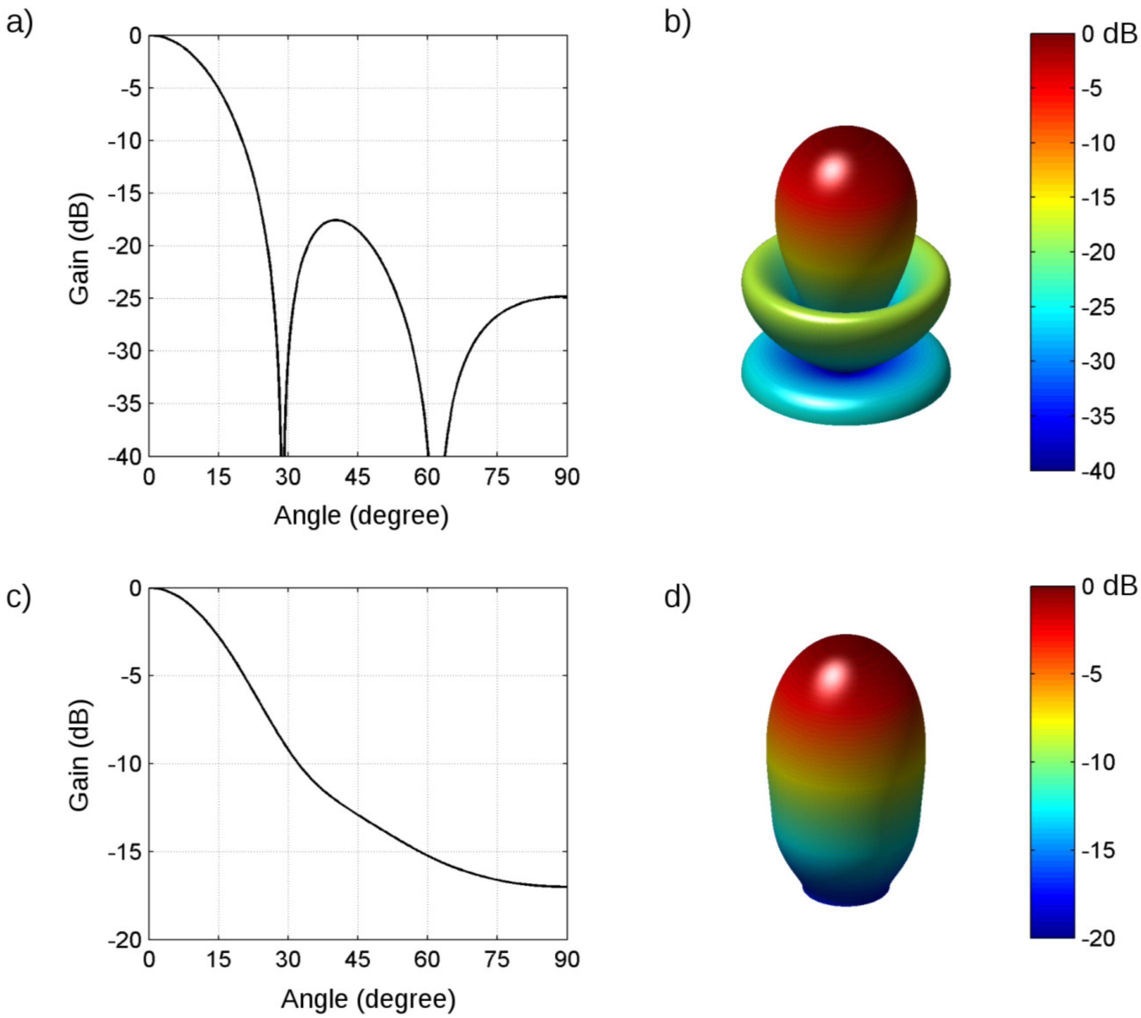


Figure 7. Axially Symmetric Acoustic Beam Patterns

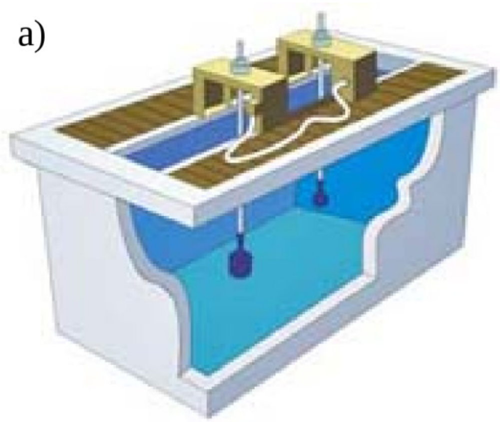
In instances where the transmitted signal wavelength was of sufficiently short wavelength and small bandwidth that the development of multiple sidelobes was expected, it was advantageous to reorient the projector for deployment from a rotator as shown in figure 6. The beam patterns measured in this way included hundreds of individual measurements with fine angular resolution. In instances where the transmitted signal was of sufficiently long wavelength and large bandwidth, a much simpler and smoothly varying beam pattern was produced, and it was sufficient to measure the acoustic field at few discrete angles relative to the projector MRA.

2.3.4 Acoustic Test Facilities

Among the primary considerations in selecting a facility in which to perform a given measurement was the distance from the source to the acoustic farfield and the pulse length of transmitted signals. Acoustic sources with aperture lengths that greatly exceed an acoustic wavelength required long test distances (see equation (1)) as provided by an open water test environment. In addition, survey systems that employed acoustic waveforms with pulse widths exceeding a few milliseconds were also tested in open water. Where both the distance to the acoustic farfield and the acoustic pulse widths were sufficiently short, testing was performed in an enclosed laboratory facility. In addition, where the precision required to control the measurement geometry exceeded the capability of Navy open-water test facilities, measurements were performed on a fixed and stable platform in an enclosed laboratory. In certain cases, the acoustic farfield criteria of equation (1) were compromised in favor of precise control over the measurement geometry as will be detailed in the discussions for affected geophysical survey systems.

2.3.4.1 Acoustic Open Tank Facility. The acoustic open tank facility (OTF) located in Newport, Rhode Island is a Navy test facility for evaluation of underwater acoustic devices. The facility features a large open water tank, automated data acquisition systems, and associated mechanical support equipment. The test tank measures 9.1-m long, 4.6-m wide, and 4.6-m deep (see figure 8a). The sides and bottom are concrete. The mechanical support equipment is rated for a maximum test article mass of 450 kg. The facility includes working deck for personnel access (see figure 8b) and a precision rotator with an angular accuracy of $\pm 0.1^{\circ}$. The minimum operational frequency for the facility is 1 kHz.

a)



b)

Figure 8. Open Tank Facility (OTF)

2.3.4.2 Leesburg Acoustic Test Facility. The Leesburg acoustic test facility (LEFAC) is an open water facility located in Bugg Spring near Leesburg, Florida. Bugg Spring (figure 9a) has a mean discharge of 0.32 m^3/s (reference 7) and discharges into a run that flows about 2.4 km north and east into Helena canal. The spring has a deep circular pool about 120 m in diameter and 50-m deep. A sub-bottom profile taken beneath the test facility barge showed the bottom is covered with about 3 m of soft sediment. A multibeam sonar scan of the spring (figure 9b) shows the nearly vertical limestone walls on all sides except the western shoreline. No boil is evident on the surface due to the depth of the spring vent and large pool volume. Except for algae, there is little aquatic vegetation.

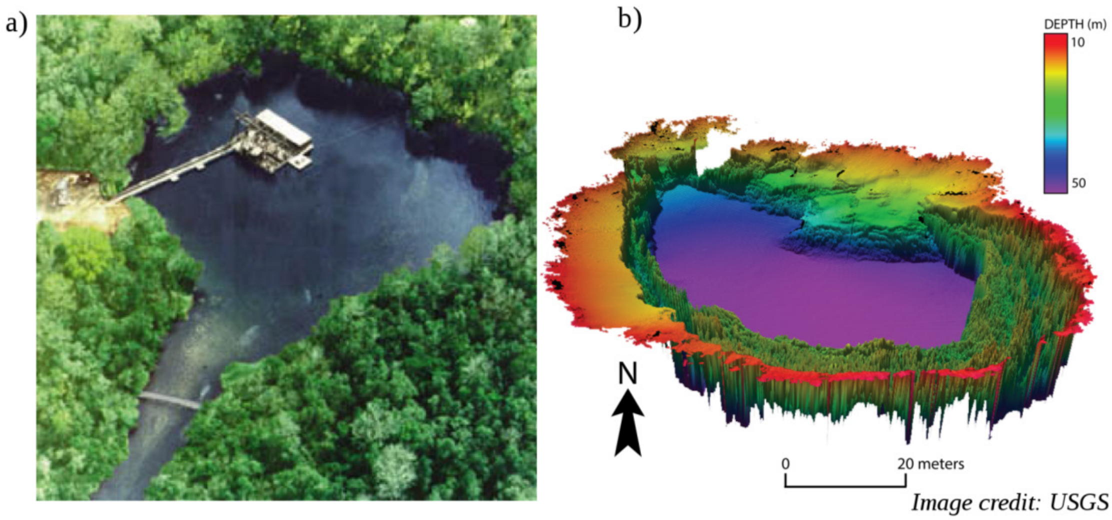


Figure 9. Bugg Spring–Leesburg, Florida

***2.3.4.3 Woods Hole Oceanographic Institution*.** Acoustic measurements for the sparkers and the Applied Acoustics S-Boom were performed at the Woods Hole Oceanographic Institution (WHOI) in Falmouth, Massachusetts. Data were collected in the dock well at the WHOI Marine Operations Center (figure 10) in a water depth of approximately 15 m. The well includes side walls that extend to a depth of about 5 m. Data were collected with the geophysical source located near the centerline of the well and about 4 m from the side wall. While this facility does not provide the well-controlled laboratory conditions of the NUWC OTF or the low ambient noise levels of the NUWC LEFAC, it provided an adequate test environment for characterization of the transmitted signals.

Figure 10. Woods Hole Oceanographic Institution (WHOI) Test Site

2.3.5 Instrumentation and Data Collection System

Instrumentation used to collect acoustic data for this study consisted of National Instruments based data acquisition systems and Navy standard calibrated reference hydrophones. Three different data collection systems were used. Two of the systems share a common hardware configuration and differed primarily in the acquisition software. One software suite was used to perform a variety of standardized acoustic tests including the measurement of transmit beam patterns in the NUWC OTF. The second software application was a simple time series recorder used to collect data for subsequent post-processing. The majority of acoustic data were collected with the time series recorder and processed with special-purpose data reduction software developed over the course of this study. In both cases, data were collected at a maximum sample rate of 5 Mz with 12-bit precision for up to 8 channels simultaneously. Both of these data collection systems included a set of analog preamplifiers to condition the hydrophone signals as needed to optimize use of the limited dynamic range provided by the 12-bit analog-to-digital converters.

A third acoustic measurement system was used for certain measurements at the NUWC LEFAC. The system used National Instruments acquisition boards with a maximum sample rate of 250 kHz on four channels with 16-bit precision. In addition to collection of acoustic data, this system was used to record data from a rotator assembly during beam pattern measurements.

Three different Navy standard hydrophone models were used for the collection of acoustic data. Acoustic data for the sub-bottom profiling systems were acquired using Navy Type F42D hydrophones with a nominal sensitivity of -207 dB re 1V/µPa. The F42D hydrophone consists of a lead zirconate titanate (PZT) spherical shell encapsulated in polyurethane and fitted with a 30-m cable. The hydrophone has a first resonance at about 150 kHz and was used for collection of data for frequencies below 75 kHz, or one octave below the resonance frequency.

Acoustic data for the multibeam and side-scan sonar systems were collected using Navy Type E27 hydrophones with a nominal sensitivity of -223 dB re 1V/µPa. The E27 hydrophone consists of an array of seven PZT disks arranged in a hexagon and cemented directly to a butyl rubber acoustic window. The E27 hydrophone has a first resonance at about 750 kHz and was used for source level measurements for frequencies ranging from 100 kHz to 445 kHz.

Acoustic data for EdgeTech sub-bottom profiling system beam pattern measurements were collected with a Navy Type F37 reference hydrophone with a sensitivity of -203.7 dB re 1V/µPa. All of the F42D and E27 hydrophones were calibrated after the geophysical source data collection was complete. Calibration curves for the hydrophones are shown in figure 11.

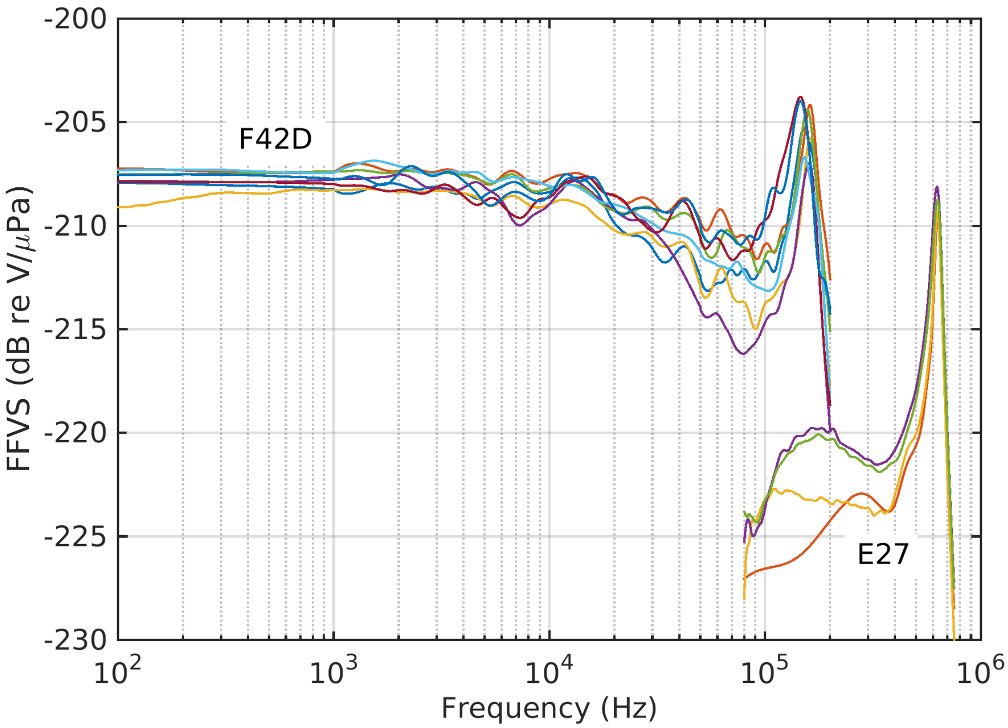


Figure 11. Reference Hydrophone Free-Field Voltage Sensitivity (FFVS)

2.3.6 Measurement Uncertainty

Uncertainties for the acoustic parameters presented in this report were developed in accordance with United States and international standards[8,9] for the estimation and presentation of measurement uncertainty. In all cases, the reported uncertainties include a Type B evaluation or analysis by means other than a statistical analysis of repeated observations. Type B evaluations of uncertainty were based on engineering and scientific judgment using available information including the measurement history for the respective test facilities, uncertainties in the calibration data for the reference standards, manufacturer's specifications for the data acquisition systems, and the accuracy and precision of the measurement geometry achievable at each of the test facilities. Where a measurement included repeated observations suitable for statistical analysis, a Type A evaluation of uncertainty was also performed using the procedures of references 8 and 9 and included in the reported measurement uncertainty.

In all cases, measurement precision was characterized using the *expanded uncertainty* with a coverage factor of $k = 2$. That is, the combined standard uncertainty (i.e., Type A and B) was multiplied by the factor, k, such that the measurement result and expanded uncertainty define the interval on which the true value of the measurand lies with high probability (i.e., 95%). The expanded measurement uncertainty for the sub-bottom profiling systems was 1 dB with 0.5 dB allocated to uncertainty in the reference hydrophone calibrations and the remainder allocated to the experiment geometry and data collection systems. The expanded measurement uncertainty for the multibeam and side-scan sonars was 1.5 dB where an additional contribution to the measurement uncertainty was allocated to the orientations and directional response patterns for the E27 hydrophones.

Measurement uncertainty at the WHOI was largely controlled by uncertainties in the locations of the reference hydrophones and the geophysical survey sources. A significant factor was the presence of a tide-driven current running through the test well. The current acted on the survey sources and reference hydrophones. In some cases, measurement equipment was set into motion. In other cases, the orientation of the geophysical survey sources was difficult to control. In addition, the close proximity of side walls had the potential to reflect sound back into the well, thus contributing to the overall measurement uncertainty. While a precise uncertainty estimate for this facility is not known, it is unlikely to exceed 2 dB.

3. SUB-BOTTOM PROFILING SYSTEMS

3.1 SIGNAL TYPE: ACOUSTIC IMPULSE

The first, and perhaps simplest, measurement involved deployment of the sub-bottom profiling systems in their normal operational orientation for transmission of sound into the sea floor. Near-surface systems include the boomer plates and bubble gun devices where the acoustic source is based on a metal disk deployed from a catamaran and maintained at a shallow depth beneath the free surface of the water. These survey systems transmit an acoustic impulse at relatively low frequency where the close proximity of the free surface is a significant factor in the radiated acoustic field. Therefore, acoustic measurements of near-surface, sub-bottom profile systems with impulsive acoustic waveforms were performed with the sources in normal operating modes and orientations.

3.1.1 Electromechanical Transducer Systems

3.1.1.1 Applied Acoustics AA200 Boomer Plate. The Applied Acoustics Engineering 200 (AA200) boomer plate (see figure 12) is a seismic sound source designed to produce a sharp repeatable impulse from a floating position on the sea surface. The active surface of the projector is a flat, circular plate with a diameter of about 30 cm. The input signal is an electric impulse with a recommended energy range of 50 to 200 J per shot and a maximum energy of 300 J. Manufacturer product information for the transmit signal lists pulse widths ranging from 120 to 180 µs, and a (peak-to-peak) source level of 215 dB re 1µPa@1m for an energy input of 200 J. The beamwidth of the transmitted waveform is not addressed in the manufacturer's information.

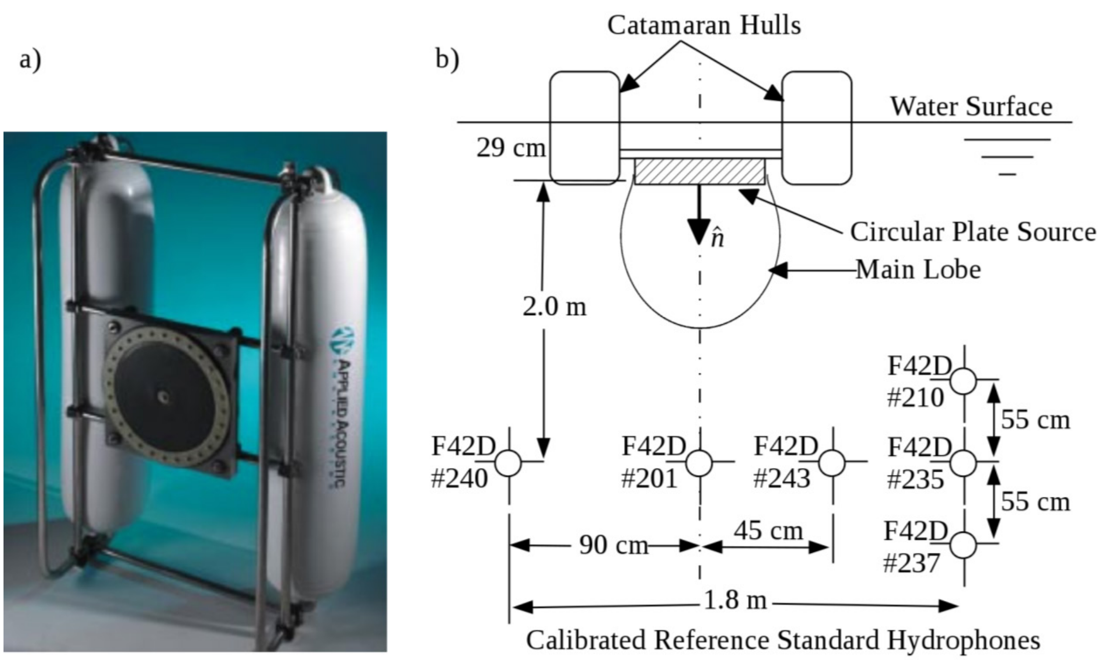


Photo credit: Applied Acoustic Engineering Ltd

Figure 12. AA200 Seismic Source and Measurement Geometry

Acoustic waveforms transmitted by the AA200 (S/N 714) were measured in the acoustic OTF in Newport, Rhode Island on 29 January 2015. The measurement setup was as shown in figure 12 where six calibrated reference standard hydrophones were used to observe the acoustic field at a variety of angles with respect to the projector's MRA. The acoustic data were sampled at 500 kHz with 12-bit precision. Each measurement included the observation of about 30 individual waveforms from which average values were computed and reported. The waveforms transmitted by the AA200 were very repeatable where the standard deviation in the observed source levels was on the order of 0.1 dB.

The acoustic pressures referred to a distance of 1 m and are shown in figure 13a for input energies of 50 and 200 J. The duration of each waveform in which 90% of the radiated energy was located is shown in red, and the peak levels are indicated with markers. The pressure spectral density (PSD) of the waveform is provided in figure 13b where the markers annotate the half-power, or -3 dB point, of the power spectra. The beam patterns radiated by the AA200 boomer plate are shown in figure 13c. Uncertainty in the source levels and reference hydrophone angular displacement are illustrated by vertical and horizontal error bars, respectively. The total uncertainty in source level was 1 dB with contributions from reference standard calibration uncertainty (~0.5 dB) and an estimated uncertainty radius of 10 cm for the locations of the reference standards due to the rigging methods used. The nominal uncertainty in angular displacement was 3°, a consequence of the aforementioned 10-cm uncertainty radius.

The half-power, or 3-dB, beamwidth of sound radiated by the AA200 was estimated by nonlinear regression of the observed source levels (rms) to an analytic model[10] of the directional response for a baffled circular piston. The acoustic intensity, I , in the farfield, normalized by the intensity on the MRA of the circular piston is

$$I \simeq \left(\frac{2J_1(ka\sin\theta)}{ka\sin\theta} \right)^2 , \tag{9}$$

where a is the piston radius, k is the acoustic wave number, θ is the angle relative to the MRA, and J_1 is the Bessel function of the first kind. Regressions were performed to estimate an effective value of ka that would account for the size of the AA200 piston and bandwidth of the radiated signal. The result of regressions performed for 50 and 200 J input energies are illustrated by the solid lines in figure 13c. The reported half-power beamwidths are based on these regressions. Note there are several important differences between an ideal baffled piston and the family of Applied Acoustics boomer plates. Perhaps most important was the presence of the air-filled catamaran hulls that were likely excited by the acoustic impulse, resulting in scattering and secondary radiation of sound as shown in figure 13a. Thus, the regressions were performed to provide an approximate, but well-understood, metric for the directivity of the radiated sound field despite the significant departure of the boomer plate from the idealized model used to represent it. Finally, the reported beamwidths encompass the full angular arc of the transmit beam and are twice the (half) angle widths shown in figure 13c. The measurements were performed in the transverse direction (relative to the ship's track) (see figure 12b).

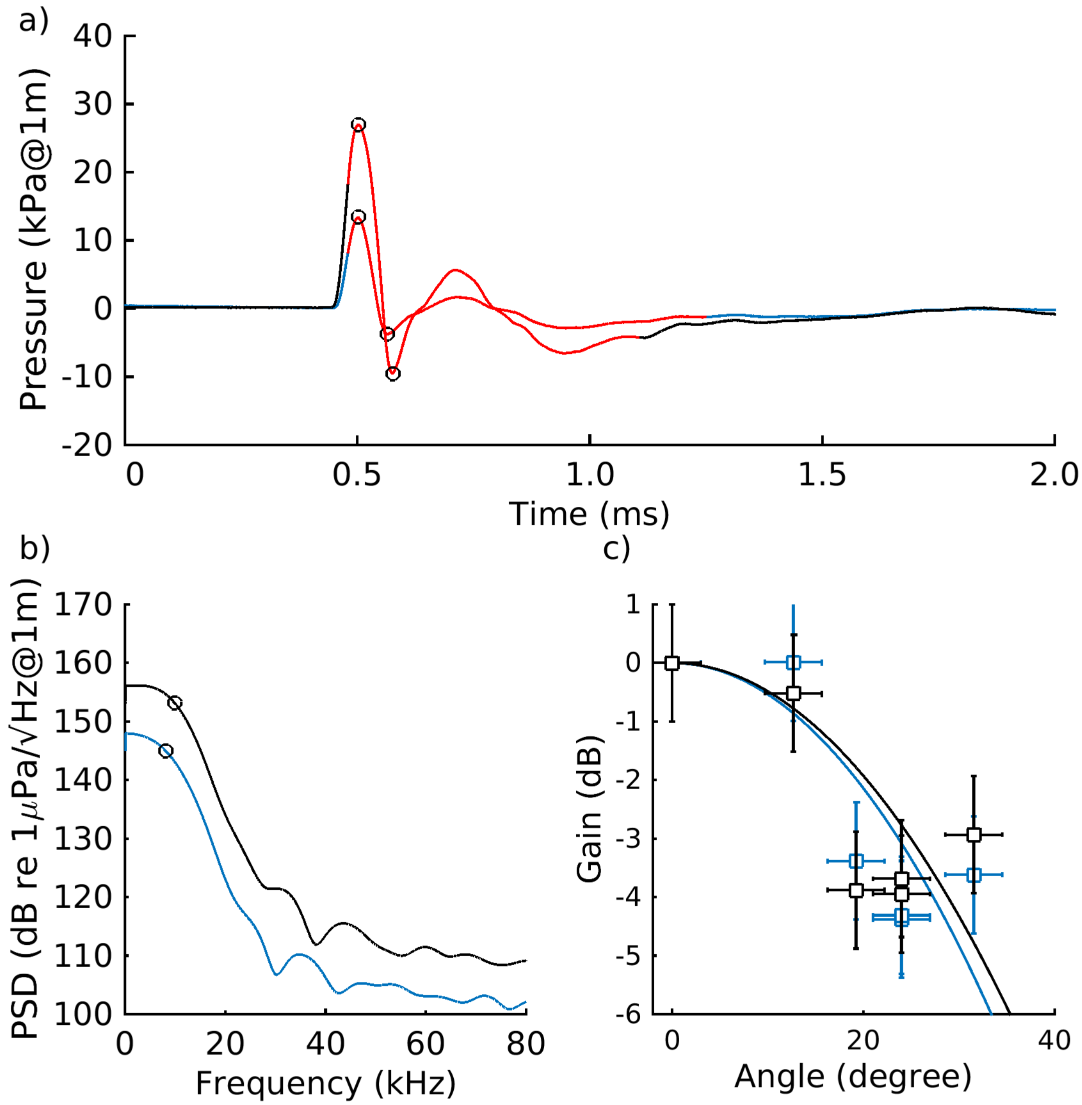


Figure 13. AA200 Acoustic Waveforms at 50 J and 200 J

Table 3 summarizes the acoustic characteristics of signals transmitted by the AA200 seismic source when supplied by an Applied Acoustics CSP-D700 Seismic Energy Source (S/N 2090490). The power settings used for each energy level are indicated in the table where energies that were multiples of 100 J employed the *high* setting, and energies that were an odd multiple of 50 J used the *low* setting. Information provided in the manufacturer's user manual indicate the low power setting applies the same energy over a longer time period using reduced voltage. It also states the high power setting is not suitable for single boomer plate systems.

Differences were noted between the manufacturer's specifications and the observed data for the peak-to-peak source level and the pulse widths. First, whereas the manufacturer specifies a peak-to-peak source level of 215 dB re 1µPa@1m when driven with a 200 J input energy, a source level of 211 dB was observed as listed in table 3.

The second difference between the manufacturer's specification and the observed performance was the pulse width of the acoustic waveforms. The manufacturer specifies pulse widths of 120 and 180 μs for input energies of 50 and 200 J, respectively. However, the observed pulse widths at these energies were 540 and 570 μs. Comparison of the waveforms observed and those provided in the product literature suggests the manufacturer may have collected data with the source present only and not the catamaran. In particular, waveforms in the manufacturer's product literature are sharp pulses with little residual oscillation beyond the impulse. The observed waveforms include a more extended post-impulse oscillation that may have been associated with secondary radiation of sound from the (air-filled) catamaran hulls.

Table 3. AA200 Acoustic Characteristics

Source Setting (Joules)	Source Level (dB re 1μPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)	Beam Pattern	
	Pk-Pk	Pk	RMS	SEL			ka	MRA Width 3 dB (deg)
50 (low)	205	203	191	160	0.8	8.1	4.0	47
100 (high)	210	208	197	165	0.6	10.6	4.1	46
150 (low)	208	205	196	165	0.7	6.2	3.3	59
200 (high)	211	209	199	166	0.6	9.8	3.8	50
250 (low)	212	209	200	169	0.8	4.3	2.3	90

3.1.1.2 Applied Acoustics AA251 Boomer Plate. The Applied Acoustics Engineering 251 (AA251) boomer plate is a seismic sound source designed to produce a sharp, repeatable impulse from a floating position on the sea surface. The input signal is an electric impulse with a recommended energy range of 50 to 200 J per shot and a maximum energy of 300 J. Manufacturer product information for the transmit signal lists pulse widths ranging from 120 to 180 μs, and a source level of 212 dB re 1μPa@1m for a 200 J input. Acoustic characteristics of sounds generated by the AA251 were measured in both the OTF and at LEFAC.

Acoustic waveforms transmitted by the AA251 (S/N 2140864) were first measured in the acoustic OTF in Newport, Rhode Island on 29 January 2015. The measurement setup was essentially the same as was used for the AA200 (see figure 12) except the line of hydrophones was located 1.9-m below the source. The acoustic data were sampled at 500 kHz with 12-bit precision. Each measurement included the observation of about 30 individual waveforms from which average values were computed and reported. Repeatability of waveforms transmitted by the AA251 was good where the standard deviations of the observations were less than 0.1 dB for effective (rms) source levels and about 0.3 dB for peak source levels.

An Applied Acoustics CSP-D700 Seismic Energy Source (S/N 2090490) was used to drive the AA251 plate. In addition to energy settings with a step size of 50 J, the source included a user selection for low- and high-power settings. Data were collected at several energy settings with both high and low power selected to investigate the effect on the transmitted waveforms.

Figure 14a illustrates time series data collected at an energy setting of 200 J for both the high- and low-power selection. The figure shows the transmitted waveforms were significantly different with the high setting producing a peak pressure of 60 kPa@1m while the low setting realized only 23 kPa@1m despite indications that the energies supplied in both cases were equal. Information provided in the manufacturer's user manual indicates the low-power setting applies the same energy over a longer time period using reduced voltage. It also states that the high-power setting is not suitable for single plate boomer systems.

Markers in the figure indicate the values used in the calculation of peak and peak-to-peak source levels. Time series data used to calculate the effective (rms) source levels are indicated in red. Also noted in the figure is that the post-impulse oscillation amplitude was significantly greater for the high setting, presumably due to greater energy input into the (air-filled) catamaran hulls that was re-radiated as sound after completion of the primary impulse.

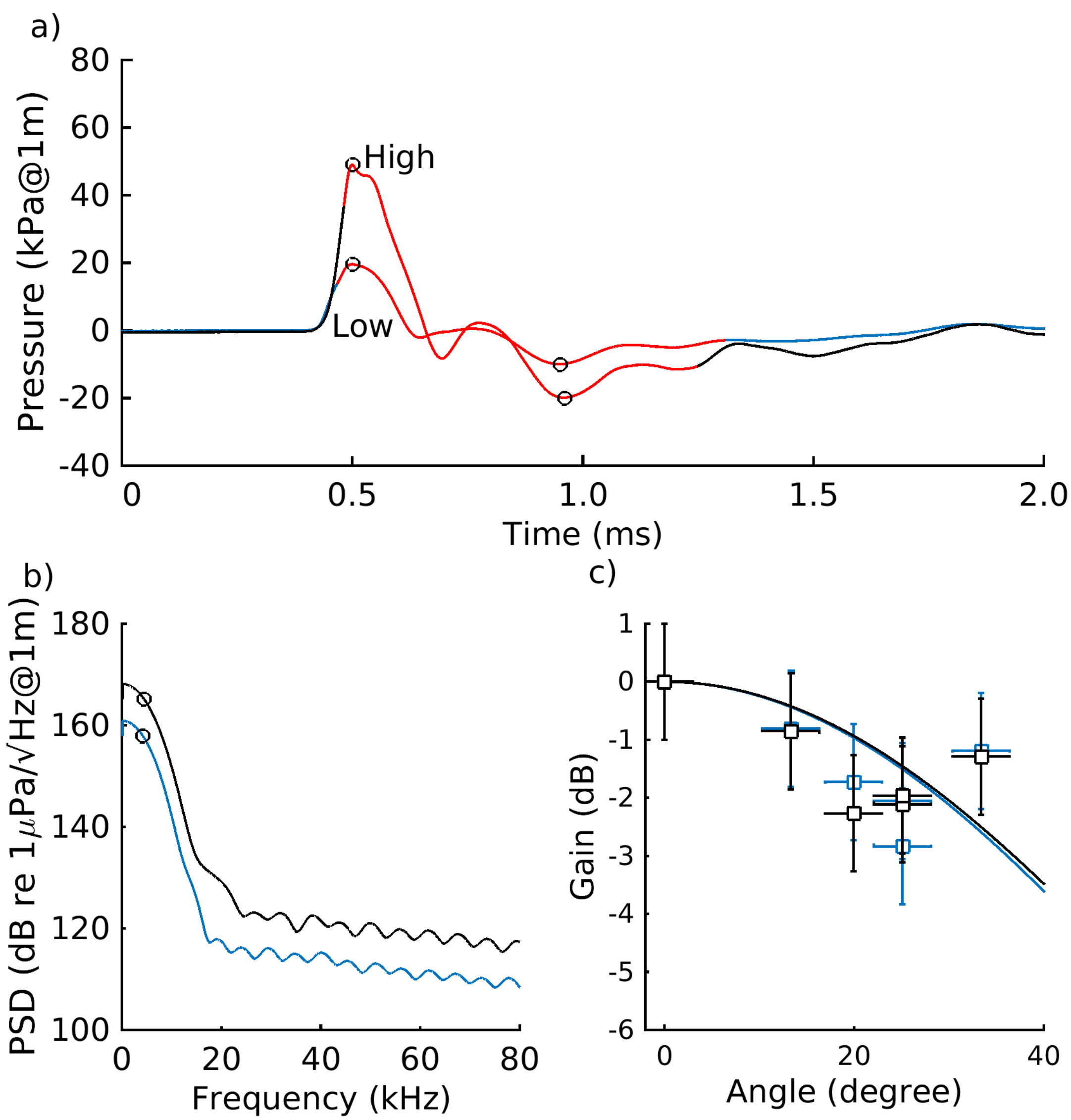


Figure 14. AA251 Acoustic Waveforms at 200 J (OTF)

A summary of measurement results for the AA251 seismic source with Applied Acoustics CSP-D700 Seismic Energy Source (S/N 2090490) as measured in the Newport OTF is provided as table 4.

Table 4. AA251 Acoustic Characteristics (OTF)

Source Setting (Joules)	Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)	Beam Pattern	
	Pk-Pk	Pk	RMS	SEL			ka	MRA Width 3 dB (deg)
50 (low)	203	200	188	158	0.9	3.9	3.9	49
100 (low)	204	201	191	160	0.8	5.3	3.8	53
100 (high)	216	213	205	174	0.8	4.3	2.7	75
200 (low)	210	206	198	167	0.8	4.1	2.7	73
200 (high)	217	214	206	175	0.8	4.3	2.7	74
250 (low)	211	207	200	169	0.9	3.8	2.6	76
300 (high)	219	216	207	176	0.7	4.3	2.8	72

Sounds radiated by the AA251 were also measured at LEFAC on 10 March 2015. Weather conditions during the measurements were calm with southeast winds at about 2 m/s and an average air temperature of 24°C. The measurement geometry is shown in figure 15 where distances to the calibrated reference standards were significantly greater than was achievable in the enclosed test facility at Newport. Greater measurement distances were used to reduce the errors propagated into the source levels when referenced to 1 m. The figure also shows the directivity of the source was measured in the longitudinal direction, or collinear with the direction of tow.

Representative waveforms for the AA251 are provided in figures 16 and 17 for transmit energies ranging from 50 to 300 J. Waveforms transmitted with the low-power setting were similar for transmit energies of 50, 150, and 250 J where the peak-to-peak source levels varied by only 2 dB (i.e., 208±1 dB re 1µPa@1m). The source levels observed at transmit energies of 100, 200, and 300 J were similarly grouped for the high-power setting as shown in figure 17 where the peak-to-peak source levels ranged from 214 to 216 dB re 1µPa@1m. The figures also show that sound was radiated more uniformly in the longitudinal direction than was observed in transverse direction measurements performed in an open tank. The asymmetry in the radiated acoustic field may be related to asymmetries in the boomer plate system, the air-filled catamarans in particular. Measurement results are summarized in table 5.

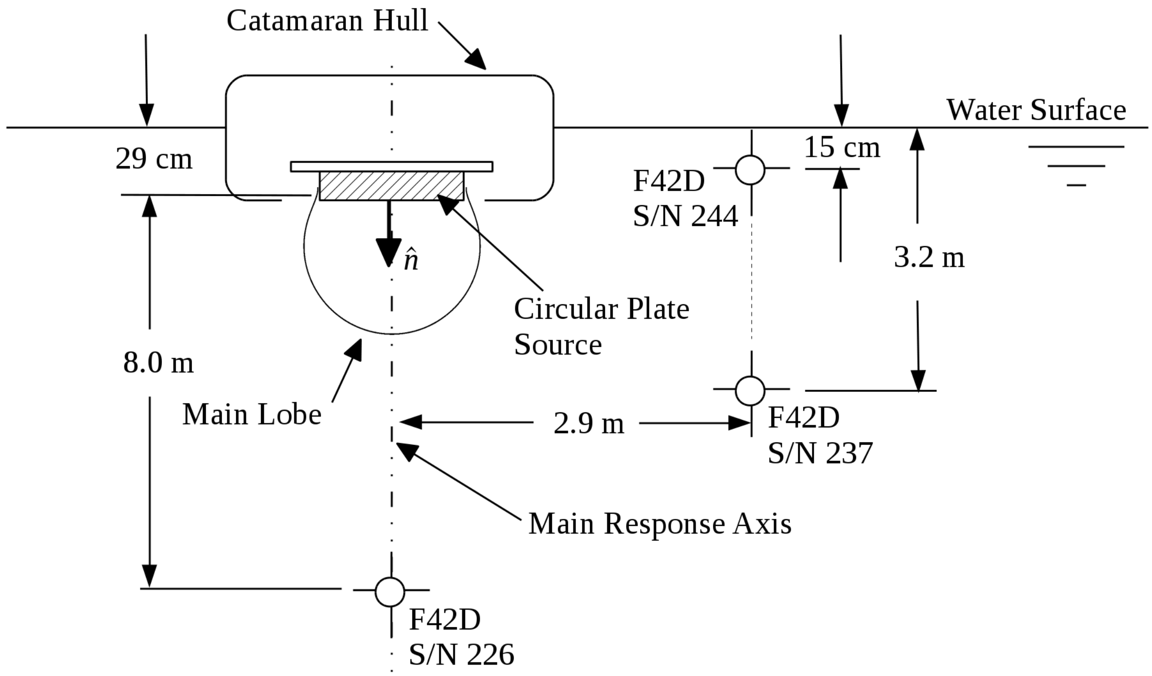


Figure 15. AA251 Seismic Source Measurement Geometry, LEFAC

Table 5. AA251 Acoustic Characteristics (LEFAC)

Source Setting (Joules)	Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)	Beam Pattern	
	Pk-Pk	Pk	RMS	SEL			ka	MRA Width 3 dB (deg)
50 (low)	207	204	197	166	0.9	3.7	1.1	N/A
100 (high)	214	211	204	169	0.7	4.6	1.4	N/A
150 (low)	209	206	200	169	0.8	4.0	1.1	N/A
200 (high)	214	211	204	173	0.7	4.4	1.2	N/A
250 (low)	208	204	198	167	0.8	4.1	0.7	N/A
300 (high)	216	212	205	174	0.8	4.1	1.2	N/A

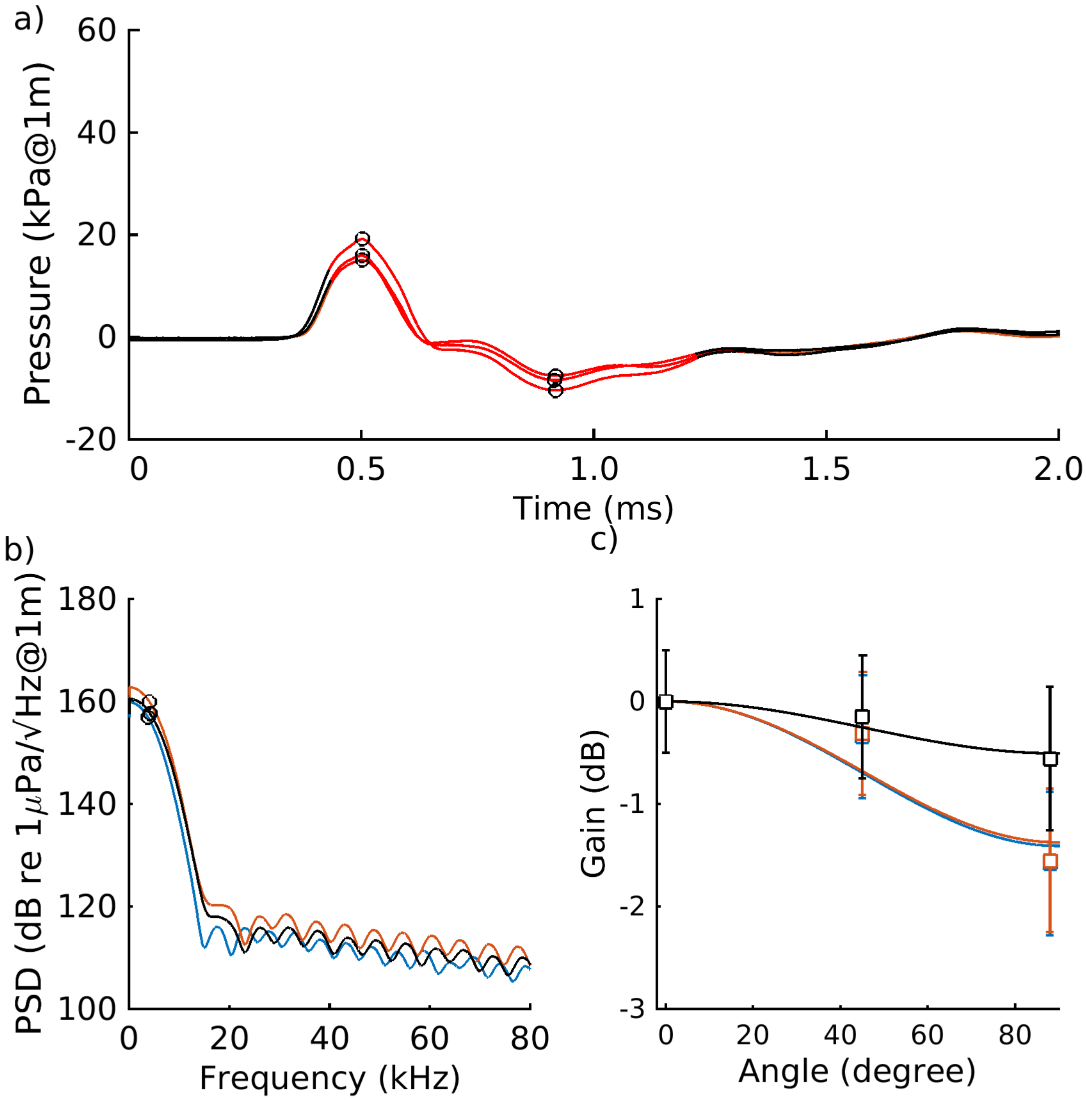


Figure 16. AA251 Acoustic Characteristics at 50, 150, and 250 J (Low Power)

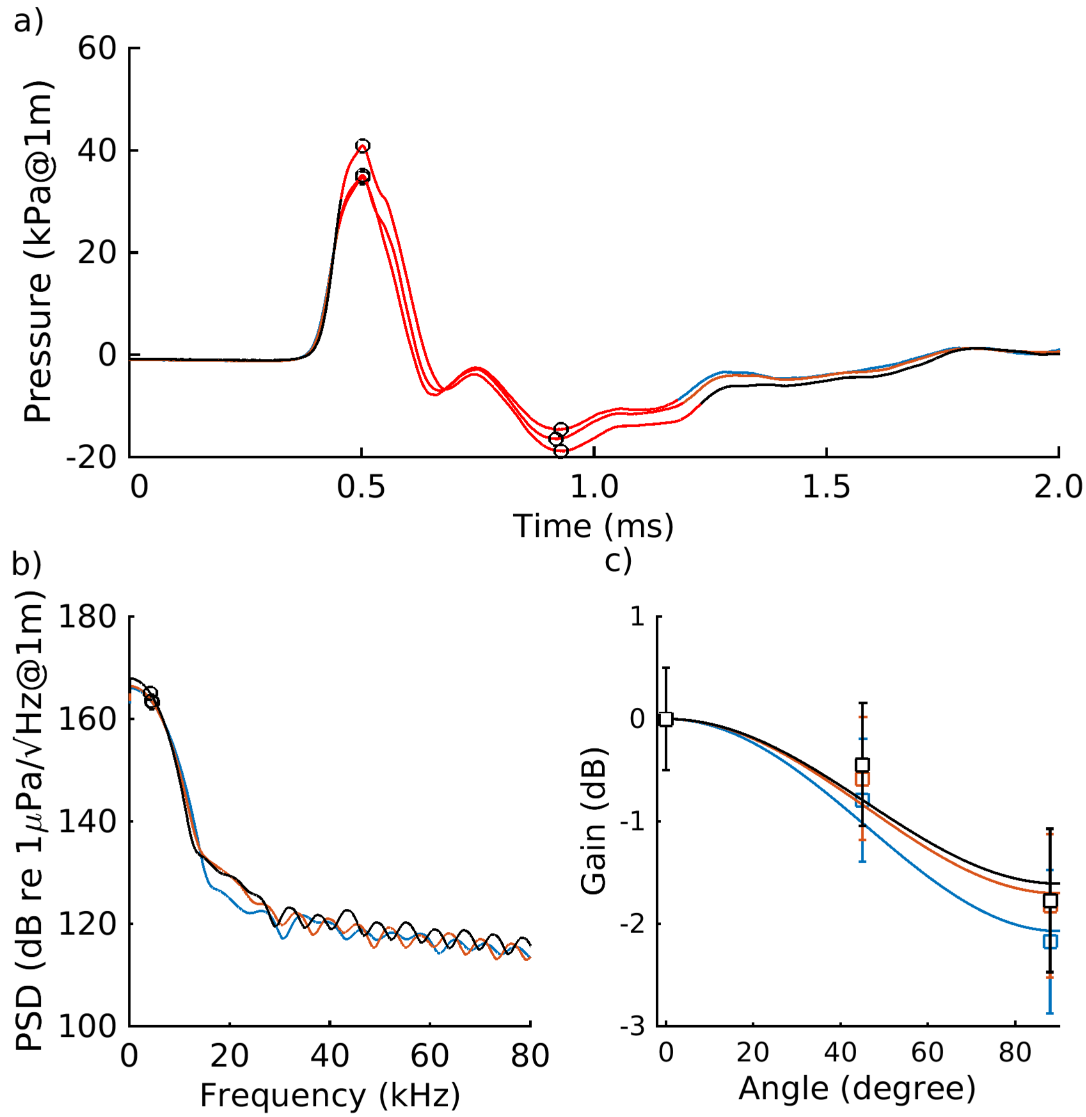


Figure 17. AA251 Acoustic Characteristics at 100, 200, and 300 J (High Power)

3.1.1.3 Applied Acoustics S-Boom. The AA S-Boom system is a seismic sound source composed of three AA252 boomer plates arranged in a line (figure 18). The system produces a sharp repeatable impulse from a floating position on the sea surface. The input signal is an electric impulse with a recommended energy range of 700 to 1,000 J per shot and a maximum energy of 1,000 J. Manufacturer information for the transmit signal list pulse widths ranging from 300 to 500 μs and a source level of 228 dB re 1μPa@1m for a 1,000-J input. Note the product information lists the source level as 222 dB re 1μPa@2m, and thus was converted to a reference distance of one meter by engineering convention. An Applied Acoustics CSP-D700 Seismic Energy Source (S/N 2090490) was used to drive the AA S-Boom plates with a maximum energy output of 700 J. Data were collected at several energy settings while driving various combinations of the AA S-Boom plates, including one, two, and three plates simultaneously.

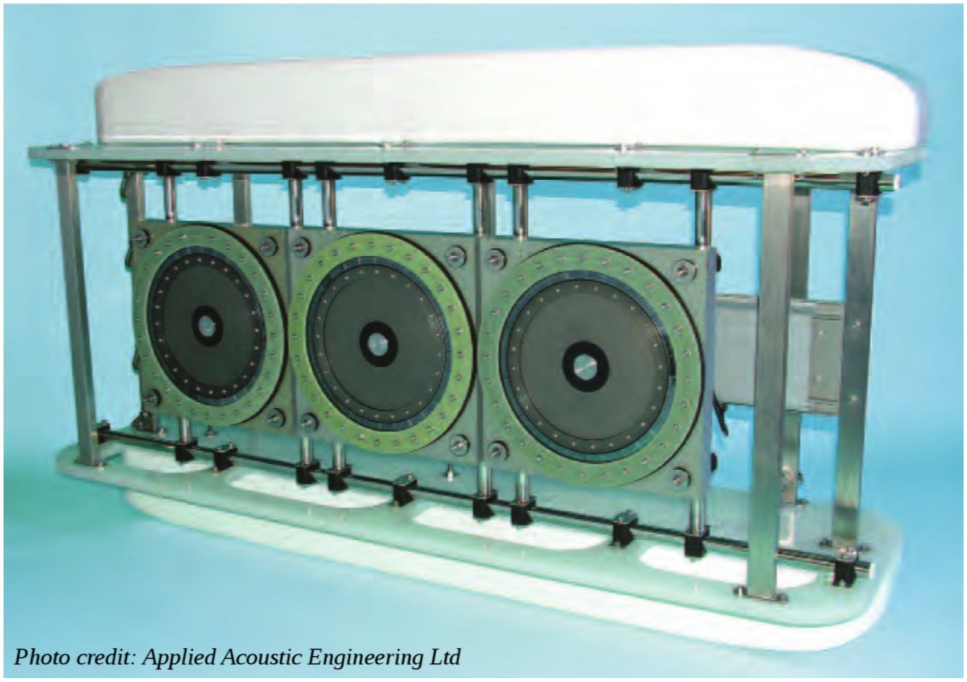


Figure 18. Applied Acoustics S-Boom System

Sounds radiated by the AA S-Boom were measured at LEFAC on 9 March 2015. Weather conditions during the measurements were calm with southeast winds at about 2 m/s and an average air temperature of 27°C. The measurement geometry is shown in figure 19 where the directivity of the source was measured in the longitudinal direction, or collinear with the direction of tow.

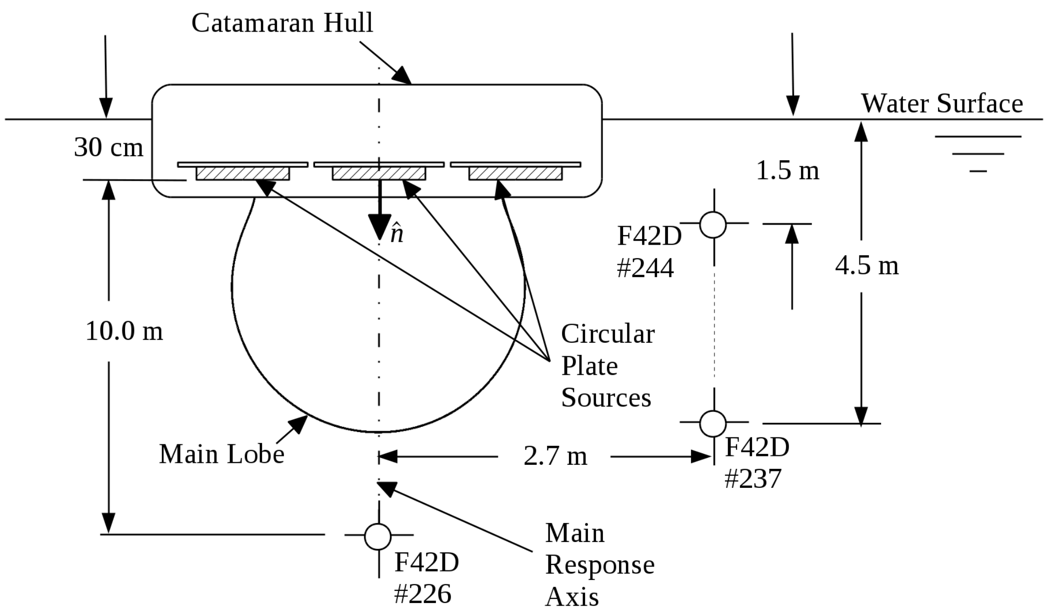


Figure 19. Applied Acoustics S-Boom Measurement Geometry LEFAC

Figure 20 illustrates the acoustic waveforms generated by the AA S-Boom for transmit energies ranging from 300 to 700 J with a 100-J step size. The figure presents the acoustic performance observed when operating all three plates. The figure shows the waveforms, power spectra, and directivity patterns were all consistent where the only significant difference among them was the increase in amplitude commensurate with the increased energy output by the CSP-D700 Seismic Energy Source.

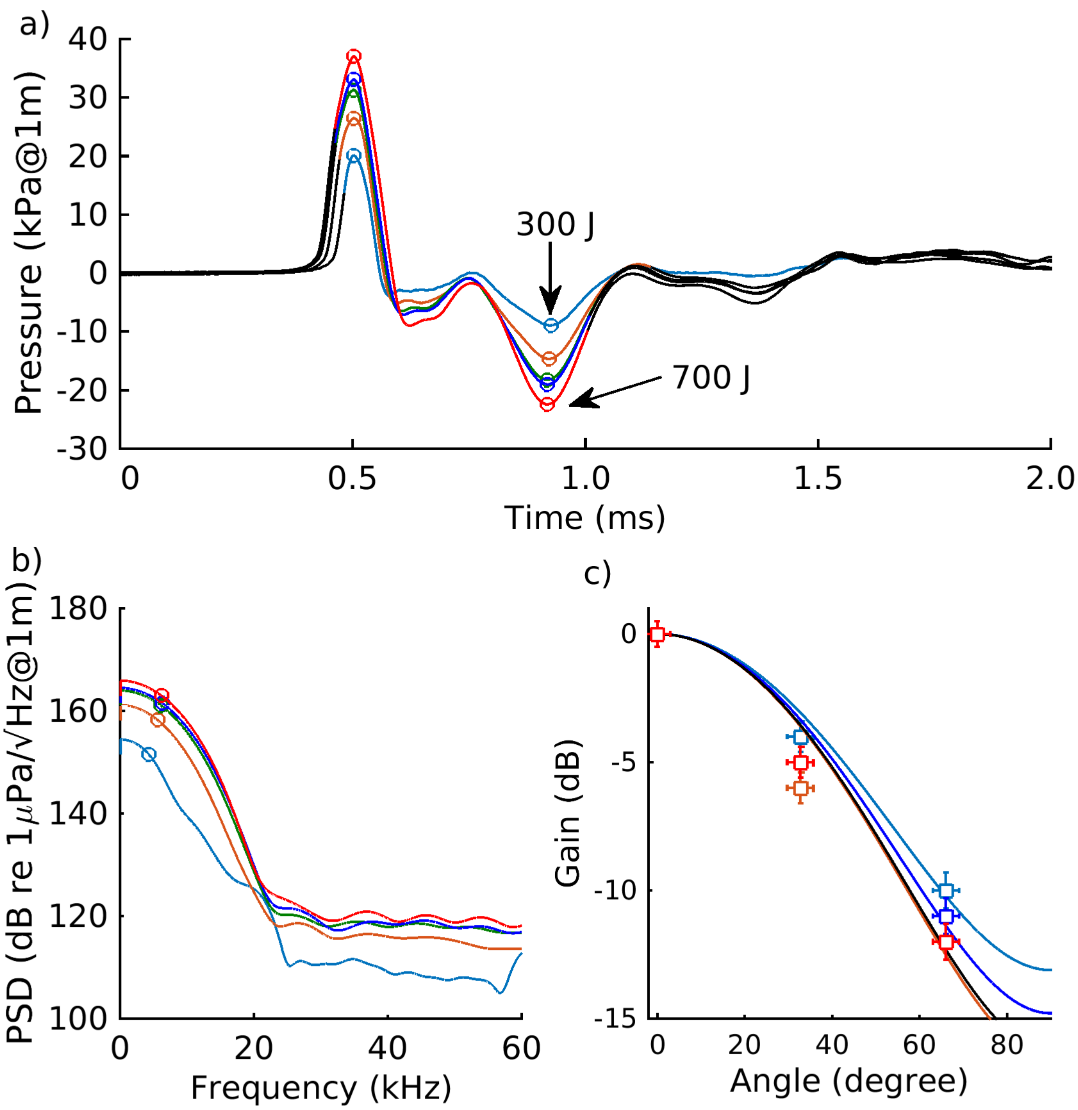


Figure 20. Applied Acoustics S-Boom Triple Plate, 300 to 700 J

Figure 21 illustrates the acoustic output of the AA S-Boom system when supplied with 300 J but with differing number of plates driven. As figure 21a shows, the transmitted waveforms were generally consistent but with modestly increased peak amplitude for an increasing number of driven plates. The specific plate combinations provided in the figure were the center plate, the forward and aft plates, and all three plates. Other combinations provided similar results where the most significant difference was that as the number of driven plates increased, the 3-dB beamwidth of the radiated signal decreased as would be expected for increasing aperture length.

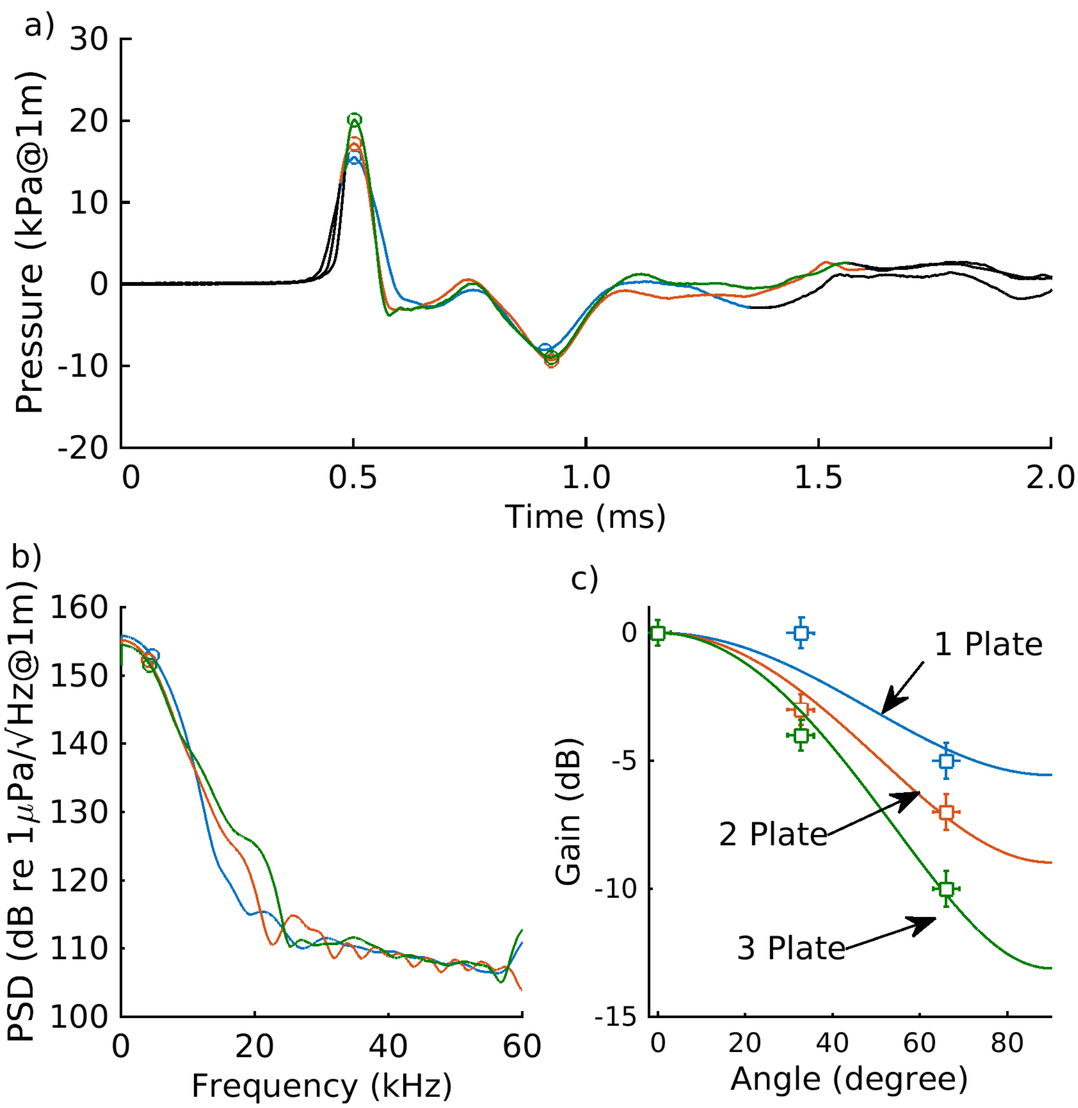


Figure 21. Applied Acoustics S-Boom at 300 J

A summary of the acoustic characteristics for the AA S-Boom system when supplied with a CSP-D700 Seismic Energy Source is provided as table 6. As noted in the table, the source level was primarily determined by the energy supplied to the AA S-Boom plates. For example, the source level observed when 300 J was supplied to a single plate was 194±1 dB re 1μPa@1m (rms). The source level increased by only 1 dB when more than one plate was driven. The maximum source level observed was 205 dB re 1μPa@1m (rms) for an input energy of 700 J. Greater transmit energies were not measured due to the 700-J capacity of the available seismic energy source.

Table 6. Applied Acoustics S-Boom Acoustic Characteristics

Source Setting (Joules)	Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)	Beam Pattern	
	Pk-Pk	Pk	RMS	SEL			ka	MRA Width 3 dB (deg)
100 (1)	202	199	189	157	0.6	7.5	1.2	N/A
100 (2)	202	199	187	157	1.1	4.4	2.1	98
100 (3)	199	196	185	155	1.2	3.3	2.6	78
100 (1,2)	203	200	190	158	0.6	9.1	3.0	66
100 (1,3)	203	200	188	157	0.8	5.4	3.1	64
200 (1)	203	201	191	159	0.7	5.7	0.6	N/A
200 (2)	204	201	190	160	1.0	4.4	2.1	98
200 (3)	202	199	187	158	1.2	3.5	2.5	82
200 (1,2)	205	202	192	160	0.7	6.4	2.9	67
200 (1,3)	205	202	189	160	1.3	4.1	2.8	70
300 (1)	207	203	195	164	0.8	4.5	0.0	N/A
300 (2)	208	204	195	164	0.9	4.6	2.1	98
300 (3)	206	202	193	163	0.9	4.0	2.1	98
300 (1,2)	209	205	196	165	0.8	4.8	2.5	80
300 (1,3)	209	205	194	165	1.1	4.1	2.7	75
300 (1,2,3)	209	206	194	165	1.1	4.3	3.1	62
400 (1,2)	212	208	200	168	0.6	6.1	2.7	75
400 (2,3)	212	208	199	168	0.8	5.0	2.9	68
400 (1,3)	212	208	197	168	1.2	4.0	2.6	78
400 (1,2,3)	212	208	200	168	0.7	5.6	3.2	60
500 (1,2)	213	209	202	170	0.7	5.5	2.6	76
500 (2,3)	214	209	201	170	0.8	4.8	2.8	71
500 (1,3)	213	209	199	170	1.2	3.8	2.5	80
500 (1,2,3)	214	210	202	170	0.6	6.1	3.2	61
600 (1,2)	214	209	202	170	0.6	5.7	2.5	81
600 (2,3)	214	210	201	171	0.9	4.6	2.8	71
600 (1,3)	214	209	200	170	1.2	3.6	2.5	80
600 (1,2,3)	214	210	203	171	0.6	6.3	3.2	60
700 (1,2,3)	216	211	205	172	0.6	6.2	3.2	61
NOTE: (1) Forward Plate, (2) Middle Plate, (3) Aft Plate								

Acoustic measurements were also performed at WHOI on 19 August 2015. Data were collected in the dock well at the WHOI Marine Operations Center in a water depth of approximately 15 m (figure 22). The well included side walls that extended to a depth of about

5 m. Four F42D hydrophones were used to collect data at a depth of 10 m. The objective was to observe the acoustic characteristics of the AA S-Boom system when driven at the maximum input energy of 1,000 J. An Applied Acoustics CSP-N Seismic Energy Source (S/N 2140620) was used to drive the AA S-Boom.

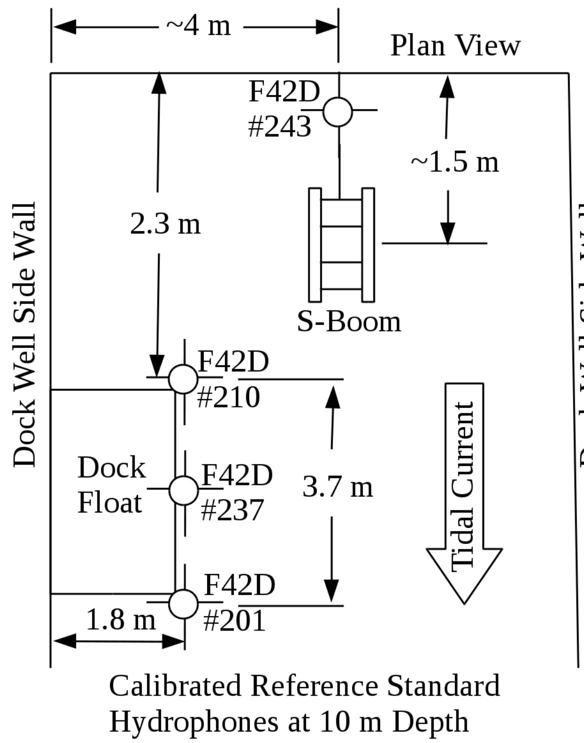


Figure 22. Applied Acoustics S-Boom Measurement Geometry WHOI

Figure 23 illustrates the acoustic waveforms generated by the AA S-Boom for transmit energies of 500, 750 and 1,000 J. The figure presents the acoustic performance observed when operating all three plates. The figure shows the waveforms, power spectra, and directivity patterns were all consistent where the only significant difference among them was the increase in amplitude commensurate with the increased energy output by the CSP-N Seismic Energy Source.

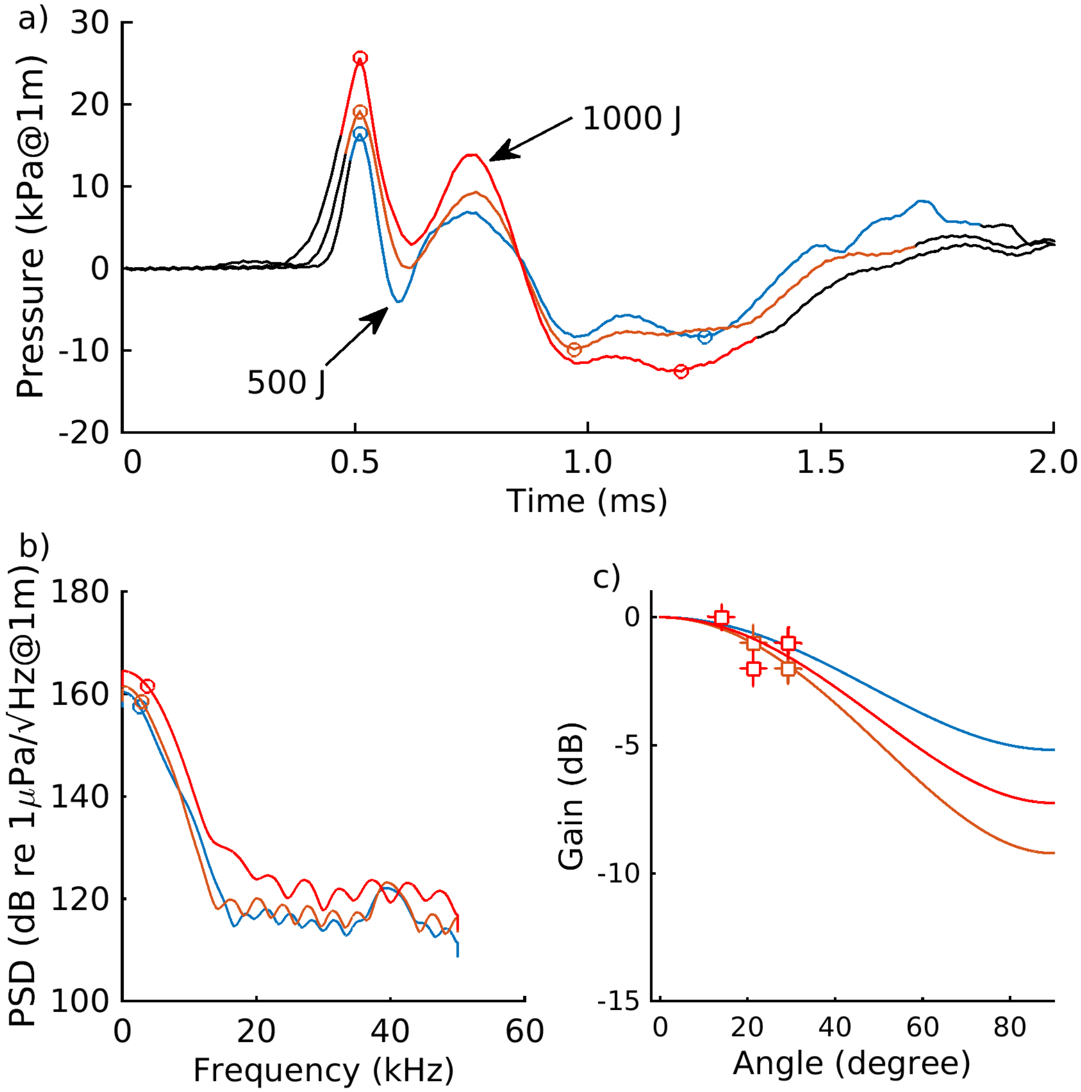


Figure 23. Applied Acoustics S-Boom with CSP-N Energy Source

Measurements at 1,000 J were repeated with the AA S-Boom system moved closer to the side wall to assess the effect that side wall reflections may have had on the received signals. Figure 24 shows acoustic waveforms observed with the AA S-Boom located in the approximate center of the channel and with the system moved adjacent to the side wall. As shown in the figure, the waveforms were not significantly affected by the proximity of the source to the side wall. Thus, reflections from the channel side walls are unlikely to have influenced the measurement results.

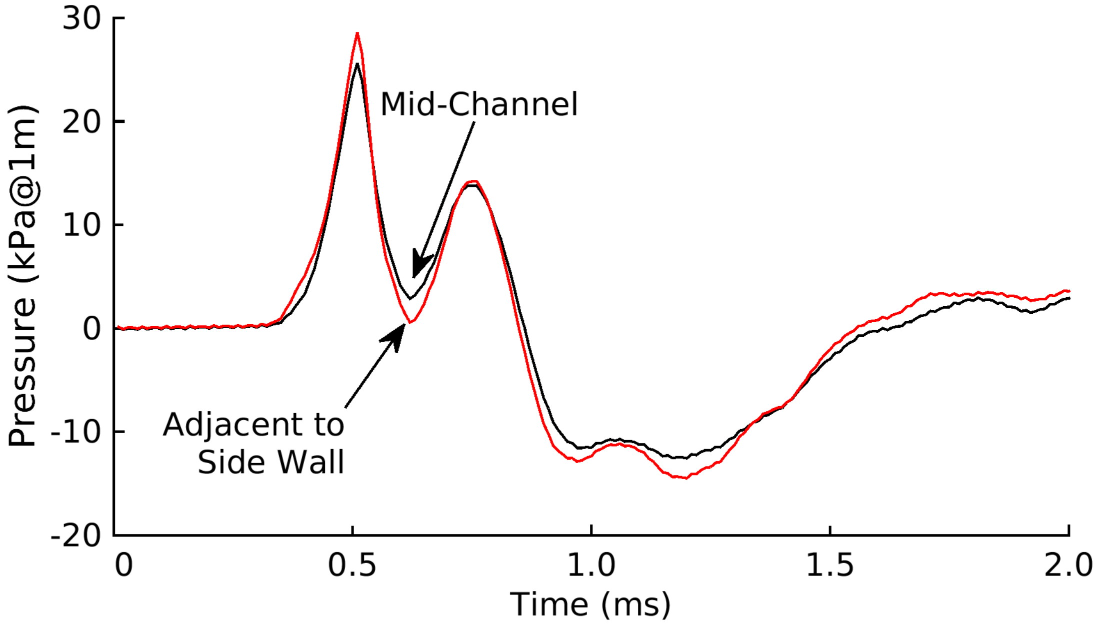


Figure 24. Applied Acoustics S-Boom with CSP-N at 1,000 J

Measurement results for the AA S-Boom and CSP-N energy source are provided in table 7. Comparison of these results and those acquired using CSP-D700 energy source in Leesburg show the AA S-Boom produced significantly lower source levels when driven with the CSP-N. For example, the observed source levels were 196 and 202 dB re 1µPa@1m when driven by the CSP-N and CSP-D700, respectively. The acoustic waveforms for these two cases are provided in figure 25 where both the peak amplitude and waveform shape following the peak arrival were significantly different for the two energy sources.

Table 7. Applied Acoustics S-Boom with CSP-N Energy Source

Source Setting (Joules)	**Source Level (dB re 1µPa@1m)**				**Pulse Width (ms)**	**Bandwidth 3 dB (kHz)**	**Beam Pattern**	
	Pk-Pk	**Pk**	**RMS**	**SEL**			**ka**	**MRA Width 3 dB (deg)**
500	209	204	196	168	1.3	2.6	2.1	100
750	209	206	198	168	1.2	2.8	2.6	75
1000	212	208	202	171	0.9	3.7	2.4	75
1000*	213	209	203	172	0.9	3.8	2.5	80
NOTE: Source moved closer to side wall								

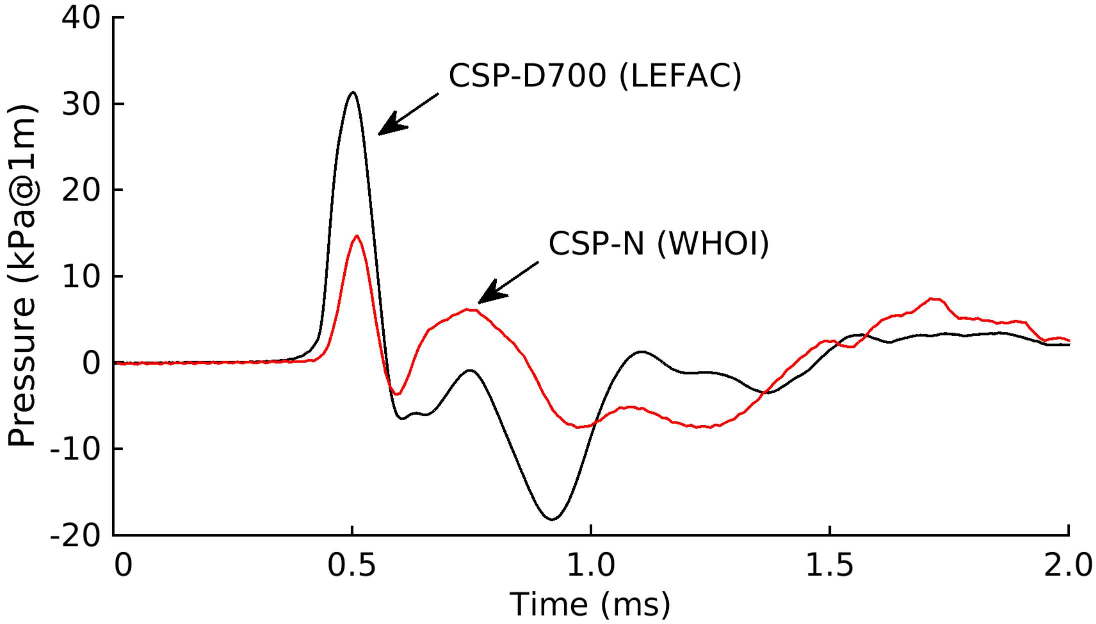


Figure 25. Applied Acoustics S-Boom at 500 J

3.1.1.4 Falmouth Scientific, Inc., HMS-620D Dual Source Bubble Gun. The FSI HMS-602D is a dual-plate, low-frequency seismic source. The tow body includes three air-filled trimaran hulls from which are suspended two independent bubble gun source plates. The hulls remain on the surface while the plates are lowered on chains to a normal operating depth of 86 cm. Each plate is an independent electromagnetic source with a contained air volume that precludes the need for an air compressor.

The system is designed to produce a repeatable impulse from a floating position on the sea surface by driving a single plate or two plates simultaneously for increased source level and bottom penetration. The manufacture's product information lists the source levels as 200 and 204 dB re 1µPa@1m when operating in single- and dual-plate modes, respectively. The nominal bandwidth of the transmitted signal is 1.7 kHz.

Acoustic signals transmitted by the system were measured in two configurations as shown in figure 26. The first round of measurements used plastic cable wraps to bind the plates to the tow body frame such that the plate operating depth was reduced to about 15 cm. The acoustic characteristics were measured in this configuration to assess a potential operating mode for use in very shallow water. The second round of measurements was performed with the sources at their normal operating depth of 86 cm.

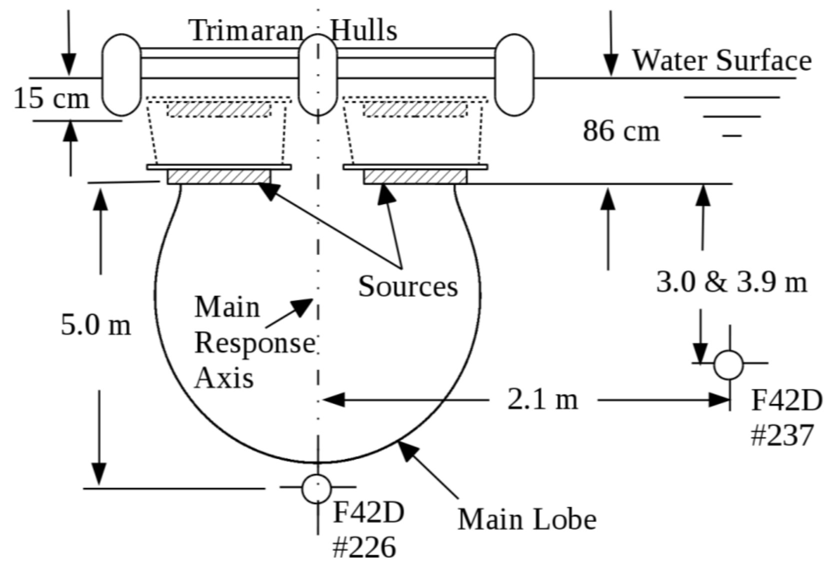


Figure 26. FSI HMS-620D Bubble Gun Measurement Geometry

Acoustic measurements performed at an operating depth of 15 cm include both single-plate and dual-plate operations. Signals radiated by each plate were measured separately before operating both plates in tandem. The FSI bubble gun transceiver and the acoustic data collection system shared a common trigger, thus acquisition gate timing was precisely controlled for all data collected.

Figure 27 illustrates the signals transmitted when operating each plate independently. As shown in figure 27a, neither the signal amplitude nor the timing were consistent for the two plates where the peak amplitude of channel 1 was about 3 dB greater and occurred 0.6 ms later than was observed when transmitting on transceiver channel 2. Note the time scale in the figure is provided relative to the waveform trigger in both cases.

Figures 27b and 27c provide the power spectrum of data included in calculations based on effective (rms) pressure and the effective pressure observed at an angle of 35° relative to the MRA. Least-squares regression of the acoustic data to an ideal model for a baffled piston source was not computed because the idealized source is not a good approximation for the FSI bubble gun due to its greater operating depth.

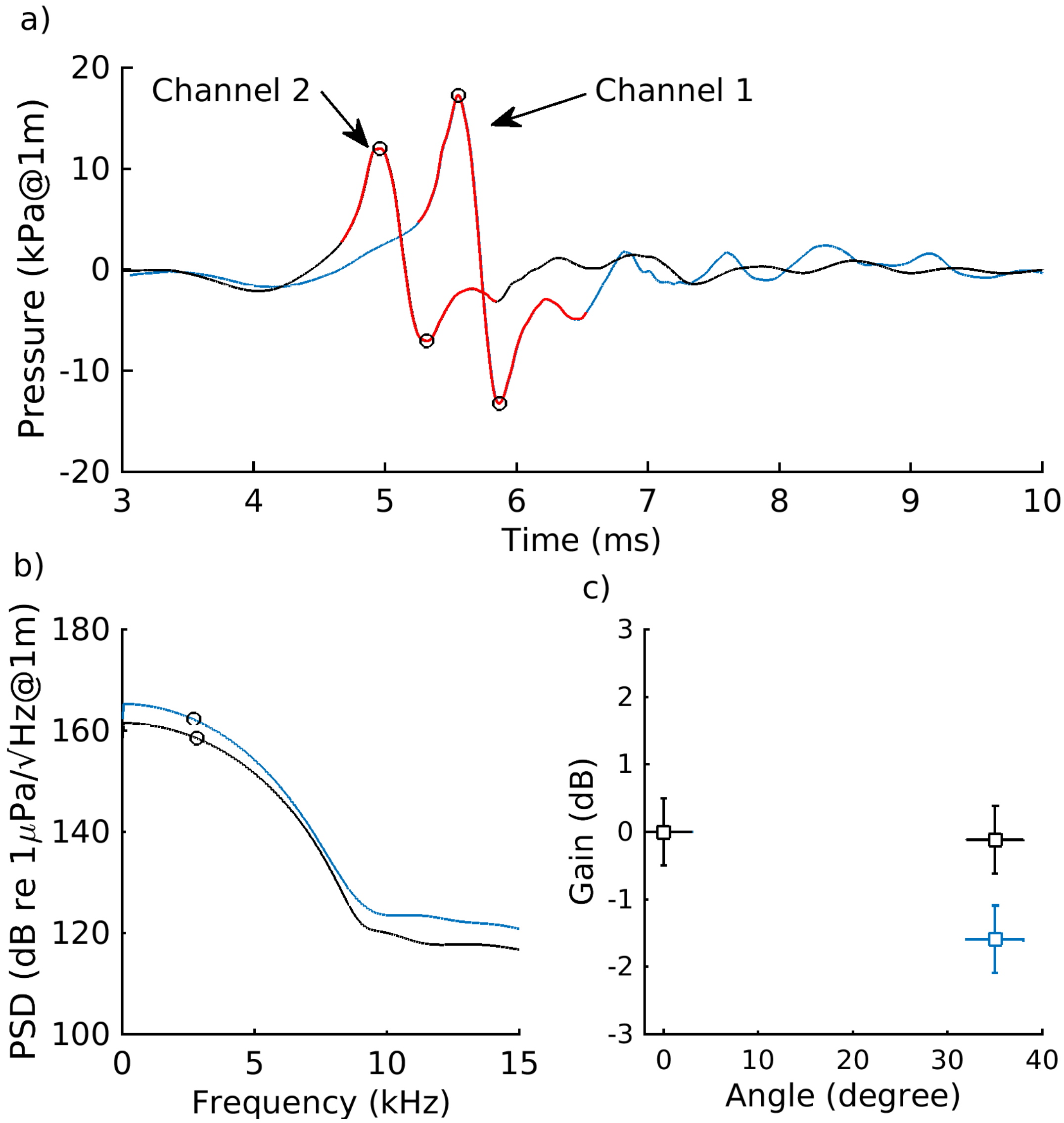


Figure 27. FSI Bubble Gun at 15 cm Depth, Single Plate

Figure 28 shows data collected with the FSI bubble gun operating in dual-plate mode where the effect of the timing and amplitude mismatch in the transceiver channels is clear. While the dual-plate operating mode was intended to simply double the amplitude of a single plate for improved bottom penetration, non-synchronous triggering of the two transmit channels resulted in a double-peaked waveform where the intended peak amplitude was significantly reduced. The figure also shows the observed waveform was virtually indistinguishable from the superposition of waveforms transmitted by each channel independently.

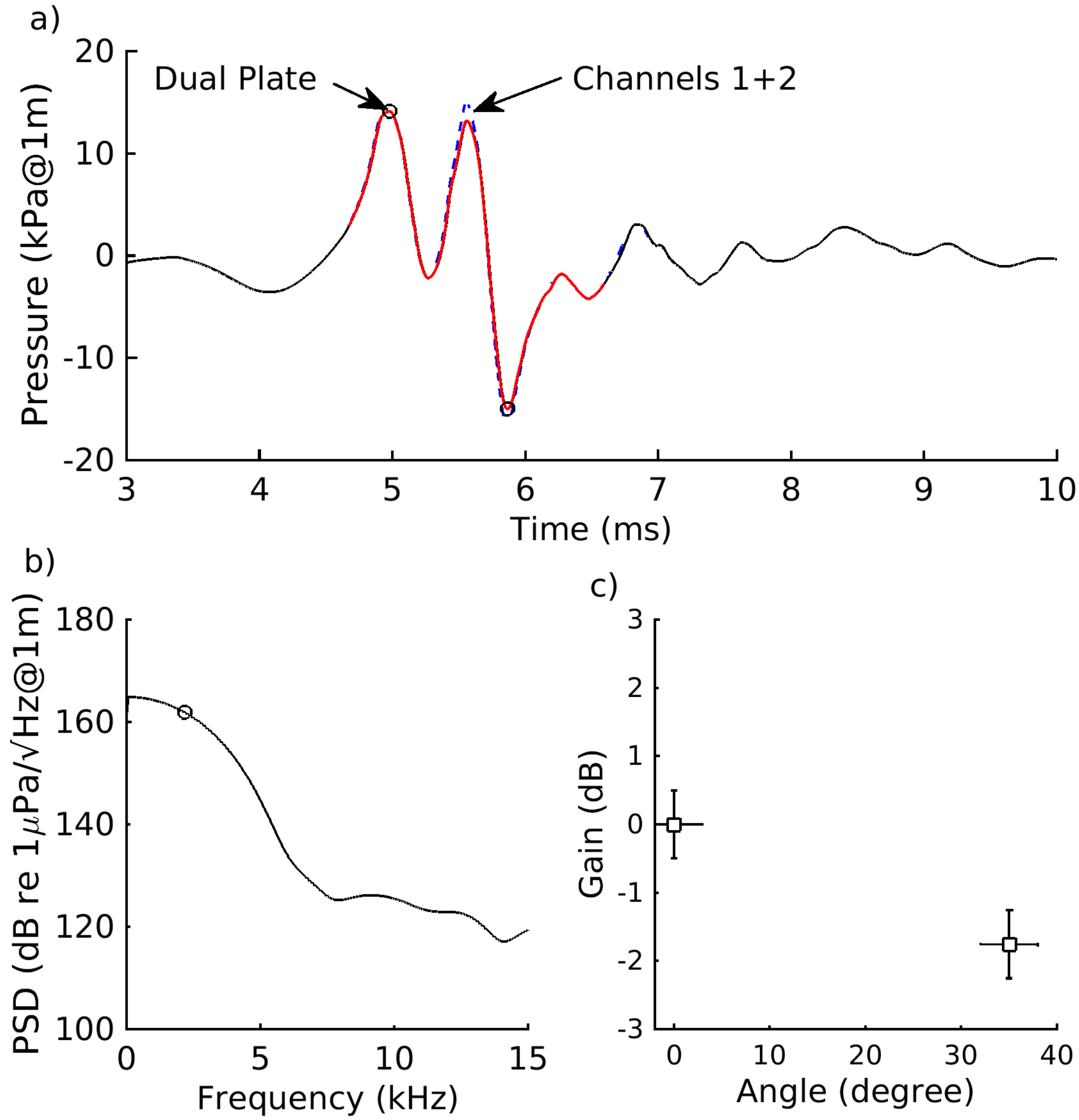


Figure 28. FSI Bubble Gun at 15 cm Depth, Dual Plate

Figure 29 shows the acoustic waveforms transmitted for both single- and dual-plate modes with the plates at the normal operating depth of 86 cm. Additional operating anomalies were noted when transceiver channel 2 was used to generate acoustic waveforms in single-plate mode. In particular, the system transitioned from signals transmitted on channel 2 to signals transmitted on both channels (i.e., dual-plate mode) in a seemingly random fashion over a short period of time. Figure 30 shows data collected for 107 individual waveforms transmitted while operating in single-plate mode on transceiver channel 2. Only 19 of the collected waveforms were consistent with a single operating plate while the remainder were consistent with signals transmitted in the dual-plate operating mode as comparison of figures 29a and 30 confirms.

Acoustic characteristics of sounds radiated by the FSI HMS-620D bubble gun are summarized in table 8. The observed levels are consistent with the manufacturer's specification of 200 and 204 dB re 1µPa@1m for single- and dual-plate modes, respectively. The specified bandwidth of 1.7 kHz is also consistent with the observed bandwidth of about 1.6 kHz when operating at the intended depth of 86 cm.

Note the source levels observed when transmitting with transceiver channel 2 (single- and dual-plate) are unlikely to be representative of sounds radiated by a fully functional system due to anomalies noted with transceiver channel 2. However, given the good waveform to waveform repeatability of the individual transmissions (see figure 30), a reasonable estimate of source levels associated with dual plate operations can be had by adding 6 dB to levels provided in table 8 for single plate operations on transceiver channel 1 where it is assumed the peak amplitudes for both plates would be well-matched in a fully functional system.

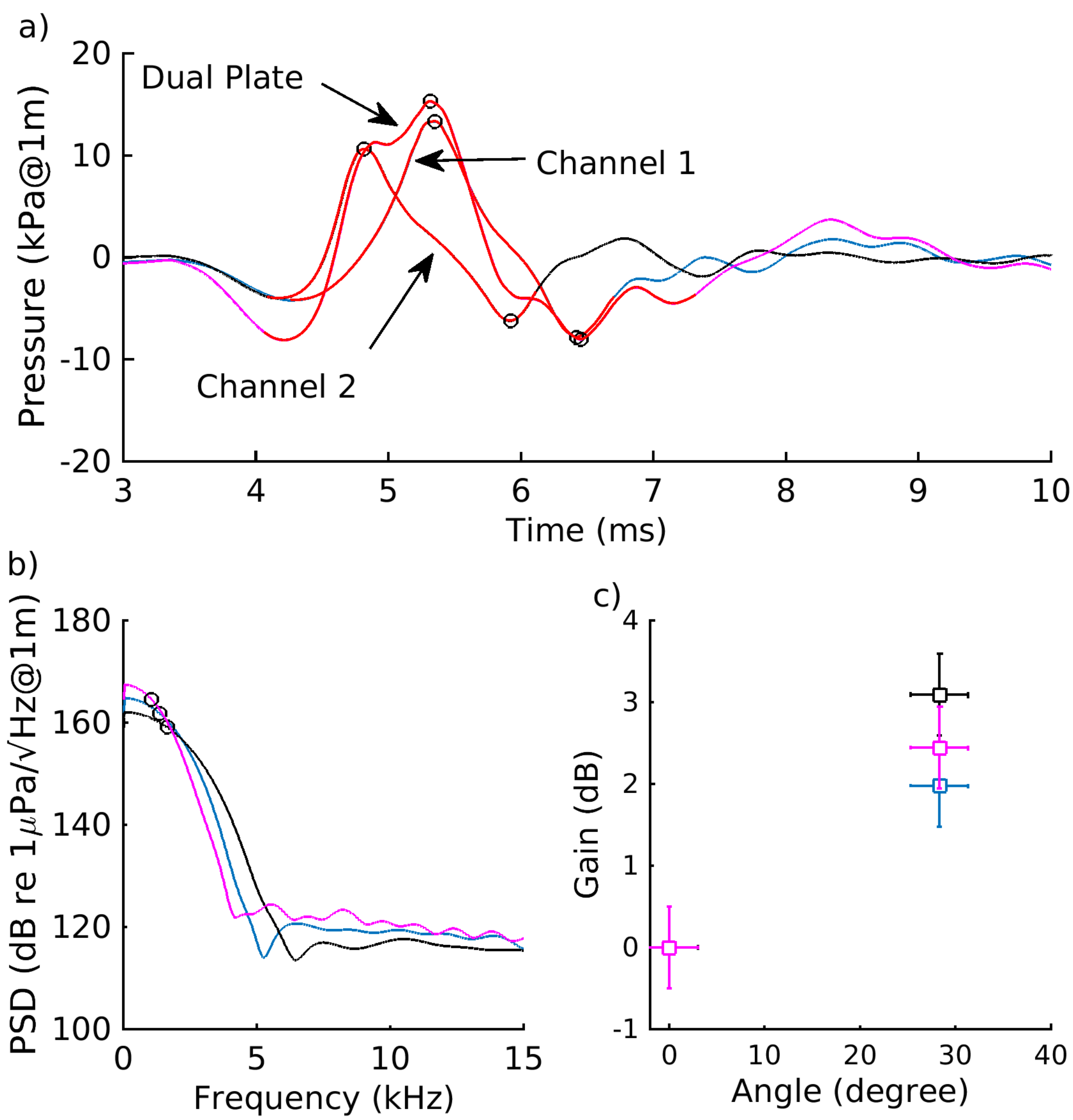


Figure 29. FSI Bubble Gun at 86-cm Depth

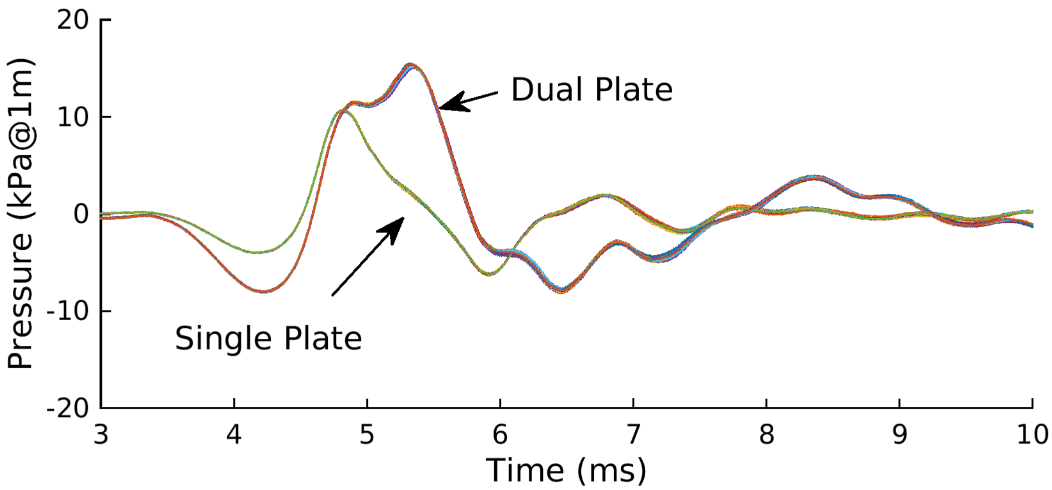


Figure 30. FSI Bubble Gun Transceiver Channel 2 Transitions, Single to Dual Plate

Table 8. FSI HMS-620D Bubble Gun Acoustic Characteristics

Source Settings		Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Channel	**Depth**	**Pk-Pk**	**Pk**	**RMS**	**SEL**		
1	15 cm	210	205	199	170	1.3	2.7
2	15 cm	206	202	196	167	1.1	2.8
Dual*	15 cm	209	203	199	171	2.1	2.2
1	86 cm	207	203	196	170	2.4	1.6
2	86 cm	205	201	194	167	2.0	1.6
Dual*	86 cm	207	204	198	173	3.3	1.1
* Channels 1 and 2 did not trigger simultaneously.							

3.1.2 Electrode Sparkers

Sparkers comprise a class of seismic sources commonly used for high-resolution marine surveying. They function by the electric discharge of a high-voltage impulse across one or more electrode tips and a ground point on the sparker body. Resultant heating of the surrounding seawater (i.e., electrolyte) generates a rapidly expanding steam bubble with a nearly ideal positive impulse. Continued expansion of the steam bubble beyond the equilibrium hydrostatic pressure results in collapse and the formation of a second high-pressure impulse followed by a series of bubble pulse oscillations of diminishing amplitude until all of the energy is dissipated. This oscillation increases the duration of the source signature well beyond the initial impulse with the potential to contribute a non-negligible quantity of energy to the radiated sound.[1] Thus, the acoustic field radiated by the decaying bubble pulse in the sparker waveform may also contribute to the environmental impact associated with the operation of these geophysical survey systems.

Since the physical principal of sparker operation requires an electrolyte to function, testing could not be performed in the freshwater facilities maintained by USRD. Thus, acoustic measurements were performed at WHOI where a saltwater test environment was available. The measurements were performed on 19 August 2015. Data were collected in the dock well at the WHOI Marine Operations Center in a water depth of approximately 15 m (see figure 31). The well included side walls that extended to a depth of about 5 m. Measurements were performed with the sparkers located near the centerline of the well about 4 m from the side wall. Four F42D hydrophones were used to collect data at a depth of 10 m. Due to the tidal current flowing through the test well (see figure 31), uncertainty in the measurement geometry was increased relative to measurements performed at the USRD acoustic test facilities. Thus, while data were collected at multiple locations in the dock well, results are reported only for data collected nearest the MRA of the acoustic sources (i.e, sparkers).

An additional consideration for measurements performed in the WHOI dock well was the potential for side-wall reflections to influence the observed acoustic waveforms. To evaluate this potential source of measurement error, acoustic waveform data were collected with a sparker located on the surface at two locations. The first set of measurements was performed with the Applied Acoustics Dura-Spark located near the dock well centerline. A second set of measurements was performed with the sparker located adjacent to the side wall. Results of these two observations are provided as figure 32 where there was little change in the observed waveform timing as would have been expected if there was a significant contribution from side-wall reflections. The reduced amplitude for sounds radiated near the side wall may have been the result of the greater angular displacement between the MRA of the Dura-Spark source and the calibrated reference hydrophone.

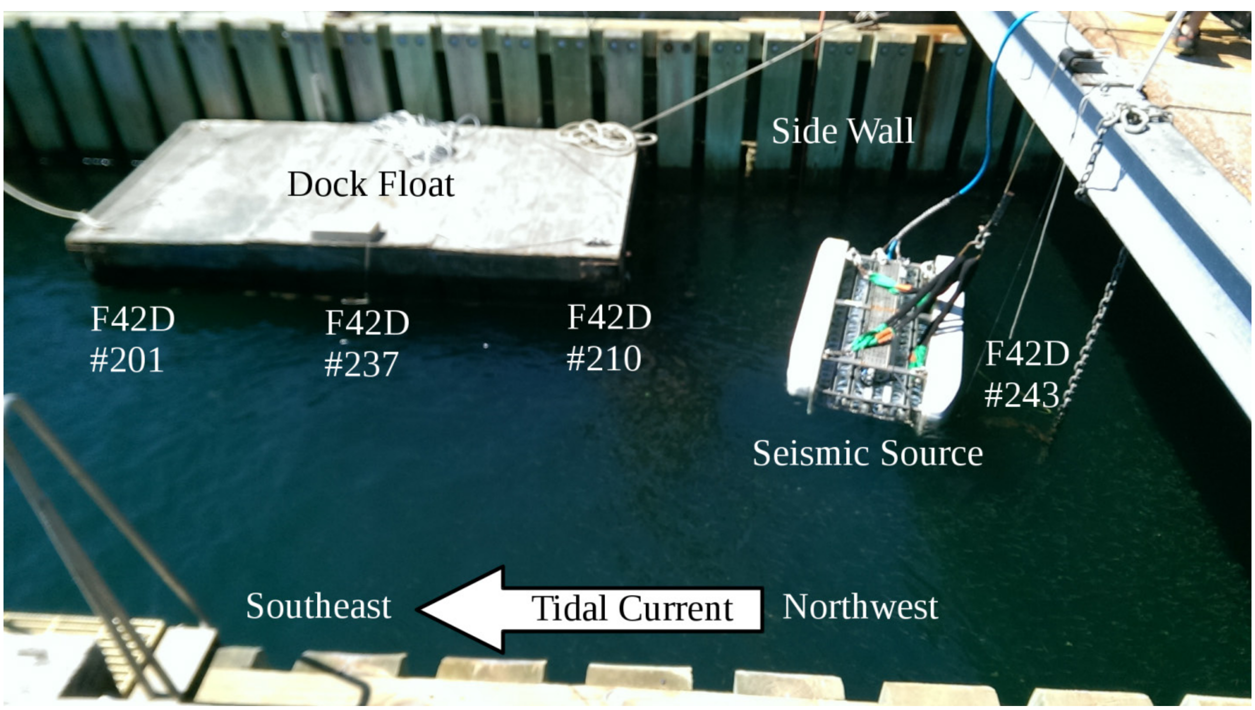


Figure 31. Dock Well at Woods Hole Oceanographic Institution

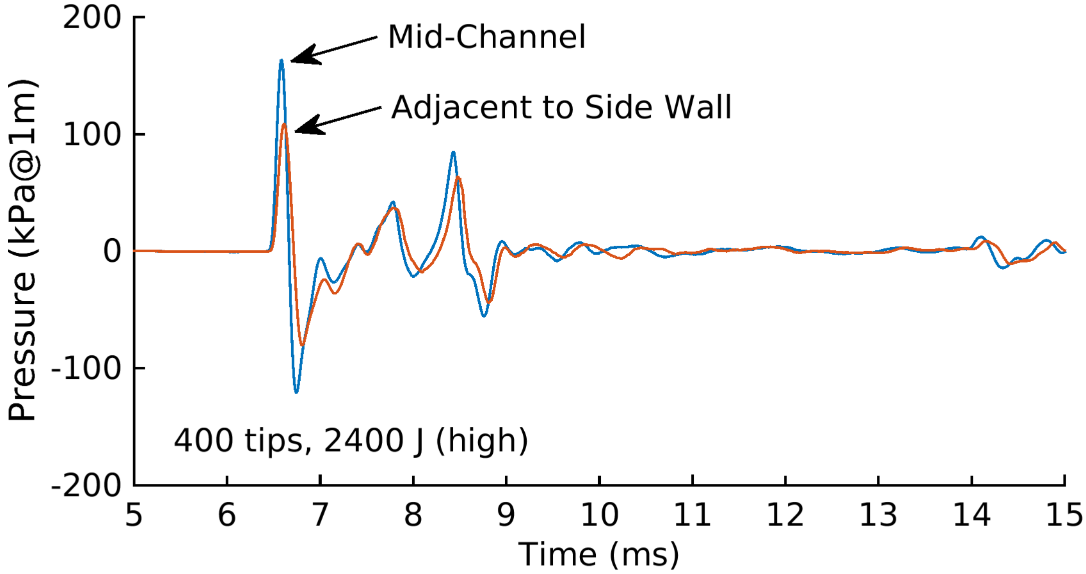


Figure 32. Dura Spark Near Side Wall

3.1.2.1 SIG ELC 820 Sparker. The SIG ELC 820 Sparker is a small, lightweight seismic source measuring 1.0 by 0.6 m with a mass of 1.8 kg (see figure 33a). The source is designed for towing behind small survey vessels at a shallow depth beneath the surface. The system is designed to produce a repeatable impulse from a submerged position near the sea surface by discharging a high-voltage impulse. The manufacturer's product information lists the operating energy level as 750 to 1,000 J with a source level of 219 dB re 1µPa@1m. The nominal pulse width and bandwidth of the transmitted signal is 0.8 ms and 900 to 1,400 Hz. Source data provided in the product information indicate the source level realized by the ELC 820 ranges from 207 to 219 dB re 1µPa@1m for input energies ranging from about 200 to 1,800 J.

Acoustic signals transmitted by the system were measured as shown in figure 33b using an Applied Acoustics CSP-N seismic energy source. Due to the relatively high uncertainty in the measurement geometry, data collected by the reference hydrophone located approximately beneath the source (i.e., F42D, S/N 243) were used to characterize the acoustic waveforms generated by the ELC 820 sparker.

a)

b)

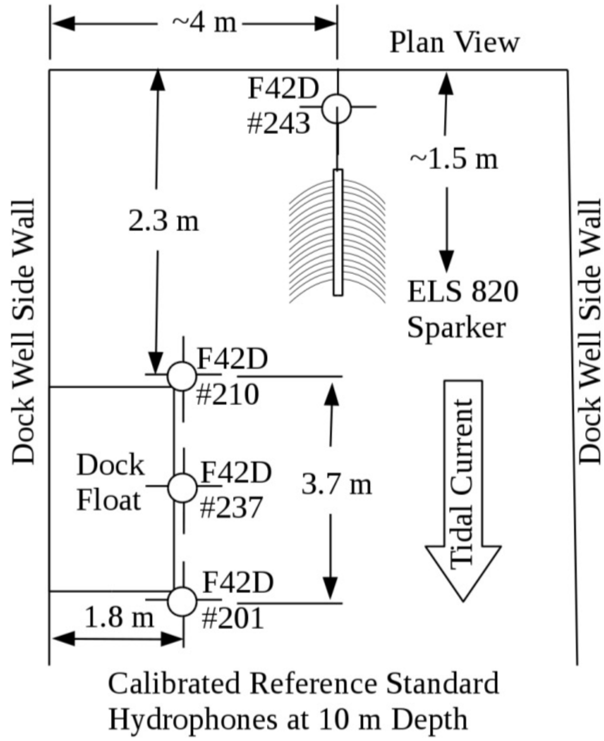


Figure 33. SIG ELC 820 Sparker Measurement Geometry

Data were collected at several energy settings ranging from 300 to 750 J for both the low and high settings of the CSP-N seismic energy source. Example waveforms collected with the sparker located about 1 m beneath the surface are shown in figure 34. Approximately 30 waveforms were collected with the energy source set to low (figure 34a) and with the energy source set to high (figure 34b). In both cases the transmit energy was 500 J. While the waveforms were fairly repeatable for the low setting, significant variations were observed for the high setting. In particular, the initiation time for the waveform and the peak acoustic pressure observed at 5 to 6 ms following actuation by the energy source was more variable where the (local) peak pressure varied by nearly 6 dB over the span of 30 waveforms.

Data were also collected with the sparker located about 5 m beneath the surface while transmitting the same set of signals as were transmitted at 1-m depth. Example waveforms are provided in figure 35. Approximately 30 waveforms were collected with the energy source set to low (figure 35a) and high (figure 35b). Waveforms transmitted at 5 m were significantly different than were observed at 1 m. Most notably, waveform duration was significantly reduced at the 5 m operating depth where the secondary oscillations did not extend more than about 2 ms beyond the initial peak acoustic pressure. At both operating depths, there was a secondary peak pressure associated with the collapse and secondary expansion of the steam bubble beginning about 1 ms after the initial peak pressure. While bubble oscillations were observed at both operating depths, they were more prolonged for the 1-m operating depth (see figure 34).

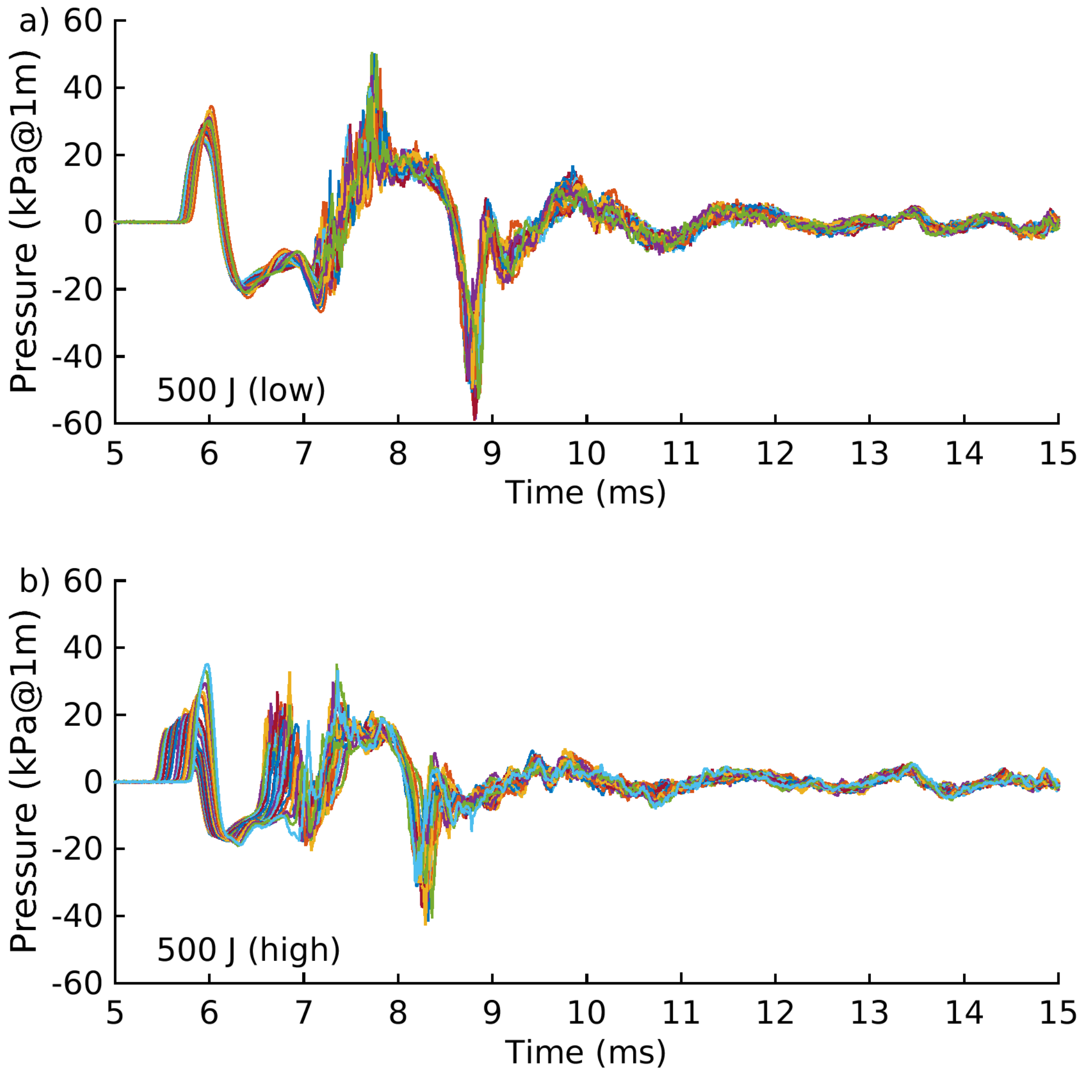


Figure 34. ELC820 Waveforms at 500 J and 1-m Operating Depth

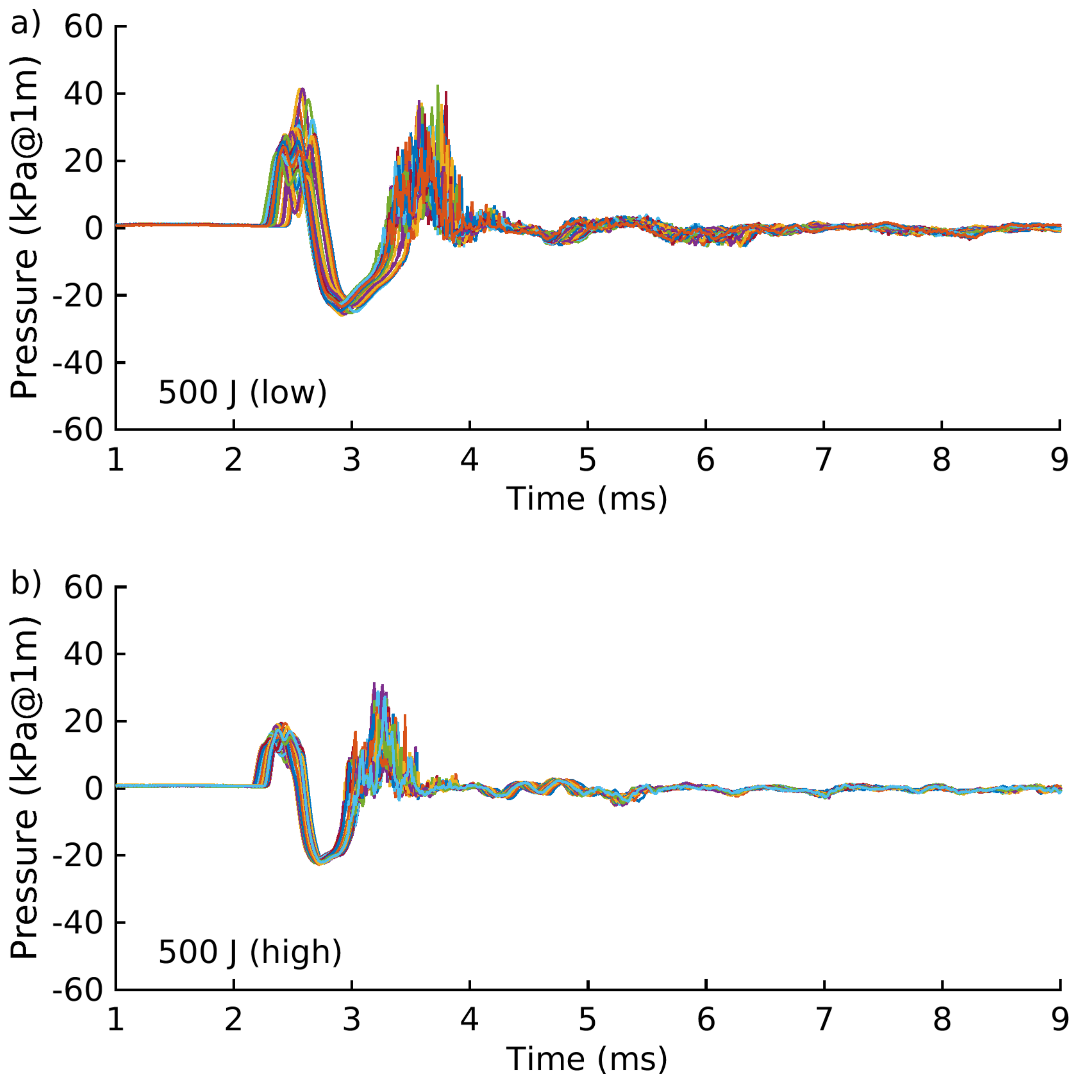


Figure 35. ECL820 Waveforms at 500 J and 5-m Operating Depth

Acoustic characteristics of sounds radiated by the ELC 820 Sparker are summarized in table 9. The observed levels are largely consistent with the manufacturer's specification where source levels ranging from 207 to 219 dB re 1µPa@1m were specified for transmit energies ranging from 200 to 1,800 J. This compares reasonably well with the observed peak acoustic pressures where levels ranged from 204 to 214 dB re 1µPa@1m (peak). Also note the signal pulse widths and bandwidths observed for an operating depth of 5 m were more consistent with manufacturer's specifications than signals generated at an operating depth of only 1 m.

Table 9. ELC820 Sparker Acoustic Characteristics

Source Settings		Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Energy (Joules)	Depth* (m)	Pk-Pk	Pk	RMS	SEL		
300 (low)	1	212	207	198	174	4.1	1.7
300 (low)	5	212	207	196	171	4.1	3.7
300 (high)	1	209	204	195	171	3.5	2.4
300 (high)	5	210	205	200	168	0.7	4.6
400 (low)	1	215	212	201	177	3.9	1.4
400 (low)	5	213	208	195	174	7.2	1.6
500 (low)	1	219	214	204	180	3.8	1.2
500 (low)	5	215	210	200	176	4.7	1.9
500 (high)	1	215	210	201	177	3.8	1.3
500 (high)	5	213	208	200	173	2.2	3.1
600 (low)	1	220	215	205	181	3.7	1.1
600 (low)	5	216	212	201	177	5.0	1.6
700 (low)	1	220	215	206	182	3.6	1.1
700 (low)	5	217	214	201	179	6.4	1.0
750 (high)	1	220	214	206	182	3.9	1.2
750 (high)	5	217	213	203	178	3.4	1.9
* Source depths are approximate							

3.1.2.2 Applied Acoustics Dura-Spark. The Applied Acoustics Dura-Spark employs up to 400 electrode tips to generate stable, repeatable waveforms for geophysical surveys. The manufacturer's product information lists the maximum electrical input as 2,400 J. The system can be operated with 80, 240, or 400 electrodes to allow tuning of the acoustic waveform for specific applications, with no more than 5 J per electrode recommended to minimize the bubble collapse component. The manufacturer lists the (typical) source level as 226 dB re 1µPa@1m with a pulse width of 0.5 to 1.5 ms. The electrode arrays are housed within a stainless steel framework and mounted to a catamaran for surface tow (see figure 36a).

Figure 36b illustrates the measurement geometry where acoustic data used to characterize this source were collected approximately beneath the source (i.e., F42D S/N 243) at a depth of 10 m.

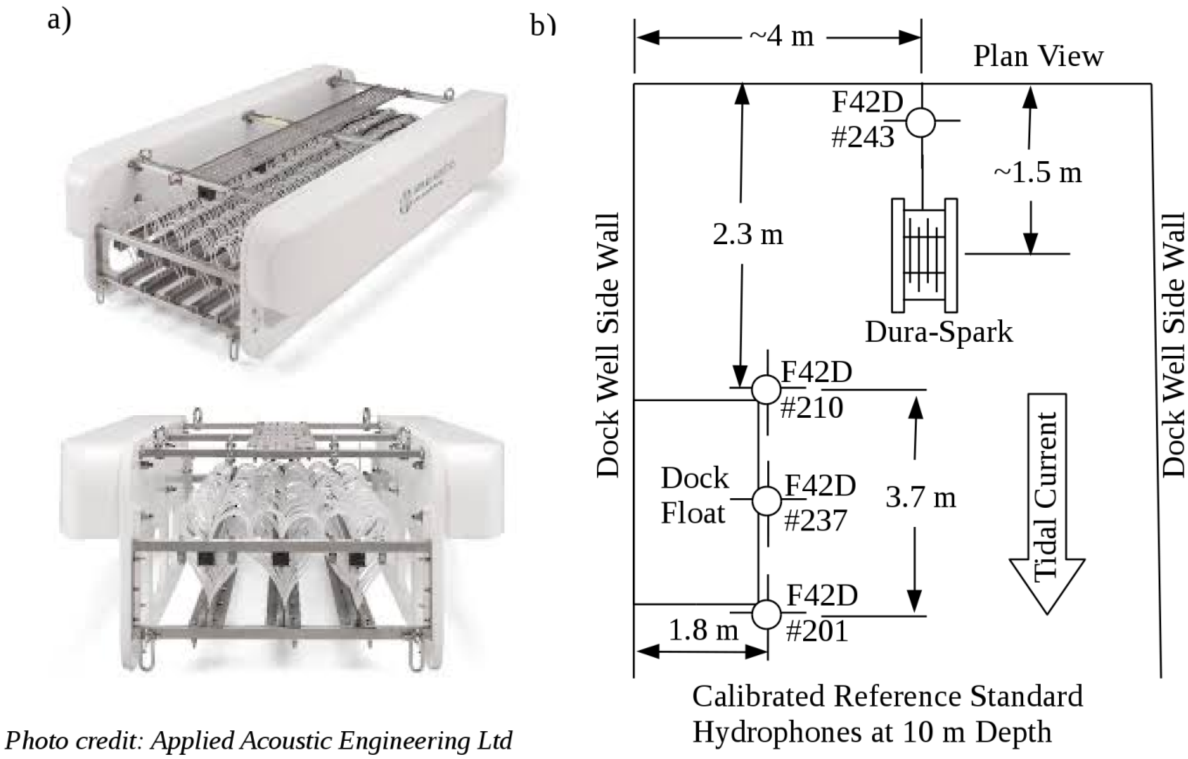


Figure 36. Applied Acoustics Dura-Spark Measurement Geometry

Sounds radiated by the Dura-Spark were measured for input energies ranging from 100 to 2,400 J provided by an Applied Acoustics CSP-N seismic energy source. The sparker was operated with 80, 240, and 400 electrodes. Figure 37 illustrates two sets of waveforms generated with an input energy of 500 J. The figure shows the pressure amplitude realized when operating 240 electrodes at 2.1 J each was about 98 kPa@1m while the peak pressure when operating 400 electrodes with 1.2 J each was about 38 kPa@1m, which corresponds to 219 and 211 dB re 1µPa@1m, respectively. Figure 37a also shows a more complex bubble pulse sequence following the initial impulse than was observed when operating with the same input energy using fewer electrodes (figure 37b).

Figure 38 illustrates waveforms generated using total input energies of 1,000 and 2,000 J but with 4.2 and 5.0 J per electrode, respectively. The figure shows waveform characteristics were quite similar with (peak) source levels of 223 and 224 dB re 1µPa@1m for 1,000 and 2,000 J, respectively. Thus, important characteristics of the radiated sounds, including the peak acoustic pressure, appear to vary not only with the total energy supplied to the source but also with the energy provided to each electrode.

Acoustic characteristics for all observed operating modes are provided in table 10.

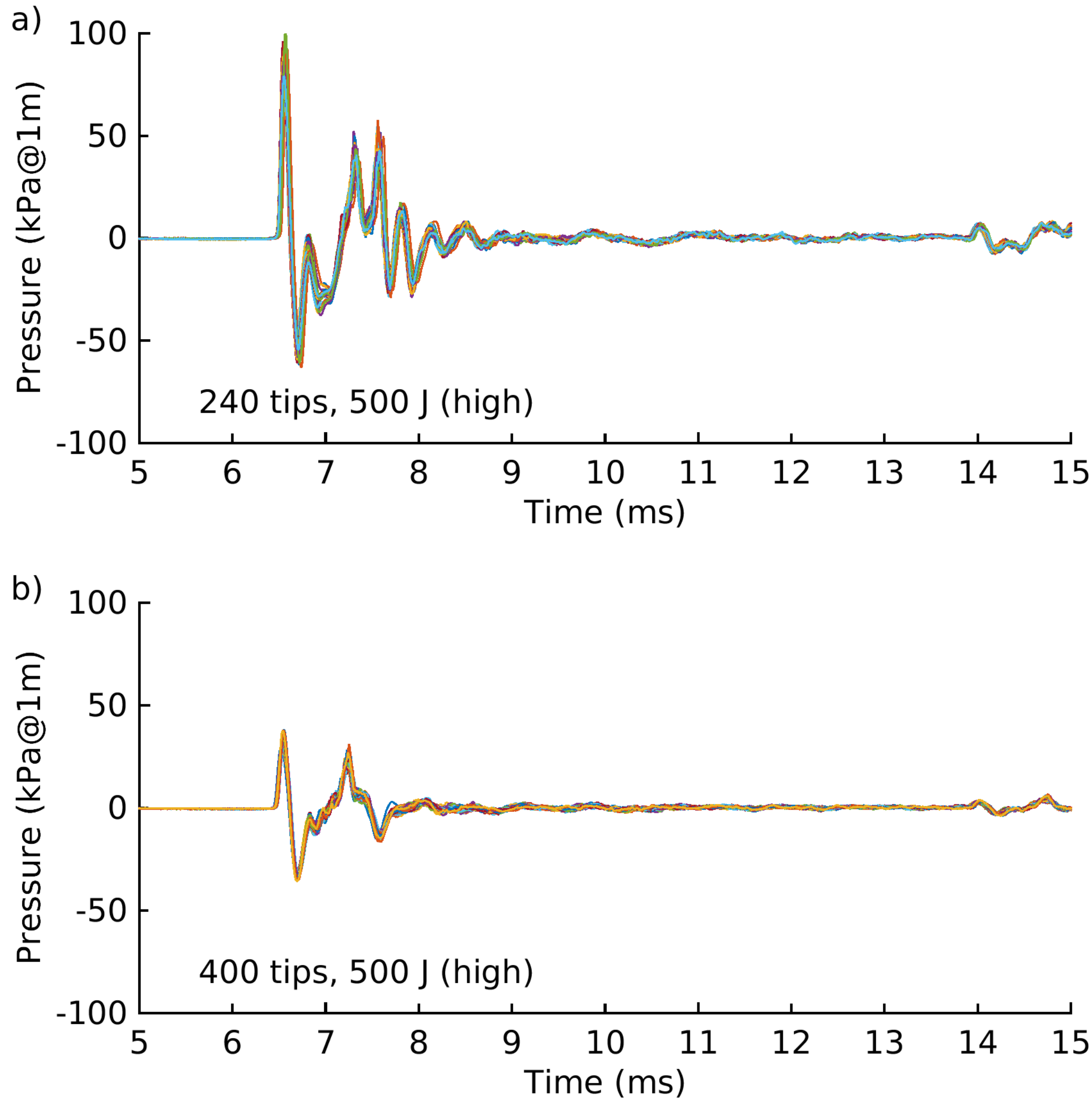


Figure 37. Applied Acoustics Dura-Spark Waveforms, 500 J

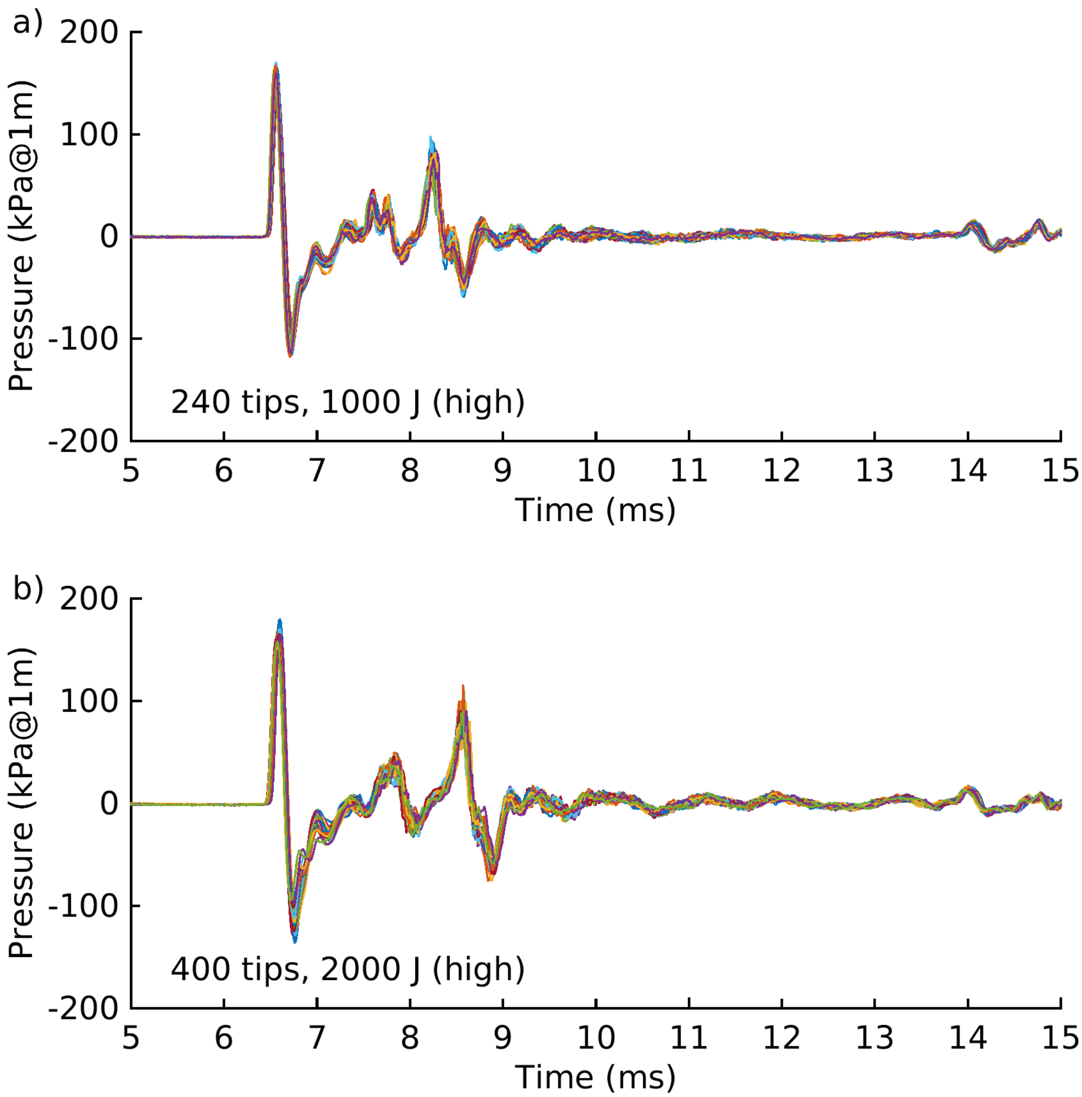


Figure 38. Applied Acoustics Dura-Spark, 1,000 J and 2,000 J

Table 10. Applied Acoustics Dura-Spark Acoustic Characteristics

Source Settings		Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Energy (Joules)	Tips	Pk-Pk	Pk	RMS	SEL		
100	80	213	207	200	173	2.2	2.6
200 (high)	80	216	212	203	177	2.2	2.8
400 (low)	80	222	218	207	182	2.8	1.9
500 (high)	240	223	219	209	181	1.4	4.4
1,000 (high)	240	228	223	213	186	2.1	3.2
1,250 (high)	240	229	225	214	187	2.3	2.8
500 (high)	400	216	211	203	174	1.1	4.6
2,000 (high)	400	229	224	214	188	2.4	2.8
2,400 (high)	400	229	225	214	188	2.2	2.9
2,400 (high)*	400	226	221	212	185	2.3	2.7
* Source moved closer to side wall							

3.1.2.3 Applied Acoustics Delta Sparker. The Applied Acoustics Delta Sparker is a high-capacity source employing six electrodes arranged as three pairs along the length of the 2.5 m long tow frame (see figure 39a). While the sparker frame is deployed from a set of floats to maintain the source at a fixed depth beneath the surface during tow (see figure 39b), the floats were not present for these acoustic measurements. The specified range of input energy for the Delta Sparker is 1,000 to 12,000 J with a typical source level of 226 dB re 1µPa@1m when supplied with 6,000 J. Typical pulse widths provided by the manufacturer are 0.3 to 5.0 ms.

Figure 39c illustrates the measurement geometry employed for the Delta Sparker. While acoustic source data were collected at a variety of locations, the data used to characterize this source were collected 10 m beneath the surface and approximately below the sparker.

Acoustic waveforms radiated by the Delta Sparker are shown in figure 40 at input energies of 500, 1,000, and 2,000 J. In each case, the initial impulse arrived at the calibrated reference hydrophone at 4 ms while the arrival time for the secondary impulse varied with input energy. In particular, the arrival time increased from about 5 ms for a 500 J input to more than 8 ms for an input energy of 2,000 J. Also note that in all cases the peak acoustic pressure was associated with the secondary impulse following bubble collapse. As a result of the bubble collapse arrival time and continued oscillation beyond that, the observed pulse widths were considerably longer than suggested by the manufacturer's product information.

Acoustic characteristics of sounds radiated by the Delta Sparker are provided as table 11. Source levels measured at an operating depth of 1 m were somewhat greater than were observed at 5 m. In particular, the effective (rms) source levels at 1-m depth were 2 to 5 dB greater than source levels measured at 5 m for the same system settings. Differences in peak source levels were less. Also note the observed pulse widths were about 5 to 10 ms due in large part to the secondary bubble oscillations as illustrated in figure 40.

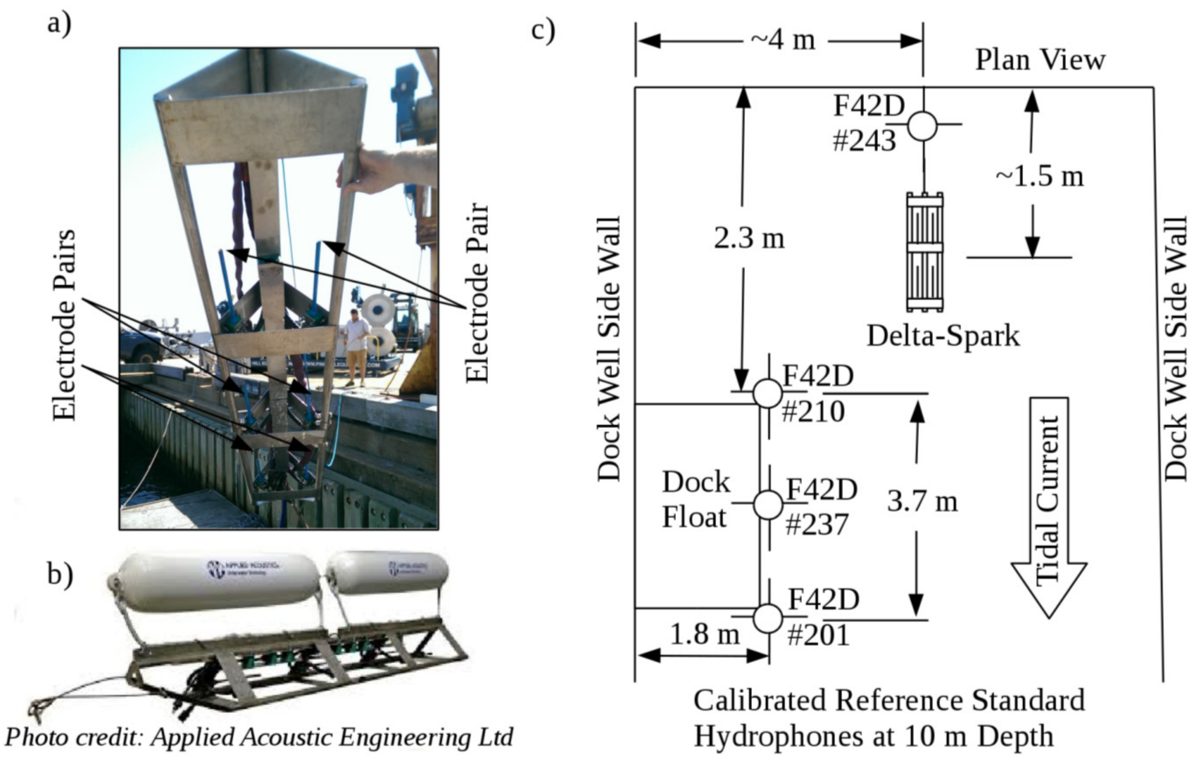


Figure 39. Applied Acoustics Delta Sparker and Measurement Geometry

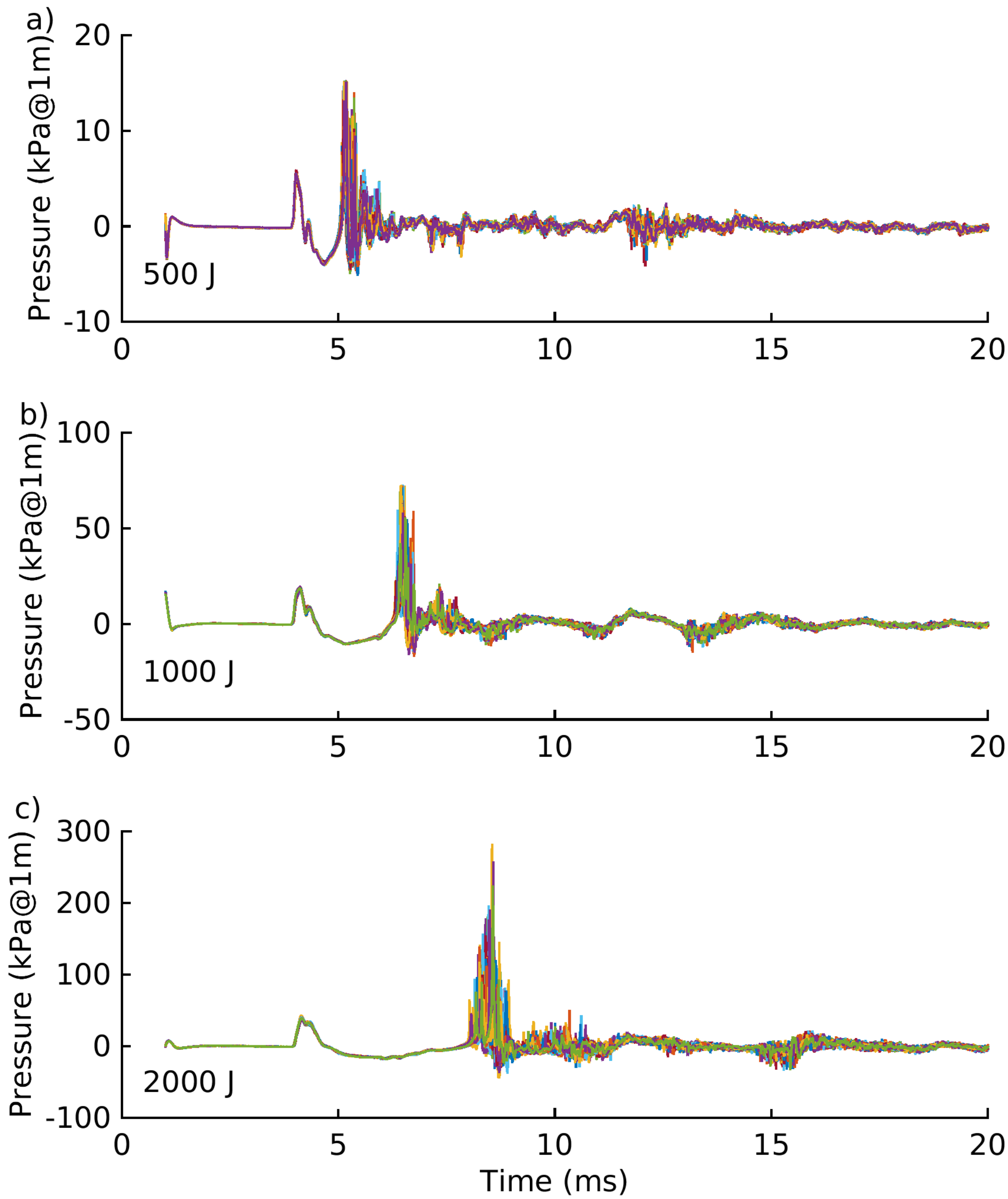


Figure 40. Applied Acoustics Delta Spark at 5-m Depth

Table 11. Applied Acoustics Delta Sparker Acoustic Characteristics

Source Settings		Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Energy (Joules)	Depth* (m)	Pk-Pk	Pk	RMS	SEL		
500	1	209	206	190	167	5.3	1.5
500	5	206	203	185	163	7.5	1.3
750	1	215	213	197	175	5.7	1.1
750	5	214	212	192	172	8.7	0.8
1,000	1	219	217	201	179	6.3	0.8
1,000	5	217	215	196	176	9.2	0.8
1,250	1	221	218	203	181	7.3	0.6
1,250	5	219	218	199	179	9.6	0.7
1,500	1	223	220	204	183	9.1	0.5
1,500	5	222	220	201	181	9.8	0.6
1,750	1	224	221	205	184	9.4	0.5
1,750	5	223	221	202	182	9.2	0.7
2,000	1	225	222	206	185	9.7	0.5
2,000	5	224	223	204	183	9.7	0.7
2,250	1	225	222	205	185	9.3	0.5
2,250	5	224	222	203	183	9.4	0.7
2,400	1	224	221	205	185	9.5	0.5
2,400	5	223	222	203	182	9.4	0.7
* Source depths are approximate							

3.1.3 Sercel Mini-Generator-Injector (Mini-GI) Airgun

Airguns function by the rapid release of compressed air into the surrounding water to create an impulsive acoustic waveform. The acoustic waveforms typically exhibit a prominent bubble pulse in the time history. The bubble pulse is a secondary source of sound generated by the oscillating expansion and collapse of air under hydrostatic pressure after it has been released and during its ascent to the surface. The energy contained in the bubble pulse can result in notches in the acoustic intensity spectrum where the frequencies affected depend on the bubble oscillation period. Sounds associated with the bubble pulse can create "multiples" in the seismic section that can complicate interpretation of the geology.[1]

The Mini-GI airgun is a small seismic source developed to reduce or suppress the bubble oscillations that are common to traditional seismic airguns. The GI airgun illustrated in figure 41a consists of a generator to create the acoustic impulse and an injector to reduce or suppress the bubble oscillations. The total airgun volume is 980 cm^3 (60 $in.^3$) divided equally between the generator and the injector. The GI airgun first generates the initial impulse and the associated air bubble. When the bubble reaches its maximum size, an additional volume of air is injected into it. Depending on the characteristics of the injection, the bubble oscillations can be reshaped and reduced, or suppressed.

Acoustic measurements were performed at USRD LEFAC using seven calibrated reference hydrophones arranged as shown in figure 41b. The acoustic field was observed at three locations including 10 m beneath the airgun at an angle of 0°, adjacent to the airgun (i.e, 90°) at a distance of 1.2 m, and at oblique angles of 30° to 37° and distances of 12 to 15 m (depending on airgun depth). Two of the observation locations were configured to not only measure the acoustic pressure but to also collect data to estimate the acoustic particle velocity as will be discussed in detail later.

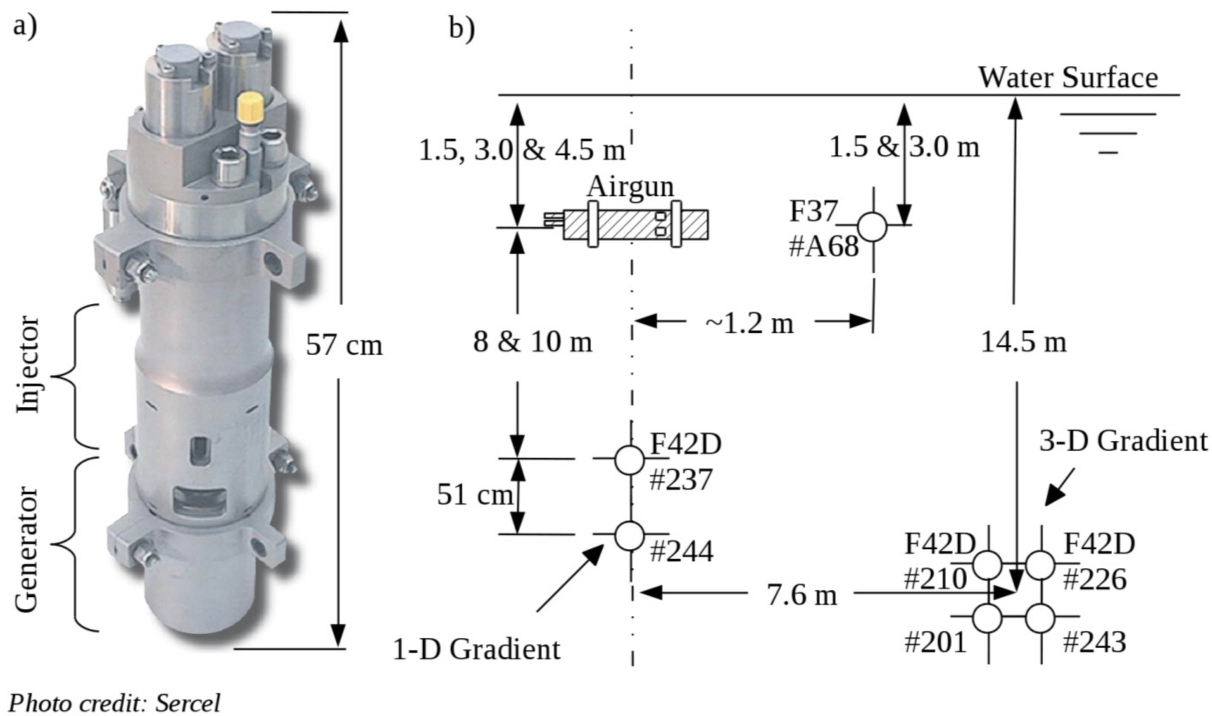


Figure 41. Sercel Mini-GI Airgun Measurement Geometry

Figure 42 illustrates waveform characteristics referred to a distance of 1 m for the Mini-GI airgun when operated at a depth of 3 m using 14 MPa (2,000 psi) compressed air. The time series observed directly beneath (figure 42a) and adjacent to (figure 42b) the airgun illustrate the difference between a traditional (generator only) airgun and the GI airgun. While the first bubble oscillation is clearly evident at about 80 ms when the airgun was operated with only the generator, the bubble oscillation was significantly reduced when the airgun was operated in the GI mode. Suppression of the bubble oscillation also resulted in significantly reduced notches in the frequency spectrum below about 200 Hz, a feature that is particularly well expressed in figure 42d for the hydrophone located adjacent to the airgun.

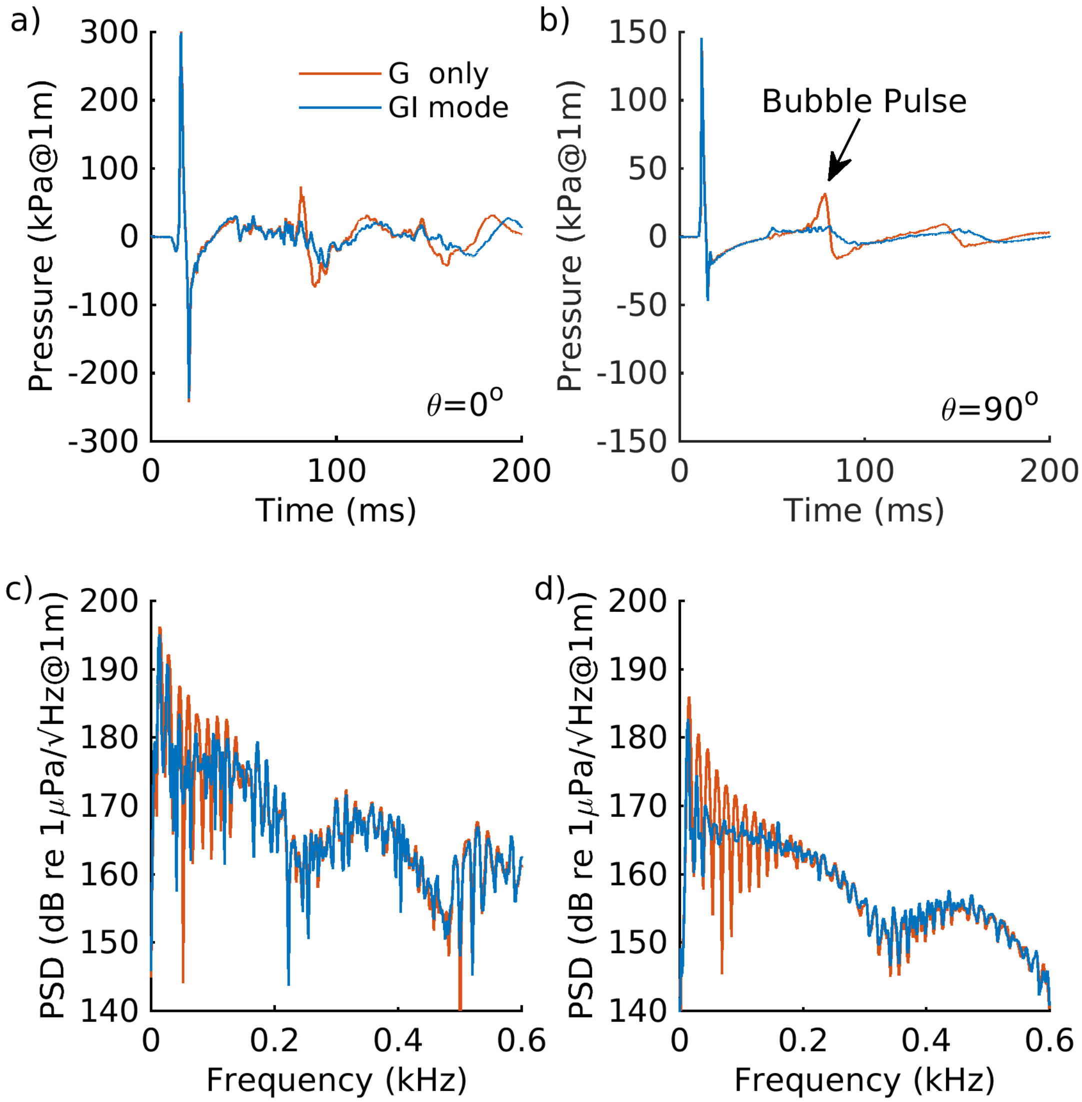


Figure 42. Generator Only (G) and Generator-Injector (GI) Waveforms

Data used to characterize the sounds emitted by the Sercel airgun were collected by the tetrahedral hydrophone array (labeled “3-D Gradient” in figure 41b) that was located at an oblique angle relative to the vertical axis passing through the airgun. Attempts to collect acoustic data from directly beneath the airgun were not generally successful because it was impractical to isolate these hydrophones from the shock and vibration resulting from operation of the airgun. Since it was necessary to suspend these hydrophones from the same overhead rigging as was used to support the airguns, the transmission of vibration from the airguns into the hydrophones could not be reliably avoided. However, the hydrophones making up the tetrahedral array were deployed from the rotator assembly where the transmission of vibration from the airguns through the measurement facilities structures to the hydrophones was negligible. Therefore, data collected by these hydrophones were used to characterize the observed source levels.

Figure 43 illustrates the annotated time history for the waveform transmitted by two airguns operated in tandem. The airguns were operated at a depth of 3 m while separated by a horizontal distance of 2 m, and pressurized to 13.8 MPa (2000 psi). That segment of the waveform in which 90% of the energy was located is shown in red and labeled in the figure. Calculations of the effective (i.e., rms) acoustic pressure, pulse width, and bandwidth were based on this part of the waveform. Figure annotations for peak-to-peak (Pk-Pk) and peak (Pk) acoustic pressures are also provided.

Note the time history does not include the bubble pulse oscillation illustrated in figure 42 at about 80 ms. Data used to estimate the observed source levels were selected to minimize the influence of reflections and secondary radiation of sound from vibration of the composite floats used to support the measurement facility barge. In particular, the acoustic field intensity resulting from airgun operation was sufficient to cause non-negligible vibrations throughout the test facility structures including the barge floats. Since the duration of these vibrations extended into times at which the bubble pulse signature was observed, it was edited from the acoustic time histories prior to calculating source levels. While this selection had no effect on the peak-to-peak and peak source level measurements, it may have influenced the effective (i.e., rms) source level by including only those data associated with the initial airgun firing impulse and not the subsequent radiation of sound from the bubble pulse oscillations. However, since the Sercel Mini-GI airgun was designed specifically to suppress the bubble pulse oscillation, measurement errors resulting from the exclusion of data arriving at the later times should be minimal for the GI operating mode.

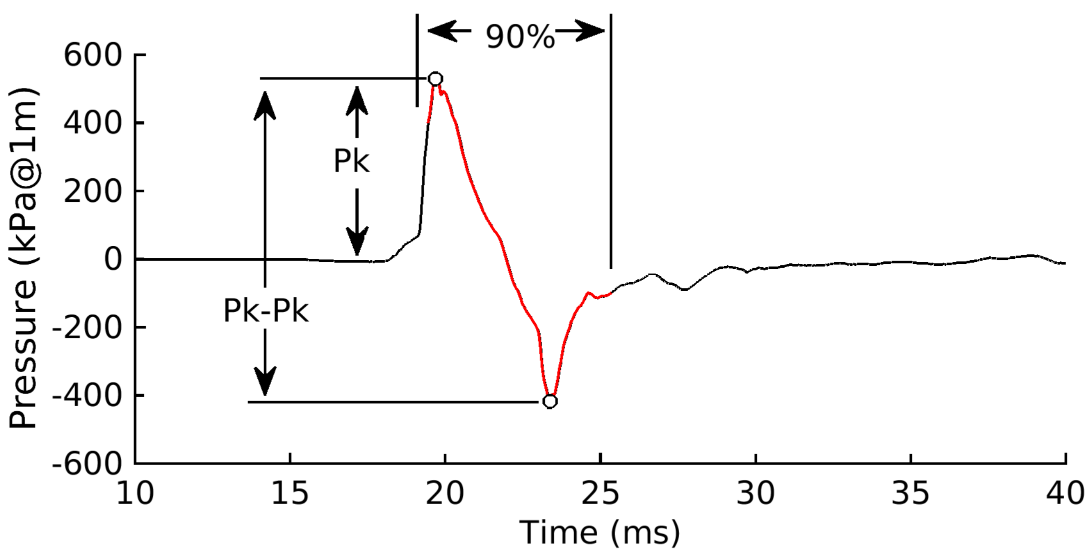


Figure 43. Sercel Mini-GI Waveform for Two Guns at 3-m Depth and 13.8 MPa

Acoustic waveforms generated by the Sercel Mini-GI airgun were quite consistent as illustrated in figure 44a where four separate airgun signals are shown. The data were collected while operating at a depth of 1.5 m and pressurized to 13.8 Mpa (2000 psi). Note the four time histories are virtually indistinguishable from each other.

Figure 44b compares signals generated at an operating depth of 3 m with the airgun charged to pressures ranging from 10.3 to 20.7 MPa (1,500 to 3,000 psi). In these cases, the waveforms were quite similar with the primary difference being peak amplitudes realized for each of the different airgun charge pressures.

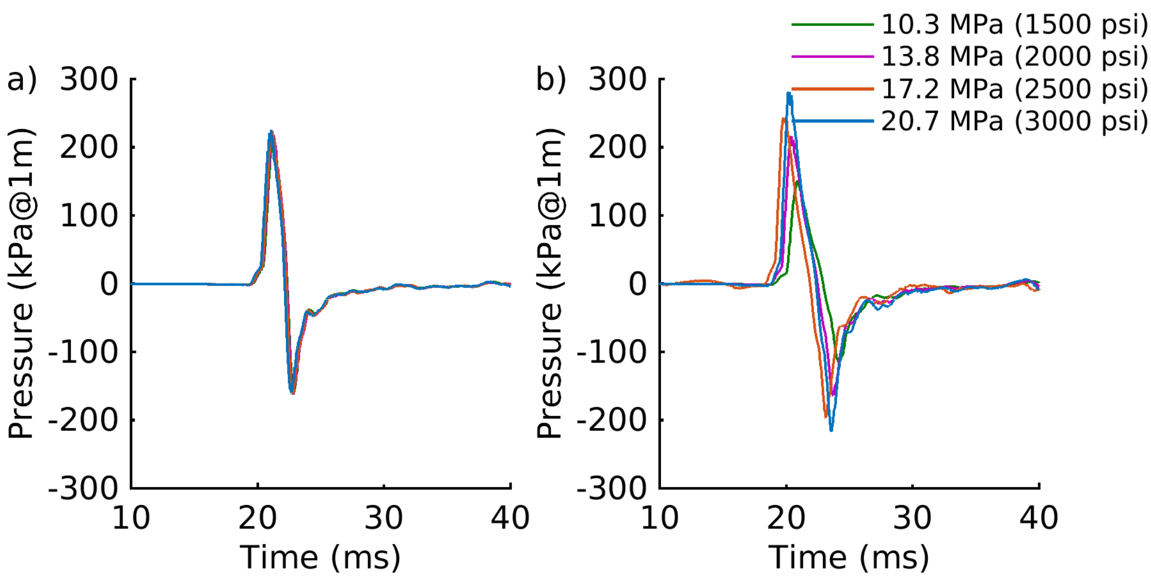


Figure 44. Sercel Mini-GI Airgun Waveforms

Figure 45 summarizes the source level data collected for 106 airgun shots performed using charge pressures ranging from 9.0 to 17.2 MPa (1,300 to 2,500 psi) and operating depths ranging from 1.5 to 3.0 m. Data were also collected with volume reducers installed in Gun 1 such that the generator volume was reduced to 213 cm^3 (13 $in.^3$) while the injector volume was reduced to 393 cm^3 (24 $in.^3$).

As indicated in the figure legend, Gun 1 is represented by a total of 64 observations including 21 observations with the volume reducers installed. Gun 2 is represented by 28 observations and tandem firing of both guns is represented by 14 observations. The observed source levels varied from 217 to 228 dB re 1µPa@1m and were consistent for each charge pressure with variations limited to about 1 dB in most cases.

Figure 45 also shows trend lines for the observed source level when one gun was operated (with and without volume reducers) and when two airguns were operated in tandem. The trend lines were determined by assuming the acoustic pressure observed was linearly related to the potential energy stored in the gun prior to firing. Thus, the trend lines are the result of linear regressions of the observed effective acoustic pressure to the charge pressure used to operate the airguns. The trend line for a single gun operating with volume reducers installed was about 1-dB less than when operating without the volume reducers. The trend line for a single airgun and for two airguns operated in tandem differed by 5.5 dB (without volume reducers). The expected value for two independent (i.e., non-interacting) sources is 6 dB. Thus, the interaction between two Sercel Mini-GI airguns when operated in tandem and separated by 2 m, was relatively weak.

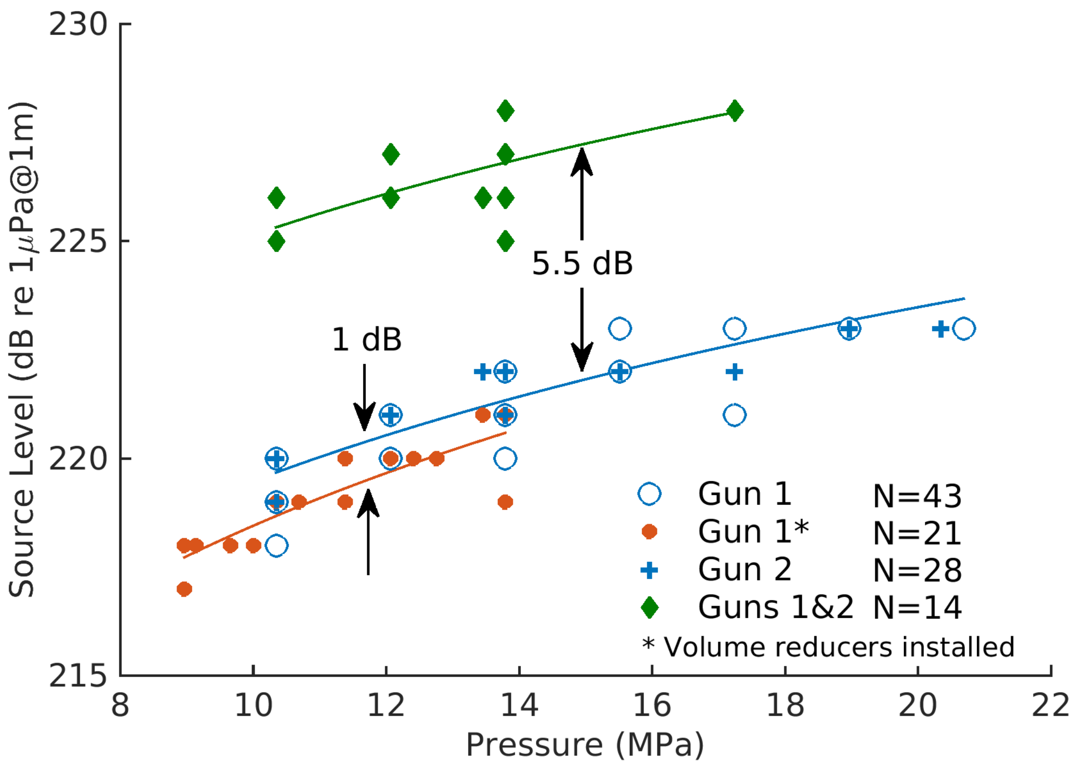


Figure 45. Sercel Mini-GI Airgun Source Levels

Summary results for the Sercel Mini-GI airgun are provided in table 12. Data are provided for each operating pressure and depth. While the observed source levels were relatively insensitive to operating depth, the pulse widths were strongly influenced. As the table shows, pulse width varied with operating depth ranging from about 3.6 to 7.9 ms for 1.5 and 4.5 m, respectively. Pulse widths increased with depth due to the greater time required for the surface reflection (i.e., ghost) to arrive at the hydrophone locations. A commensurate change in bandwidth was also observed. However, it should be noted the record lengths (i.e., pulse widths) used for estimation of the power spectrum had a non-negligible influence on the estimated bandwidths.[11]

Table 12. Sercel Mini-GI Airgun Acoustic Characteristics

Source Settings				Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (Hz)
Nr. Guns	Pressure (MPa)	(psi)	Depth (m)	Pk-Pk	Pk	RMS	SEL		
1*	9.0	1,300	1.5	228	223	218	193	3.7	120 to 420
1*	9.7	1,400	1.5	228	223	218	193	3.5	120 to 420
1*	9.7	1,500	1.5	228	224	219	194	3.6	120 to 410
1	10.3	1,500	1.5	229	225	220	196	3.7	120 to 430
1	10.3	1,500	3.0	230	225	219	197	5.6	70 to 250
1	10.3	1,500	4.5	230	225	218	197	8.1	40 to 160
1*	12.1	1,750	1.5	230	224	220	195	3.4	130 to 430
1	12.1	1,750	1.5	231	226	221	197	3.7	120 to 430
1	12.1	1,750	3.0	231	226	220	198	5.6	70 to 250
1*	13.8	2,000	1.5	231	225	221	196	3.3	130 to 430
1	13.8	2,000	1.5	232	228	222	198	3.6	130 to 440
1*	13.8	2,000	3.0	231	226	219	197	6.0	60 to 230
1	13.8	2,000	3.0	232	227	221	199	5.7	70 to 250
1	13.8	2,000	4.5	232	228	220	199	7.7	50 to 170
1	15.5	2,250	1.5	233	229	223	198	3.6	130 to 440
1	15.5	2,250	3.0	233	228	222	199	6.3	70 to 250
1	17.2	2,500	1.5	234	229	223	199	3.6	130 to 440
1	17.2	2,500	3.0	233	228	223	199	5.2	80 to 260
1	17.2	2,500	4.5	233	229	221	200	7.4	50 to 170
1	19.0	2,750	3.0	234	229	223	200	5.3	80 to 260
1	20.7	3,000	3.0	235	230	223	201	5.2	80 to 260
2	10.3	1,500	1.5	235	231	225	201	4.2	110 to 400
2	10.3	1,500	3.0	236	231	225	203	5.8	70 to 230
2	12.1	1,750	1.5	237	232	227	203	3.8	120 to 410
2	13.8	2,000	1.5	237	232	227	203	4.1	120 to 410
2	13.8	2,000	3.0	238	233	227	204	5.7	70 to 230
2	17.2	2,500	3.0	239	235	228	206	5.7	70 to 230

* Volume reducer installed: 213 cm^3 (13 $in.^3$) generator, 393 cm^3 (24 $in.^3$) injector

3.1.3.1 Acoustic Particle Velocity Estimates. In addition to traditional acoustic pressure measurements, the acoustic particle motion was estimated in proximity to the Sercel Mini-GI airgun during operation. The acoustic vector field describes the motion (i.e., displacement, velocity, and acceleration) of the fluid medium in which an acoustic field exists. The acoustic vector field (i.e., particle motion) is related to the acoustic scalar field (i.e., pressure) by the momentum equation for acoustic processes[12] as

$$-\nabla p \quad = \quad \rho \frac{\partial \vec{u}}{\partial t}, \tag{10}$$

where p is the acoustic pressure, $\vec{u}$ is the particle velocity vector, ρ is the fluid density, and t is time.

Acoustic vector field measurements are frequently performed using an *inertial acoustic vector sensor* composed of a neutrally buoyant accelerometer or geophone to make a direct measurement of the acoustic particle motion. An alternate method requires knowledge of the scalar field gradient, ∇p, in combination with the fluid density, ρ, to arrive at an estimate of the acoustic particle acceleration, $\partial \vec{u} / \partial t$. The pressure gradient, ∇p, can be approximated using data provided by four hydrophones arranged at the vertices of a regular tetrahedron as seen in figure 46 where the acoustic center of the *pressure gradient sensor* is located at the geometric center of a cube with edge length L (see figure 46a).

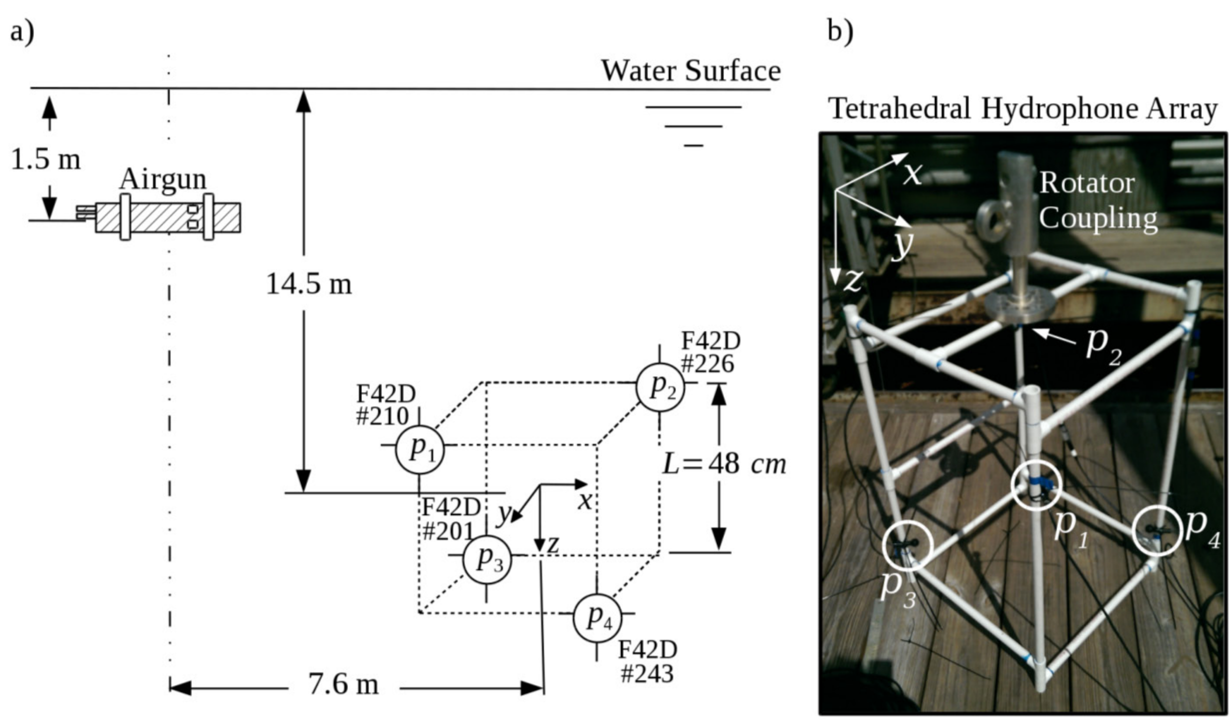


Figure 46. Estimation of Acoustic Particle Motion

The pressure gradient was estimated at the acoustic center of the tetrahedral hydrophone array using first order, finite differences of the acoustic pressure estimated along each of the cardinal directions for the right-handed system of Cartesian coordinates illustrated in figure 46a. The size, L, of the array was determined to be about one-sixth of an acoustic wavelength at the upper frequency limit of 500 Hz. In addition, each pressure from which components of the gradient were estimated was the average of the pair of hydrophones that spanned the plane normal to the coordinate axes. For example, the x-component of the pressure gradient at the center of the tetrahedral array (see figure 46b) was approximated as

$$\frac{\partial p}{\partial x} \approx \frac{p_2 + p_4 - (p_1 + p_3)}{2L}. \tag{11}$$

Thus, components of the acoustic particle acceleration were estimated as

$$\frac{\partial u_x}{\partial t} = \frac{-1}{\rho}\frac{\partial p}{\partial x}, \tag{12}$$

$$\frac{\partial u_y}{\partial t} \approx \frac{-1}{\rho}\frac{p_1 + p_4 - (p_2 + p_3)}{2L}, \tag{13}$$

$$\frac{\partial u_z}{\partial t} \approx \frac{-1}{\rho}\frac{p_3 + p_4 - (p_1 + p_2)}{2L}, \tag{14}$$

and the acoustic pressure, p, estimated at the center of the array was

$$p \approx \frac{p_1 + p_2 + p_3 + p_4}{4}. \tag{15}$$

Since the gradient sensor designed for this measurement was a band-limited device with an upper frequency limit of about 500 Hz, it was necessary to filter the acoustic data to prevent the introduction of errors from higher frequency signal components. Thus, a finite impulse response (FIR) filter of order 256 with a passband of 30 to 500 Hz was used to filter the pressure time series prior to estimation of the gradient. The magnitude response of the filter is shown in figure 47 where the maximum sidelobe level was about 60 dB less than the passband response. The 128 sample group delay of the filter was corrected prior to integration.

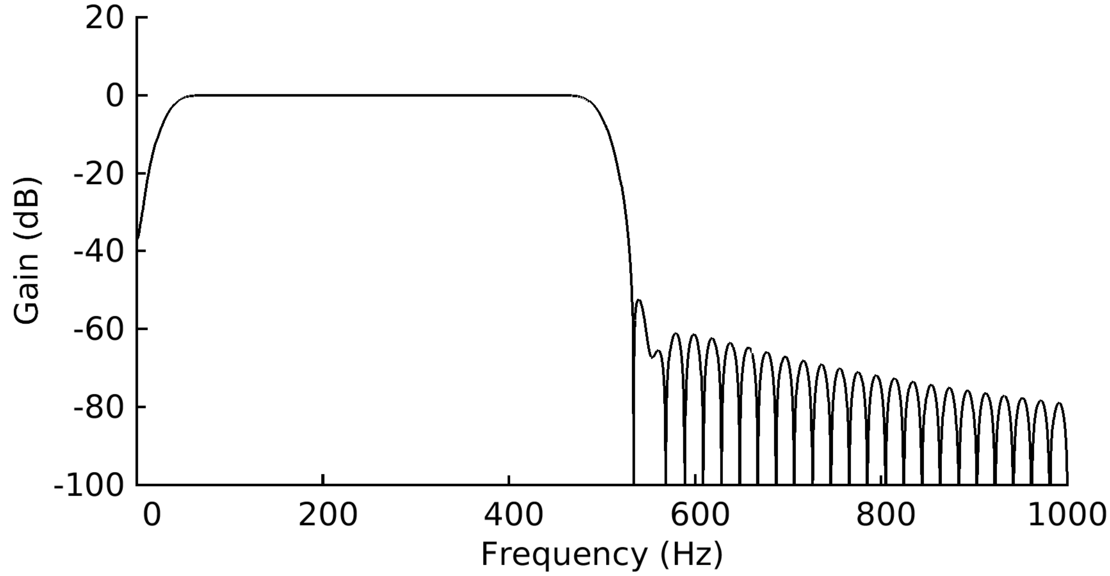


Figure 47. Pressure Gradient Estimation Bandpass Filter Response (Hbp)

Following estimation of the acoustic particle acceleration using equations (11) through (14), the particle velocity was estimated by numerical integration. A second-order digital integrator with fractional delay[13] was used to implement polynomial integration (i.e., Simpson's Rule) of the acceleration time series. The transfer function (i.e., Z-transform) for the integration filter was

$$Hsi(z) \quad = \quad \frac{\Delta t}{6}\left(\frac{7+16z^{-1}+z^{-2}}{3-2z^{-1}-(1-eps)z^{-2}}\right), \tag{16}$$

where $z = e^{j\omega}$ with ω the radian frequency ordinate, Δt is the sample period, and $eps = 10^{-3}$ is a small constant to stabilize the filter. The filter transfer function is illustrated in figure 48, where the frequency response is compared to that of the ideal (continuous) integrator.

Data processing used to estimate the acoustic vector field observed during operation of the airgun is summarized in figure 49. In short, the pressure time series observed by four calibrated reference hydrophones were bandpass filtered to eliminate frequency components that were above the upper limit of 500 Hz determined by the size of the tetrahedral array. The low-frequency limit of 30 Hz was set to prevent accumulation of errors during integration that may have been associated with sensor bias and/or fixture vibration in response to the airgun shots. The bandpass filtered time series were then used to estimate the three-dimensional acoustic particle acceleration by evaluation of equations (11) through (14). The acceleration time series were then integrated using the fractional step digital filter provided as equation (16) and illustrated in figure 48 to yield the three-dimensional acoustic particle velocity. The acoustic pressure at the center of the array was estimated as the average of the pressures observed at the vertices of the tetrahedron as indicated in equation (15).

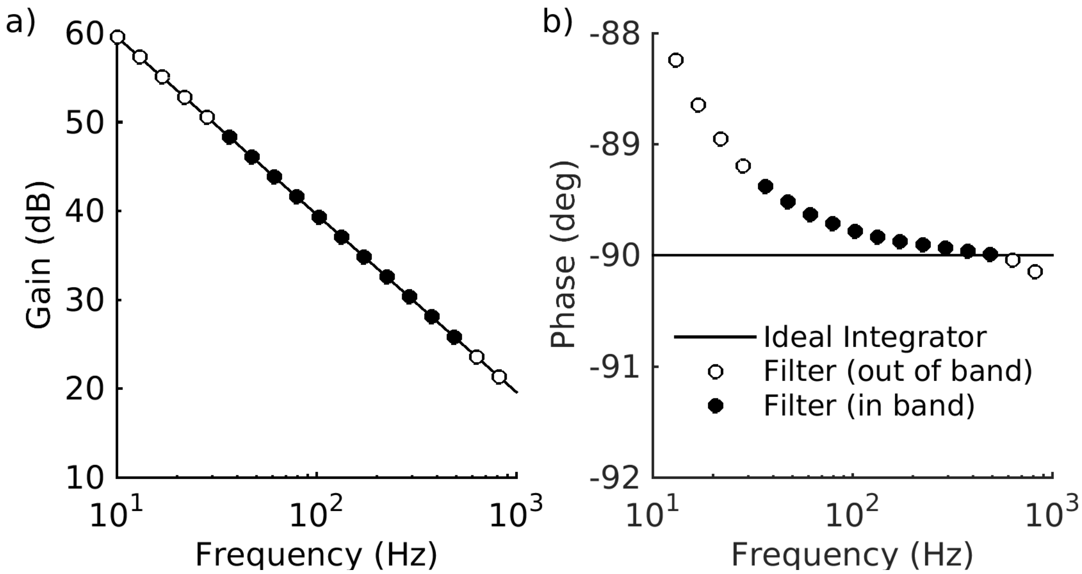


Figure 48. Digital Integration Filter Response (Hsi)

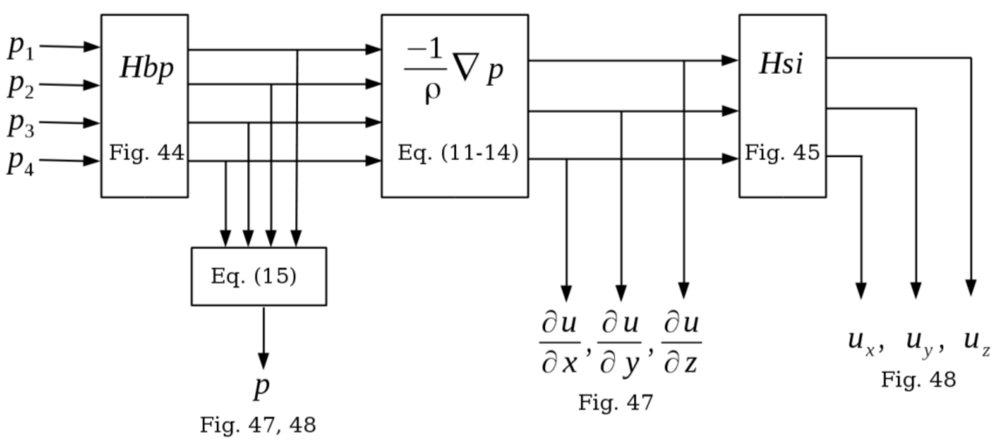


Figure 49. Data Processing Sequence

The acoustic field estimates for an airgun shot performed at a depth of 1.5 m with a charge pressure of 13.8 MPa (2,000 psi) is illustrated in figure 50. The acoustic pressure estimated at the center of the array is shown in figure 50a. The three-dimensional acoustic particle acceleration is illustrated in figures 50b through 50d. Note the array was oriented such that the acoustic particle motion should have been confined to the x-z plane as shown in figure 46a. In addition, the system of coordinates was defined such that the initial motion resulting from operation of the airgun was in the +x and +z directions. Inspection of figure 50 confirms there was little motion observed in the y-direction and motions in the x- and z-directions were both positive, or oriented away from the airgun, as was expected. Finally, the peak acceleration magnitudes observed in the x and z-directions were 6.6 and 14.0 m/s^2, respectively.

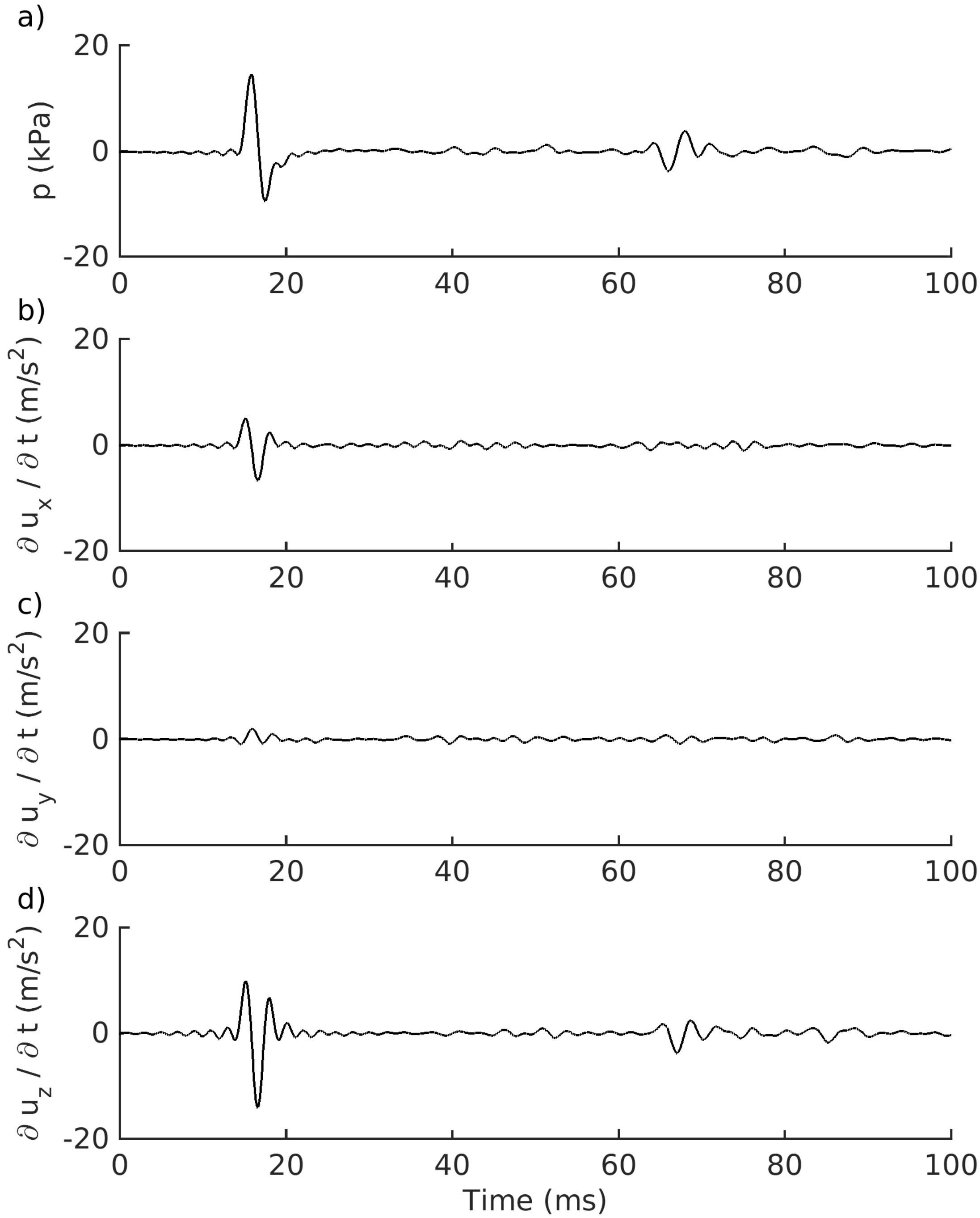


Figure 50. Acoustic Particle Acceleration, One Gun at 1.5-m Depth and 13.8 MPa

The estimated acoustic particle velocity for the same airgun shot is illustrated in figure 51. The acoustic pressure estimated at the center of the array is shown in figure 51a. The three components of the acoustic particle velocity are illustrated in figures 51b through 51d. The velocities were largely confined to the x-z plane where the velocity magnitudes observed in the horizontal and vertical direction were 15.7 and 8.3 mm/s, respectively. This corresponds to a wavefront propagating at an angle of 28° with respect to the vertical–a value that was consistent with the known angle of 30° based on consideration of the measurement geometry.

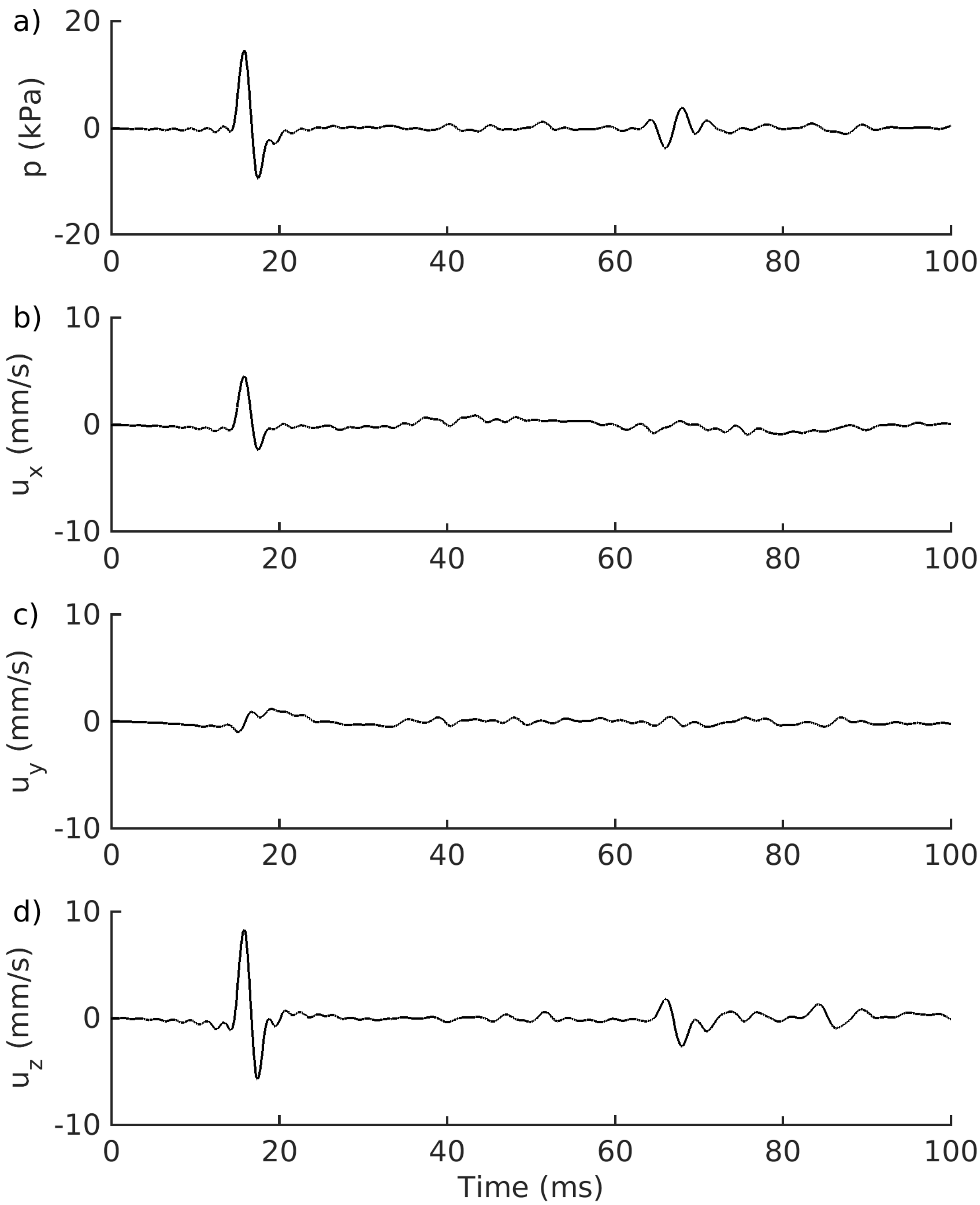


Figure 51. Acoustic Particle Velocity, One Gun at 1.5-m Depth and 13.8 MPa

A final check of the velocity estimate was performed by consideration of the specific acoustic impedance for a spherically divergent acoustic field. It was assumed the airgun was well approximated by a simple source such that the scalar acoustic field was

$$p = \frac{P_o}{r} e^{j(\omega t - kr)}, \qquad (17)$$

where P_o is the pressure at a distance r of 1 m, and k is the acoustic wavenumber. Note the surface reflection can be neglected without loss in generality since it can be introduced by the addition of a virtual source that contributes to the total acoustic field by superposition. Substituting equation (17) into equation (10) and integrating with respect to time yields

$$u = \frac{p}{\rho c}\left(1 + \frac{1}{jkr}\right), \qquad (18)$$

for the acoustic particle velocity. The specific acoustic impedance, z, is defined as

$$z = \frac{p}{u} = \rho c \left(1 + \frac{1}{jkr}\right)^{-1}. \qquad (19)$$

Equation (19) shows the specific acoustic impedance of a spherically divergent acoustic field reduces to the characteristic impedance, ρc, of the medium at large distances with respect to an acoustic wavelength such that $k \gg 1$ where the field may be approximated as a plane propagating wave. Since the data were filtered to a passband of 30 to 500 Hz and the distance from the airgun to the tetrahedral array was 15 m, the minimum wavenumber-range product was $kr = 1.9$ and increased with frequency. Thus, the observed acoustic field should be reasonably well approximated by a plane propagating wave.

Figure 52 shows the estimated acoustic vector field magnitudes. The acceleration magnitude is provided in figure 52a, and the velocity magnitude is provided in figure 52b. The acoustic particle velocity magnitude estimated by integration of the acceleration time series is compared to the velocity magnitude for a plane propagating wave computed using the wave impedance where $p = \rho c u$. The peak velocity magnitudes at 15.7 and 17.4 mm/s that were estimated by numerical integration of the acceleration time series agreed to within 3% of that computed by consideration of the characteristic impedance of freshwater $\rho c = 1.49 \times 10^6$ kg m^{-2} s^{-1}.

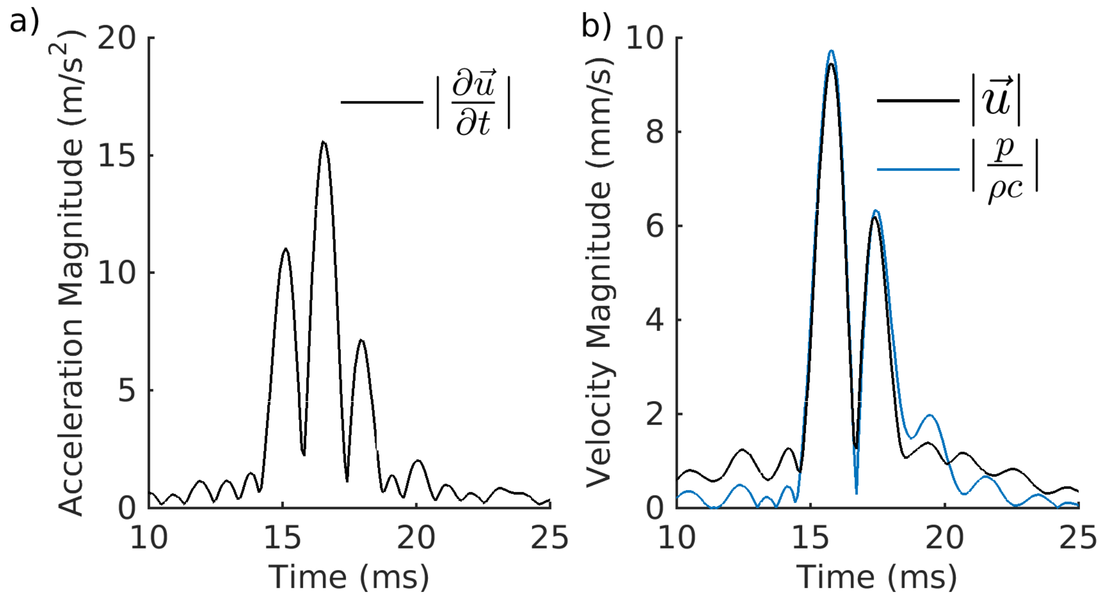


Figure 52. Acoustic Vector Field Magnitudes, One Gun at 1.5-m Depth and 13.8 MPa

Table 13 provides a summary of acoustic vector field parameters for a select set of airgun shots observed during the first several shots where peak-to-peak accelerations ranged from 20.4 to 31.2 m/s^2 at 10.3 and 17.2 MPa, respectively. The corresponding acoustic particle velocity magnitudes were 12.2 and 18.2 mm/s peak-to-peak. All data reflect the observed field quantities at the observation distance of 15 m and were not referred back to a reference distance of 1 m as was done for the acoustic pressure measurements. Finally, the validity of the vector field estimate was assessed by comparing the estimate to a prediction provided by a quite simple acoustic model of the wave impedance where excellent agreement was found between the predicted and estimated acoustic particle velocities.

Table 13. Acoustic Vector Field Parameter Estimates, One Gun

Source Settings			Particle Acceleration (m/s^2)			Particle Velocity (mm/s)		
Pressure (MPa) (psi)		Depth (m)	Pk-Pk	Pk	RMS	Pk-Pk	Pk	RMS
10.3	1,500	1.5	20.4	12.1	7.2	12.2	7.4	4.9
12.1	1,750	1.5	24.1	14.2	8.6	14.3	8.6	5.7
13.8	2,000	1.5	26.7	15.6	9.4	15.6	9.5	6.3
15.5	2,250	1.5	29.2	17.1	10.3	17.2	10.3	6.8
17.2	2,500	1.5	31.2	18.3	11.0	18.2	11.0	7.2
Note: All shots observed at a distance of 15 m from airgun.								

3.2 SIGNAL TYPE: AMPLITUDE-FREQUENCY MODULATED WAVEFORM

3.2.1 EdgeTech 424 Sub-Bottom Profiling System

The EdgeTech 424 sub-bottom profiling system employs the variable depth source illustrated in figure 53. The tow body is designed to operate anywhere in the water column from the surface to near the sea floor as required to achieve the required signal penetration into the marine sediments. Since reflection of sound from the water surface is usually not a significant contributor to the acoustic intensity along the MRA of these sources, they were deployed at greater depth to better emulate the acoustic environment during normal operations. While reflection of acoustic energy from the sea floor during a geophysical survey does have a significant impact on the total radiated acoustic field intensity in the water column, accounting for this effect was beyond the scope of this study since the reflected acoustic field is strongly influenced by the composition of the sea floor.[14] However, data acquired during this study can be used in conjunction with a computational acoustic model and an estimate of the sea floor reflection coefficient to predict the total acoustic field resulting from operation of these sources during geophysical surveys.

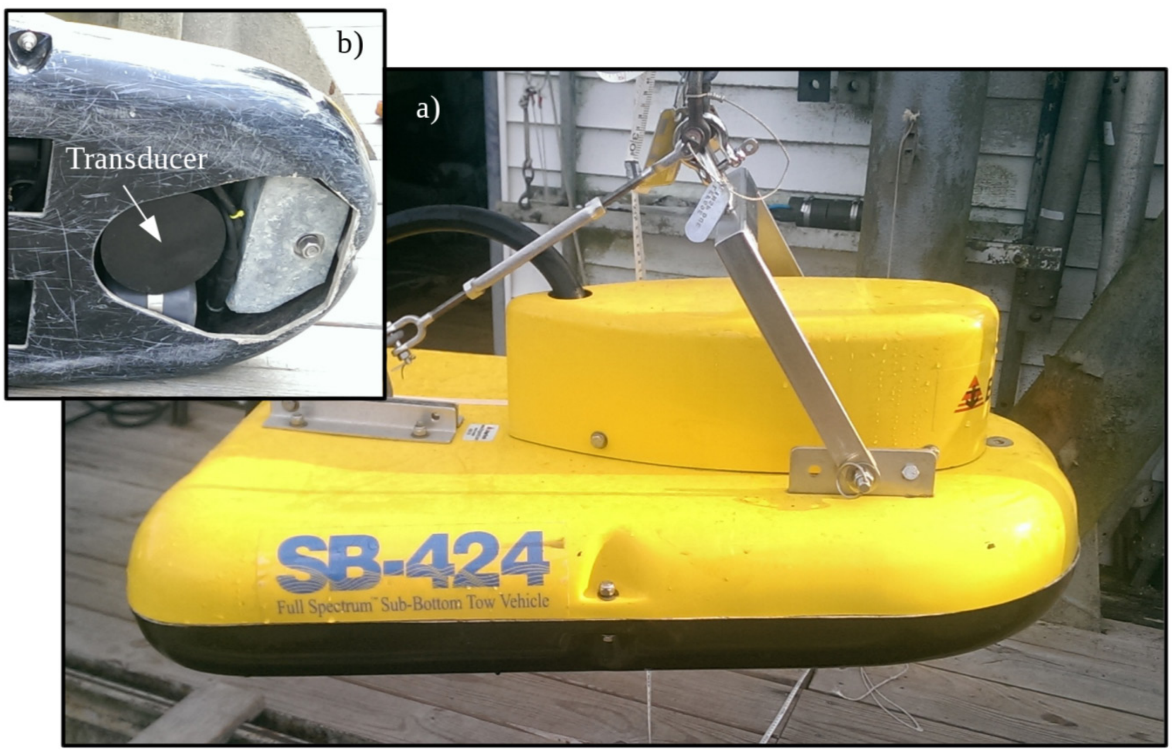


Figure 53. EdgeTech 424 Sub-Bottom Profiling System Tow Body

Sounds radiated by the EdgeTech 424 were observed using two distinct measurement geometries. An extensive set of measurements was performed to characterize the radiated acoustic field referenced to a distance of 1 m on the projector's MRA. This measurement geometry is illustrated in figure 54a where a number of calibrated reference standards were arranged to observe the sound field directly beneath the source as it was operated in the normal orientation for projection of sound into the sea floor. Figure 54b shows the measurement geometry used to characterize the directionality (i.e., beam pattern) of sounds transmitted by the EdgeTech 424.

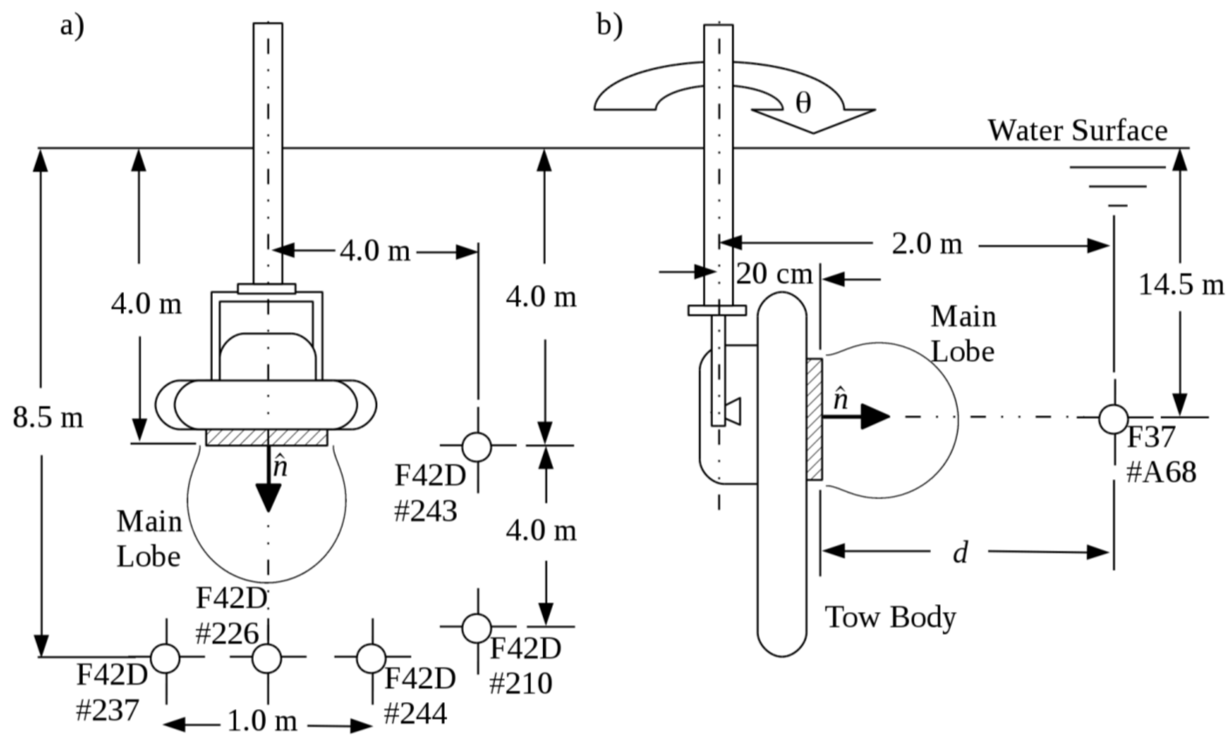


Figure 54. EdgeTech 424 Measurement Geometry

Two sonar control systems were used to drive the EdgeTech 424 tow body to assess the effect that choice of topside processor on sounds radiated by the tow body. The EdgeTech 3100P Portable Sub-bottom Topside Processor was used during source level measurements for two different tow bodies (S/Ns 27302 and 48706). Figure 55 shows a typical waveform with a pulse width of 10 ms and bandwidth of 4 to 20 kHz that was transmitted using the 100% power setting. Figure 55a provides the time series where markers denote the locations of the observed minimum and maximum pressures. The portion of the waveform in which 90% of the radiated energy was found is indicated in red. The power spectrum for the waveform is provided as figure 55b where evidence of the second harmonic is shown with a power that was about 20 dB less than the fundamental. The -3-dB points used to define the observed bandwidth of the signal are indicated with markers. Source level measurements were also performed when driving the tow body (S/N 48706) with the EdgeTech 3200-XS Sub-Bottom Processor. Measurement results are provided as tables 14 through 16.

The nominal source level (rms) for the EdgeTech 424 (S/N 27302) when driven by the 3100P topside processor at the 100% power setting was 165 to 168 dB re 1µPa@1m (see table 14). The nominal source level when driven at the 50% power setting was 158 to 162 dB, a reduction of 6 to 7 dB. Note that a 6-dB reduction in source level is not consistent with a 50% reduction in power supplied to the acoustic projector. However, it is consistent with a 50%

reduction in drive voltage. Therefore, transmit power indications provided by the 3100P topside processor were more consistent with control over the transmit voltage applied to the projector than with the radiated acoustic power.

The source levels for EdgeTech 424 (S/N 48706) when driven by the 3100P topside processor at the 100% power setting were 167 to 171 dB re 1µPa@1m. When driven by the 3200-XS topside processor, the observed source levels were 176 to 180 dB, a 9-dB increase due to the greater power output of the 3200-XS amplifier.

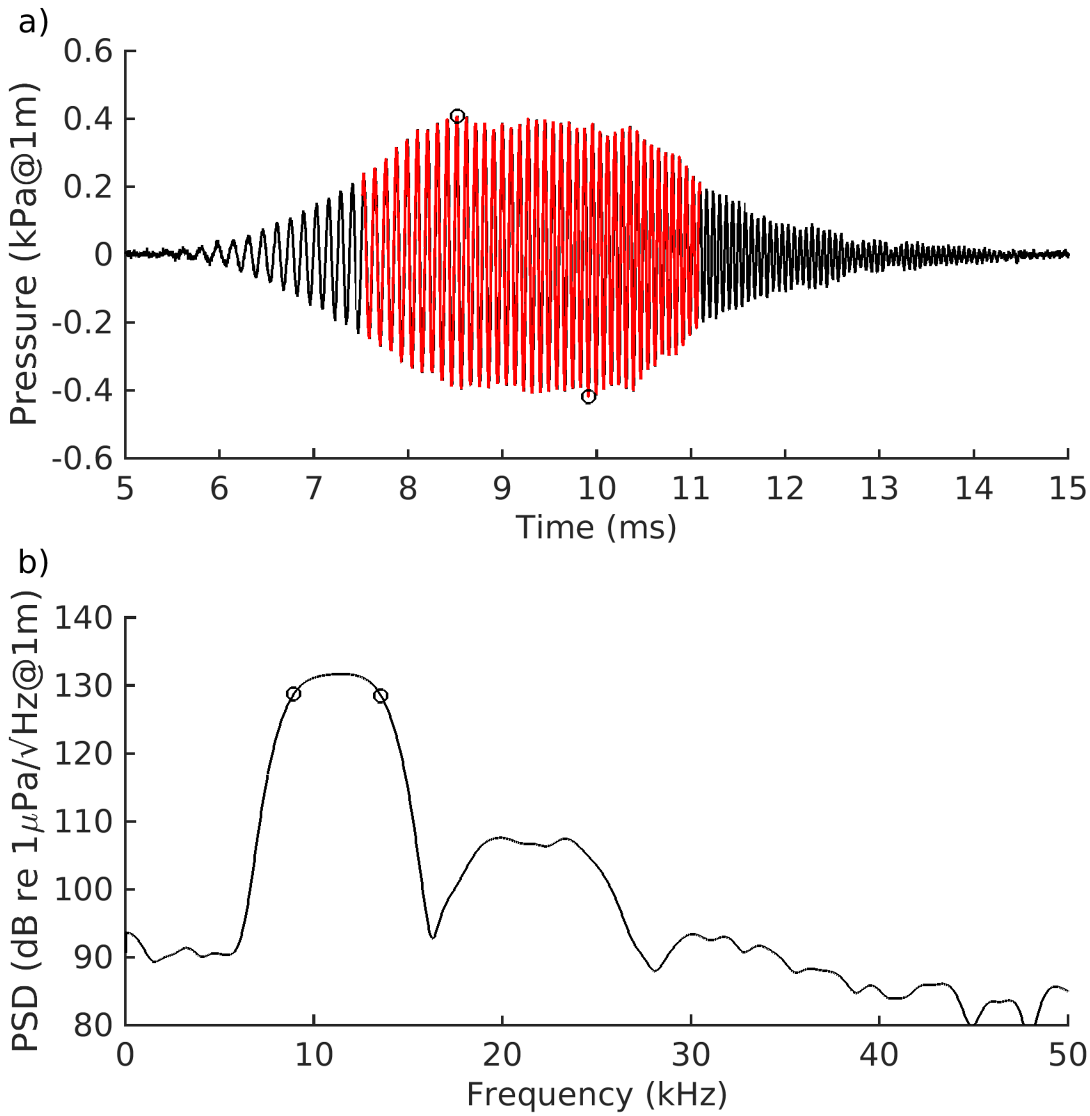


Figure 55. EdgeTech 424 Waveform, 10 ms, 4 to 20 kHz, 100% Power

Table 14. EdgeTech 424 (S/N 27302) with 3100P Topside Processor

Source Settings			Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power (%)	Pulse Width (ms)	Bandwidth (kHz)	Pk-Pk	Pk	RMS	SEL		
50	5	4 to 24	171	165	159	132	2.3	9.7 to 14.8
50	10	4 to 24	171	165	159	135	4.3	9.8 to 14.4
75	5	4 to 24	174	168	163	136	2.1	9.8 to 14.8
75	10	4 to 24	174	168	162	139	4.2	9.8 to 14.3
100	5	4 to 24	177	171	165	138	2.1	9.8 to 14.7
50	10	4 to 16	173	168	162	138	4.0	8.2 to 11.3
50	1	4 to 20	173	167	161	129	0.6	5.7 to 17.1
50	2	4 to 20	173	167	162	132	1.0	7.4 to 15.2
50	5	4 to 20	172	166	161	134	1.9	8.7 to 13.7
50	10	4 to 20	172	166	161	137	3.8	9.0 to 13.5
50	10	4 to 20*	173	167	161	139	6.3	7.3 to 13.3
50	1	4 to 24	172	166	158	128	1.1	7.9 to 16.8
50	2	4 to 24	172	166	160	131	1.2	8.5 to 15.6
75	10	4 to 16	177	171	166	142	4.0	8.2 to 11.5
75	1	4 to 20	177	171	166	133	0.5	2.7 to 17.8
75	2	4 to 20	176	170	166	135	0.9	7.3 to 14.9
75	5	4 to 20	175	169	165	137	1.9	8.7 to 13.4
75	10	4 to 20	176	169	165	141	3.7	9.0 to 13.5
75	10	4 to 20*	176	171	164	142	6.2	7.3 to 13.2
75	1	4 to 24	176	170	164	131	0.6	6.7 to 18.0
75	2	4 to 24	176	170	164	134	1.1	8.5 to 15.7
100	10	4 to 16	180	174	168	144	4.0	8.2 to 11.4
100	1	4 to 20	179	173	168	135	0.5	3.0 to 17.8
100	2	4 to 20	179	173	168	138	0.9	7.3 to 15.2
100	5	4 to 20	178	172	167	140	1.9	8.7 to 13.6
100	10	4 to 20	178	172	167	143	3.7	8.9 to 13.1
100	10	4 to 20*	179	173	167	145	6.1	7.3 to 13.2
100	1	4 to 24	178	172	166	134	0.5	6.2 to 18.2
100	2	4 to 24	178	172	167	137	1.1	8.4 to 15.7
100	10	4 to 24	177	171	165	141	4.2	9.8 to 14.3
* Wideband								

Table 15. EdgeTech 424 (S/N 48706) with 3100P Topside Processor

Source Settings			Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power (%)	Pulse Width (ms)	Bandwidth (kHz)	Pk-Pk	Pk	RMS	SEL		
50	10	4 to 16	176	170	165	140	3.5	8.2 to 11.1
50	1	4 to 20	175	169	164	130	0.4	3.0 to 18.0
50	2	4 to 20	175	169	164	133	0.8	6.3 to 14.2
50	5	4 to 20	175	169	163	136	1.7	8.4 to 12.7
50	10	4 to 20	175	169	163	139	3.4	8.9 to 12.3
50	10	4 to 20*	176	169	164	141	4.9	7.3 to 11.7
50	1	4 to 24	174	168	161	128	0.5	4.2 to 17.3
50	2	4 to 24	174	168	162	131	0.8	6.7 to 15.0
50	5	4 to 24	173	167	161	133	1.8	8.8 to 14.1
50	10	4 to 24	173	167	161	136	3.6	9.2 to 13.2
75	10	4 to 16	179	174	169	144	3.5	8.2 to 11.1
75	1	4 to 20	179	173	168	134	0.4	0.0 to 18.4
75	2	4 to 20	178	173	168	137	0.8	6.2 to 14.5
75	5	4 to 20	178	172	167	139	1.7	8.4 to 12.9
75	10	4 to 20	178	172	167	142	3.4	8.9 to 12.2
75	10	4 to 20*	179	173	167	144	4.8	7.3 to 11.7
75	1	4 to 24	178	172	166	132	0.4	3.4 to 18.8
75	2	4 to 24	178	172	166	135	0.8	6.5 to 14.9
75	5	4 to 24	176	170	164	137	1.8	8.8 to 14.0
75	10	4 to 24	176	170	164	140	3.5	9.2 to 13.2
100	10	4 to 16	182	176	171	147	3.5	8.2 to 11.1
100	1	4 to 20	181	176	170	136	0.4	0.0 to 18.8
100	2	4 to 20	181	175	170	139	0.8	6.1 to 14.5
100	5	4 to 20	181	175	169	142	1.7	8.4 to 12.9
100	10	4 to 20	181	175	169	145	3.4	8.9 to 12.2
100	10	4 to 20*	182	176	170	147	4.8	7.4 to 11.6
100	1	4 to 24	180	174	169	134	0.4	0.0 to 19.1
100	2	4 to 24	180	174	169	138	0.8	6.4 to 14.8
100	5	4 to 24	179	173	167	139	1.7	8.8 to 13.7
100	10	4 to 24	179	173	167	142	3.5	9.2 to 13.1

* Wideband

Table 16. EdgeTech 424 (S/N 48706) with 3200-XS Topside Processor

Source Settings			Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power (%)	Pulse Width (ms)	Bandwidth (kHz)	Pk-Pk	Pk	RMS	SEL		
50	10	4 to 16	185	180	174	150	3.6	8.2 to 11.0
50	5	4 to 20	184	178	173	145	1.7	8.3 to 12.8
50	10	4 to 20	184	178	173	148	3.4	8.7 to 12.4
50	5	4 to 24	182	177	171	143	1.6	8.7 to 13.8
50	10	4 to 24	182	177	171	146	3.3	9.1 to 13.7
75	10	4 to 16	189	184	178	153	3.6	8.0 to 11.0
75	5	4 to 20	187	182	176	148	1.7	8.2 to 12.8
75	10	4 to 20	187	181	176	151	3.5	8.6 to 12.1
75	10	4 to 20*	190	184	177	154	4.6	7.4 to 11.1
75	5	4 to 24	186	180	174	146	1.6	8.6 to 14.1
75	10	4 to 24	186	180	174	149	3.3	9.0 to 13.7
100	10	4 to 16	192	186	180	156	3.7	8.0 to 11.1
100	5	4 to 20	190	184	178	151	1.7	8.1 to 12.6
100	10	4 to 20	189	184	178	154	3.5	8.5 to 12.4
100	10	4 to 20*	192	187	180	156	4.6	7.2 to 11.0
100	5	4 to 24	188	182	177	149	1.6	8.6 to 14.1
100	10	4 to 24	188	182	176	152	3.4	9.0 to 13.7
* Wideband								

The directional response, or beam patterns, for the variable depth sub-bottom profiling sources were measured as seen in figure 54b. The figure shows the acoustic sources were rigged to a rotator shaft such that the MRA were oriented in the horizontal plane where a stationary reference standard hydrophone was used to observe the acoustic field pressure as the source was rotated about the vertical axis. Note that while reference 2 stipulates the axis of rotation should pass through the acoustic center of the source, practicalities of rigging precluded this arrangement for many of the geophysical survey systems that were evaluated. Instead, the axis of rotation and acoustic center were (in some cases) separated by the distance, r, such that the effect of both rotation and translation of the acoustic source were included in the observations. Where the distance, d, from the acoustic source to the reference standard hydrophone varied with rotation angle as indicated in figure 53b, it was accounted for in the acoustic field calculations.

Data resulting from these measurements correspond to the acoustic field generated in the vertical plane containing the MRA and orthogonal to the direction of tow (i.e., the vertical transverse plane) during a geophysical survey. Corresponding measurements for the vertical plane parallel to the direction of tow (i.e., the vertical longitudinal plane) were not performed nor were they necessary due to the axial symmetry of the acoustic field radiated by the plane circular piston sources used in these systems.[2] In short, data collected during these measurements can be used to characterize the radiated acoustic field in any vertical plane that also contains the MRA of the source (i.e., the vector normal to the piston face). Figure 56 shows beam pattern data for the EdgeTech 424 while transmitting a 2- to12-kHz waveform. The figure includes annotations for the -3 and -10-dB beamwidths in addition to the beam levels observed at 90° and 180° radials. Beam pattern data for a variety of waveforms are summarized as table 17 using these four parameters.

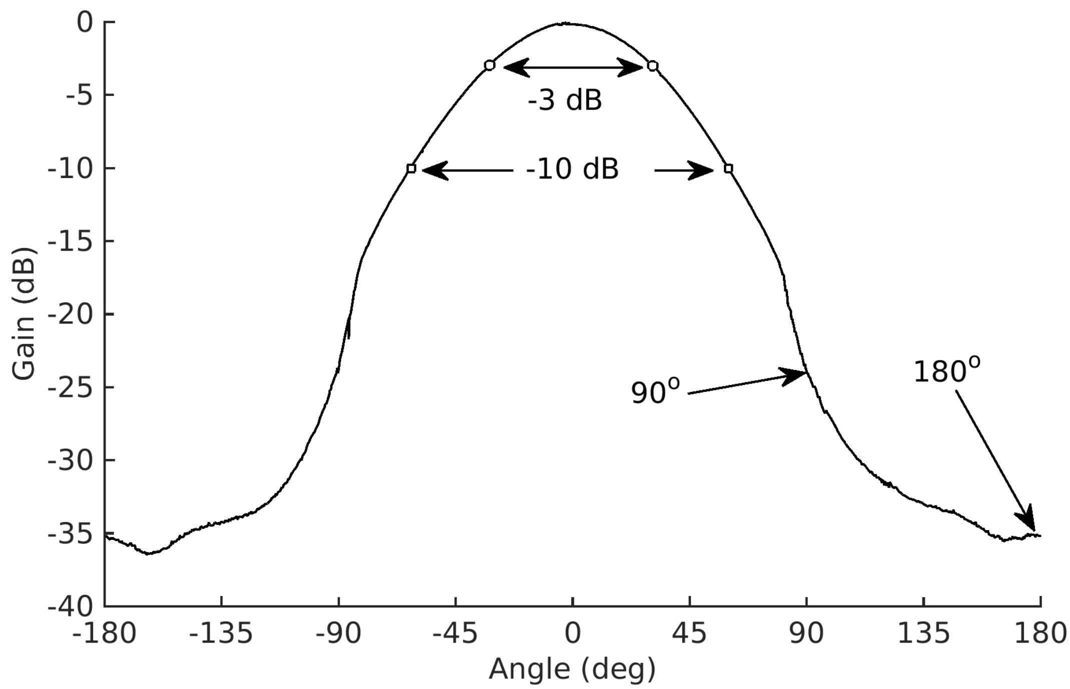


Figure 56. EdgeTech 424 Beam Pattern, 20 ms, 2 to 12 kHz, 100% Power

Table 17. EdgeTech 424 Beam Pattern Summary

Source Settings			Beamwidth (degrees)		Gain (dB)	
Power (%)	Pulse Width (ms)	Bandwidth (kHz)	-3 dB	-10 dB	90°	180°
100	20	2 to 12	63	122	-24	-35
100	20	2 to 15	63	116	-26	-36
100	1	4 to 20	68	113	-28	-36
100	10	4 to 24	60	102	-28	-35
100	10	4 to 20	68	114	-25	-35
100	10	4 to 20*	71	118	-22	-33
* Wideband						

3.2.2 EdgeTech 512i Sub-Bottom Profiling System

The EdgeTech 512i sub-bottom profiling system employs the variable depth source illustrated in figure 57. Like the EdgeTech 424, the tow body can be operated near the water surface, in the mid-water column, or in relatively close proximity to the sea floor as needed to ensure adequate signal penetration into the marine sediments. The tow body uses two acoustic transducers to transmit signals over a broad frequency band. The transducers (see figure 57b) include a high-frequency (HF) projector with 17-cm diameter and a larger low-frequency (LF) transducer with 34-cm diameter. The system includes the 3200-XS topside processor for waveform generation, amplification, and transmission.

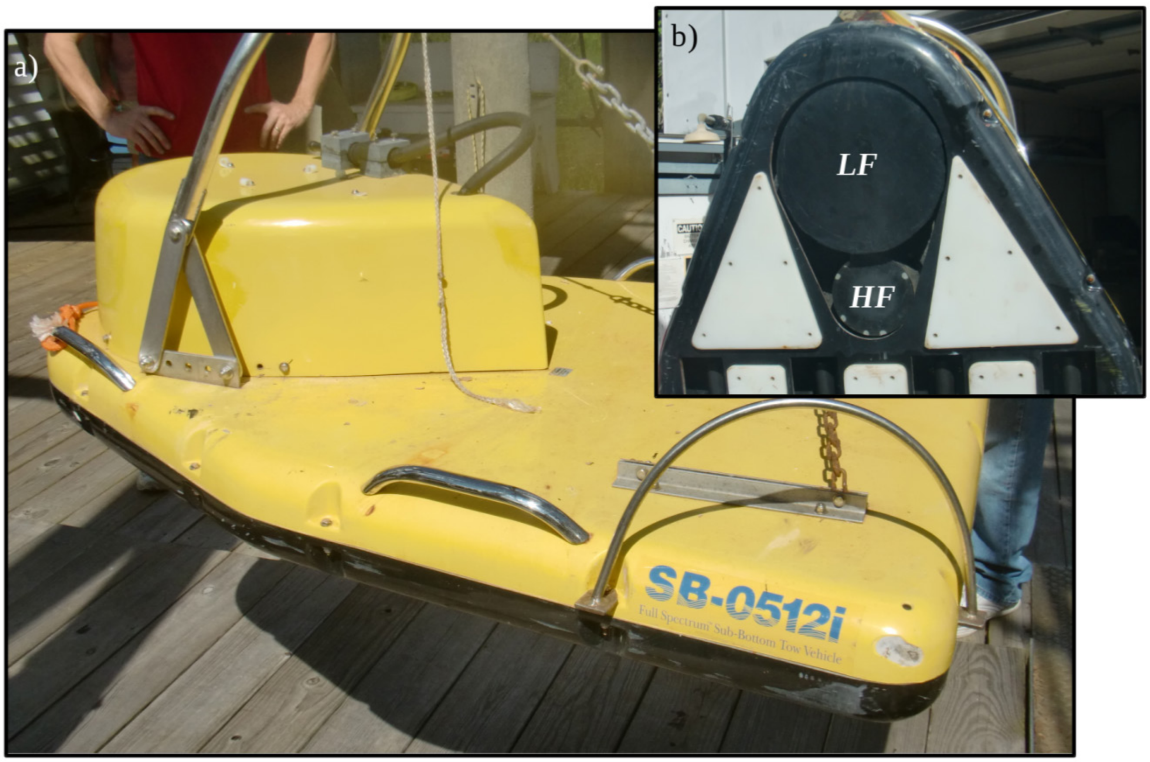


Figure 57. EdgeTech 512i Sub-Bottom Profiling System Tow Body

Sounds radiated by the EdgeTech 512i were observed using two distinct measurement geometries. An extensive set of measurements was performed to characterize the radiated acoustic field referenced to a distance of 1 m on the projector's MRA. This measurement geometry is illustrated in figure 58a where a number of calibrated reference standards were arranged to observe the sound field directly beneath the source as it was operated in the normal orientation for projection of sound into the sea floor. Figure 58b shows the measurement geometry used to characterize the directionality (i.e., beam pattern) of transmitted sounds.

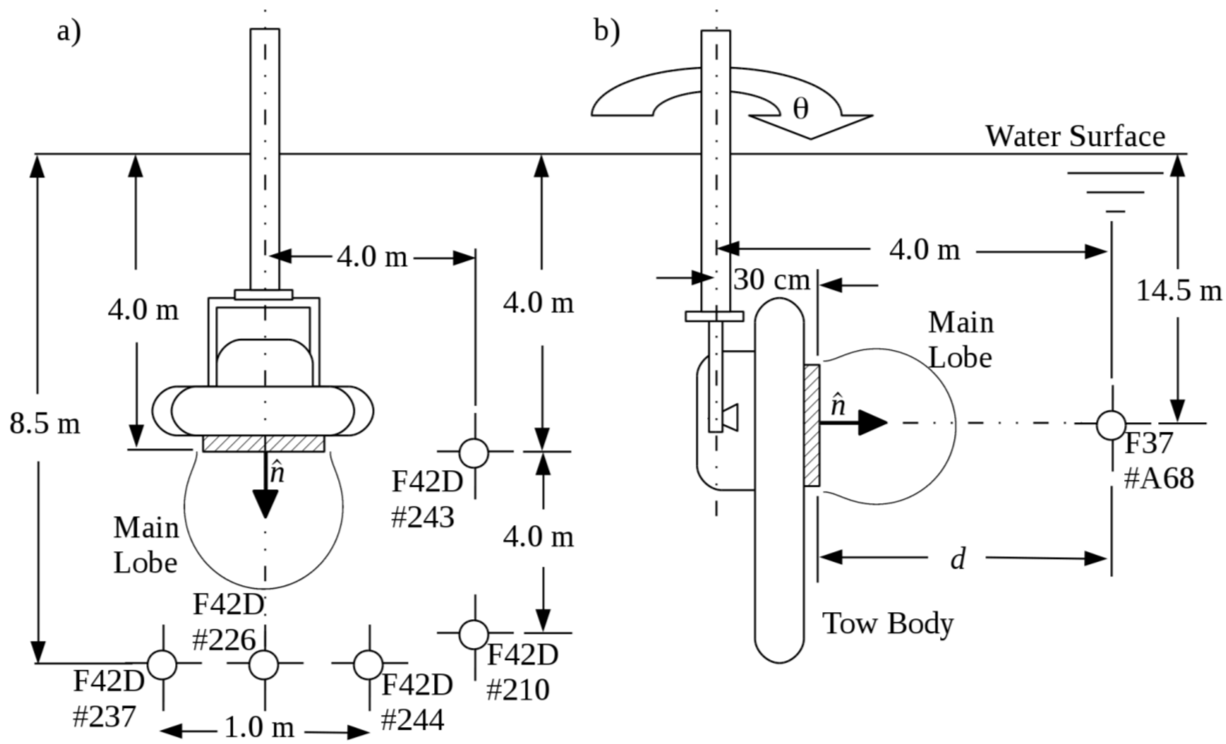


Figure 58. EdgeTech 512i Measurement Geometry

Two different tow bodies (S/N 35418 and 027076) were tested to assess the consistency of sounds radiated by the different transducers. While the source levels realized by both tow bodies were measured for a wide variety of waveform and transmit power settings, beam pattern measurements were performed only with S/N 35418.

The low-frequency acoustic performance of the tow bodies was not consistent. In particular, the low-frequency transducer in tow body S/N 027076 was either not functioning or was operating at greatly reduced power. Figure 59 compares the acoustic signals transmitted by the two systems. The illustrated signal was a 0.5- to 4.5-kHz frequency modulated waveform with a Gaussian envelope. The pulse width was 50 ms and the transmit power level was 100%. Figures 59a and 59b illustrate the time series and power spectrum of the signal transmitted by tow body S/N 35418. Figures 59c and 59d present the same information for tow body S/N 027076. The significant difference between the two time series is clearly evident by casual inspection of the respective figures. Whereas one source (S/N 35418) transmitted a waveform that was 50-ms long and included two distinct sub-pulses, the other (S/N 027076) transmitted only the latter half of the waveform. Inspection of the power spectra provides similar information where the double-peaked spectrum with a relative minimum at 2.6 kHz that was radiated by one source (S/N 35418) was missing from the other (S/N 027076). In addition, the harmonic content of the two signals were quite different with two harmonics clearly resolved in the spectrum radiated by tow body S/N 027076, but only a broad region of acoustic power with similar levels and total frequency extent evident in the signal radiated by S/N 35418.

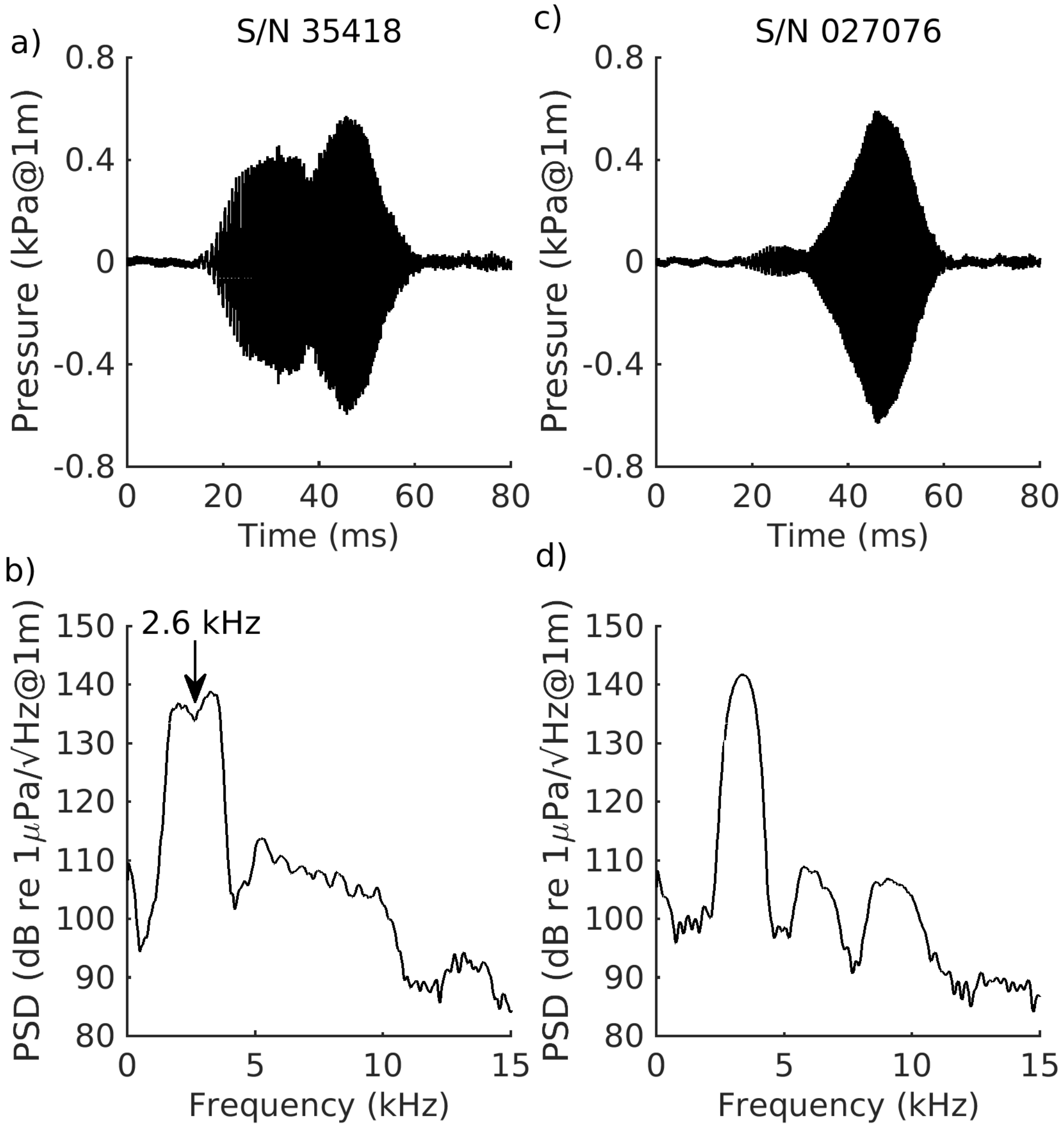


Figure 59. EdgeTech 512i Signal Comparison

Envelopes of the transmitted signals were also compared to more clearly elucidate differences between sounds radiated by the two tow bodies. The envelopes are presented as the magnitude of the analytic (complex) signal representations calculated using the *Hilbert Transforms* of the observed time series: a standard signal processing technique[1] for time series analysis. Figure 60 shows the signals were quite different until about 40 ms after which both tow bodies produced signals with nearly identical envelopes. Prior to 40 ms, the frequency content of the signal was less than 2.6 kHz and the larger, low-frequency transducer radiated most of the acoustic power. Beyond 40 ms, the frequency content of the signal exceeded 2.6 kHz and the acoustic output was radiated by the smaller, high-frequency transducer. Thus, the low-frequency transducer in tow body S/N 027076 was either not functioning or was transmitting at greatly reduced power.

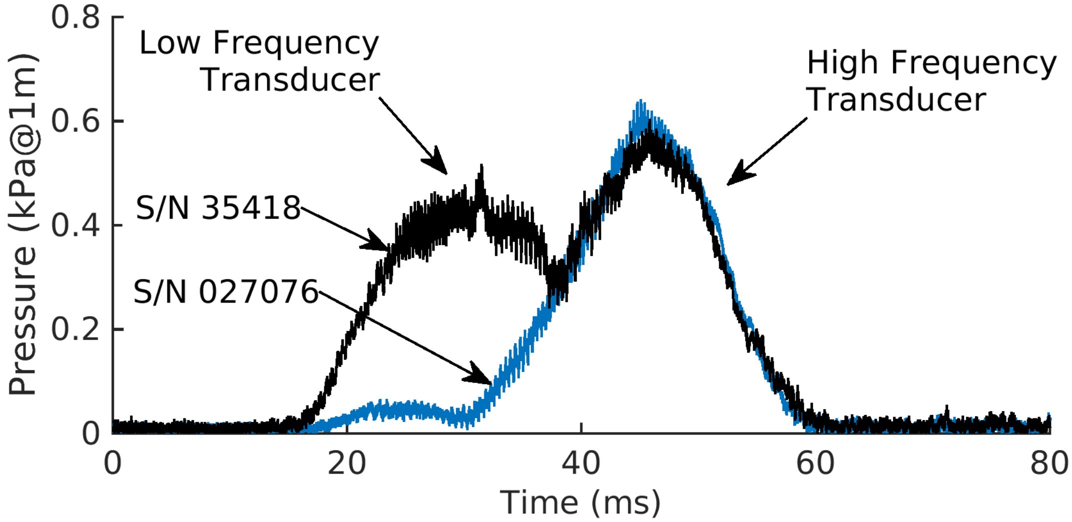


Figure 60. EdgeTech 512i Signal Envelopes

Acoustic characteristics of sounds radiated by the EdgeTech 512i are summarized in table 18 for S/N 35418 and table 19 for S/N 027076. A wide variety of waveform types and power settings were observed for both sources in order to facilitate comparison of sounds radiated by the two different tow bodies. As would be expected from the previous discussion, the source level of sounds transmitted by the two systems was most different for signals with significant low-frequency content. In the case of the example presented in figures 59 and 60, the signal was a 0.5- to 4.0-kHz frequency modulated sweep with 50-ms pulse width transmitted at the 100% power setting. The peak-to-peak, peak, and effective (rms) source levels were the same for both sources at 182, 176, and 170 dB re 1µPa@1m, respectively. However, the SEL produced by tow body S/N 027076 was 2 dB less–a direct result of the shorter effective pulse width (i.e., 14.9 versus 27.8 ms) generated without any significant contribution from the low-frequency transducer. Comparison of the source levels realized by the tow bodies for other waveform parameters indicates the levels were generally within 1 or 2 dB after discounting signals with significant low-frequency content.

The directional response, or beam patterns, for the EdgeTech 512i were measured as illustrated in figure 58b. As seen in the figure, the acoustic source was rigged to a rotator shaft such that the MRA was oriented in the horizontal plane where a stationary reference standard hydrophone was used to observe the acoustic field pressure as the source was rotated about the vertical axis. Eccentricity due to the horizontal offset between the axis of rotation and the acoustic center of the source was accounted for in the acoustic field calculations.

Table 18. EdgeTech 512i (S/N 35418) Source Level Summary

Source Settings			Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power (%)	Pulse Width (ms)	Bandwidth (kHz)	Pk-Pk	Pk	RMS	SEL		
50	40	1.0 to 6.0	182	176	170	152	15.0	3.2 to 4.4
50	5	1.0 to 10.0	182	176	172	145	2.0	4.0 to 7.7
50	20	2.0 to 12.0	183	177	173	152	9.0	5.7 to 8.9
50	40	0.4 to 4.0	177	172	165	149	25.4	1.1 to 2.1
50	100	0.5 to 2.2	178	173	166	152	42.3	1.2 to 1.9
50	50	0.5 to 4.5	176	170	164	149	27.9	2.4 to 3.6
50	9	0.5 to 6.0	181	175	169	145	3.9	2.8 to 4.7
50	20	0.5 to 7.0	184	178	171	153	14.4	3.3 to 5.5
50	30	0.5 to 7.2	182	176	171	151	11.6	3.3 to 4.8
50	5	0.5 to 8.0	184	176	171	143	1.9	2.7 to 6.2
50	20	0.7 to 12.0	183	177	172	152	9.0	5.2 to 8.6
75	40	1.0 to 6.0	185	179	174	155	14.4	3.2 to 4.4
75	5	1.0 to 10.0	186	180	175	148	2.0	4.0 to 7.7
75	20	2.0 to 12.0	187	181	176	156	9.1	5.7 to 9.0
75	40	0.4 to 4.0	183	178	169	153	25.6	1.1 to 1.8
75	100	0.5 to 2.2	182	176	170	156	40.2	1.3 to 1.8
75	50	0.5 to 4.5	179	173	167	152	27.8	2.4 to 3.4
75	9	0.5 to 6.0	186	181	173	148	3.7	2.7 to 4.7
75	20	0.5 to 7.0	187	182	175	157	14.7	3.4 to 6.0
75	30	0.5 to 7.2	186	180	174	155	11.2	3.4 to 4.9
75	5	0.5 to 8.0	186	180	174	147	1.8	2.7 to 6.3
75	20	0.7 to 12.0	187	181	176	156	9.0	5.2 to 8.6
100	40	1.0 to 6.0	189	183	176	158	14.4	3.2 to 4.5
100	5	1.0 to 10.0	188	182	178	151	2.0	4.0 to 7.7
100	20	2.0 to 12.0	190	184	179	159	9.1	5.7 to 9.0
100	40	0.4 to 4.0	188	184	172	156	25.2	1.0 to 1.9
100	100	0.5 to 2.2	187	181	175	160	35.7	1.4 to 1.8
100	50	0.5 to 4.5	182	176	170	154	27.8	1.8 to 3.6
100	9	0.5 to 6.0	190	185	175	151	3.6	2.7 to 4.8
100	20	0.5 to 7.0	191	186	178	159	14.6	1.8 to 6.0
100	30	0.5 to 7.2	191	184	177	157	11.3	3.3 to 5.2
100	5	0.5 to 8.0	191	184	177	150	1.8	2.8 to 6.6
100	20	0.7 to 12.0	189	183	179	158	9.0	5.2 to 8.6
* Wideband								

Table 19. EdgeTech 512i (S/N 027076) Source Level Summary

Source Settings			Source Level (dB re 1mPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power (%)	Pulse Width (ms)	Bandwidth (kHz)	Pk-Pk	Pk	RMS	SEL		
50	40	1.0 to 6.0	183	177	171	152	11.7	3.3 to 4.3
50	5	1.0 to 10.0	181	175	171	144	2.3	4.0 to 7.7
50	20	2.0 to 12.0	185	179	173	153	8.8	6.5 to 8.8
50	40	0.4 to 4.0*	174	168	162	143	12.7	2.8 to 3.5
50	100	0.5 to 2.7	162	156	146	134	65.8	1.2 to 1.6
50	50	0.5 to 4.5	176	170	165	147	15.5	3.0 to 3.8
50	9	0.5 to 6.0	182	176	171	145	2.3	2.3 to 5.2
50	20	0.5 to 7.0*	183	177	172	152	9.0	3.4 to 5.9
50	30	0.5 to 7.2	183	177	172	151	9.4	3.4 to 4.5
50	5	0.5 to 8.0	No Data					
50	20	0.7 to 12.0	184	178	173	152	9.1	5.8 to 8.8
75	40	1.0 to 6.0	186	180	175	155	11.9	3.3 to 4.3
75	5	1.0 to 10.0	185	179	174	148	2.2	4.1 to 7.9
75	20	2.0 to 12.0	188	182	177	156	8.8	6.3 to 8.9
75	40	0.4 to 4.0*	177	171	165	146	12.6	2.8 to 3.6
75	100	0.5 to 2.7	166	160	151	138	51.1	1.2 to 1.8
75	50	0.5 to 4.5	180	174	168	150	15.0	3.0 to 3.8
75	9	0.5 to 6.0	186	181	175	148	2.3	2.3 to 5.2
75	20	0.5 to 7.0*	187	182	176	155	8.9	3.4 to 5.6
75	30	0.5 to 7.2	187	181	175	155	9.5	3.4 to 4.5
75	5	0.5 to 8.0	186	180	174	147	1.7	2.5 to 6.2
75	20	0.7 to 12.0	187	181	176	156	9.1	5.7 to 8.6
100	40	1.0 to 6.0	189	183	177	158	11.8	3.3 to 4.3
100	5	1.0 to 10.0	187	181	177	150	2.2	4.1 to 7.9
100	20	2.0 to 12.0	191	185	180	159	8.7	6.3 to 8.9
100	40	0.4 to 4.0*	180	173	168	149	11.7	2.8 to 3.6
100	100	0.5 to 2.7	168	162	153	140	47.2	1.2 to 1.8
100	50	0.5 to 4.5	182	176	170	152	14.9	3.0 to 3.8
100	9	0.5 to 6.0	190	185	177	150	2.4	2.4 to 5.2
100	20	0.5 to 7.0*	190	184	178	157	8.9	3.4 to 5.5
100	30	0.5 to 7.2	189	183	177	157	9.4	3.4 to 4.7
100	5	0.5 to 8.0	189	183	177	149	1.7	2.5 to 6.2
100	20	0.7 to 12.0	190	184	179	158	9.0	5.9 to 8.7
* Wideband								

Two example beam patterns are provided in figure 61 where the effect of signal bandwidth is clearly illustrated. Note the sound was relatively more focused for the 2- to 12-kHz signal when compared to the 0.5- to 4.5-kHz signal as would be expected for a signal with more content at higher frequencies and shorter wavelengths. Thus, the directionality of a radiated signal is a function of both the source geometry and the signal content. Table 20 provides a summary of relevant beam pattern parameters for a variety of waveforms transmitted by the EdgeTech 512i.

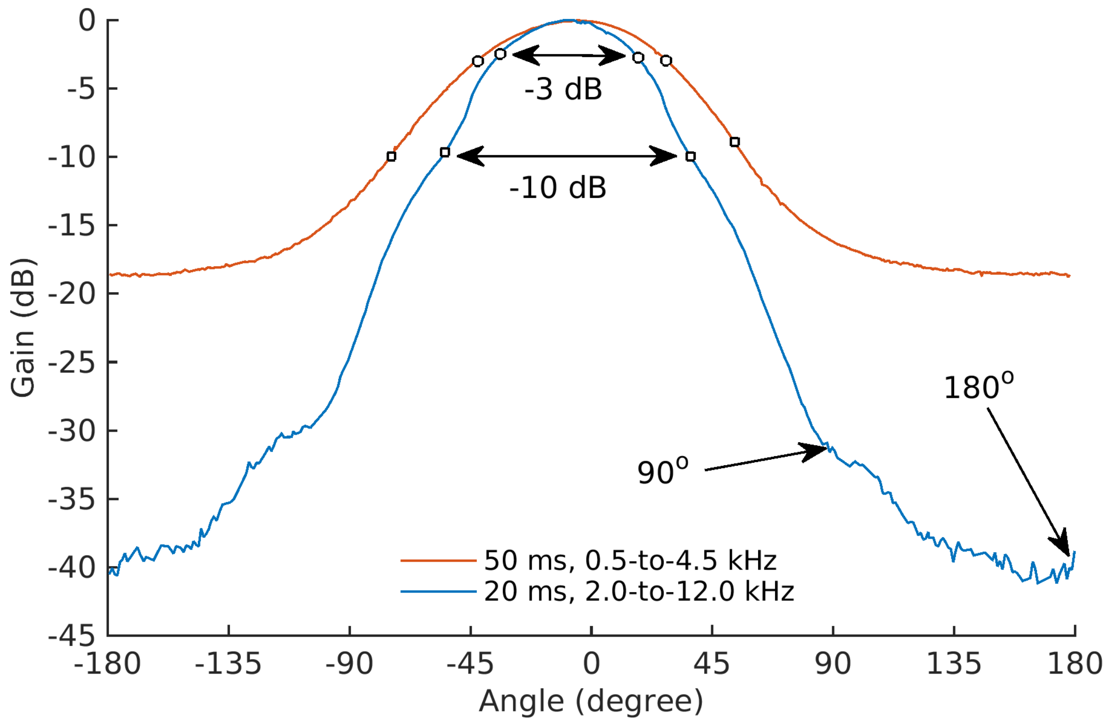


Figure 61. EdgeTech 512i (S/N 35418) Beam Pattern Examples

Table 20. EdgeTech 512i (S/N 35418) Beam Pattern Summary

Source Settings			Beamwidth (degrees)		Gain (dB)	
Power (%)	**Pulse Width (ms)**	**Bandwidth (kHz)**	**-3 dB**	**-10 dB**	**90°**	**180°**
100	20	2.0 to 12.0	51	91	-31	-40
100	40	1.0 to 6.0	66	112	-27	-31
100	5	1.0 to 10.0	65	110	-29	-32
100	20	0.7 to 12.0	60	99	-26	-29
100	5	0.5 to 8.0	70	108	-25	-26
100	30	0.5 to 7.2	71	112	-24	-26
100	20	0.5 to 7.0*	71	127	-20	-26
100	9	0.5 to 6.0	65	108	-23	-25
100	50	0.5 to 4.5	70	128	-16	-19
100	40	0.4 to 4.0*	80	153	-15	-20
100	100	0.5 to 2.7	74	150	-16	-22
* Wideband						

3.2.3 Knudsen 3202 Echosounder

The Knudsen Chrip Sounder is a sub-bottom profiling system that uses frequency modulated acoustic signals transmitted by one or more Massa TR-1075 tonpilz acoustic transducers to generate high-intensity, directional sound fields. The system includes a topside processor and amplifier that supply the drive voltage to each transducer. The TR-1075 transducer provides a TVR of about 150 dB re 1µPa/V@1m with a power rating of 600 W for a 30% duty cycle, or 200 W for continuous duty. Two transducers were tested, S/N 3217 and a second transducer for which the serial number was obscured and unreadable.

The source level and beam patterns of the Knudsen sub-bottom profiling system were measured at LEFAC on 2 March 2015. The measurements were performed in favorable weather conditions with an average air temperature of 22°C and a wind speed of about 2 m/s. Two transducers were mounted to a custom bracket that interfaced with the test facility rotator assembly as illustrated in figure 62.

Figure 63 illustrates the measurement geometry. The arrangement was typical of that used for the measurement of beam patterns of acoustic transducers with the exception of a slight offset of the acoustic centers of the sources relative to the axis of rotation. While the offsets were small relative to the source-receiver distance, they were included in the calculations nonetheless. Acoustic data were collected using a Navy Type F37 (S/N A68) calibrated reference standard hydrophone. Sounds radiated by the TR-1075 transducers and the angle of rotation of the transducers were recorded simultaneously. Signals were sampled at 250 kHz with

16-bits of precision. The Knudsen topside processor neither provided nor accepted an external trigger as needed to synchronize the data collection windows with the transmitted signals. Therefore, an F42D hydrophone was affixed to the transducer mounting bracket to provide a signal from which a trigger was synthesized and provided to the data acquisition system.

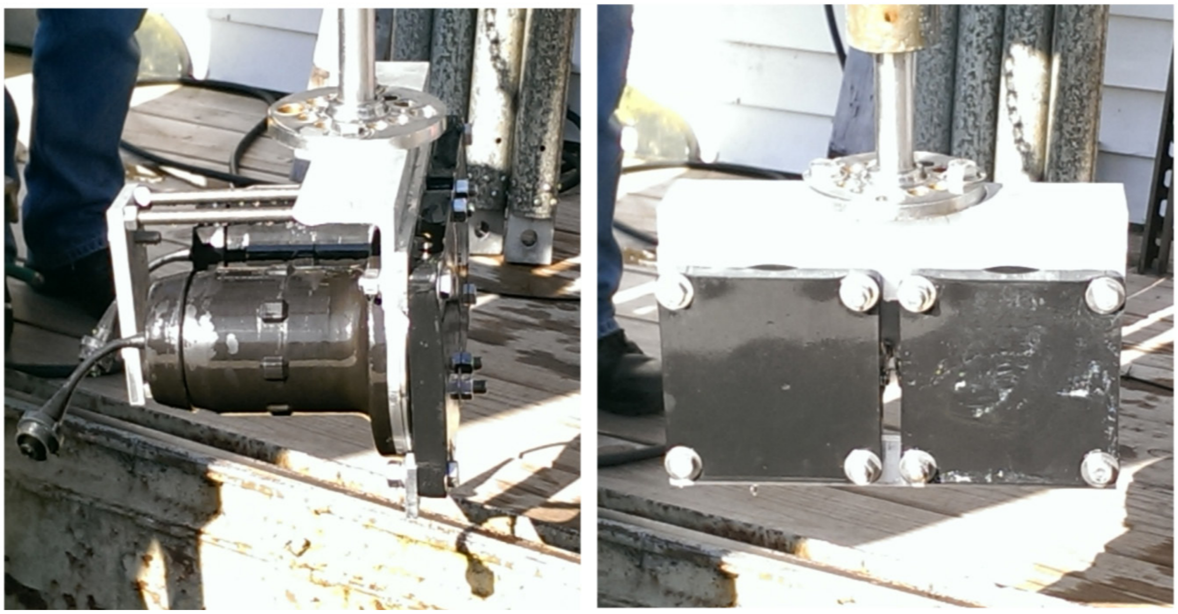


Figure 62. Massa TR-1075 Sub-Bottom Profiling Transducers

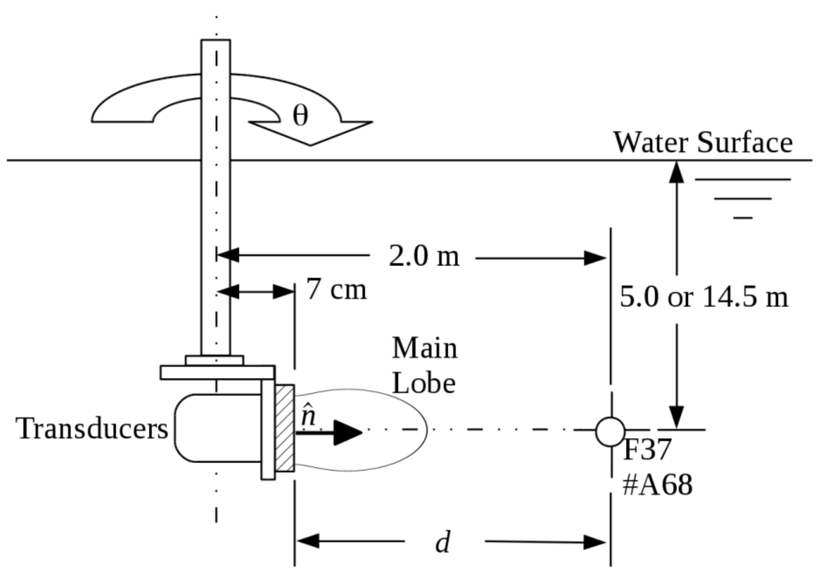


Figure 63. Knudsen Measurement Geometry

Figure 64a illustrates a typical acoustic waveform transmitted by a single TR-1075 transducer (S/N 3217) at power setting 4 (i.e., maximum power) and 8-ms pulse width. Data samples from which the peak and peak-to-peak source levels were computed are indicated with markers. The part of the waveform in which 90% of the radiated acoustic energy was located and used to calculate the effective (rms) source level and SEL is indicated in red. The source spectrum is provided as figure 64b where the 3-dB bandwidth is indicated with markers. Note the source spectrum was calculated using the same part of the waveform as was used for the effective source level (i.e., 90%) where the effective pulse width was 5.2 ms. The peak-to-peak, peak, and effective source levels were 212, 206, and 201 dB re 1μPa@1m, respectively. The half-power bandwidth extended from 3.2 to 5.5 kHz.

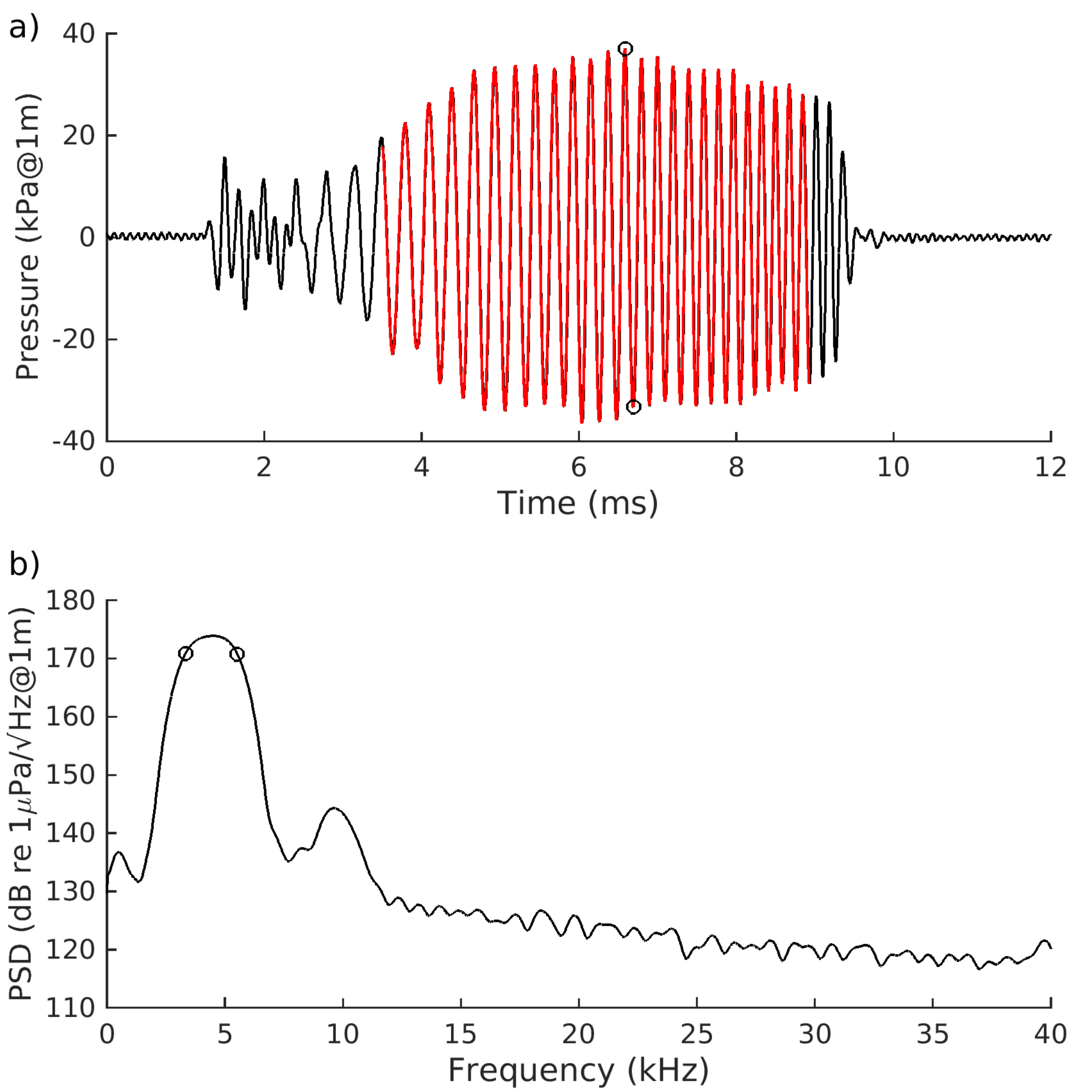


Figure 64. Knudsen Signal Example–Power Setting 4 with 8-ms Pulse Width

Acoustic characteristics of sounds transmitted using a single TR-1075 transducer (S/N 3217) are provided as table 21. The effective source level varied from 199 to 208 dB re 1µPa@1m for power settings 1 through 4 and were generally independent of pulse width. The acoustic characteristics of sounds transmitted by two TR-1075 transducers operated in tandem are provided as table 22 where the effective source level increased by 2 to 3 dB relative to the source levels achieved by a single transducer.

Table 21. Acoustic Characteristics Summary for Knudsen (Single Transducer)

Source Settings		Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power Setting	Pulse Width (ms)	Pk-Pk	Pk	RMS	SEL		
4	32	217	211	207	190	22.2	3.4 to 5.5
4	16	217	212	207	187	11.0	3.3 to 5.4
4	8	217	211	207	184	5.4	3.4 to 5.7
4	4	218	212	208	182	2.6	2.3 to 6.9
4	2	217	212	208	179	1.3	2.3 to 6.8
4	1	217	212	208	177	0.8	0.0 to 8.7
3	32	216	210	205	188	22.0	3.4 to 5.4
3	16	215	209	204	185	11.2	3.3 to 5.4
3	8	216	210	205	183	5.3	3.5 to 5.8
3	4	215	209	205	180	2.7	3.5 to 6.3
3	2	215	210	205	177	1.3	2.3 to 7.0
3	1	216	210	205	174	0.7	0.0 to 8.8
2	32	215	209	204	187	22.0	3.4 to 5.7
2	16	214	208	204	184	10.9	3.5 to 5.7
2	8	214	208	204	181	5.5	3.4 to 5.8
2	4	214	208	204	178	2.7	3.1 to 5.7
2	2	214	208	204	175	1.4	2.2 to 6.6
2	1	214	208	204	173	0.8	1.5 to 8.1
1	32	210	204	199	183	22.1	3.5 to 5.4
1	16	210	204	199	180	11.2	3.4 to 5.4
1	8	210	204	199	177	5.8	3.3 to 5.6
1	4	210	204	199	174	3.1	3.1 to 5.8
1	2	210	204	199	171	1.7	2.5 to 6.3
1	1	210	204	199	169	0.9	0.0 to 7.9

Table 22. Acoustic Characteristics Summary for Knudsen (Two Transducers)

Source Settings		Source Level (dB re 1µPa@1m)				Pulse Width (ms)	Bandwidth 3 dB (kHz)
Power Setting	Pulse Width (ms)	Pk-Pk	Pk	RMS	SEL		
4	32	220	214	209	193	21.7	3.3 to 5.7
4	16	220	214	210	190	10.8	3.3 to 5.5
4	8	220	214	210	187	5.3	3.3 to 5.5
4	4	220	214	210	184	2.8	3.1 to 6.0
4	2	220	214	210	181	1.4	2.1 to 6.5
4	1	220	214	210	178	0.7	0.0 to 8.7
3	32	217	211	207	190	21.5	3.3 to 5.4
3	16	217	211	207	187	10.8	3.4 to 5.7
3	8	217	211	207	184	5.3	3.3 to 5.7
3	4	217	211	207	181	2.7	3.0 to 5.7
3	2	217	211	207	178	1.3	2.2 to 6.8
3	1	217	211	207	175	0.7	0.0 to 8.9
2	32	216	210	205	189	21.6	3.4 to 5.7
2	16	215	210	206	186	10.7	3.4 to 5.4
2	8	216	210	206	183	5.3	3.4 to 5.7
2	4	216	210	206	180	2.7	3.1 to 5.9
2	2	216	210	206	177	1.4	2.1 to 6.6
2	1	216	210	205	174	0.9	1.3 to 8.0
1	32	213	207	202	185	21.8	3.6 to 5.7
1	16	213	207	202	182	10.9	3.6 to 5.6
1	8	213	207	202	179	5.4	3.5 to 5.4
1	4	213	207	202	176	2.7	3.2 to 5.7
1	2	212	207	202	173	1.4	2.1 to 6.8
1	1	212	206	202	171	0.8	0.0 to 8.7

Example beam patterns measured for one and two TR-1075 transducers are provided as figure 65 for waveforms transmitted at a power setting 4 and a pulse width of 4 ms. The observed half-power (i.e., -3 dB) beamwidths for single and double transducer transmissions were 77° and 38°, respectively. A summary of beam pattern parameters for the Knudsen sub-bottom profiling system are provided as table 23 where the directivity of the system varied only with additional acoustic transmit aperture provided by the second transducer.

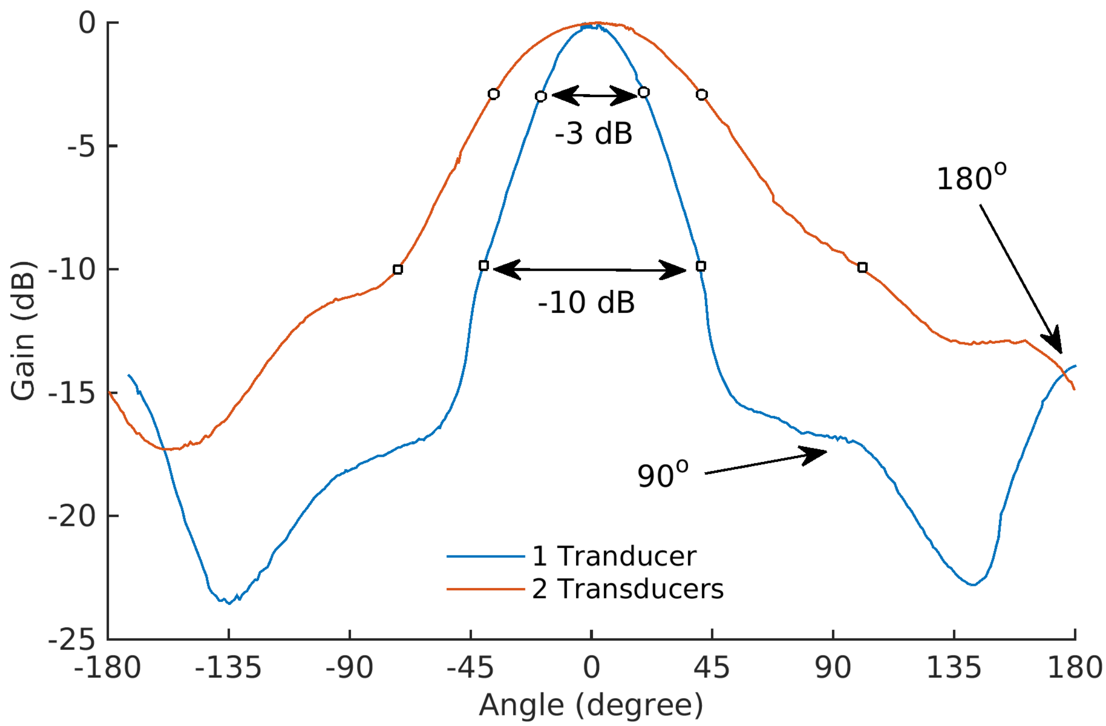


Figure 65. Knudsen Sub-Bottom Profiling System Beam Patterns

Table 23. Knudsen Sub-Bottom Profiling System Beam Pattern Summary

Source Settings		Beamwidth (degrees)		Gain (dB)	
Pulse Width (ms)	**Transducers (1 or 2)**	**-3 dB**	**-10 dB**	**90°**	**180°**
2	1	79	171	-10	-15
4	1	77	173	-9	-15
8	1	82	187	-8	-15
16	1	83	192	-8	-14
32	1	78	196	-8	-15
2	2	38	80	-17	-14
4	2	38	81	-17	-14
8	2	36	81	-18	-14
16	2	40	82	-16	-14
32	2	41	82	-17	-14

4. SEA FLOOR MAPPING SYSTEMS

Sea floor mapping systems, including multibeam bathymetric echosounders, interferometers, and side scan sonars, employ acoustic sources that generate more complex beam patterns that lack the simple axial symmetry of strictly downward-looking devices such as sub-bottom profilers and single-beam echo sounders. These sea floor mapping systems scan a wide swath on either side of the ship's track using a transmit beam that is broad in the across-track direction and narrow in the along-track direction as shown in figure 66. Each transmission of the sonar system is processed to form a line scan of the sea floor bathymetry on either side of the ship's track with multiple sequential lines combined to form a sea floor map. Thus, the greatest acoustic intensities associated with operation of these systems may span a significant distance in the across-track direction, but they are confined to a narrow swath in the along-track direction as seen in figure 66. These systems achieve the desired distribution of acoustic energy by use of linear or rectangular transmit apertures to focus sound as required by the application.

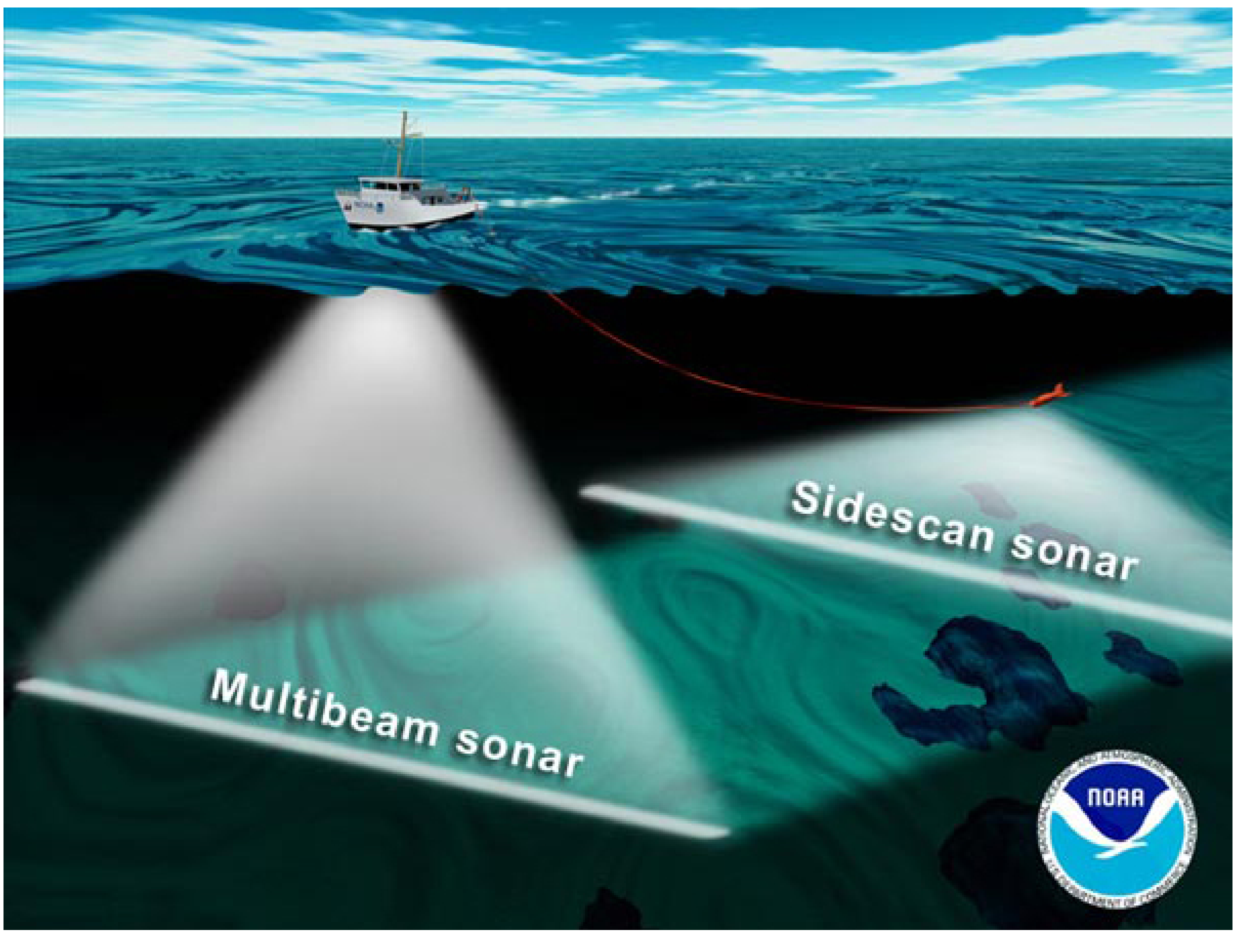


Figure 66. Multibeam and Side-Scan Sea Floor Mapping Systems

4.1 BATHYOMETRIC ECHOSOUNDERS

Transmit arrays for multibeam and swath bathymetry survey systems are shown in figure 67 as each was rigged for source level and beam pattern measurements. The transmit array for the Reson SeaBat T20P multibeam echosounder is shown in figure 67a as it was mounted to the flange coupling at the foot of the rotator shaft. Transmit arrays for the Bathyswath SWATHplus-M interferometer sonar and Reson 7111 multibeam echosounder are shown in figures 67b and 67c as each was being prepared for measurements.

Figure 67b illustrates the geometry used to define the measurement planes for the multibeam and swath bathymetry sonar source arrays. As seen in the figure, the sources were attached to the rotator coupling using an adapter that maintained the system in an orientation for projection of the main beam in the horizontal direction. The first measurement plane is defined as the plane that contains both the major axis and the outward normal vector, $\hat{n}$, at the aperture face. Beam pattern measurements in this plane correspond to the along-track direction when in operational use. Details for the measurement geometry are provided in figure 68 where the source-receiver separation was 10 m, the practical maximum that could be achieved with the 30 m reference hydrophone cable length. This facility limitation resulted in the collection of acoustic data at distances that were, in some cases, somewhat less than optimal as the measurements did not always satisfy the acoustic far field requirement of reference 2.

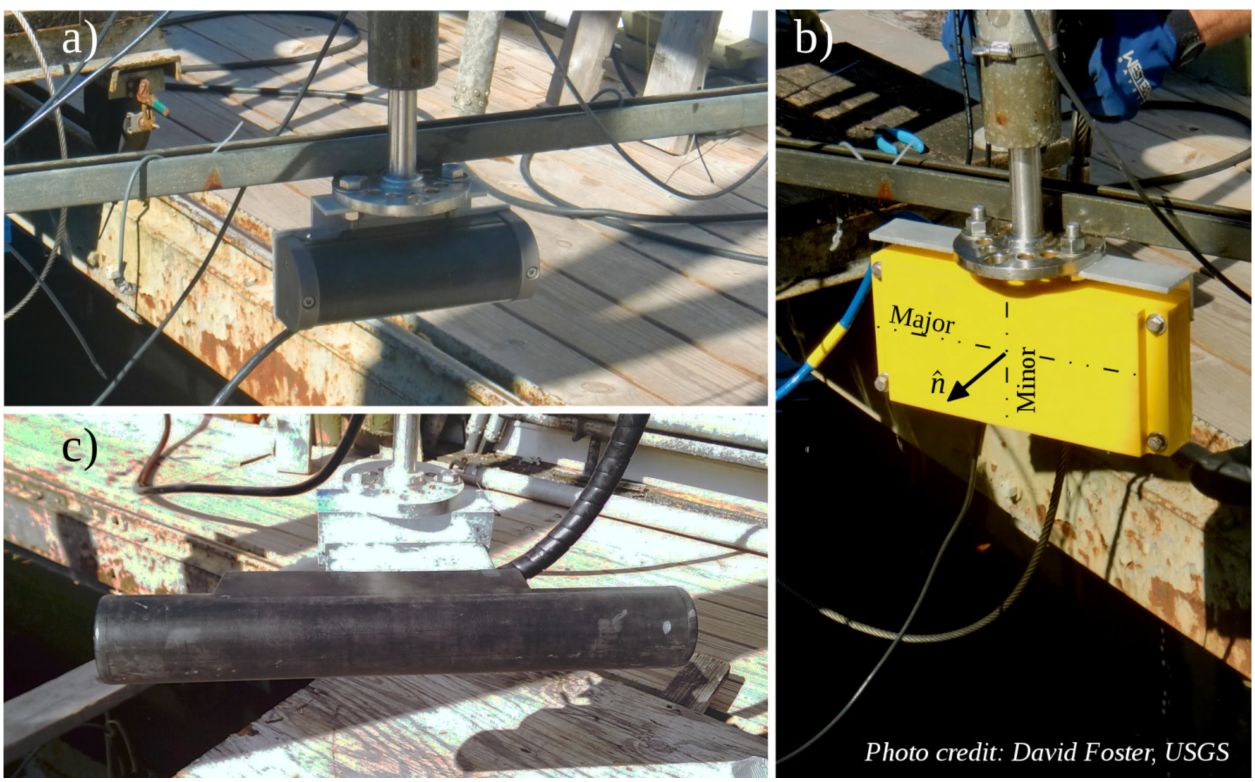


Figure 67. Multibeam and Swath Bathymetry Sonars Rigged for Measurement

Acoustic data were observed using three Navy Type E27 high-frequency hydrophones arranged in a horizontal line as shown in figure 68b where the hydrophones spanned a total length of 27 cm. This arrangement provided three observations spaced at 0.5° for each transmitted waveform, thus providing for improved angular resolution and better characterization of the main beamwidths for these sources.

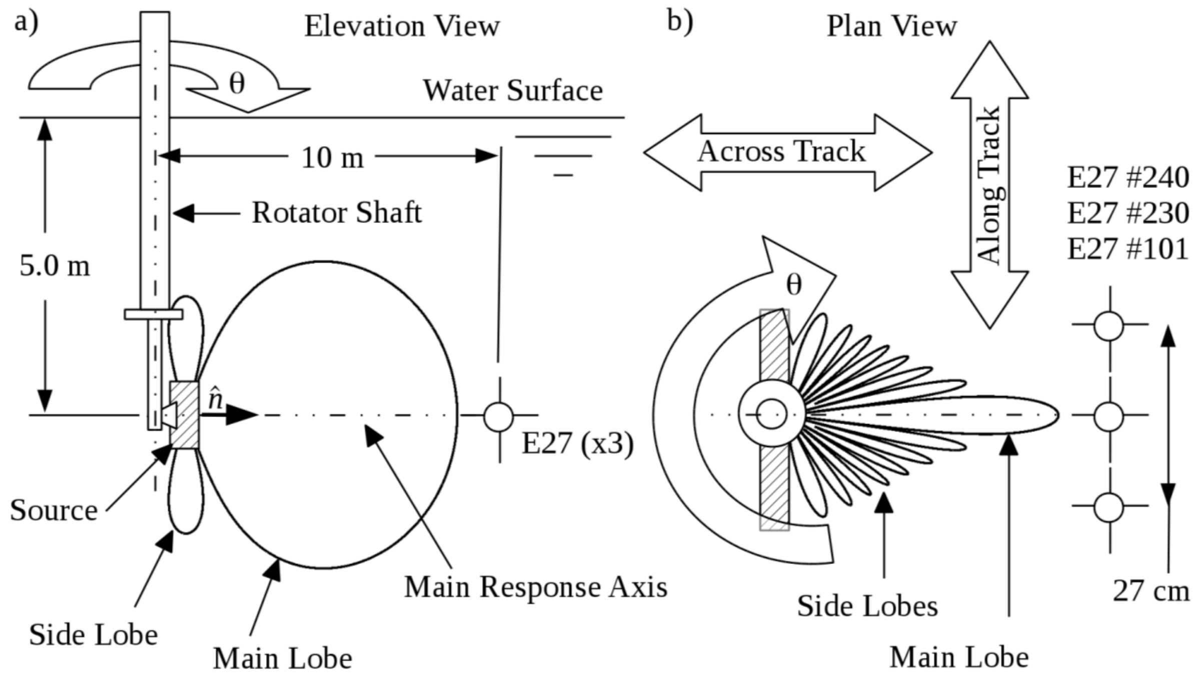


Figure 68. Multibeam Sonar Measurement Geometry (LEFAC)

The second measurement plane contained both the minor axis and the outward normal vector. The beam patterns measured in this plane correspond to the across track direction. Measurement of the transmit beam pattern in this plane containing the outward normal vector and minor axis of the aperture is shown in figure 69. Note the acoustic source is shown rotated about the outward normal vector by 90° relative to figure 68 such that the major axis was oriented vertically. Note that measurements performed in this plane required precise control over the measurement geometry to keep the narrow main beam oriented toward the reference standard hydrophone. Therefore, these measurements were performed in the OTF in Newport where the facility provides for more precise control than is available on the floating test platform in Leesburg. However, the source-receiver separation in the OTF was only 2 m, which was well short of the farfield distance prescribed by reference 1–a necessary compromise to facilitate observation of the across-track beam pattern.

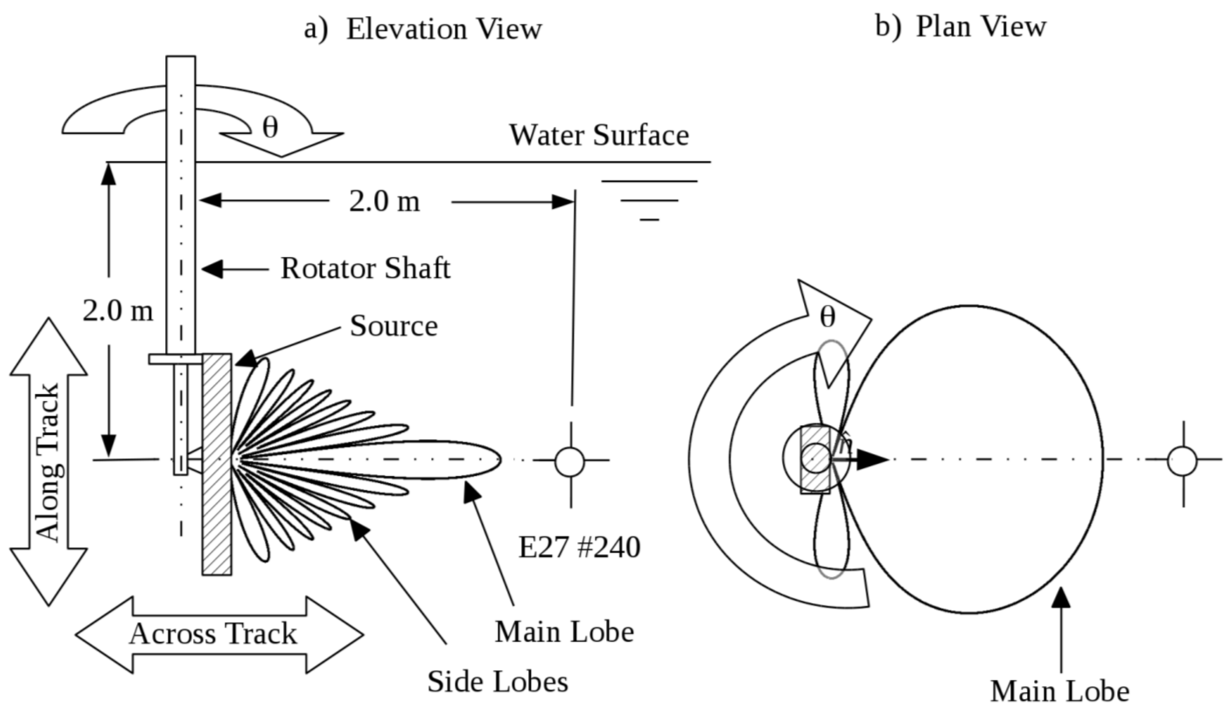


Figure 69. Multibeam Sonar Measurement Geometry (OTF)

4.1.1 Reson Seabat 7111 Multibeam Echosounder System

The Reson Seabat 7111 multibeam echosounder employs a single-frequency source that transmits at 100 kHz using an acoustic aperture of 49 cm. The system generates a variety of operator selectable waveforms with various pulse widths and source levels. The system also provides operator selectable (along-track) beamwidths of 1.5°, 3.0°, and 6.0°.

Figure 67c shows the transmit array rigged for measurement of the along-track beam patterns by mounting to the foot of the rotator assembly stringer. The measurement geometry is illustrated in figure 68. The measurement geometry for waveform characterization and along-track beam patterns satisfied the source-receiver requirement articulated by equation (1) (see reference 2) where the source-receiver separation was 14.7 m while the estimated distance to the acoustic farfield was 13 m.

Figure 70a shows an example of a 100-kHz continuous wave signal with a pulse width of 1.5 ms and an along-track beamwidth of 3.0°. The associated power spectral density is provided as figure 70b. The figure shows five harmonics were clearly resolved in the acoustic data as indicated by the vertical lines at frequencies greater than the transmit frequency. The locations of sub-harmonic frequencies are likewise indicated by vertical lines at frequencies less than 100 kHz where no sub-harmonics of the transmit frequency were detected.

Figure 70c illustrates the along-track beam pattern observed for a 1.5-ms waveform with 3° beamwidth. The measured 3-dB width of the transmitted signal was 2.6°, and the first sidelobe was about 15 dB down from the main beam level and located at a 7° angle. The source produced a complex set of sidelobes at angles ranging from forward to aft (with respect to the track line) as expected for a high-frequency source with significant aperture length (with respect to an acoustic wavelength). This result was consistent among all of the pulse widths where the main beamwidth was 2.6 ±0.2° and the first sidelobe was 15 dB down. Beamwidths observed for signals transmitted with the 6.0° setting were 5.2 ±0.2°. No difference was observed between the observed and selected beamwidth at 1.5°. The first sidelobes were 14 to 15 dB down.

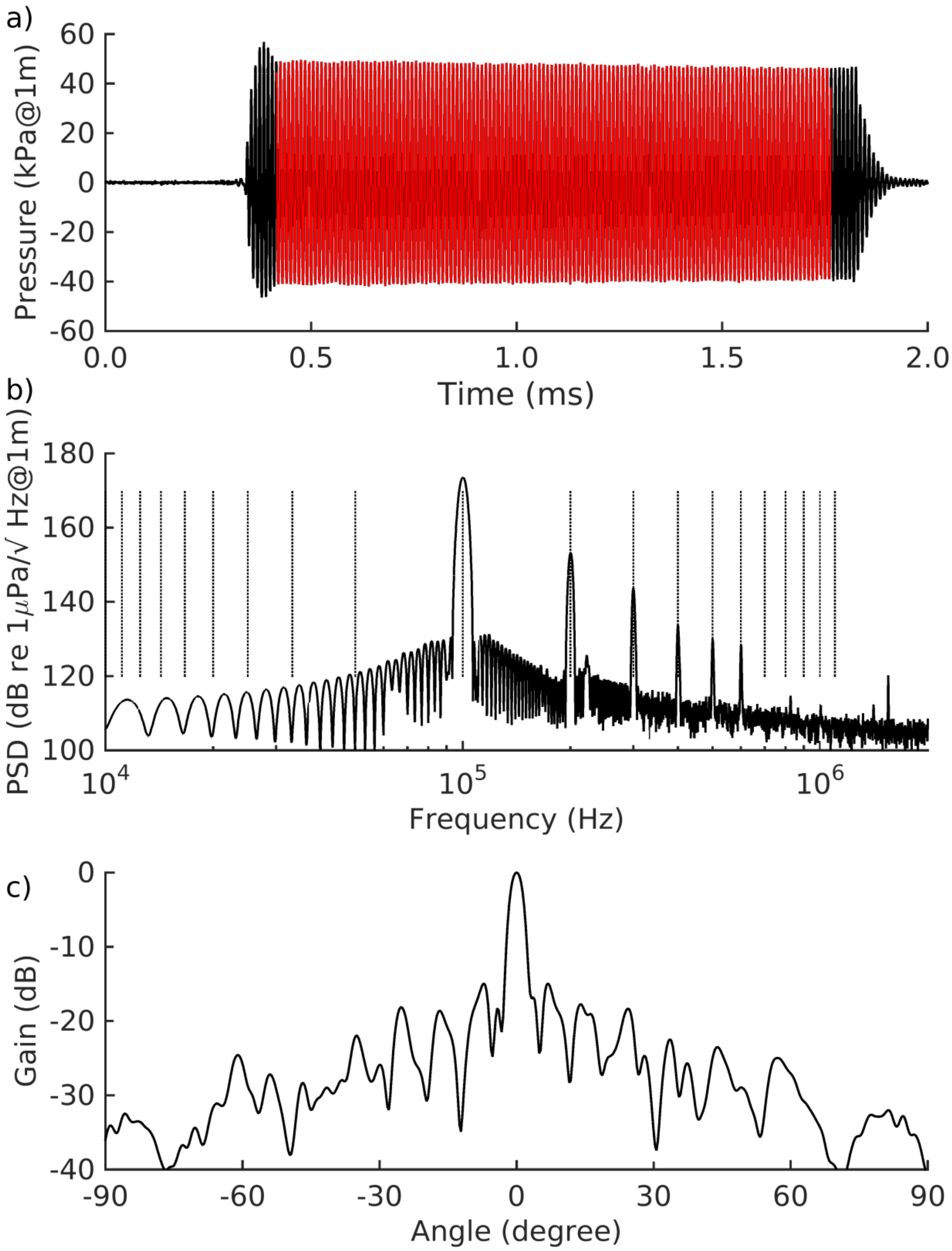


Figure 70. Reson Seabat 7111 Waveform 230 dB re 1µPa@1m, 1.5 ms, 3.0° Beamwidth

Figure 71 illustrates the across-track beam patterns observed for a pulse width of 0.17 ms in the OTF. The geometry employed for these measurements is shown in figure 69. These measurements were performed in the OTF because observation of the across-track beam required more precise control over the measurement geometry than could be achieved on the floating test platform at Leesburg. The measurements were performed with a source-receiver separation of only 2 m, considerably less than the desired distance. While a longer measurement distance was preferred, the shorter distance was a compromise required to maintain the narrow along-track beam oriented toward the reference hydrophone as shown by figure 69. The 3- and 10-dB beamwidths were about 160° and 200°, respectively.

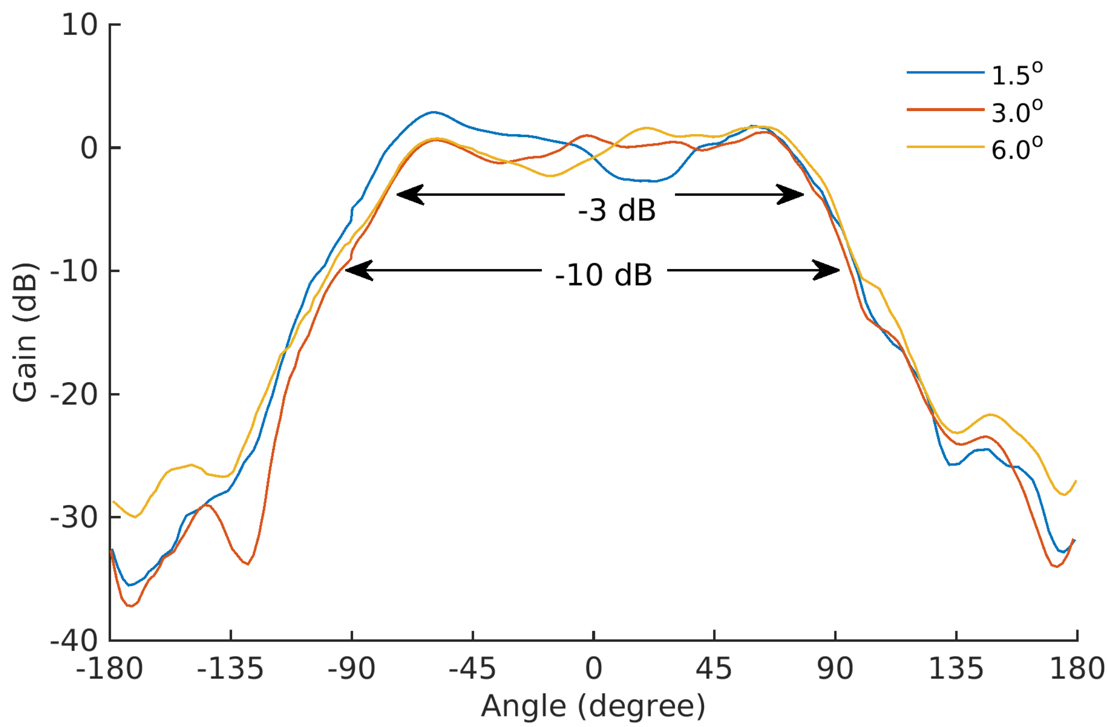


Figure 71. Reson Seabat 7111 Across Track Beam Patterns

Table 24 provides a summary of the observed waveform characteristics. User selectable waveform parameters include source level, pulse width, and transmit beamwidth. The observed source levels were within 2 dB of the operator selected level when the transmit beamwidth selection was set to 1.5°. However, the observed source level decreased by about 6 dB for each doubling of beamwidth (i.e., 3° and 6°). The observed sources levels were generally independent of pulse width for equal transmit beamwidth.

Table 24. Reson Seabat 7111 Waveform Characteristics

Source Settings			Source Level (dB re 1µPa@1m)				Effective Pulse Width (ms)
Source Level (dB)	Pulse Width (ms)	Beamwidth (deg)	Pk-Pk	Pk	RMS	SEL	
230	0.17	1.5	233	228	224	185	0.15
230	0.17	3.0	228	222	218	179	0.15
230	0.17	6.0	221	215	211	173	0.15
230	1.5	1.5	233	227	223	195	1.35
230	1.5	3.0	227	221	218	189	1.35
230	1.5	6.0	220	214	211	182	1.35
230	3.0	1.5	233	227	223	197	2.68
230	3.0	3.0	226	220	217	191	2.69
230	3.0	6.0	No Data				
215	0.17	1.5	220	214	211	172	0.15
215	0.17	3.0	214	208	205	166	0.15
215	0.17	6.0	208	202	197	159	0.15
215	1.5	1.5	220	214	210	181	1.34
215	1.5	3.0	214	208	204	176	1.34
215	1.5	6.0	208	202	198	169	1.45
215	3.0	1.5	220	214	210	184	2.69
215	3.0	3.0	214	208	204	179	2.70
215	3.0	6.0	208	202	198	172	2.70
200	0.17	1.5	206	200	196	158	0.16
200	0.17	3.0	201	196	190	152	0.16
200	0.17	6.0	197	191	184	146	0.16
200	1.5	1.5	206	200	196	167	1.35
200	1.5	3.0	201	195	190	161	1.37
200	1.5	6.0	198	192	184	155	1.46
200	3.0	1.5	206	200	196	170	2.72
200	3.0	3.0	203	197	190	164	2.76
200	3.0	6.0	200	194	184	159	2.95

4.1.2 Reson Seabat T20P Multibeam Echosounder System

The Reson Seabat T20P multibeam echosounder is a multiple frequency source with transmit center frequencies of 200, 300, and 400 kHz with an acoustic aperture of 28 cm. The system generates a variety of operator selectable waveforms with various pulse widths, power levels, and center frequencies for both continuous wave and frequency modulated waveforms.

Figure 72a shows the transmit array for the T20P rigged for measurement of the along-track beam patterns by mounting to the foot of the rotator assembly stringer. Also shown in the figure is a crossbar mounted above the tow body with two Navy Type F42D hydrophones affixed to either end. These hydrophones were included in the test setup to provide a redundant source of rotation angle data using an out-of-band acoustic signal to estimate the rotation angles using phase differences between the hydrophones. The measurement geometry is illustrated in figure 68.

Measurement geometry for waveform characterization and along-track beam patterns satisfied the source-receiver requirement articulated by equation (1) (see reference 2) for the 200-kHz waveform where the estimated distance to the acoustic farfield was 8 m. The measurement geometry fell short of the desired distances of 12 and 16 m for the 300- and 400-kHz waveforms, respectively. While it is unlikely the non-optimum measurement geometry for the 300- and 400-kHz signals introduced significant error in the measured source levels, it may have influenced the off-axis measurements (reference 15) and sidelobe levels that were observed.

Figure 72a shows an example of a 200-kHz continuous wave signal with a pulse width of 300 μs. The associated power spectral density is provided as figure 72b. As shown in these figures, the transmit waveforms included tapers at the leading and trailing edges. The first two harmonics were clearly resolved in the acoustic data as indicated by the vertical lines at frequencies greater than the transmit frequency in figure 72b. The locations of sub-harmonic frequencies are likewise indicated by vertical lines at frequencies less than 200 kHz where no sub-harmonics of the transmit frequency were detected.

Figure 72c illustrates the along-track beam pattern observed for the 200-kHz waveform where the 3-dB width of the transmitted beam was 1.9° and the first sidelobe was about 19 dB down from the main beam level and located at a 6° angle. The source produced a complex set of sidelobes at angles ranging from forward to aft (with respect to the track line) as expected for a high-frequency source with significant aperture length (with respect to an acoustic wavelength). This result was consistent with the continuous wave signals at all transmit frequencies where the main beam width was 1.8 ±0.2° and the first sidelobe was 19 dB down.

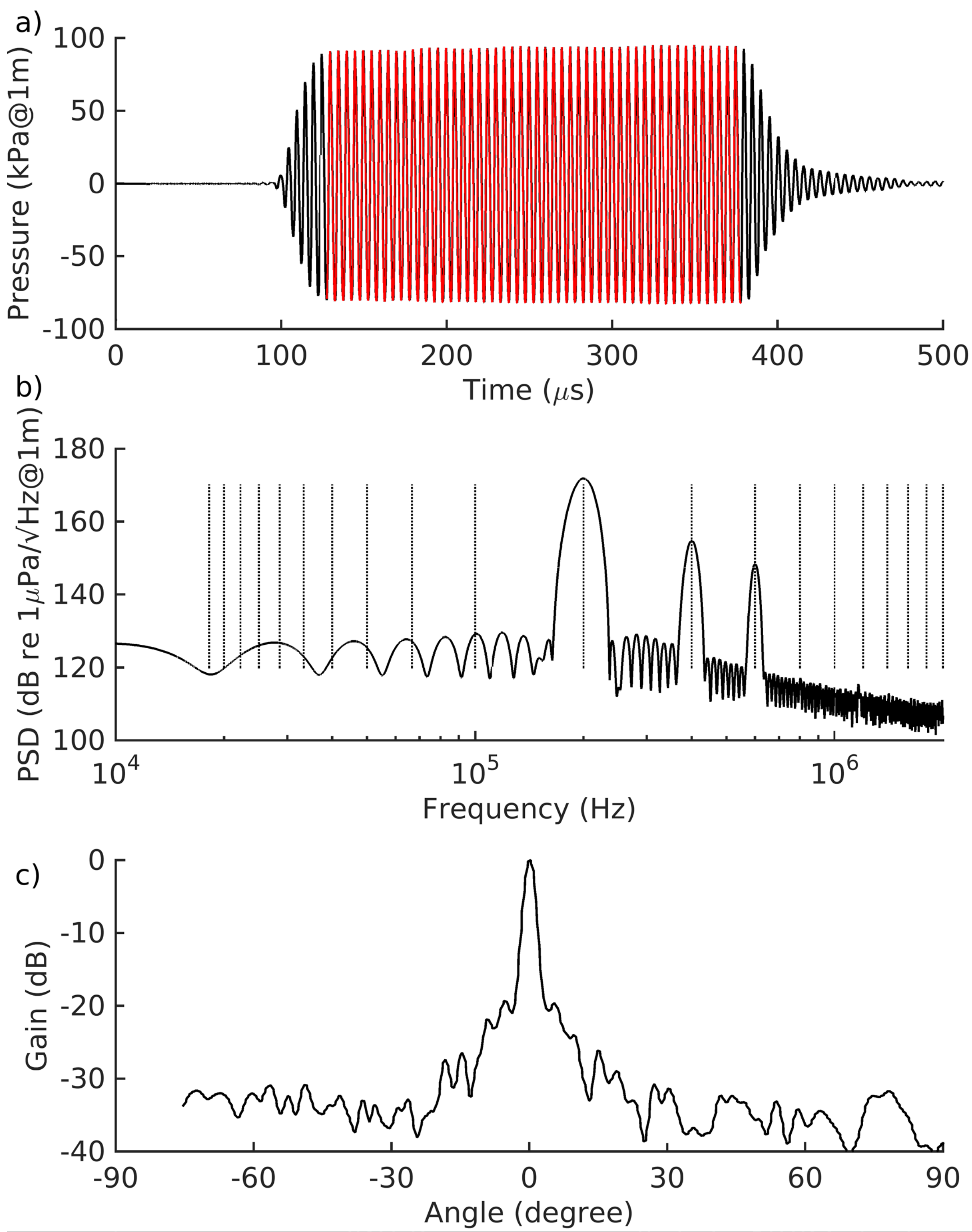


Figure 72. Reson T20P CW Waveform, 200 kHz, 300us, 220 dB re 1µPa@1m

Figure 73 illustrates the across-track beam patterns observed at 200 and 300 kHz in the OTF. The geometry employed for these measurements is shown in figure 69. These measurements were performed in the OTF because observation of the across-track beam required more precise control over the measurement geometry than could be achieved on the floating test platform at Leesburg. The measurements were performed with a source-receiver separation of only 2 m, considerably less than the desired distance. While a longer measurement distance was preferred, the shorter distance was a compromise required to maintain the narrow along-track beam oriented toward the reference hydrophone as shown in figure 69. The 3- and 10-dB beamwidths were about 150° and 180°, respectively. The first sidelobes were located at ±140° off the MRA and were about 25 dB down relative to levels on the main beam.

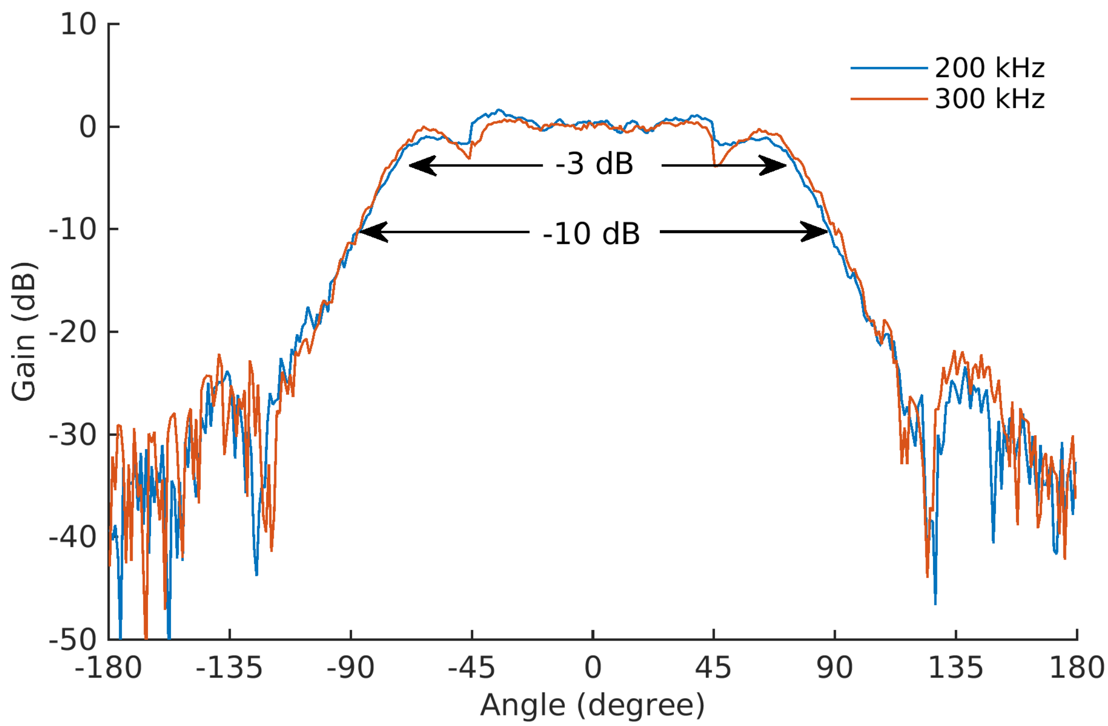


Figure 73. Reson T20P Across Track Beam Patterns

User selectable output power levels for the T20P are provided as source level. Measurements were performed at three user settings including 220, 205, and 190 dB re 1µPa@1m. The observed source levels for the T20P varied slightly from the source levels indicated where the greatest difference was noted at the lowest source level setting. For example, at 300 kHz the observed (rms) source levels were 221, 205, and 185 dB re 1µPa@1m. Results at other operating frequencies were similar. Source level measurements for all three transmit frequencies are summarized in table 25.

Table 25. T20P Waveform Characteristics–Continuous Wave

Source Settings			Source Level (dB re 1µPa@1m)				Effective Pulse Width (µs)
Freq. (kHz)	Source Level (dB)	Pulse Width (µs)	Pk-Pk	Pk	RMS	SEL	
200	220	300	226	221	218	182	250
200	205	300	213	208	204	168	248
200	190	300	193	187	184	150	254
300	220	300	232	227	221	185	253
300	205	300	215	210	205	169	252
300	190	300	197	191	185	149	254
400	220	300	229	223	220	184	254
400	205	300	214	208	204	168	257
400	190	300	197	191	185	150	269

The T20P also provides a set of FM waveforms with pulse widths ranging from 1 to 10 ms. Figure 74a shows the time series for a frequency modulated waveform with a center frequency of 200 kHz transmitted at 220 dB re 1µPa@1m with a pulse width of 2 ms. The waveform tapers are evident as is a somewhat variable pressure amplitude throughout the duration of the waveform. As was the case for the continuous wave signals, the FM waveforms showed the first two harmonics clearly resolved but no evidence of sub-harmonic content (see figure 74b). Significant properties of the beam patterns were also similar where the 3-dB width of the mainlobes were 1.5 ±0.5° and the first sidelobe was 20 to 23 dB down.

Source level observations for select FM waveforms are tabulated in table 26. Differences between the user selected and the effective source levels were somewhat greater than was noted for the continuous wave signal due in large part to the non-steady waveform amplitude observed in the FM signals. Signals with pulse widths greater than 6 ms were not included in the tabulation due to crosstalk between the electrical transmit signals provided to the T20P transducer and the hydrophone signals. While the crosstalk was also present for waveform pulse widths of 6 ms (and less), the crosstalk and hydrophone signals were resolved in time by the source-receiver travel time, thus the received acoustic data were not contaminated.

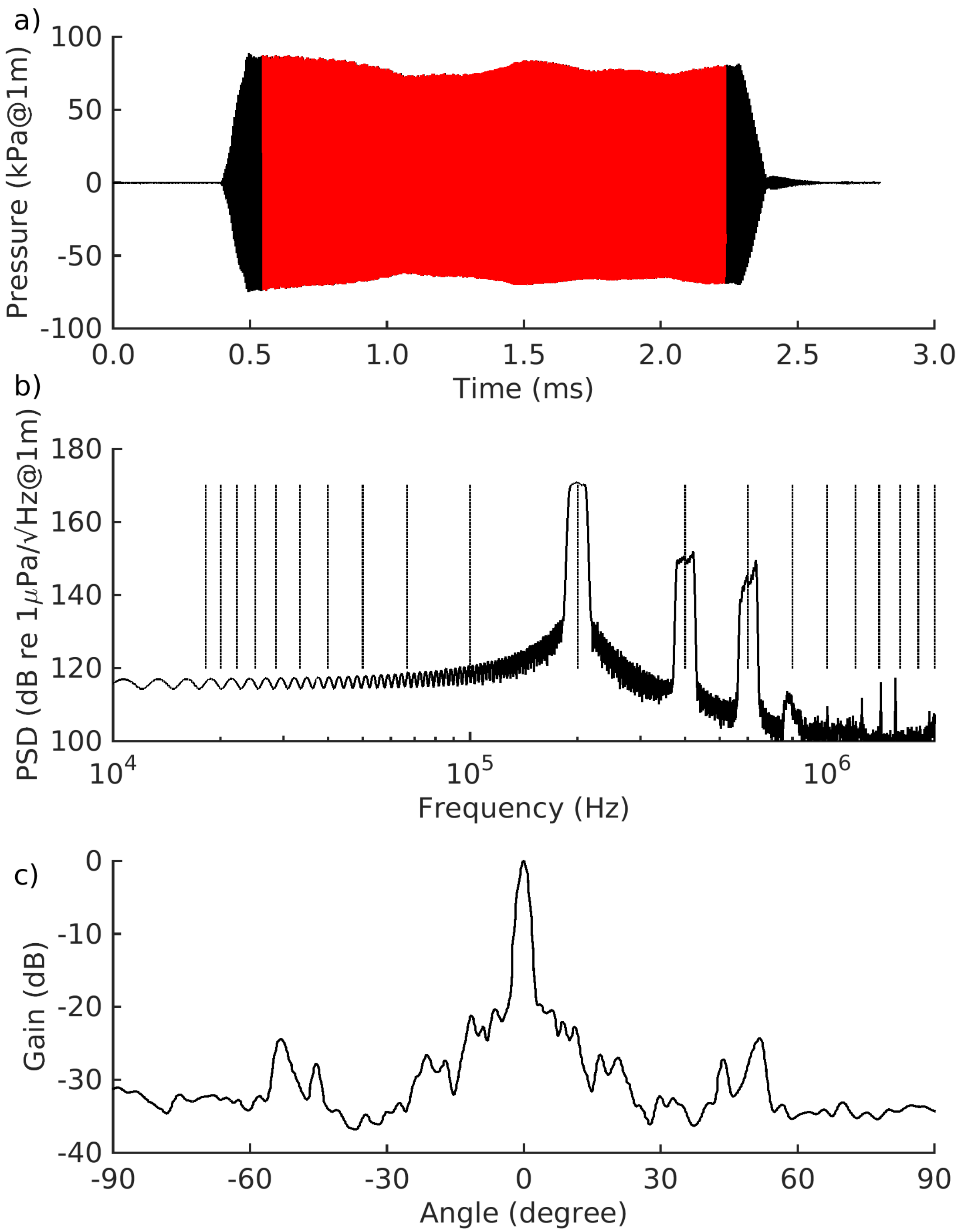


Figure 74. Reson T20P FM Waveform, 200 kHz, 2 ms, 220 dB re 1mPa@1m

Table 26. Reson T20P Waveform Characteristics–Frequency Modulated

Source Settings			Source Level (dB re 1µPa@1m)				Effective Pulse Width (ms)	Effective Bandwidth (kHz)
Freq. (kHz)	Source Level (dB)	Pulse Width (ms)	Pk-Pk	Pk	RMS	SEL		
200	220	2	227	222	216	188	1.7	22.3
200	220	4	228	223	216	191	3.4	19.0
200	220	6	228	223	216	193	5.1	18.8
300	220	2	230	225	218	190	1.6	20.0
300	220	4	230	225	218	194	3.2	20.1
300	220	6	230	225	218	195	4.9	20.5
400	220	2	226	221	216	188	1.7	21.2
400	220	4	226	220	216	191	3.3	17.9
400	220	6	227	221	216	193	4.9	17.5

4.1.3 Bathyswath SWATHplus-M Interferometric Sonar System

The Bathyswath SWATHplus-M interferometer sonar is a 234-kHz single-frequency source with an acoustic aperture of 35 cm. The system generates a variety of operator selectable waveforms with various pulse widths and power levels. Figure 67b shows the transmit array for the Bathyswath SWATHplus-M rigged for measurement of the along-track beam patterns by mounting to the foot of the rotator assembly stringer. The measurement geometry is illustrated in figure 68.

Measurement geometry for waveform characterization and along-track beam patterns did not satisfy the source-receiver requirement articulated by equation (1) (see reference 3) where the estimated distance to the acoustic farfield was 15 m. While it is unlikely the non-optimum measurement geometry introduced significant error in the measured source levels, it may have influenced data collected in the off-axis directions (reference 15) and sidelobe levels that were observed.

Figure 75a shows an example of a 234-kHz continuous wave signal consisting of 50 cycles, or about 215 µs. The associated power spectral density is provided as figure 75b. As seen in these figures, the transmit waveforms included tapers at the leading and trailing edges. Five harmonics were clearly resolved in the acoustic data as shown in figure 75b. The locations of sub-harmonic frequencies are likewise indicated by vertical lines at frequencies less than 234 kHz where no sub-harmonics of the transmit frequency were detected.

Figure 75c illustrates the along-track beam pattern observed for the 234-kHz waveform where the 3-dB width of the transmitted beam was 1.3° and the first sidelobe was about 15 dB down from the main beam level and located at a 3° angle. The source produced a complex set of sidelobes at angles ranging from forward to aft (with respect to the track line). This result was consistent with the continuous wave signals for all waveforms where the main beamwidth was 1.2 ±0.2° and the first side lobe was 14 to 17 dB down.

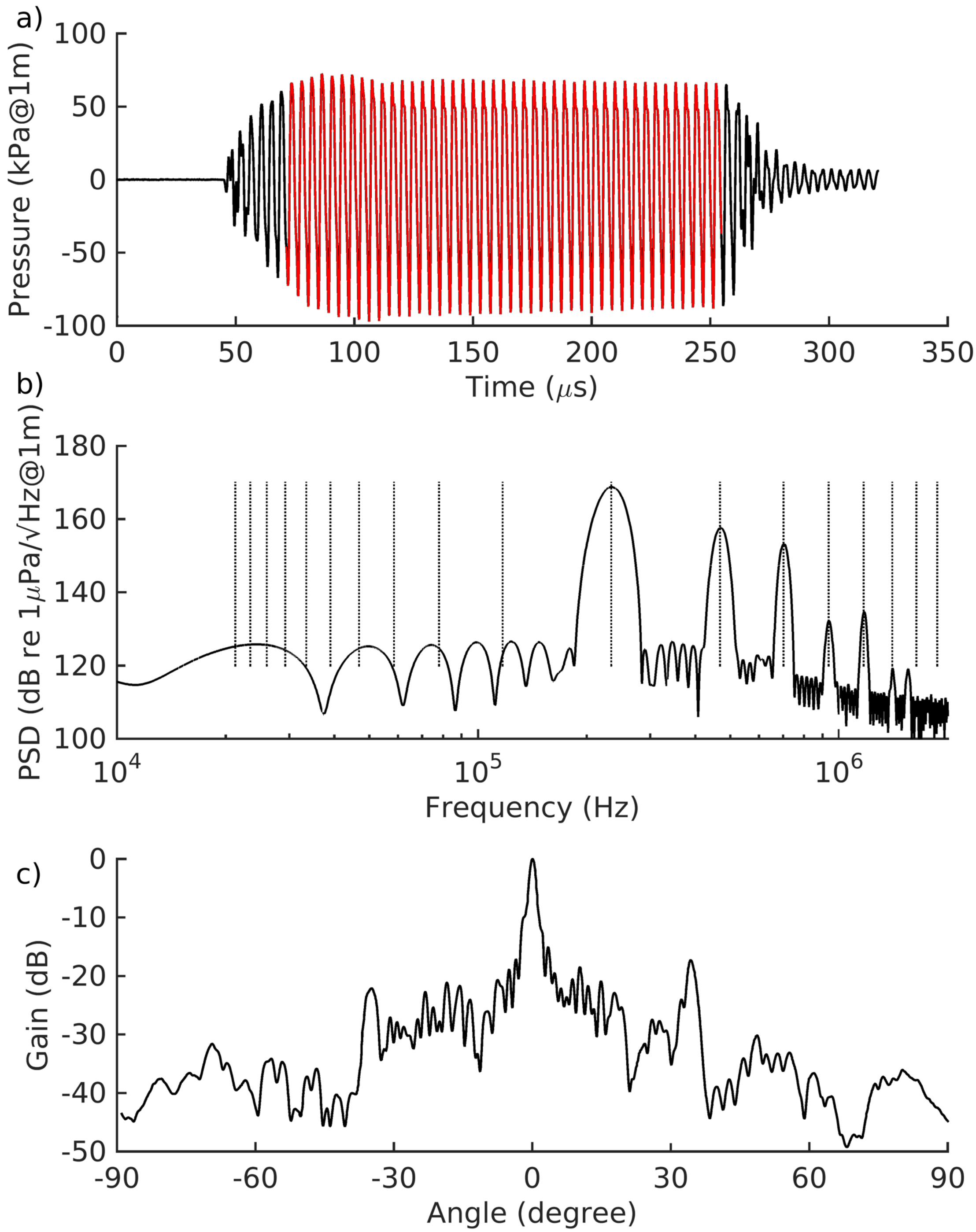


Figure 75. Bathyswath SWATHplus-M Waveform, 234 kHz, 50 Cycles, 100% Power

Figure 76 illustrates the across-track beam patterns observed in the open tank facility OTF. The geometry employed for these measurements is shown in figure 69. These measurements were performed in the OTF because observation of the across-track beam required more precise control over the measurement geometry than could be achieved on the floating test platform at Leesburg. The measurements were performed with a source-receiver separation of only 2 m, considerably less than the desired distance. While a longer measurement distance was preferred, the shorter distance was a compromise required to maintain the narrow along-track beam oriented toward the reference hydrophone as seen in figure 41. The 3- and 10-dB beamwidths were about 50° and 120°, respectively. The sidelobe pattern was asymmetric with a single well-defined sidelobe located at about 90° and 23 dB down relative to the main beam.

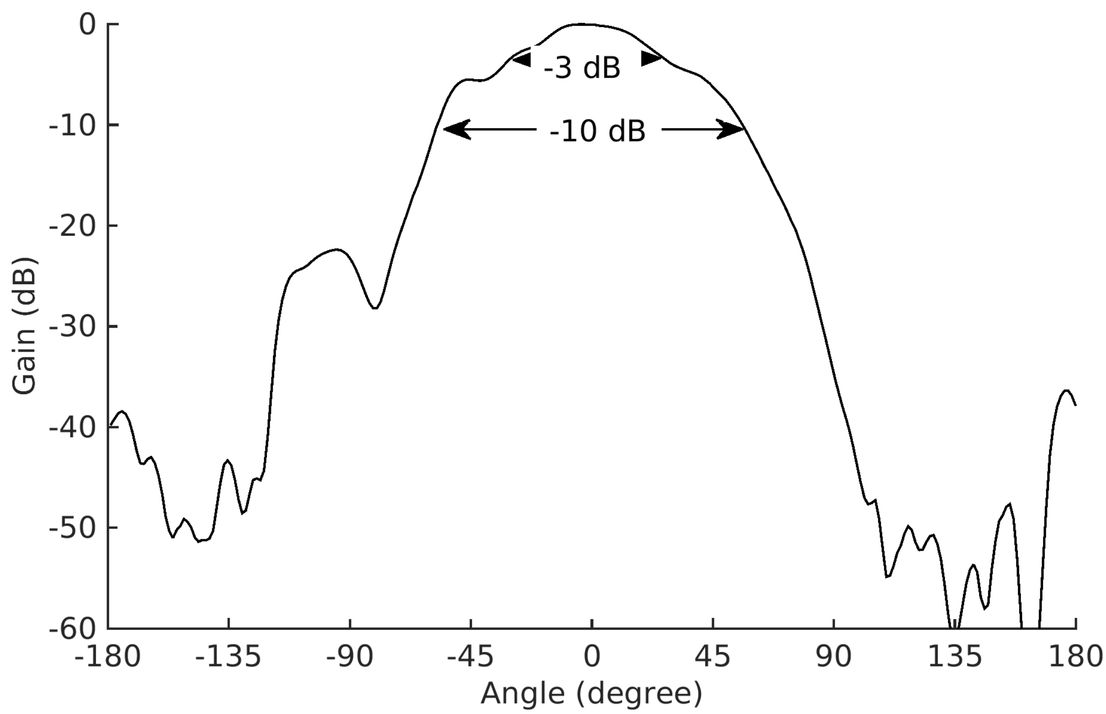


Figure 76. Bathyswath SWATHplus-M Across Track Beam Patterns

User selectable output power levels for the Bathyswath SWATHplus-M include pulse widths specified as number of cycles and output power specified as percent relative to maximum. Measurements of waveforms with numbers of cycles varying from 2 to 500 found that the source level was not independent of pulse width as shown in table 27. The shortest waveform observed consisted of two cycles. However, the source continued to radiate sound beyond two cycles as the transducer continued to oscillate for several additional cycles. As a result, the effective pulse width of 32 µs was about 3.7 times longer than the duration of two waveform periods at 234 kHz (i.e., 8.5 µs). Also noted was that the peak source level of 216 dB re 1µPa@m was 9 dB less than realized for the waveform composed of 10 cycles suggesting the transducer may require more than two waveform cycles to reach a steady state.

Table 27. Bathyswath SWATHplus-M Acoustic Waveform Characteristics

Source Settings		Source Level (dB re 1µPa@1m)				Effective Pulse Width (µs)
Power Setting (%)	Pulse Width (cycles)	Pk-Pk	Pk	RMS	SEL	
100	2	222	216	207	163	32
100	10	230	225	218	174	39
100	50	228	223	218	180	183
100	100	223	218	213	179	369
100	250	217	211	207	177	927
100	500	213	207	202	175	1845
100	50	228	223	218	180	183
90	50	228	223	218	181	185
80	50	228	222	218	180	185
70	50	227	222	217	180	187
60	50	227	222	217	179	186
50	50	226	220	215	178	188
40	50	225	219	214	176	191
30	50	220	215	209	172	192

Measurements showed the source level varied inversely with pulse width where the effective acoustic pressure diminished by 16 dB as the number of cycles was increased from 50 to 500. However, due to the increased waveform durations, the SEL was diminished by only 5 dB. Acoustic data were also collected for waveforms composed of 50 cycles at various power settings ranging from 100% to 30%. The observed source levels ranged from 218 to 209 dB re 1µPa@1m. With the exception of the 30% power setting, changes in source level were consistent with the indicated power setting. For example, the 50% power setting produced a source level that was 3 dB down relative to the 100% setting as expected. However, the source level observed at the 30% power setting was about 4 dB less than would be expected from power considerations alone.

4.1.4 *Echotrac CV100 Single-Beam Echosounder*

The Teledyne Odom Echotrac CV100 is a single-beam echosounder that operates at 200 kHz. The system generates a variety of operator selectable waveforms with various pulse widths and output power levels. The measurement geometry is illustrated in figure 77. The measurements were performed in the OTF in Newport, Rhode Island.

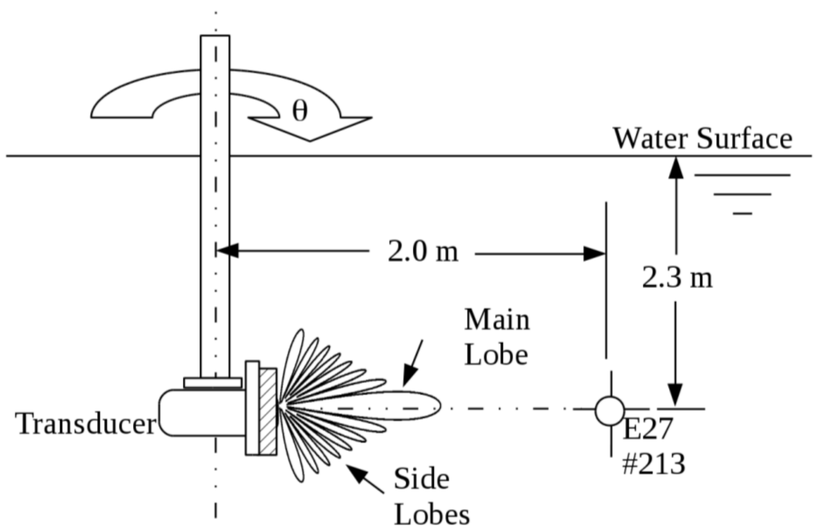


Figure 77. Echotrac CV100 Measurement Geometry

Figure 78a shows an example of a 200-kHz continuous wave signal consisting of 80 cycles for a nominal pulse width of 400 µs. The associated power spectral density is provided as figure 78b. The figure shows the first two harmonics were clearly resolved in the acoustic data as indicated by the vertical lines at frequencies greater than the transmit frequency. The locations of sub-harmonic frequencies are likewise indicated by vertical lines at frequencies less than 200 kHz where no sub-harmonics of the transmit frequency were detected. Figure 78c illustrates the beam pattern. The measured 3-dB width of the transmitted signal was 7.0° and the first sidelobe was 14 dB down from the main beam level and located at a 12° angle.

A variety of waveform options were observed with pulse widths varying from 10 cycles (50 µs) to 256 cycles (1.28 ms). The output power level was varied from 4 to 12 as indicated in the sonar operator interface. The observed source level varied from 175 to 193 dB re 1µPa@1m. Source levels were independent of pulse width. Waveform characteristics for all tested signals are provided in table 28.

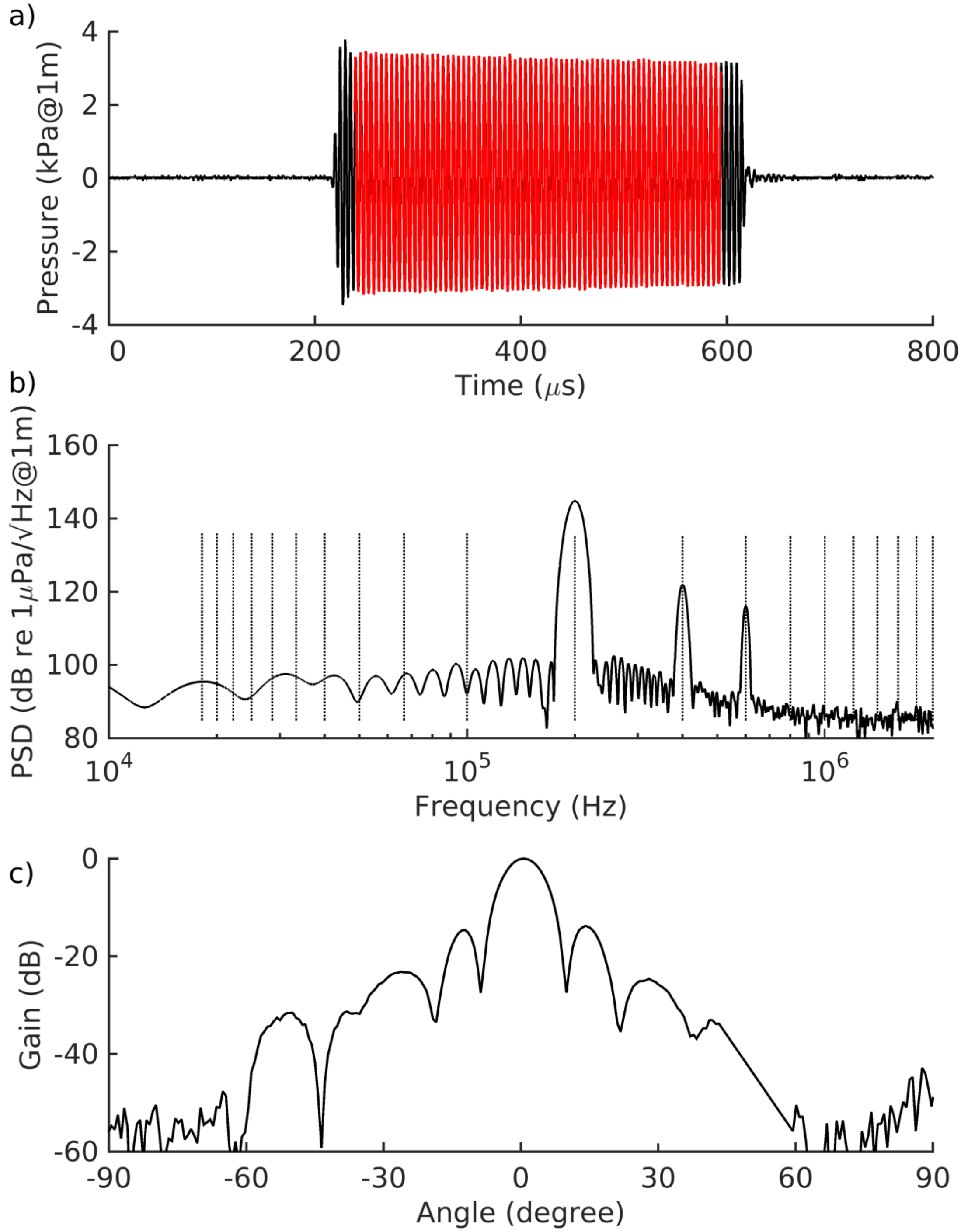


Figure 78. Echotrac CV100 Waveform, 200 kHz, Power Setting 8, 80 Cycles

Table 28. Echotrack CV100 Waveform Characteristics

Source Settings		Source Level (dB re 1µPa@1m)				Effective Pulse Width (µs)
Power Setting	Pulse Width (cycles)	Pk-Pk	Pk	RMS	SEL	
12	10	201	195	192	149	45
8	10	197	192	188	144	45
4	10	185	179	176	133	46
12	20	199	193	190	150	90
8	20	197	191	188	147	88
4	20	185	180	176	136	95
12	40	202	196	193	156	181
8	40	197	191	187	150	180
4	40	186	180	176	138	184
12	80	202	196	193	159	360
8	80	196	191	187	153	356
4	80	185	179	176	141	357
12	160	203	197	194	163	711
8	160	196	191	187	155	708
4	160	185	179	175	144	712
12	256	189	192	190	161	1130
8	256	194	188	184	155	1129
4	256	185	180	175	145	1133

4.2 SIDE-SCAN SONAR SYSTEMS

Figures 79 and 80 illustrate the mounting and measurement geometry for the side-scan sonar systems. The tow body was attached to the rotator coupling using a tow point adapter that maintained the system in a straight and level orientation. As a result, beam pattern measurements were not acquired in the two primary orthogonal planes as was done for the multibeam sonar systems. Instead, the MRA was angled down as in operational use with reference standard hydrophones placed at a distance and depth needed to observe the acoustic field on the MRA of the array. Acoustic data were collected at a source-receiver distance of 14.1 m–the practical maximum that could be achieved with the 30-m reference hydrophone cable length. This facility limitation resulted in the collection of acoustic data at distances that were, in some cases, somewhat less than optimal as the measurements did not always satisfy the acoustic farfield requirement of reference 2.

Acoustic data were observed using three Navy Type E27 high-frequency hydrophones arranged in a horizontal line to as shown in figure 80b where the hydrophones spanned a total length of 27 cm. This arrangement provided three observations spaced at 0.8° for each transmitted waveform, thus providing for improved angular resolution and better characterization of the main beamwidths for these sources.

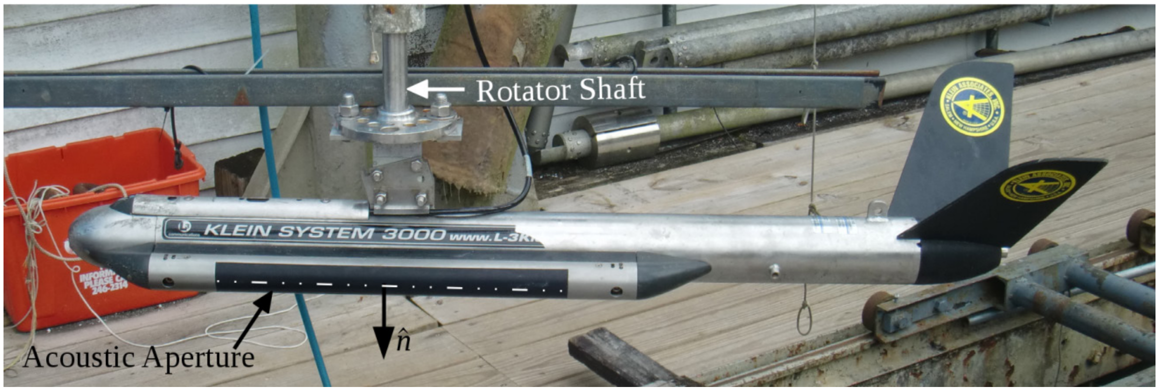


Figure 79. Klein 3000 Side-Scan Sonar Rigged for Measurement

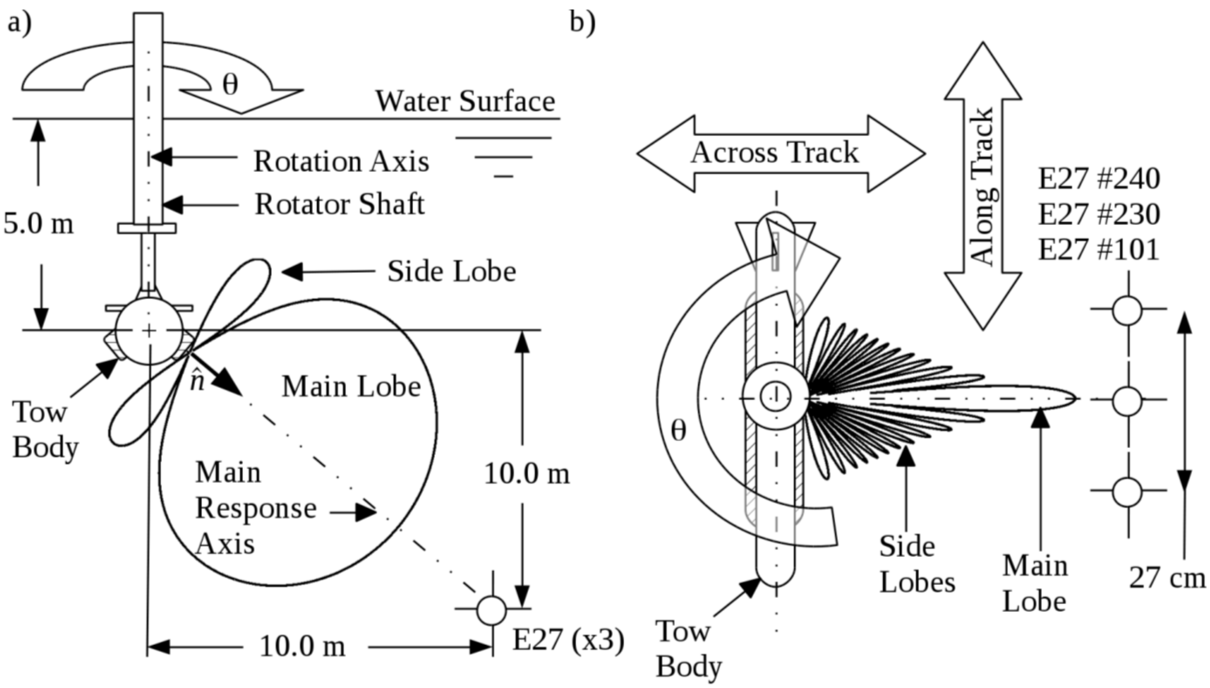


Figure 80. Side-Scan Sonar Measurement Geometry

4.2.1 Klien 3000 Side-Scan Sonar

The Klien 3000 side-scan sonar is a dual-band source with transmit frequencies of 132 and 445 kHz with an acoustic aperture of about 45 cm in length. The system generates a wide variety of operator selectable waveforms with pulse widths ranging from 25 to 400 μs. The system includes 15 different range settings from 25 to 1,000 m. While longer pulse widths are available to support surveys at longer ranges, the output source levels remained constant for each transmit frequency.

The measurement geometry satisfied the source-receiver requirement articulated by equation (1) (see reference 2) for the 132-kHz waveforms where the estimated distance to the acoustic farfield was 13 m and acoustic data were collected at more than 14 m. The farfield requirement was not satisfied for the 445-kHz waveforms where the farfield distance was estimated to be 45 m–a measurement distance that exceeded the facility capability. While the non-optimum measurement geometry for the 445-kHz signals may not have introduced serious errors in the measured source levels, it likely influenced the off-axis measurements (reference 15) including the sidelobe levels that were observed.

Figure 81a shows an example of a 132-kHz waveform with a pulse width of 400 μs. The associated power spectral density is provided as figure 81b. The figure shows the transmit waveforms included tapers at the leading and trailing edges, presumably to help reduce excitation of the transient response for the transmit system. However, the first four harmonics were clearly resolved in the acoustic data as indicated by the vertical lines at frequencies greater than the transmit frequency in figure 81b. The narrowband component observed near 1 MHz is of unknown origin. The locations of sub-harmonic frequencies are likewise indicated by vertical lines at frequencies less than 132 kHz where no sub-harmonics of the transmit frequency were detected.

Figure 81c illustrates the beam pattern observed for the 132-kHz waveform where the 3-dB width of the transmitted beam was 1.8° and the first sidelobe levels were about 10 dB down from the main beam level. The source produced a complex set of sidelobes at angles ranging from forward to aft (with respect to the track line) as expected for a high-frequency source with significant aperture length (with respect to an acoustic wavelength).

Results for the Klien 3000 sonar system are summarized in table 29 for a variety of acoustic waveforms. Effective (rms) source levels were 220 and 223 dB re 1μPa@1m at 132 and 445 kHz, respectively. Variations in the observed SEL were due solely to pulse width differences among the waveforms of a given transmit frequency. The beamwidths of the MRA were about 2° and 1° at 132 and 445 kHz, respectively.

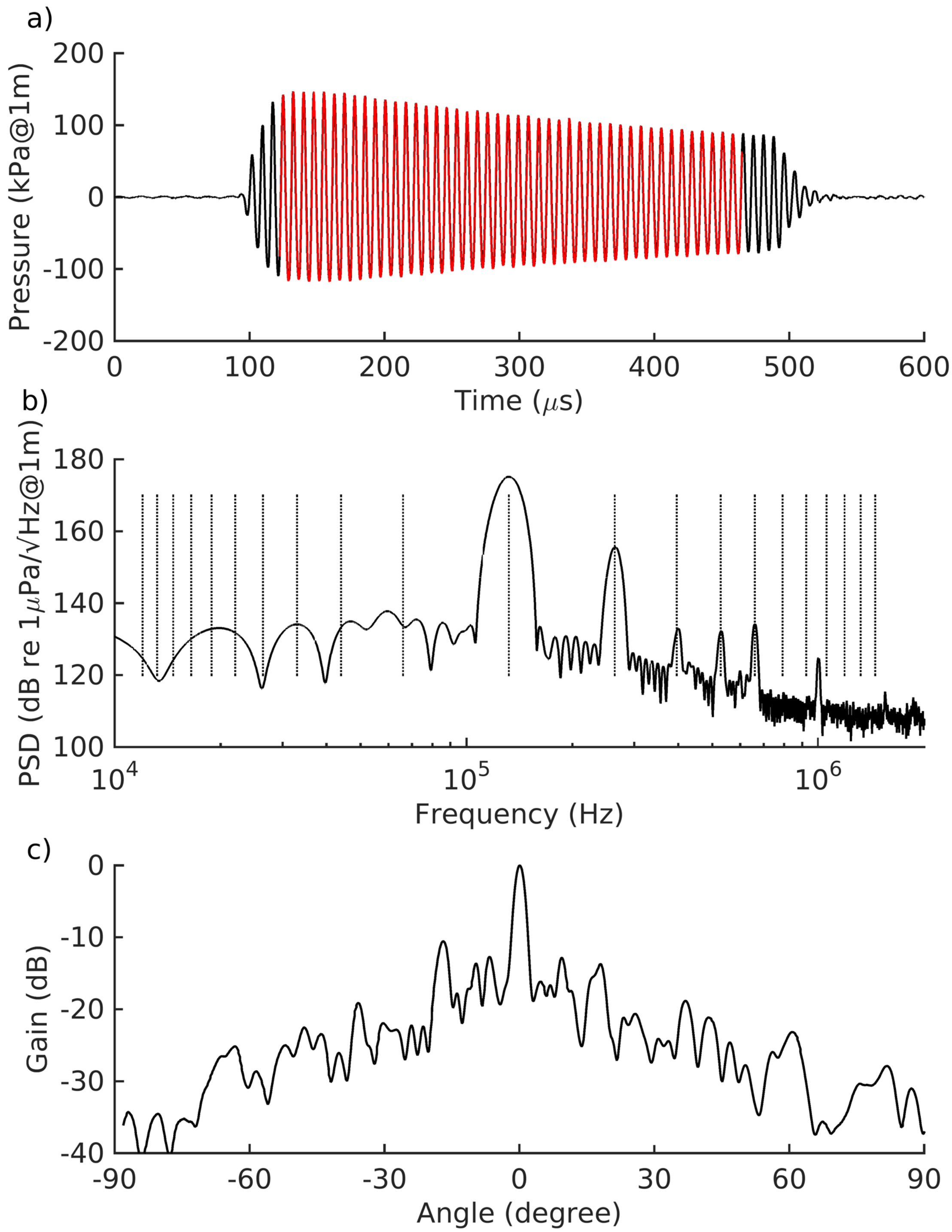


Figure 81. Klein 3000 Side-Scan Sonar Waveform Example

Table 29. Klein 3000 Side-Scan Sonar Acoustic Characteristics

Source Settings			Source Level (dB re 1µPa@1m)				Eff. Pulse Width (µs)	Main Lobe	Max. Side Lobe	
Freq. (kHz)	Pulse Width (µs)	Range (m)	Pk-Pk	Pk	RMS	SEL		Width (3 dB) (deg)	Angle (deg)	Gain (dB)
132	50	25	229	224	219	176	44	2.4	-16	-10
132	50	50	229	224	220	176	44	2.4	-17	-9
132	50	100	229	224	220	176	42	2.2	-17	-10
132	50	400	230	225	220	176	44	1.9	-17	-10
132	50	600	230	225	220	176	44	2.2	-17	-9
132	100	100	230	224	220	179	81	2.1	-17	-10
132	200	200	230	225	220	182	168	1.8	-17	-10
132	400	400	230	224	219	184	343	1.7	-17	-11
132	400	600	230	224	219	184	343	1.8	-17	-11
445	25	50	233	227	224	177	21	1.2	-5	-16
445	25	600	233	227	223	177	21	0.8	-5	-17
445	100	100	233	227	223	182	88	1.2	-5	-19

4.2.2 Klein 3900 Side-Scan Sonar

The Klien 3900 side-scan sonar is a dual-band source with transmit frequencies of 445 and 900 kHz with an acoustic aperture of about 40 cm in length. The system generates a variety of operator selectable waveforms with pulse widths for different range settings. The system includes 11 different range settings from 10 to 200 m. While longer pulse widths are available to support surveys at longer ranges, the output source level remained constant for the 445-kHz waveforms. Data were not collected for the 900-kHz waveforms as they were beyond the maximum frequency of interest defined for the study.

Figure 82 shows the Klein 3900 rigged for measurement by mounting to the foot of the rotator assembly stringer. Also shown is a crossbar mounted above the tow body with two Navy Type F42D hydrophones affixed to either end. These hydrophones were included in the test setup to provide a redundant source of rotation angle data using an out-of-band acoustic signal to estimate the rotation angles using phase differences between the hydrophones.

The measurement geometry did not satisfy the source-receiver requirement articulated by equation (1) (see reference 2) for the 445-kHz waveforms where the estimated distance to the acoustic farfield was 38 m. While the non-optimum measurement geometry for the 445-kHz signals may not have introduced serious errors in the measured source levels, it likely influenced the off-axis measurements (reference 15) including the observed sidelobe levels.

Figure 82. Klein 3900 Side-Scan Sonar Rigged for Measurement

Figure 83a shows an example of a 445-kHz waveform with a pulse width of 100 µs. The associated power spectral density is provided as figure 83b. The figures show the transmit waveforms included tapers at the leading and trailing edges, presumably to help reduce excitation of the transient response for the transmit system. However, there was some evidence of the second harmonic in the acoustic data as indicated by the vertical lines at frequencies greater than the transmit frequency in figure 83b. The locations of sub-harmonic frequencies are likewise indicated by vertical lines at frequencies less than 445 kHz where no sub-harmonics of the transmit frequency were detected.

Figure 83c illustrated the beam pattern observed for the 445-kHz waveform where the 3-dB width of the transmitted beam was 1.3° and the first sidelobe levels were about 20 dB down from the main beam level. The source produced a complex set of sidelobes at angles ranging from forward to aft (with respect to the track line) as expected for a high-frequency source with significant aperture length (with respect to an acoustic wavelength). Beam pattern details are provided for information only as it was not feasible to perform these measurements in the acoustic farfield of this sonar system.

Results for the Klein 3900 sonar system are summarized in table 30 for select acoustic waveforms. Effective (rms) source levels were 220 dB re 1µPa@1m at 445 kHz. Variations in the observed SEL were due solely to pulse width differences among the waveforms of a given transmit frequency.

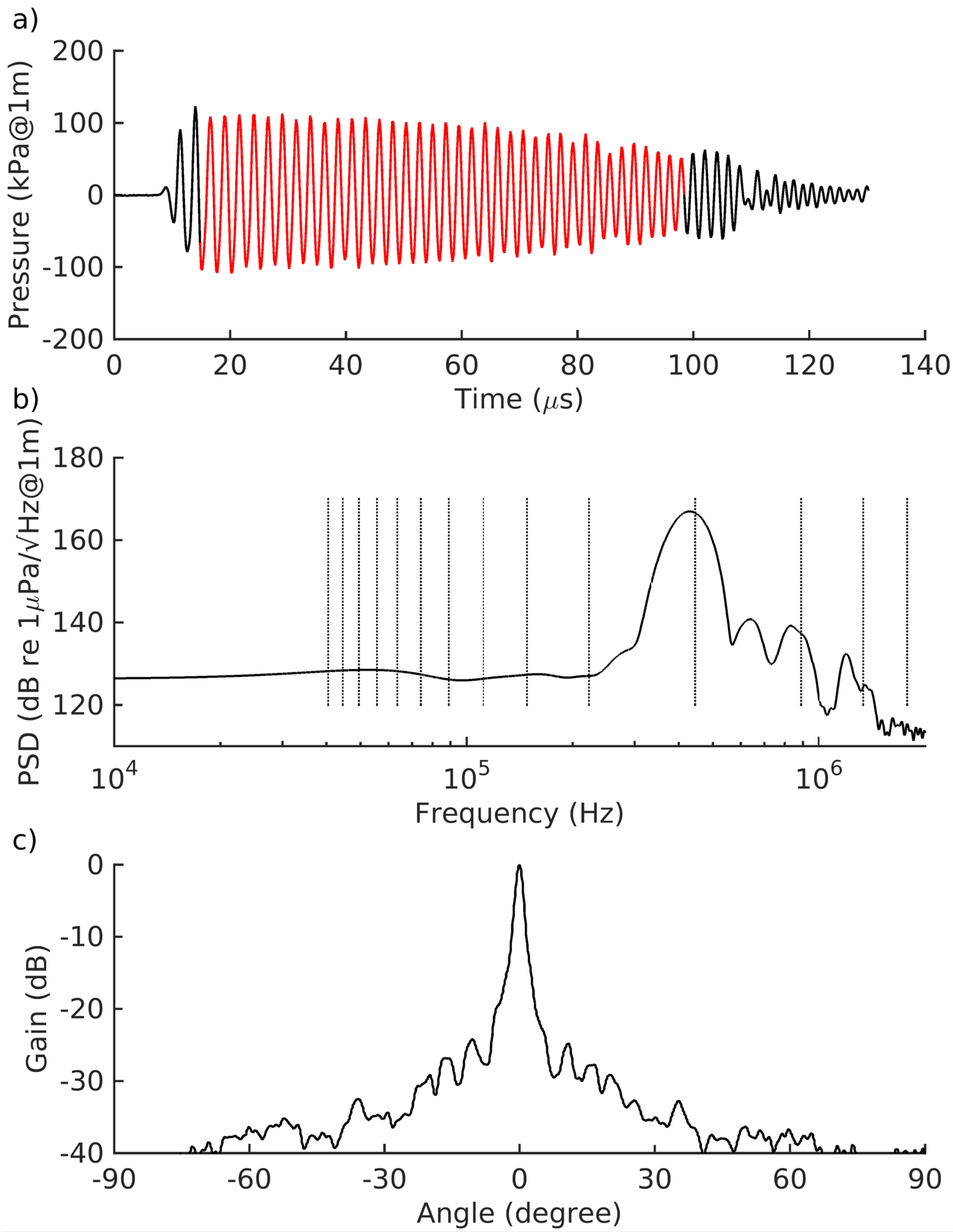


Figure 83. Klein 3900 Side-Scan Sonar Waveform Example

Table 30. Klein 3900 Side-Scan Sonar Acoustic Characteristics

Source Settings			Source Level (dB re 1µPa@1m)				Eff. Pulse Width (us)	Mainlobe	Max. Sidelobe	
Freq. (kHz)	Pulse Width (µs)	Range (m)	Pk-Pk	Pk	RMS	SEL		Width (3 dB) (deg)	Angle (deg)	Gain (dB)
445	100	150	232	226	220	179	84	1.3	3	-20
445	32	150	230	224	220	175	31	1.6	-5	-18
445	25	150	229	223	220	173	20	1.8	-5	-16
445	16	150	229	223	220	172	16	1.6	4	-20

4.2.3 EdgeTech 4200 Side-Scan Sonar

The EdgeTech 4200 side-scan sonar is a dual-band source with nominal center frequencies of 100 and 400 kHz with an acoustic aperture of about 50 cm in length. The system generates a variety of operator selectable waveforms with range settings from 50 to 400 m. The system is shown rigged for measurement in figure 84.

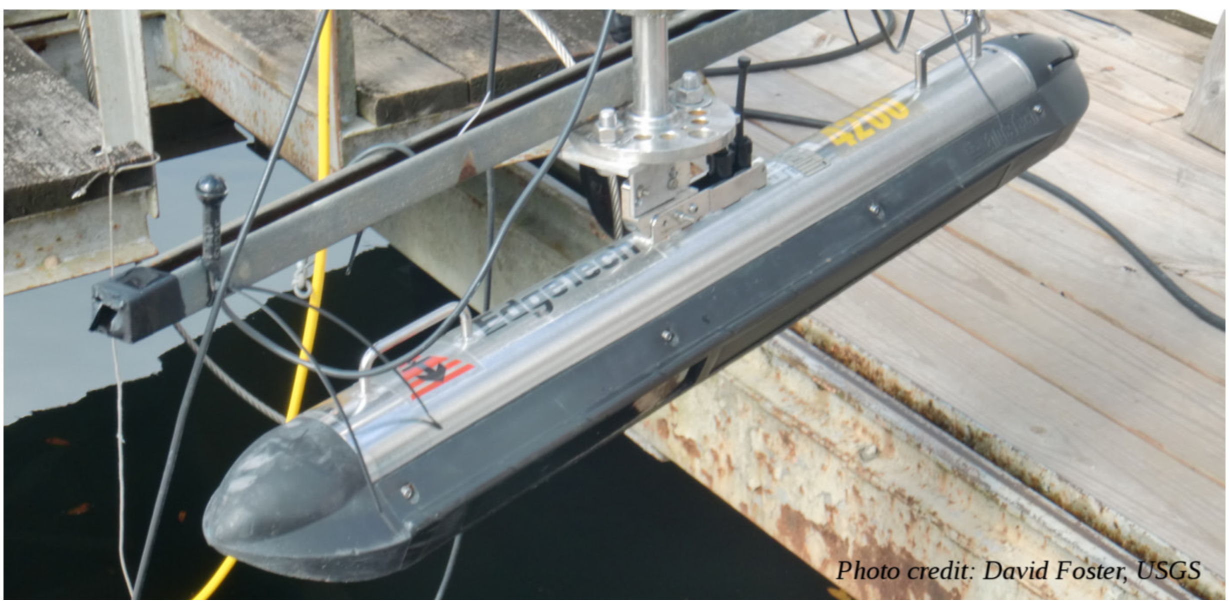


Figure 84. EdgeTech 4200 Side-Scan Sonar Rigged for Measurement

The measurement geometry satisfied the source-receiver requirement articulated by equation (1) (see reference 1) for the 100-kHz waveforms where the estimated distance to the acoustic farfield was 13 m and acoustic data were collected at more than 14 m. The farfield requirement was not satisfied for the 400-kHz waveforms where the farfield distance was estimated to be 53 m, a measurement distance that exceeded the facility capability. While the non-optimum measurement geometry may not have introduced series errors in source level measurements for the 400-kHz signals, it likely influenced the off-axis measurements (reference 15) including the sidelobe levels that were observed.

Figure 85a shows an example of a 100-kHz waveform (actual center frequency ~125 kHz) transmitted at 100% power with range setting of 400 m where the effective (90%) pulse width was 7.2 ms. The associated power spectral density is provided as figure 85b. As seen in these figures, the transmitted signals were Gaussian amplitude-modulated waveforms. Harmonic frequencies are indicated by vertical lines at locations exceeding the transmit frequency where the second harmonic was resolved. Sub-harmonic frequencies are likewise indicated by vertical lines at locations less than the transmit frequency. Inspection of figure 85b reveals the presence of significant signal power, labeled as EMI (electromagnetic interference), at the frequency corresponding to the first sub-harmonic of the transmit frequency.

Figure 85c illustrates the beam pattern observed for the 100-kHz waveform where the 3-dB width of the transmitted beam was 1.3° and the first sidelobe levels were about 20 dB down from the main beam level. The source produced a complex set of sidelobes at angles ranging from forward to aft (with respect to the track line) as expected for a high-frequency source with significant aperture length (with respect to an acoustic wavelength).

Analysis showed the energy in the vicinity of the first sub-harmonic of the transmit frequency was due to EMI and was not an acoustic signal radiated by the Edgetech 4200. Figure 86 shows the spectrogram of the same waveform illustrated in figure 85. The acoustic reception (and second harmonic) is clearly resolved from about 15 to 30 ms. Also noted in this figure is a continuous, periodic oscillation at about 60 kHz that was not associated with active transmission from the side-scan sonar. Thus, while this interference appeared in a frequency band that was associated with the first sub-harmonic of the transmit frequency, temporal characteristics observed in the spectrogram revealed it to be electronic interference and not acoustic in origin. Figure 86 also shows elevated noise levels at discrete frequencies including 20, 160, 200, and 240 kHz and broadband transient doublets at about 5, 12, 22, and 28 ms. All of these sources were of unknown origin and within about 10 dB of the measurement system noise floor.

Analysis also showed the EMI observed in figure 85b was not entirely absent from data collected with the other side-scan sonar systems despite the apparent lack of a prominent feature at about 60 kHz. Figure 87a compares the power spectrum of waveforms radiated by the Klein 3000 and EdgeTech 4200 sonar systems. While the two sonar systems transmitted signals with similar frequencies, the pulse widths were significantly different at 0.3 and 7.2 ms for the Klein and EdgeTech, respectively.

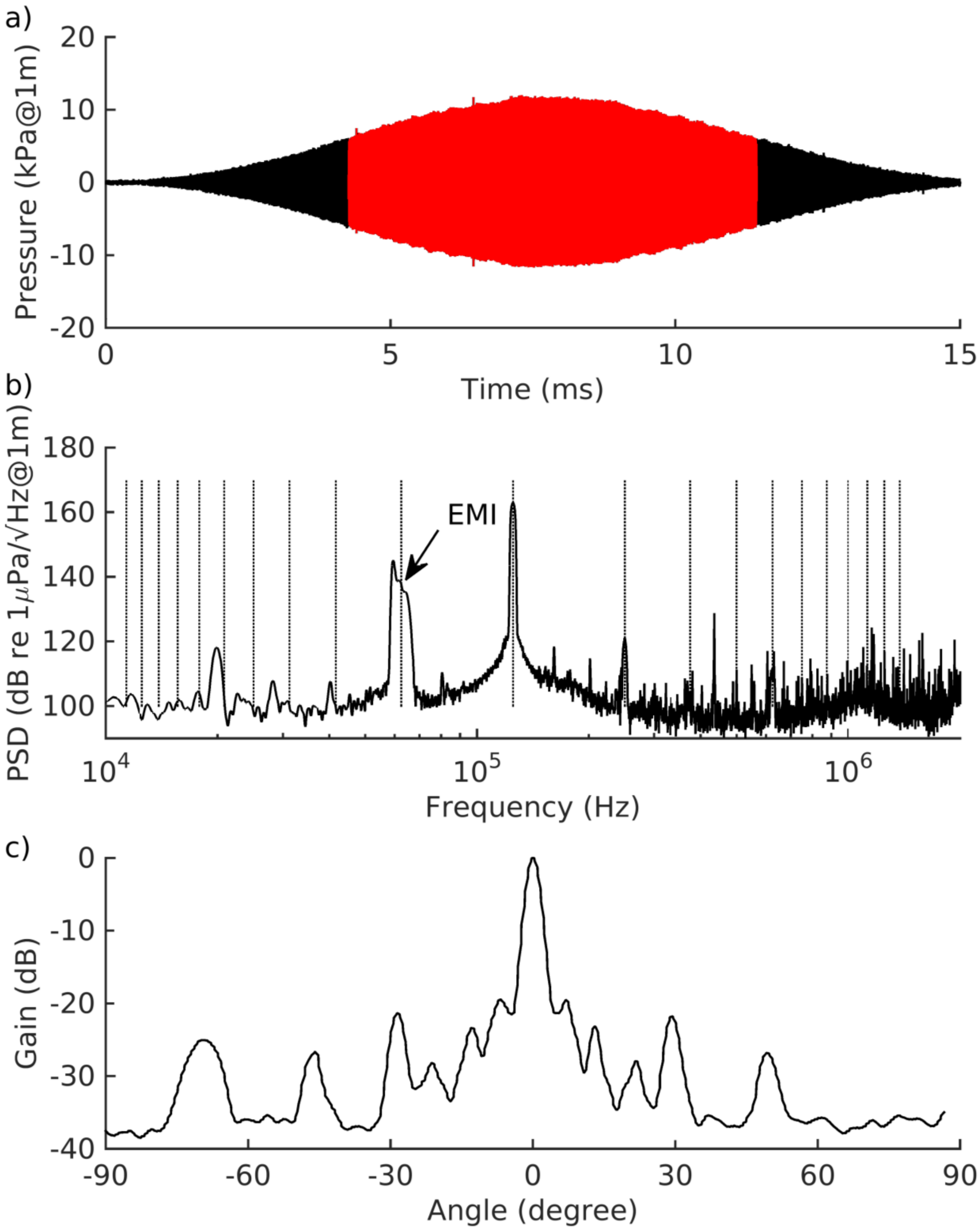


Figure 85. EdgeTech 4200 Waveform Example

As previously discussed, Welch's Method (reference 5) was employed for estimation of the waveform power spectrum. In accordance with common signal processing methods, a Hamming window was applied to the time series prior to power spectrum estimation. Thus, the underlying signal spectrum was convolved with the frequency spectrum of the Hamming window resulting in a general broadening of the peak at the transmit frequency and the addition of an extensive set of sidelobes (reference 16) that, for sufficiently short time windows (i.e., pulse width), can control the effective dynamic range of the power spectrum. For example, figure 87b presents the power spectrum for two simulated, noiseless signals with the same transmit frequency, amplitude and pulse widths as the Klein 3000 and EdgeTech 4200 side-scan sonars. Note the effective dynamic range in the power spectrum of the simulated Klein waveform (i.e., 132 kHz, 0.3 ms) is controlled by sidelobes in the frequency spectrum that are about 50 dB less than the peak at the transmit frequency. However, the effective dynamic range in the power spectrum of the simulated EdgeTech signal (i.e., 125 kHz, 7.2 ms) was significantly greater: a direct result of the longer record length. Thus, the prominent interference at about 60 kHz in the power spectrum of the EdgeTech waveform was not unique to this sonar. The same level of interference was present in the Klein waveform but was obscured by sidelobes in the frequency spectrum.

Careful inspection of the power spectrum for the Klein sonar, facilitated by comparison of figures 87a and 87b, reveals the presence of EMI at 60 kHz despite the absence of the prominent feature that is apparent in the EdgeTech sonar data. In short, the apparent dynamic range of the power spectrum for the EdgeTech sonar data was controlled by the noise floor of the measurement system. In contrast, the apparent dynamic range of the power spectrum for the Klein sonar data was controlled by sidelobes in the frequency spectrum–an unavoidable artifact of the signal processing methods used.

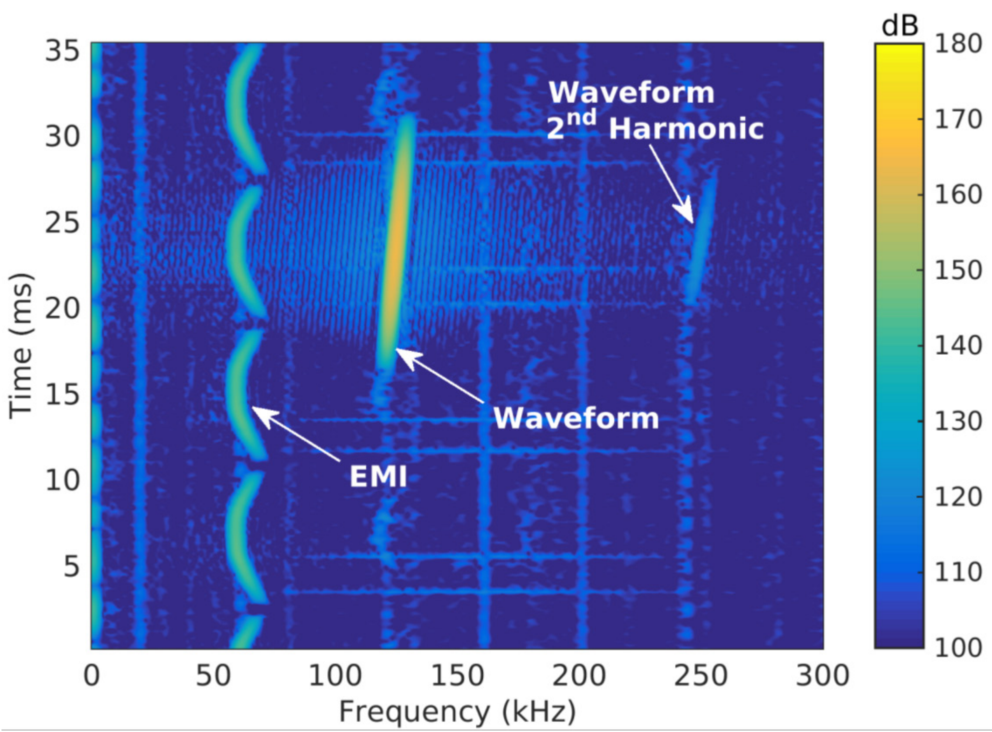


Figure 86. EdgeTech Waveform with Electromagnetic Interference

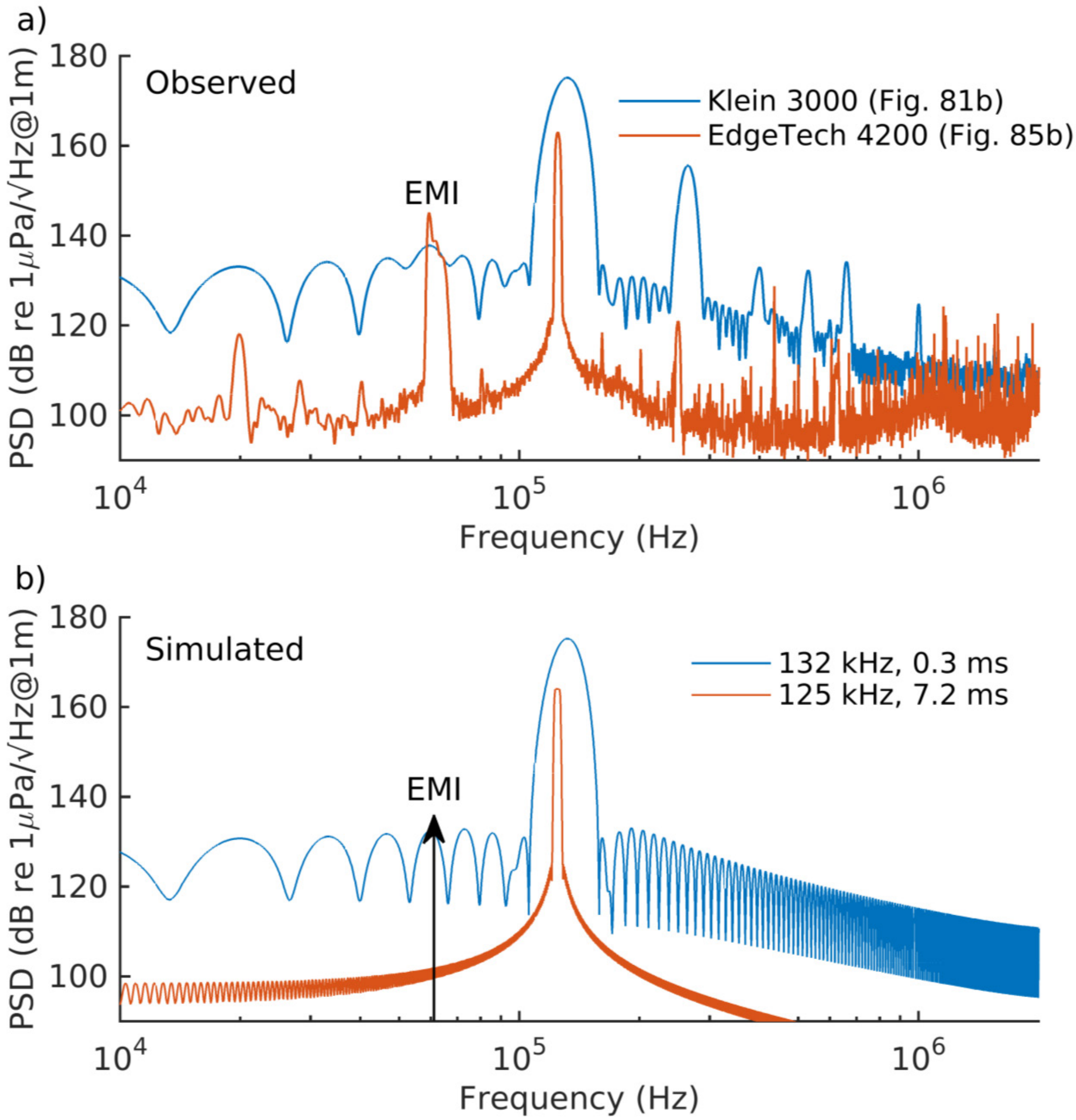


Figure 87. Power Spectrum of Observed and Simulated (Noiseless) Sonar Signals

While characteristics of the EMI suggest fluorescent lighting may have been the source, attempts to isolate and eliminate the interference were not successful. Nonetheless, the interference did not significantly influence the calculated acoustic parameters as it was well out of the analysis band for these signals.

Results for the EdgeTech 4200 sonar system are summarized in table 31 for a variety of acoustic waveforms. The (rms) source level at 100 kHz and 100% power was 201 dB re 1µPa@1m independent of range setting. The effective source level at 50% power was reduced by 6 dB, a finding more consistent with a 50% reduction in projector drive voltage than with a 50% reduction in transmit power. The effective source level at 400 kHz and 100% power was 205 dB re 1µPa@1m.

Table 31. EdgeTech 4200 Side-Scan Sonar Acoustic Characteristics

Source Settings			Source Level (dB re 1µPa@1m)				Eff. Pulse Width (ms)	Main Lobe	Max. Sidelobe	
Freq. (kHz)	Power (%)	Range (m)	Pk-Pk	Pk	RMS	SEL		Width (3 dB) (deg)	Angle (deg)	Gain (dB)
100	100	400	212	206	201	179	7.2	2.1	-7	-19
100	100	200	212	206	201	176	3.7	2.5	-7	-19
100	100	100	212	206	201	175	2.6	2.6	-7	-18
100	100	50	212	206	201	171	1.1	1.6	-7	-19
100	75	50	209	203	198	168	1.2	2.1	8	-18
100	50	50	206	200	195	165	1.1	1.9	7	-19
400	100	400	216	210	205	176	1.3	2.6	11	-20
400	100	200	216	210	205	176	1.3	1.8	-3	-17
400	100	100	216	210	205	176	1.1	1.9	10	-22
400	100	50	216	210	205	176	1.1	1.9	-8	-22
400	75	50	215	209	204	174	1.1	2.4	7	-22
400	50	50	210	204	198	169	1.1	1.8	-7	-21

5. CONCLUSIONS

Given the significant scientific questions and uncertainty about the potential impacts associated with noise in the marine environment, an increasing number of regulatory requirements and precautionary mitigation strategies are being applied to minimize the risk associated with high-resolution marine geophysical surveys performed in U.S. waters. Agencies of the U.S. government both regulate and operate geophysical survey systems in the performance of their respective missions. While BOEM is the agency responsible for ensuring that environmental mitigation requirements are scientifically supported, cost effective, operationally feasible and impact reducing, the USGS is required to comply with those regulations in the performance of their Coastal and Marine Geology Program. Other government agencies, academic institutions, and commercial interests are similarly affected. However, information required to assess the ecological risks associated with the operation of a given high-resolution survey system has not been generally available. Therefore, characterizing the acoustic fields radiated by these systems is a critical first step to understanding the potential impacts to marine ecosystems.

This report presented results of work performed by the Underwater Sound Reference Division of the Naval Undersea Warfare Center Division Newport to quantify the characteristics of sounds radiated by a wide variety of marine geophysical survey systems. The overall objective of this study was to acquire and analyze calibrated acoustic source data for a number of commonly used geophysical sources as required to support subsequent sound source verification of these sources, in situ by future BOEM-USGS studies. This objective was satisfied by the execution of a comprehensive measurement program performed over the period of January to August 2015 at three different facilities. Among the particular findings of this study are the following items.

Many of the geophysical survey systems radiated non-negligible sound intensity at harmonics of the transmit frequency. None of the survey systems radiated detectable levels of sound at sub-harmonics of the transmit frequency. However, it is possible that sub-harmonic sound radiation may have been present but masked by sidelobes in the frequency spectrum for the shorter pulse widths (see figure 86 and related discussion). If present, such sub-harmonic content was at least 40 to 50 dB below the sound intensity at the transmit frequency.

The Reson T20P and the Reson Seabat 7111 were the only systems included in this study to report the transmit source level to the operator in decibels. The T20P operator display reported source levels that were within 2–3 dB of the measured peak source levels. The 7111 operator display reported source levels that were within 2–3 dB of the measured peak source levels for the 1.5° transmit beamwidth. The measured source level was decreased for increasing transmit beamwidth as would be expected for fixed transmit power. In particular, the measured source level of the 7111 decreased by 6 dB for each doubling of transmit beamwidth (i.e., 3.0° and 6.0°).

Operator displays provided by the EdgeTech sub-bottom profiling and side-scan sonar systems did not accurately report the effect of varying the power setting. All of the EdgeTech systems included in this study reported the transmit power in percent. However, source levels when operating at 50% power were about 6 dB lower than when operating at 100% power (see tables 14, 15, 16, 18, 19, and 31). This behavior was more consistent with a 50% reduction in drive voltage (i.e., 6 dB) than a 50% reduction in radiated acoustic power (i.e., 3 dB).

Two systems were found not to function in accordance with manufacturer's specifications. First, EdgeTech 512i sub-bottom profiling system (S/N 027076) was found to have a malfunctioning low-frequency transducer that significantly reduced the radiated intensity for frequencies below about 2.6 kHz (see figures 59 and 60). Repair or replacement of the low-frequency transducer is required for full performance of this system. Second, the FSI HMS-620D dual source bubble gun was found to have a malfunctioning transceiver. The transmit voltage signals when operating two channels were not synchronized as required to generate a single-peaked waveform (see figures 27 to 29). In addition, the system appeared to randomly transition between single-channel and dual-channel operations when attempting to operate on transmit channel 2 only (see figure 30).

The peak acoustic pressures generated by the Applied Acoustics Delta-Sparker were associated with secondary radiation of sound from the collapse and oscillation of the steam bubble and not from the initial impulse during discharge of the high-voltage impulse (see figure 40).

Acoustic particle motion in the vicinity of the Sercel Mini-GI airgun was estimated from data collected with a tetrahedral array of hydrophones deployed at a distance of 15 m from the gun. The measurement geometry and array design were configured to facilitate validation of the array and signal processing needed to estimate the acoustic particle acceleration and velocity. Data provided by the array were used to estimate the acoustic particle velocity to within 3% of the velocity predicted by consideration of the specific acoustic impedance of a plane propagating wave field. Information to design, build, and employ a similar tetrahedral array of hydrophones for the estimation of acoustic particle motion was provided.

This study reported on the acoustic characteristics of a selection of high-resolution geophysical survey systems manufactured by various companies. Their inclusion in this report does not constitute an endorsement by the U.S. government or any agency thereof.

Data presented in this report are traceable to measurement standards maintained by the USRD.

REFERENCES

1. D.C. Mosher and P.G. Simpkin, "Environmental Marine Geoscience 1. Status and Trends of Marine High-Resolution Seismic Reflection Profiling: Data Acquisition," *Geoscience Canada*, vol. 26, 1999, pp. 174-188.

2. *Procedures for Calibration of Underwater Electroacoustic Transducers*, ANSI/ASA Standard S1.20-2012.

3. X. Lurton, "Modeling of the Sound Field Radiated by Multibeam Echosounders for Acoustical Impact Assessment," *Applied Acoustics*, vol. 101, 2016, pp. 201-221. doi: 10.1016/j.apacoust.2015.07.012

4. *Acoustical Terminology*, ANSI/ASA Standard S1.1-2013.

5. P. Welch, "The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short, Modified Periodograms," *IEEE Transactions on Audio Electroacoustics*, vol. 15, 1967, pp. 70-73. doi: 10.1109/TAU.1967.1161901

6. Z.D. Deng, B.L. Southhall, T.J. Carlson, J. Xu, J.J. Martinez, M.A. Welland, and J.M. Ingraham, "200 kHz Commercial Sonar Systems Generate Lower Frequency Side Lobes Audible to Some Marine Mammals," *PLos ONE*, vol. 9, 2014. doi: 10.1371/journal.pone.0099315

7. S.J. Welch, L.L. Knowles Jr., B.G. Katz, and D.G. Strom, "Hydrology, Water Quality, and Aquatic Communities of Selected Springs in the St. Johns River Water Management District, Florida," United States Geological Survey, Reston, VA, Scientific Investigations Report 2009-5046, 2009.

8. B.N. Taylor and C. E. Kuyatt, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," National Institute of Standards and Technology, Gaithersburg, MD, NIST Technical Note 1297, 1994. [Online]. Available http://www.nist.gov/pml/pubs/tn1297/

9. "Evaluation of Measurement Data - Guide to the Expression of Uncertainty in Measurement," Bureau International des Poids et Mesures, Sèvres, France, JCGM 100:2008 2008. [Online] Available http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

10. P.M. Morse and K U. Ingard, *Theoretical Acoustics*, McGraw-Hill, New York, NY, 1968, pp. 381-388.

11. A.V. Oppenheim and R.W., Schafer, *Discrete-Time Signal Processing*, Prentice Hall, Upper Saddle River, NJ, 1999, pp. 796-799.

12. J. Lighthill, *Waves in Fluids*, Cambridge University Press, Cambridge, UK, 1978, pp. 1-5.

13. C.C. Tseng, "Digital Integrator Design Using Simpson Rule and Fractional Delay Filter," *IEEE Proceedings Visual, Image and Signal Processing*, vol. 153, 2006, pp. 79-86. doi: 10.1049/ip-vis:20045208

14. F.B. Jensen, W.A. Kuperman, M.B. Porter, and H. Schmidt, *Computational Ocean Acoustics*, Springer-Verlag, New York, NY, 2000, pp. 90-99.

15. K.G. Foote, "Discriminating Between the Nearfield and the Farfield of Acoustic Transducers," *Journal of the Acoustical Society of America*, vol. 136, 2014, pp. 1511-1517.

16. S.W. Smith, *The Scientist and Engineer's Guide to Digital Signal Processing*, California Technical Publishing, San Diego, CA, 1999, pp. 169-177.

APPENDIX
MANUFACTURER'S PRODUCT INFORMATION SHEETS

APPLIED ACOUSTICS
Underwater Technology

: Technical Specification

AA200 and AA300 Seismic Sound Source, Boomer Plates

The two boomer plates, the AA200 and AA300, produce a sharp, repeatable "industry standard" single pulse. Both models are field proven and differ in detail specification.

The Model AA200 is the 'small format' transducer which can be towed on either the CAT100 or CAT200 surface tow vehicles. It is ideal for inshore surveys for high resolution sediment analysis with the CSP-L energy source or as a higher penetration device with the CSP300-P and CSP-D models.

The Model AA300 is designed for higher power applications and has the extra advantage of use as a variable frequency boomer when used with the CSP-D range of energy sources. This allows wide ranging pulse widths not formerly available. The lengthening of the pulse width ensures even greater penetration whilst maintaining a high quality single pulse.

AA200

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United Kingdom

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W www.appliedacoustics.com

MODEL TYPES - PHYSICAL SPECIFICATION

	Size	Weight air/water	Fixing Centres
Model AA200	38cm x 38cm	18kg/10kg	31.5cm²
Model AA300	62cm x 52cm	25kg/14kg	40.6cm²

ELECTRICAL INPUT

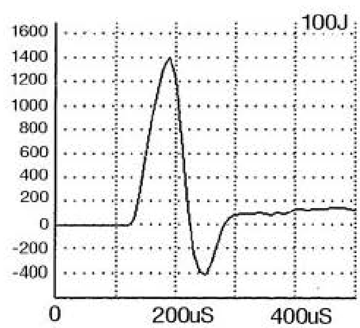
Recommended Power	AA200, 50 – 200J/shot AA300, 100 – 300J/shot
Maximum Energy Input	AA200, 300J/shot AA300, 350J/shot
Maximum power Input	AA200, 600J/second AA300, 1000J/shot

SOUND OUTPUT

Source level	AA200, 215 dB re 1 μPa at 1 metre with 200J AA300, 218 dB re 1 μPa at 1 metre with 300J
Pulse Length	AA200, 120/150/180 mS at 50/100/200J AA300, 150 – 400 mS depending on energy setting of CSP-D
Reverberation	AA200, <1/10 x initial pulse AA300, < 1/10 x initial pulse
Connector type	Enhanced Joy Plugs. Models AA201 and AA301 fitted with RMK type

COMPATIBILITY*

Energy Source	AA200, CSP-L; CSP300P; CSP-D AA300, CSP300P; CSP-D
Catamaran	AA200, CAT100; CAT200 AA300, CAT200



AA200 PULSE SHAPE

* Also compatible with older model CSP units.

Certificate No. 6447
BS: EN: ISO9001 : 2000

APPLIED ACOUSTICS
Underwater Technology

Due to continual product improvement, specification information may be subject to change without notice.

APPLIED ACOUSTICS
Underwater Technology

Applied Acoustic Engineering Ltd
Marine House, Marine Park, Gapton Hall Road, Great Yarmouth, NR31 0NB, United Kingdom

AA251, AA301 Boomer Seismic Sound Source

The AA251 and AA301 boomer plates are seismic sound sources that produce a sharp repeatable pulse from a floating position on the sea surface.

The AA251, deployed on either a robust CAT100 or CAT200 catamaran, is ideal for inshore surveys from small craft.

The AA301 is designed for higher power applications and can also be used as a variable frequency boomer when combined with the CSP-D range of energy sources.

Key Features

- Stable pulse shape clarity with minimum reverberation
- Rugged mechanical design with weight kept to a minimum
- Supplied as individual product, or with a catamaran
- Supplied with RMK connectors and locking collars as standard.
- AA251 forms part of the Inshore Boomer System, ideal for coastal surveys
- AA301 ideal for nearshore and shallow water surveys (100-150m) depending on geology

Technical Specification

PHYSICAL

	Size	Weight air/water	Fixing centres	Connector
AA251 Boomer plate	380 x 380mm	18kg/10kg	$315mm^2$	RMK 1/0
AA301 Boomer plate	620 x 520mm	25kg/14kg	485mm x 440mm	RMK 1/0

ELECTRICAL INPUT

Recommended energy	AA251	50 – 200J/shot
	AA301	100 – 300J/shot
Maximum energy	AA251	300J/shot
	AA301	350J/shot

AA251, AA301 Technical Specification continued...

Average energy	AA251	600J/second
	AA301	1000J/second
Operating voltage	3600 to 4000Vdc	

SOUND OUTPUT

Source level	AA251	Typically 212dB re 1µPa at 1 metre with 200J
	AA301	Typically 215dB re 1µPa at 1 metre with 300J
Pulse length	AA251	120/150/180µs at 50/100/200J
	AA301	200µs depending on energy setting of CSP
Reverberation	AA251	<10% of initial pulse
	AA301	<10% of initial pulse

COMPATIBLE ENERGY SOURCES

AA251	CSP-L, CSP-P, CSP-D, CSP-N1200, CSP-S1250, CSP-S4000, CSP-S6000
AA301	CSP-P, CSP-D, CSP-N1200, CSP-S1250, CSP-S4000, CSP-S6000

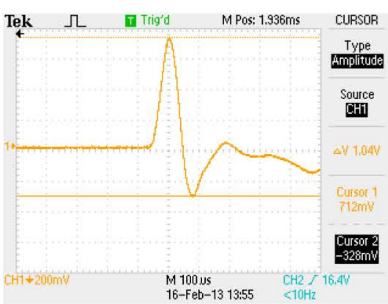
COMPATIBLE CATAMARAN

AA251	CAT 100:	940 (L) x 740 (W) x 500 (H) mm
	CAT 200:	1280 (L) x 915 (W) x 525 (H) mm
AA301	CAT 200:	1280 (L) x 915 (W) x 525 (H) mm
	CAT 300:	1700 (L) x 660 (W) 490 (H) mm

COMPATIBLE HV CABLE

AA251 and AA301	HVC 2000 Standard length 50m RMK 1/0 connectors complete with locking collars

AA301 TYPICAL PULSE SIGNATURE AT 300J



APPLIED ACOUSTICS
Underwater Technology

Due to continual product improvement, specification information may be subject to change without notice.
AA251, AA301 Boomers/Nov 2013

Registration No. U6447
BS: EN: ISO9001

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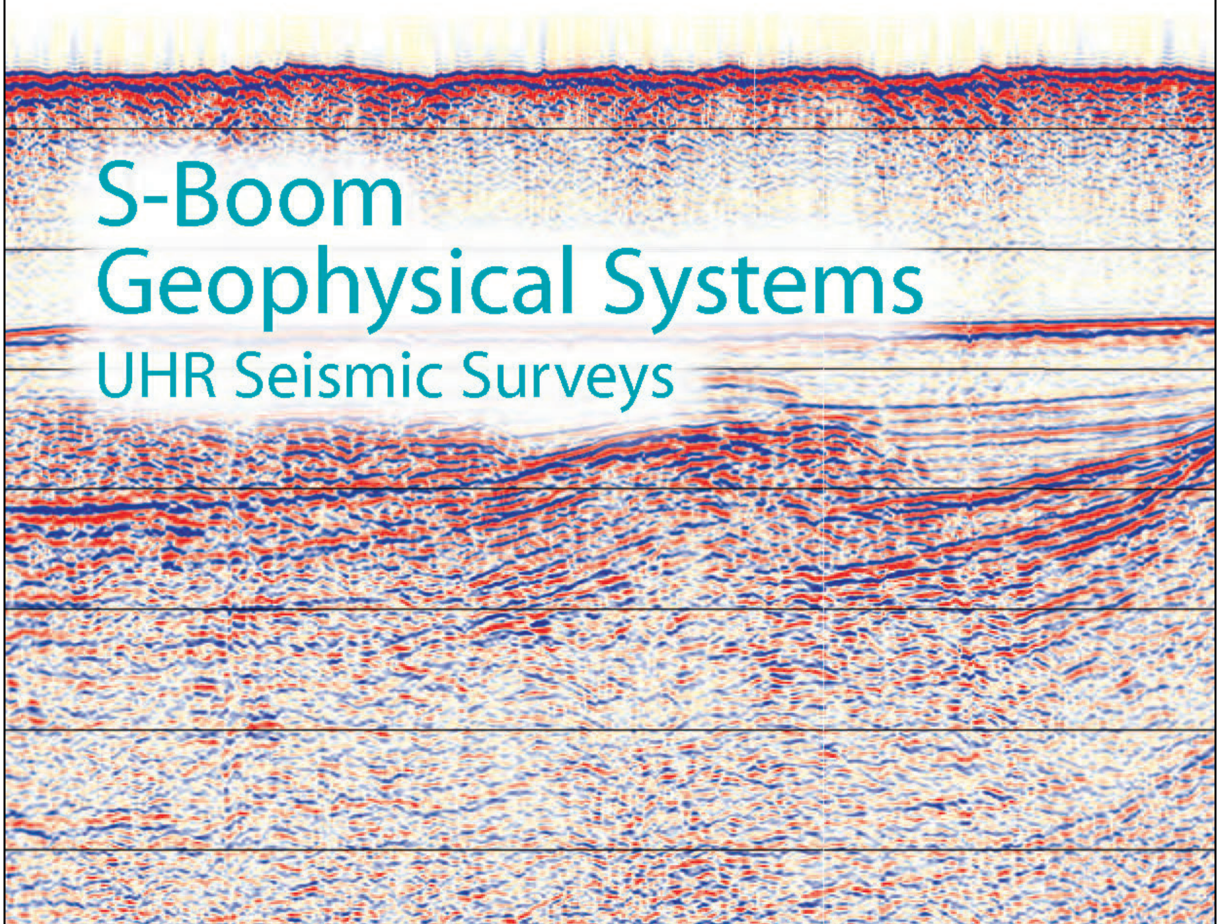
APPLIED ACOUSTICS
Underwater Technology

S-Boom Geophysical Systems

UHR Seismic Surveys



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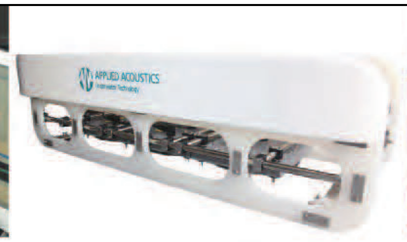


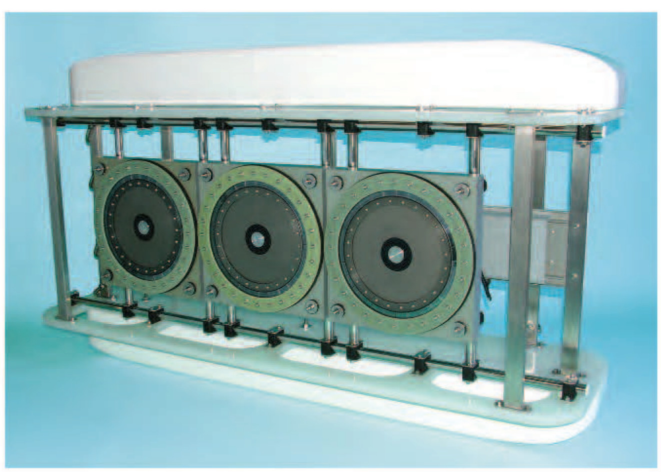
The S-Boom sub bottom profiling system is an alliance of existing and new technologies, packaged to provide a unique and powerful method of carrying out deep penetration seismic surveys with ultra-high resolution data quality.

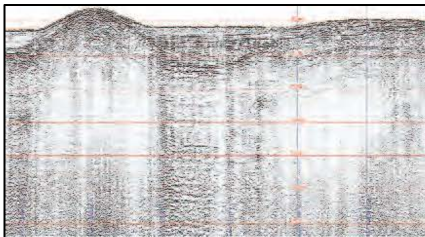
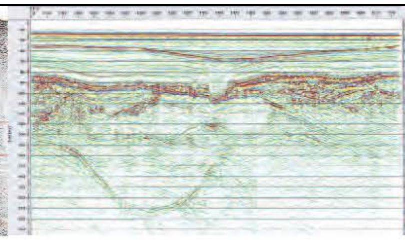
By harnessing the combined power of three proven AA252 Boomer Plates to provide one single pulse, the S-Boom System redefines the boundaries of shallow seismic surveying. The transmitted energy is focused by the array geometry to improve the directivity and beam pattern, giving a marked improvement over traditional seismic sound sources. Already recognised for producing high resolution seabed profiles, the fusion of these three transducers delivers a source level high enough to significantly increase sub-bottom penetration while maintaining a vertical resolution of better than 0.25 metres.

Innovation within the energy source sees the S-Boom capable of operating at a maximum energy output of 1000 Joules per pulse, and firing at three pulses per second. At this setting, the S-Boom has achieved penetration results of over 200ms through sand and limestone whilst delivering the high resolution records expected of boomer systems with all the quality and reliability expected of Applied Acoustics.

As with all AAE sub bottom systems, the S-Boom forms part of a modular package able to operate from a number of energy sources from the renowned CSP range. For optimum results, the fast charging CSP-N1200 power supply has been designed as the energy source of choice for this system, although the system can operate just as well with a source from the larger CSP-S range. Furthermore, some existing variants of the CSP-D range can also be used at lower settings and longer pulse intervals.

Given the frequency of operation and the transmitted power levels, the S-Boom system is suitable for use with both single and multi-channel hydrophone arrays and acquisition packages, adding to the overall system versatility and creating the perfect UHR package for many applications including research, mapping and construction geological surveys.




Technical Specification

S-BOOM SYSTEM COMPONENTS

1 x CAT303
3 x AA252 Boomer Plates
1 x HVC3000 Cable and Junction Box

Powered from a CSP-N1200 Seismic Source

S-BOOM PHYSICAL SPECIFICATION

CAT303 Catamaran

Length	1700mm
Height	490mm
Width	660mm frame 876mm including floats
Weight	60kg

AA252 Boomer Plate x 3

Length	380mm
Width	380mm
Weight	18kg (air) 10kg (water)
Connector type	RMK with locking collar

HVC3000 Cable

Outside diameter	26mm
Breaking strain	2000kg
Standard length	75m

ELECTRICAL INPUT

Recommended power	700-1000J per shot
Maximum energy input	1000J
Maximum power input	3000J/second

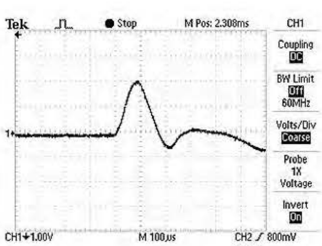
Thermal interlock protection interfaced to energy source

SOUND OUTPUT

Source level	Typically 222 dB re 1 µPa at 2 metres with 1000J
Pulse length	300 to 500µs depending on energy applied
Reverberation	<10% of initial pulse

COMPATABILITY

Energy source	CSP-N1200 (Other CSP series of power supplies can be used)
Catamaran	CAT303
Cable	HVC3000



Sample Pulse at 1000J

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HEGG MARINE SOLUTIONS
A Division of Falmouth Scientific, Inc.

HMS-620 Bubble Gun^{TM}

Ultra-Portable Low-Frequency Acoustic Seismic Systems

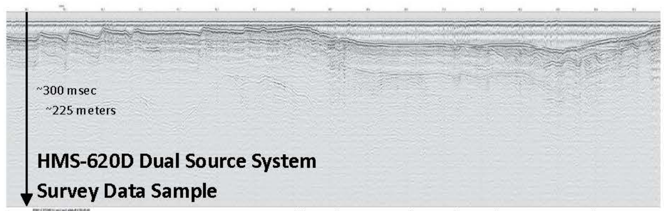
The HMS-620 Bubble Gun^{TM} uses low-frequency acoustic signals to provide superior signal penetration vertically through coarse sand, gravel tills, and other difficult-to-penetrate sediments.

Small system component size and portability make this a valuable tool for any survey platform.

Complete Single-Source Bubble Gun^{TM} System shown with source vehicle suspended on display frame and shipping case for transceiver and cables

APPLICATIONS

- Offshore Wind Turbine and Dam Site Surveys
- Cross River Surveys for Bridge Construction
- Bedrock Investigation
- Pipeline Construction Surveys
- Geotechnical Site Investigation
- Coastal Engineering



Collected in Vineyard Sound, MA (courtesy USGS)

FEATURES/BENEFITS

- **Wide-band 70-1700Hz pulse** provides bottom penetration through many sediment types
- **Very stable and repeatable source pulse without the need for external timing controllers**
- Rugged, lightweight transducer platform provides stable operation in adverse sea-state conditions
  - Electromagnetic Sound Source; **Contained Air Volume (no air compressor needed)**
  - Single and Dual Source Vehicles Available
  - No need for heavy handling or deployment equipment
- Flexible portable transceiver unit optimizes system for a wide range of sediments
  - Low-noise pre-amp with high/low pass filters and gain control
  - User-selectable trigger or external trigger
  - **Multiple Sources can be synchronized to a common trigger without need for external timing control**
  - **Repeatable Shot-to-Shot Phase and Amplitude Wavelet Correlation > 0.96**
- **Minimal Electric Power Requirements**
  - Selectable 110 or 220 VAC source of less than 1 KWatt for single source, 2 KWatt for Dual Source
  - Optional 24 VDC powered system available (two 12V batteries; no generator needed)
- Oil-filled single channel hydrophone streamer cable
  - 7-meter multi-element active section
  - 35-meter deactivation switches on each hydrophone element enable exportation outside of USA
- Compatible with industry-standard data acquisition software & multi-channel streamers

HMS-620D with Geometrics Geode and MicroEel multi-channel data acquisition system (courtesy Geometrics)

Falmouth Scientific, Inc.
www.falmouth.com

SPECIFICATIONS

HMS-620 Bubble Gun™ System Components

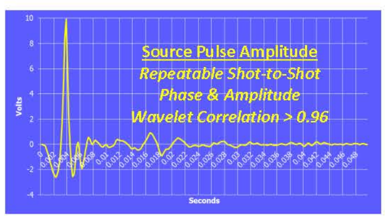
Source Vehicle and Electromechanical Tow Cable

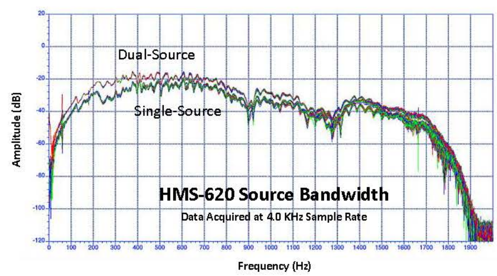
Source Type:	Electromagnetic / Contained Air Volume (no compressor needed)
Frequency:	Wide band, 70-1700Hz pulse
Acoustic Source Level:	Single: Approximately +200 dB ref 1µPa @ 1 meter Dual: Approximately +204 dB
Normalized Shot-to-Shot Cross Correlation:	Repeatable Shot-to-Shot Phase and Amplitude Wavelet Correlation > 0.96
Tow Vehicle:	Stainless steel and plastic frame, buoyant surface-towed vehicle
Tow Cable:	50-meter abrasion resistant electro-mechanical cable
Dimensions (approximate):	Single: 109.22 x 93.97 x 48.26 cm (43 x 37 x 26 in) Dual: 190.5 x 93.97 x 48.26 cm (75 x 37 x 26 in)
Weight in Air (approximate):	Single Vehicle/Source – 43.5 kg (96 lbs) Dual Vehicle/Source – 80 kg (175 lbs) Tow Cable - 12.25 kg (27 lbs)

Source vehicle is compact and easy to deploy

Seismic Transceiver

Signal Input:	Designed to operate with HMS-620 System Hydrophone Streamer Cable; 7-pin Amphenol connector
Gain:	Adjustable in 3 dB steps 0 to 45 dB
Filters:	Adjustable high- and low-pass active
Analog Interface:	±10 V Output





Power Supply

Trigger Input:	External key or manual time-based selection
Repetition Rate:	1/8 second maximum
Transducer Connector:	7-pin Amphenol to mate with HMS-620 Source Vehicle Tow cable
Packaging:	Portable splash-resistant case
Dimensions & Weight:	55.88 cm x 53.34 cm x 25.4 cm (22 in x 21 in x 10 in); 17.24 kg (38 lbs)

Hydrophone Streamer Cable

Length:	Active section - 7 meters; Single- channel, 24 elements; Leader – 50 meters
Preamplifier:	Integral preamp - 20 dB gain; Designed to operate with HMS-620 Transceiver
Power Input:	Supplied by transceiver
Weight in Air:	13.6 kg (30 lbs)

Specifications Subject to Change without Notice

05 May 2015

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SIG sparker-electrodes

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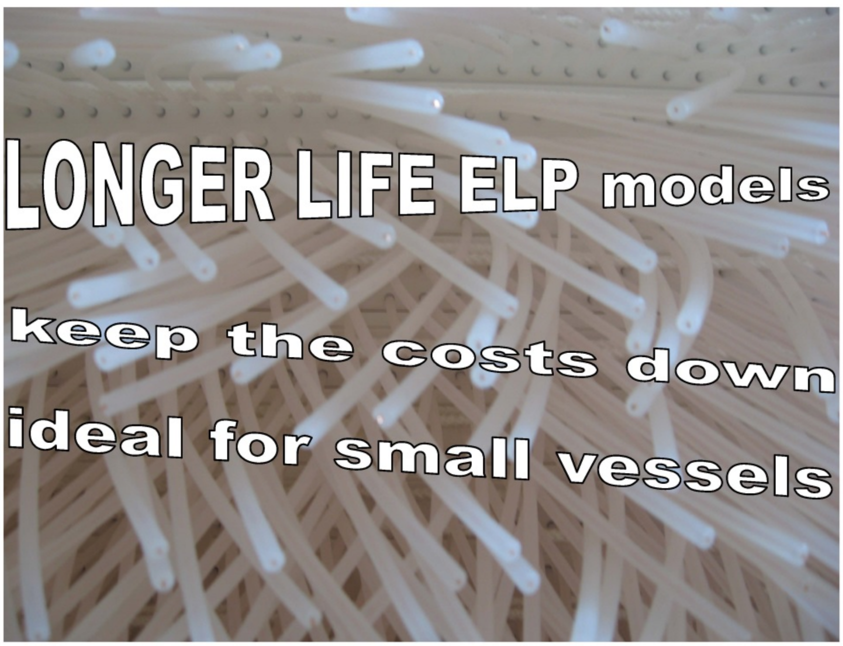
- Longer life ELP models,
- Floating spark-arrays,
- no catamaran necessary,
- Easily replaceable,
- Interchangeable on the same high voltage tow cable



SIG sparker-electrodes

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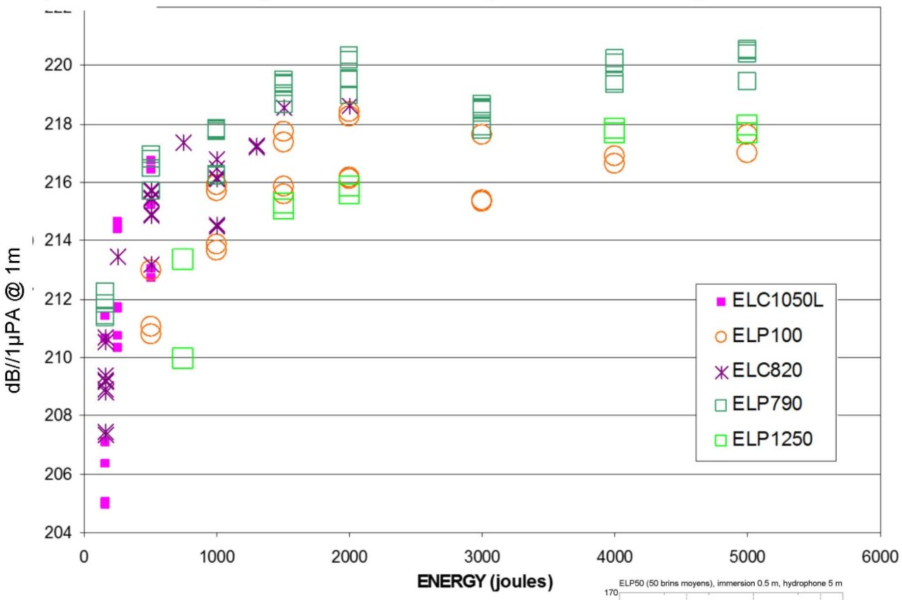
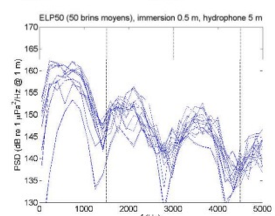
info@sigfrance.com

SIG SPARKER-ELECTRODES MODELS

- ELC 1050L
- ELC1200L
- ELC820
- EDL1020
- ELP 790
- ELP1250

Higher frequency	ELC1050L & ELC1200L	ELC820	EDL1020
Operating energy level :	250 to 750 joules	750 to 1000 joules	750 to 2500 joules
Frequency spectrum :	1000—1400 Hz	900—1400 Hz	900—1400 Hz
Acoustic power level :	217 dB re 1µPa @ 1 m	219 dB re 1µPa @ 1 m	220 dB re 1µPa @ 1 m
Pulse duration :	0.8 ms @ 250 J Immersed 20 cm	0.8 ms @ 750 J Immersed @ 20 cm	1.1 ms @ 1500 J, Immersed @ 40 cm
Dimensions :	0.50 m x 0.60 m x 0.04 m	1 m x 0.60 m x 0.04 m	1 m x 0.60 m x 0.06 m
Weight :	1.0 kg	1.8 kg	3.5 kg





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COMPROMISE BETWEEN THE LOW COST
AND THE NECESSARY TRIMMING
THE ELP SERIES IS LONGER LIFE

Lower frequency	ELP790	ELP1250
Operating energy level :	100 to 3000 joules Optimal 400-1200 joules	1000 to 6000 joules Optimal 1600 joules
Frequency spectrum :	< 800 Hz after 1000 J @ 50cm	Centered 1200 Hz @ 30cm
Acoustic power level :	220 dB re 1µPa @ 1 m	216-218 dB re 1µPa @ 1 m
Pulse duration (immersed @ 30 cm)	Primary 1.18 ms @ 500 J Delta T secondary 2.9 ms @ 1000 J	Primary 1.27 ms @ 2000 J Delta T secondary 2.8 ms @ 4000 J
Dimensions :	1 m x 0.60 m x 0.06 m	1 m x 0.60 m x 0.06 m
Weight :	2 kg	5.2 kg

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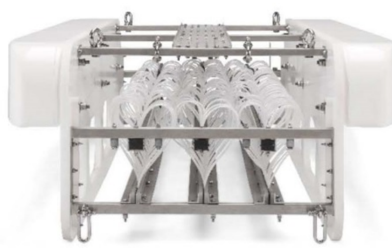
Dura-Spark, Seismic Sound Source



Key Features

- Long life, durable electrodes
- Pulse stability
- High resolution sub-bottom data, up to 25cm.
- Operator selectable source depth
- Tip array selection from on board junction box

Applications

- High and Ultra-High Resolution geophysical surveys
- Single and multi-channel acquisition
- Water depths of 5 to >1000m

The Dura-Spark has been designed to provide a stable, repeatable sound source for sub-bottom geophysical surveys. The long life, durable electrodes produce a consistent pulse signature and keep operational maintenance to a minimum. This provides increased survey efficiency and equipment reliability as the sparker tips rarely need replacement.

The Dura-Spark is based on the CAT300 catamaran, providing a stable platform whilst under tow. The catamaran has robust solid floatation and is easily deployed from all survey vessels.

The Dura-Spark consists of 3 or 5 arrays of 80 tips allowing the operator to tune the source from the vessel to their application. This flexibility together with selectable source depth allows the source to be used in both shallow and deep waters.

The typical operational bandwidth of the Dura-Spark is 300Hz to 1.2kHz. When coupled with the CSP-N Seismic Power Supply the system offers 2000J/s peak discharge rate, as well as industry leading design and safety standards.

Dura-Spark Technical Specification

PHYSICAL

Dimensions	1700mm (L) 490mm (H) 660mm (W) frame/876mm (W) including floats
Weight	Dura-Spark 240 60kg Dura-Spark 400 70kg
Connector	RMK 1/0 complete with locking collar

ELECTRICAL INPUT

Dura-Spark 240	1000J, 5J per tip to minimise bubble collapse component 1250J Maximum
Dura-Spark 400	2000J, 5J per tip to minimise bubble collapse component 2400J Maximum

SOUND OUTPUT

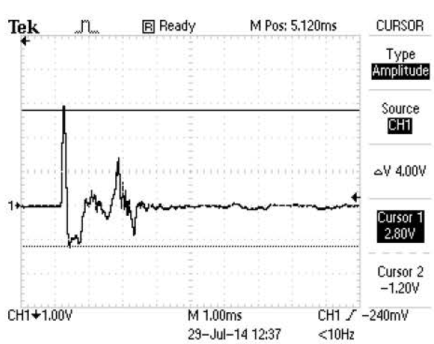
Sound Output	Dura-Spark 240; 223dB re 1uPa at 1m (Typical) Dura-Spark 400; 226dB re 1uPa at 1m (Typical)
Pulse Length	0.5 to 1.5ms depending on power
Number of Tips	240 Max total. 3 x 80 Operator selected; 80 (1 x 80) or 160 (2 x 80) or 240 (3 x 80) 400 Max total 5 x 80 Operator selected; 80 (1 x 80) or 240 (3 x 80) or 400 (5 x 80)

COMPATIBILITY

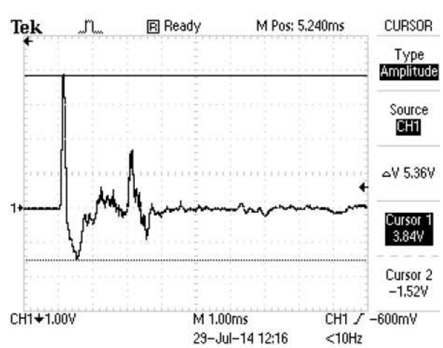
Source	Seismic Power Supply	HV Cable
Dura-Spark 240	CSP-N 1200 Negative	HVC-3500
Dura-Spark 400	CSP-N 2400 Negative	HVC-3500

TYPICAL PULSE SIGNATURES

Dura Spark 240 Typical Pulse Signature at 1000J recorded @ 2m



Dura Spark 400 Typical Pulse Signature at 2400J recorded @ 2m



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Due to continual product improvement, specification information may be subject to change without notice.
Dura-Spark/March 2015

Registration No. U6447
BS: EN: ISO9001

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Delta Sparker Seismic Sound Source

The Delta Sparker is the most powerful sparker available in the Applied Acoustics' range and is intended for deeper penetration sub-bottom profiling.

As a multi-tip sparker array, the Delta can be used in UHR multi-channel seismic surveys utilising 24 or 48 channel streamers such as during geohazard assessment, construction projects or shallow target 2D exploration.

Different sparker tips, single or multiple arrangements, can be used to increase resolution or penetration as required.

Key Features

- Powerful sparker for deep penetration surveys
- 1000-12000J, compatible with CSP-D2400 and CSP-S
- 2.5m triangular tow frame, supplied with buoys
- Tow depth can be adjusted
- Replaceable electrodes for easy field maintenance

Technical Specification

PHYSICAL

Dimensions	2550mm (L) x 350mm (W) x 250mm (H) (can be split in two for ease of shipping)
Weight	50kg approx
Frame material	Stainless steel
Buoyancy	FA6 floats x 2
Depth of tow	Adjustable
Connector	RMK 1/0 complete with locking collar

ELECTRICAL INPUT

Recommended energy	1500 – 12,000J/shot
Maximum energy	12,000J/shot
Operating voltage	3000-4000V

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Delta Sparker, Technical Specification continued...

Number of tip locations	3 (yellow, blue, red) Operator selectable
Maximum number of tips	9 single: 3(3 x 1) 135 multi-tip: 3(3 x 15)

SOUND OUTPUT

Source level	Typically 226dB re 1µPa at 1 metre with 6000J
Frequency range	300Hz – 5kHz
Pulse length	0.3 – 5.0ms Dependent on tips and power applied
Penetration	800ms achieved

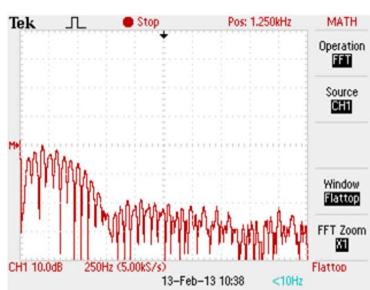
COMPATIBLE ENERGY SOURCES

Delta Sparker	CSP-D to 2400J CSP-S to 12000J

COMPATIBLE HV CABLE

Delta Sparker	HVC 3500 Standard length 75m RMK 1/0 connectors complete with locking collars

TYPICAL PULSE SIGNATURE AT 12000J



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CSP-D Seismic Energy Source

The CSP-D is a seismic energy source for boomer and sparker applications in three variants, the CSP-D700, CSP-D1200 and CSP-D2400. Each unit has the same chassis and 1500J/second HV engine.

The CSP-D incorporates dual-voltage technology that allows the operator to tune the sound source to a particular application for improved data quality.

Key Features

- **Incorporates dual-voltage technology for exceptional versatility**
- **Variable Input Power Circuitry for 'soft start'**
- **Proprietary pulse shaping circuitry for high resolution data**
- **Additional safety/protection features**
- **All settings externally selectable**
- **LED fault indicators**
- **High current and voltage solid state (semi-conductor) discharge method**
- **Meets EC emissions regulations enabling interference-free field use**
- **Supplied in robust transit case, with HV junction box (HVJ2000), mains lead and HV connector plug**

Technical Specification

PHYSICAL

Size	Transit Case (7U) with cover in place and handles flat: 50cm(H) x 58cm(W) x 74cm(D)
Weight	CSP-D700, case and cover: 60.5kg CSP-D1200, case and cover: 61.5kg CSP-D2400, case and cover: 63.5kg

ELECTRICAL SPECIFICATION

Mains Input	240Vac 45-65Hz@3.0kVA single phase. 3 pin connector Variable Input Power Circuitry (AVIP) 'soft start' circuitry
Voltage Output	2500 to 3950Vdc, 4 pin interlocked connector Solid state semi-conductor discharge method

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CSP-D Technical Specification continued…

Output Energy	Easy switch selectable in increments	
	CSP-D700	50,100,150,200,250,300,350,400,500,600,700 Joules
	CSP-D1200	50,100,150,200,250,300,350,400,450,500,550,600, 700,800,900,1000,1100,1200 Joules
	CSP-D2400	50,100,150,200,300,400,500,600,700,750,800,900, 1000,1250,1500,1750,2000,2250,2400 Joules
Charging Rate	1500J/second for continuous operation at 0-45°C ambient	
Capacitance	CSP-D700	112µF at 10^8 shot life
	CSP-D1200	208µF at 10^8 shot life
	CSP-D2400	304µF at 10^8 shot life
Trigger	+ve key opto isolated or isolated closure set by front panel switch BNC connector on front panel and remote box (optional)	
Repetition rate	6pps max Limited by charge rate, energy level and sound source rating	
Earth	M8 stainless steel stud on front panel	

SAFETY FEATURES

Main electronic control circuits and secondary layer of safety circuitry
Specially designed HV connector with interlock
High speed dump resistors for high voltage components
Capacitor bleed resistors
Open circuit shutdown
Timer shutdown
Output current monitor and shutdown
Over temperature shut-down
Cover and connector interlocks
HV fault indicator for internal temperature, low input voltage or capacitor fault
Remote control available for triggering and operation

The unit's internal design has a modular construction for ease of servicing and capacitor replacement. However, for safety reasons, only Applied Acoustics trained engineers should attempt a repair.

COMPATIBLE SOUND SOURCES

CSP-D700	AA201, AA251, AA301 Boomer plates, Squid 501 Sparker
CSP-D1200	AA201, AA251, AA301 Boomer plates, Squid 501 and Squid 2000 Sparkers
CSP-D2400	AA201, AA251, AA301 Boomer plates, Squid 501, Squid 2000 and Delta Sparkers

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Due to continual product improvement, specification information may be subject to change without notice.
CSP-D Seismic Energy Source/June 2015

Registration No. U6447
BS: EN: ISO9001

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CSP-N Seismic Energy Source

The CSP-N seismic energy source is the driving force behind Applied Acoustics' Dura-Spark range of sound sources that have extremely hard wearing electrode sparker tips. This durability is a consequence of the CSP's reverse polarity high voltage charger and unique proprietary thyristor switching.

Featuring all of the standard safety systems and operational functions found across the entire range of CSP energy sources, the CSP-N is also suitable for use with the Applied Acoustics' S-Boom and single plate boomer systems.

Key Features

- **Unique dual negative voltage output**
- **Variable Input Power Circuitry for 'soft start'**
- **Additional safety/protection features**
- **All settings externally selectable**
- **LED fault indicators**
- **High current and voltage solid state (semi-conductor) discharge method**
- **Meets EC emissions regulations enabling interference-free field use**
- **Dual voltage technology allows operator tuning to suit application**
- **Supplied in robust transit case, with HV junction box (HVJ3001), mains lead and HV connector plug**

Technical Specification

PHYSICAL

Size	Transit Case (7U) with cover in place and handles flat: 50cm(H) x 58cm(W) x 74cm(D)
Weight	CSP-N1200, case and cover: 60kg CSP-N2400, case and cover: 63.5kg

ELECTRICAL SPECIFICATION

Mains Input	240Vac 45-65Hz@4.0kVA single phase. 3 pin connector Variable Input Power Circuitry (AVIP) 'soft start' circuitry
Voltage Output	2500 to 3950Vdc, 4 pin interlocked connector Solid state semi-conductor discharge method

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CSP-N Technical Specification continued...

Output Energy	Easy switch selectable in increments	
	CSP-N1200	50,100,150,200,250,300,350,400,450,500,550,600 700,800,900,1000,1100,1200 Joules
	CSP-N2400	50,100,150,200,250,300,400,500,600,750, 800 900,1000,1250,1500,1750,2000,2250,2400 Joules
Charging Rate	2000J/second for continuous operation at 0-45°C	
Capacitance	CSP-N1200	208μF, 10^8 shot life
	CSP-N2400	304μF, 10^8 shot life
Trigger	+ve key opto isolated or isolated closure set by front panel switch BNC connector on front panel and remote box (optional)	
Repetition rate	6pps maximum Limited by charge rate, energy level and sound source rating	
Earth	M8 stainless steel stud on front panel	

SAFETY FEATURES

Main electronic control circuits and secondary layer of safety circuitry
Specially designed HV connector with interlock
High speed dump resistors for high voltage components
Capacitor bleed resistors
Open circuit shutdown
Timer shutdown
Output current monitor and shutdown
Over temperature shut-down
Cover and connector interlocks
Remote control available for triggering and operation

The unit's internal design has a modular construction for ease of servicing and capacitor replacement. However, for safety reasons, only Applied Acoustics trained engineers should attempt a repair.

COMPATIBLE SOUND SOURCES

CSP-N1200	Dura-Spark 240, 400 AA201, AA251 and AA301 Boomer plates S-Boom System
CSP-N2400	Dura-Spark 240, 400 AA201, AA251 and AA301 Boomer plates S-Boom System

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LAND
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MARINE

Marine Sources

High-performance airguns

Sercel
Ahead of the Curve℠

Marine Sources

// HIGH-PERFORMANCE AIRGUNS

Sercel has 30 years of experience in the design and manufacture of marine sources. Throughout this time, Sercel has developed sources for all applications encountered within the seismic industry, including the most demanding environments.

This expertise has provided us with the foundations for designing a turnkey marine seismic source solution that can be adapted to every customer's need and operating environment as well as be built on for future source solutions and other in-sea equipment such as float systems.

The design philosophy driving all our marine source products is ease-of-use, safety and reliability. Sercel offers the most comprehensive air gun portfolio in the industry that can be used for seismic & engineering applications such as towed streamer, shallow water/OBC and VSP surveys.


Complete Package
// G. GUN II
Streamer
Shallow Water
// Mini G. GUN & GI GUN
Borehole
// G. GUN
3

Streamer

// G. GUN II

+5% 0-Peak Output compared to conventional airguns

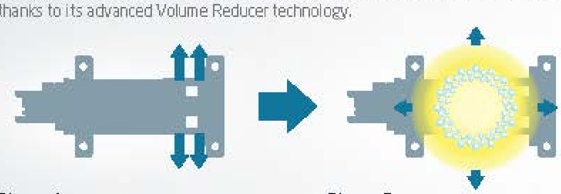
Designed to operate continuously at up to 3,000 psi (210 bars)

High degree of pulse repeatability

Recoilless

Possibility to deploy airguns at sea without pressure

The G. GUN II is the safest, easiest-to-use and most reliable air gun in the industry. It offers a lightweight, compact solution for consistent performance and flexibility thanks to its advanced Volume Reducer technology.



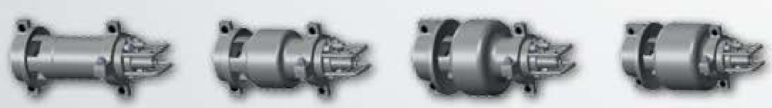
Phase 1

A special patented design allows the compressed air that is released to be deflected at the sides, resulting in recoilless shooting.

Phase 2

High-pressure air explosively released into the surrounding water generates the main acoustic pulse.

Specifications



	G. GUN II 150	G. GUN II 250	G. GUN II 380	G. GUN II 520
Available volume (cu.in)	45 • 50 • 60 • 70 • 80 • 90 • 100 • 110 • 120 • 130 • 140 • 150	180 • 200 • 210 • 220 • 250	320 • 340 • 350 • 360 • 380	520
Length	L = 597mm	L = 597mm	L = 640mm	L = 640mm
Width	W = 292mm	W = 292mm	W = 292mm	W = 292mm
Weight	55kg	65kg	85kg	90kg

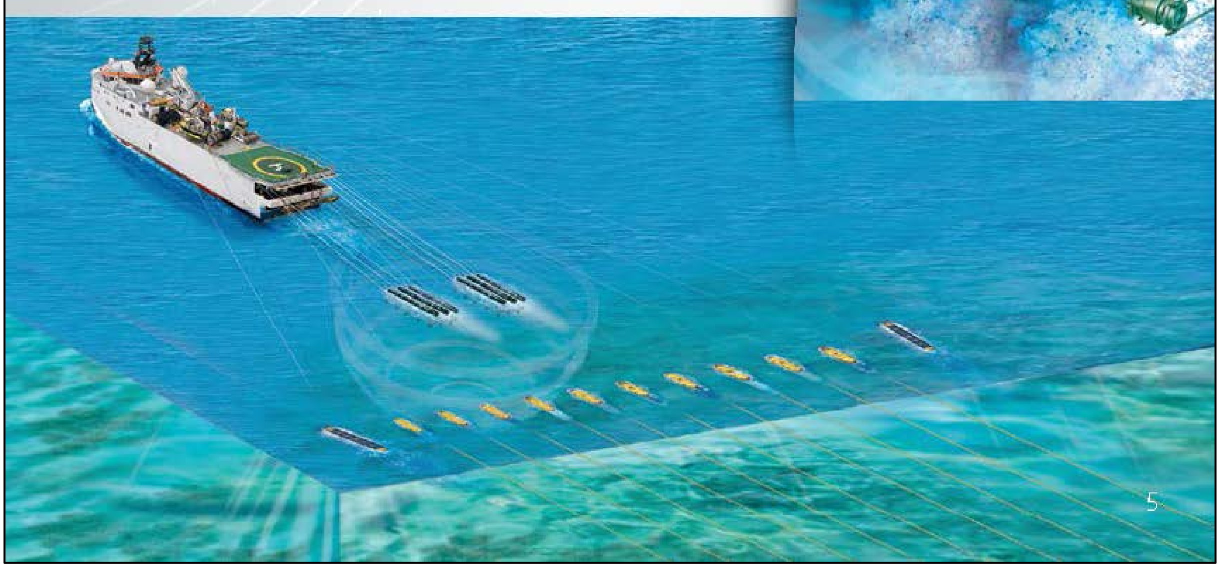
Single air gun type

Each gun volume can be easily changed by means of inexpensive "Volume Reducers" or by changing the external casing.

- Single set of spare parts for the entire G. GUN II range.
- Assemble/disassemble within minutes without special tooling.
- Firing/sensor/sleeve/shuttle system for all G. GUN II.

With its mechanical advantages and strong acoustic performance the G. GUN II is the air gun of choice for high-production seismic vessels.

For maximum energy output and high signature consistency shot after shot, G. GUN II airguns can be configured in gun clustered elements using our patented parallel cluster assembly design.



Shallow Water

// GI GUN

Clean acoustic signature

Light and compact

Flexible configuration

Sercel developed the GI GUN to reduce and suppress the bubble oscillation from a single air gun to simplify processing. The GI GUN air gun is based on the same technology as the G. GUN but is different in that it has two independent air chambers within the same casing.

- The Generator, generating the primary pulse and creating the main bubble.
- The Injector, injecting air inside the main bubble so that it collapses quickly.

Phase 1

The Generator is fired. The blast of compressed air produces the primary pulse and the bubble starts to expand.

Phase 2

Just before the bubble reaches its maximum size, the injector is fired, injecting air directly inside the bubble.

Phase 3

The volume of air released by the injector increases the internal pressure of the bubble and prevents its violent collapse. The oscillations of the bubble and the resulting secondary pressure pulses are reduced and reshaped.

Specifications



	GI GUN 210	GI GUN 255	GI GUN 355
Volume	210cu.in (G = 105 cu.in I = 105cu.in)	255cu.in (G = 150 cu.in I = 105cu.in)	355cu.in (G = 250 cu.in I = 105cu.in)
Length	L = 790mm	L = 860mm	L = 860mm
Width	W = 312mm	W = 280mm	W = 280mm
Weight	74kg	87kg	97kg

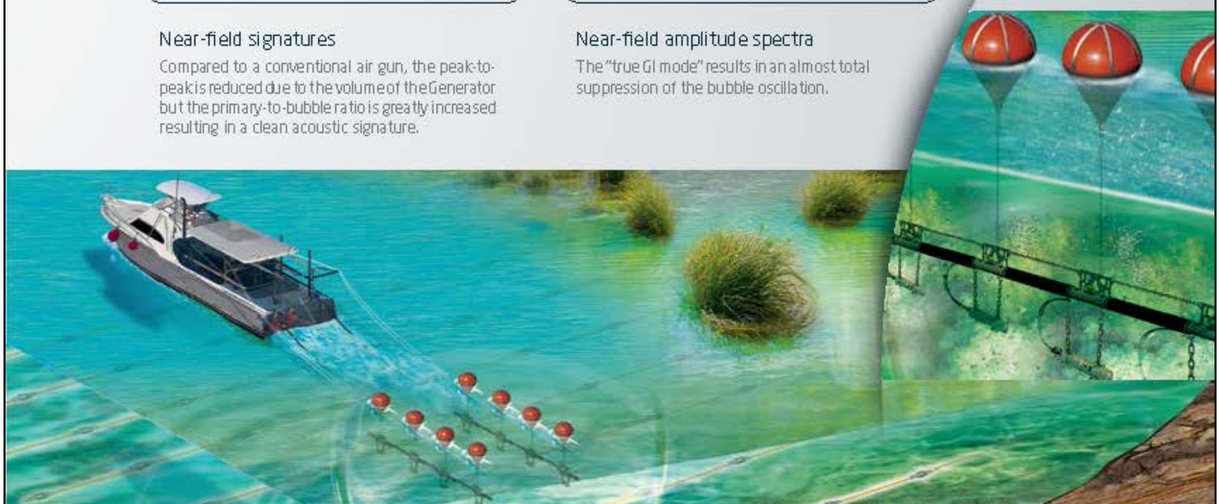
Clean acoustic signature

Near-field signatures

Compared to a conventional air gun, the peak-to-peak is reduced due to the volume of the Generator but the primary-to-bubble ratio is greatly increased resulting in a clean acoustic signature.

Near-field amplitude spectra

The "true GI mode" results in an almost total suppression of the bubble oscillation.



// Mini G. GUN / Mini GI

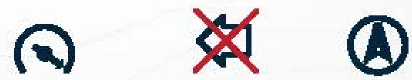
Scaled-down models from the already compact GI and G. GUN are available for high-resolution, shallow water and transition zone surveys. The Mini G. and Mini GI air guns have the same advantages as their larger counterparts, but with even simpler technology.

	Mini GI	Mini G 12	Mini G 20	Mini G 24	Mini G 40	Mini G 60
Volume	60cu.in (G = 30cu.in I = 30cu.in)	12cu.in	20cu.in	24cu.in	40cu.in	60cu.in
Length	L = 560mm	L = 390mm	L = 390mm	L = 390mm	L = 390mm	L = 390mm
Width	W = 200mm	W = 200mm	W = 200mm	W = 200mm	W = 200mm	W = 200mm
Weight	28.1kg	25.4kg	24.2kg	23.7kg	24.3kg	25.8kg

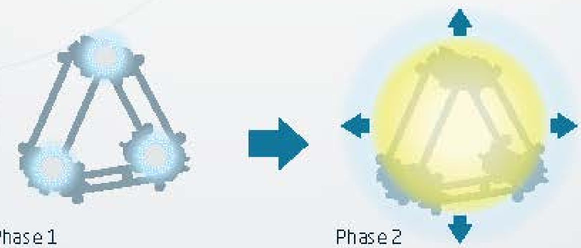
Borehole

// G. GUN FOR DELTA CLUSTER

Delta cluster



Over the years the Sercel G. GUN range of products has become the system of choice for advanced VSP surveys, in both offshore and onshore environments. The G. GUN and delta cluster combines the advantages of a powerful source and a clean acoustic performance to maximize borehole data quality.



Phase 1

The Sercel delta cluster is an air gun arrangement of three G. GUNS to provide an improved signal characteristic.

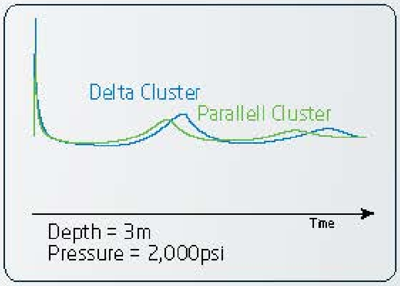
Phase 2

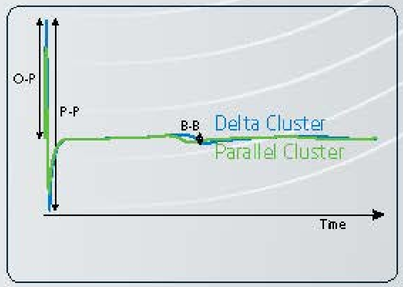
The delta-cluster arrangement provides more output and a higher peak-to-bubble ratio compared to a single airgun of an equivalent volume.

Specifications

	G. GUN 150	G. GUN 250
Volume	45 • 50 • 60 • 70 • 80 • 90 • 100 • 110 • 120 • 130 • 140 • 150	180 • 200 • 210 220 • 250
Length	L = 597mm	L = 597mm
Width	W = 292mm	W = 292mm
Weight	55kg	65kg

High-energy cluster configuration





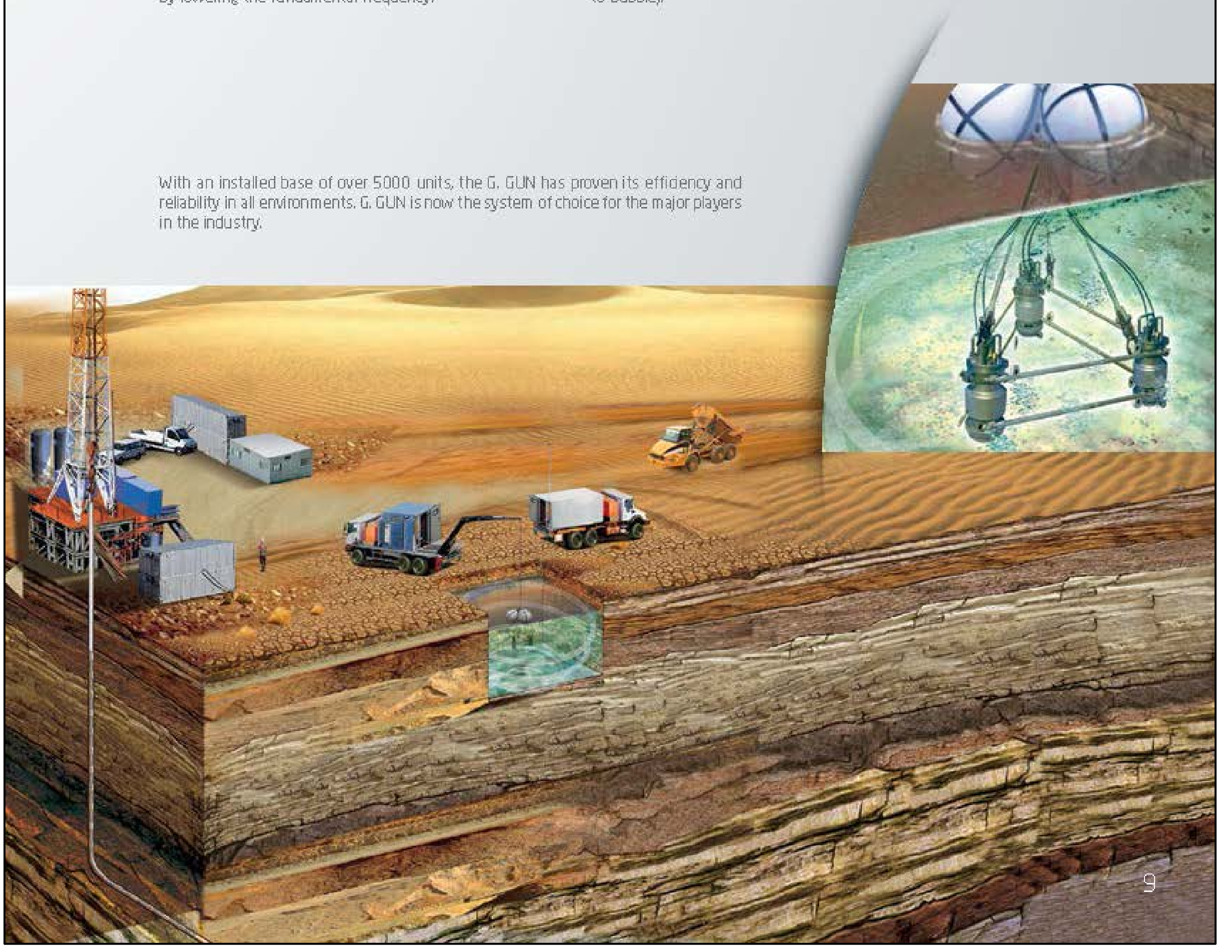
Near field signatures

The Delta Cluster & Parallel Cluster will produce a higher peak performance within a similar overall arrangement of a single gun.
The Delta cluster getting the edge over the Parallel by lowering the fundamental frequency.

Far field amplitude spectra

Sercel developed the Delta Cluster by adding a third gun to the Parallel cluster assembly. It generates great output performance with unrivalled acoustic signature (+33 % in Peak-Output, + 19% in peak-to-bubble).

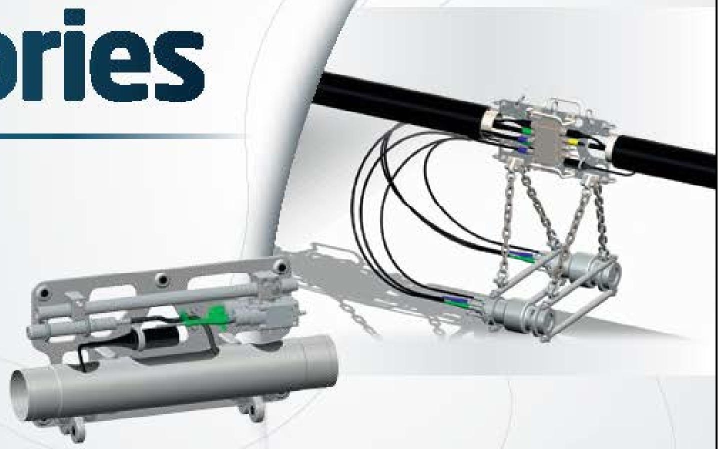
With an installed base of over 5000 units, the G. GUN has proven its efficiency and reliability in all environments. G. GUN is now the system of choice for the major players in the industry.



Accessories

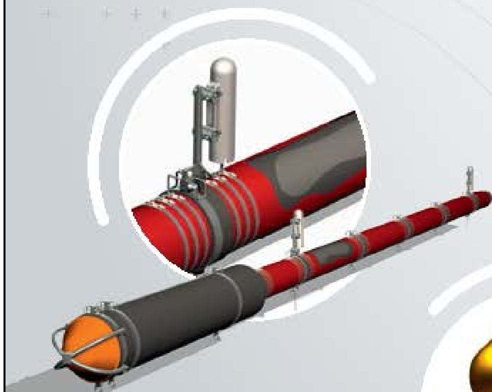
// GUN PLATES

Sercel provides heavy duty Gun plates that are compatible with all gun synchronizers available on the market.

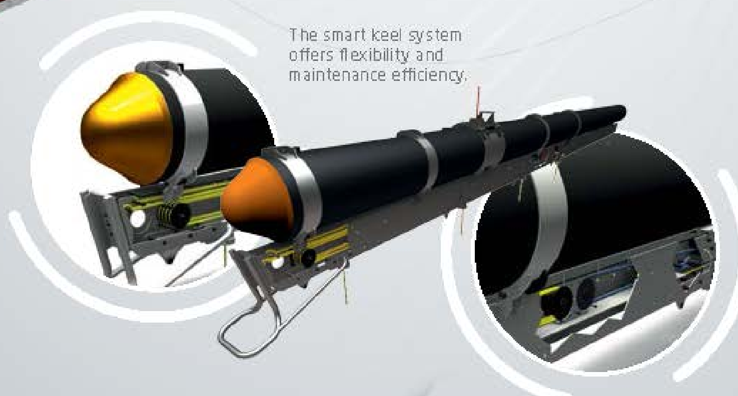


// FLOATS

Operated by major geophysical service providers, Sercel has developed float technology for rigid and flexible Handling systems:



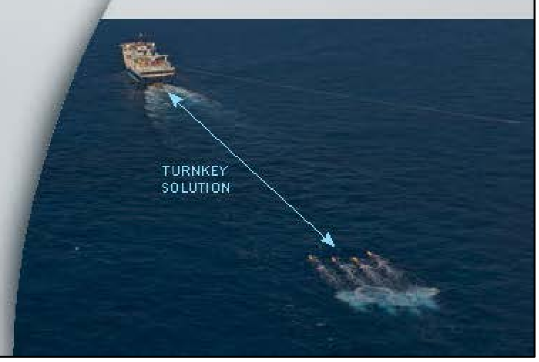
This flexible float is stable at sea due to its foam inserts & is safe as no inflation is required.



The smart keel system offers flexibility and maintenance efficiency.

// AIR GUN EQUIPMENT

For customers looking for a turnkey solution, Sercel is able to provide associated marine source peripherals such as terminated armoured umbilicals, sliprings, air swivels, back-deck cables, interface panels and gun synchronizers ensuring full compatibility between all our equipment.



Portable Solutions

Sercel is the exclusive distributor of the turn-key towing solutions designed by SeaScan Inc.

SeaScan Inc is the best partner for Sercel's turn-key solutions as the equipment is specifically designed for shallow water and transition zone areas.

The portable frames allow for quick mobilization and operations onboard multi-purpose vessels or barges.

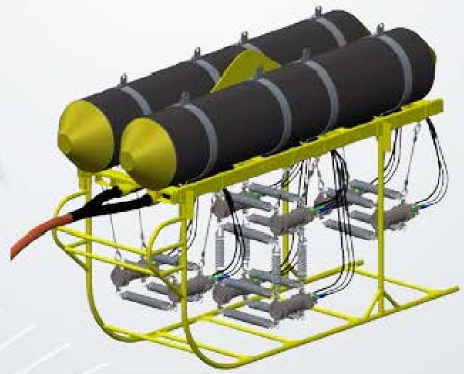
//TRI-CLUSTER®

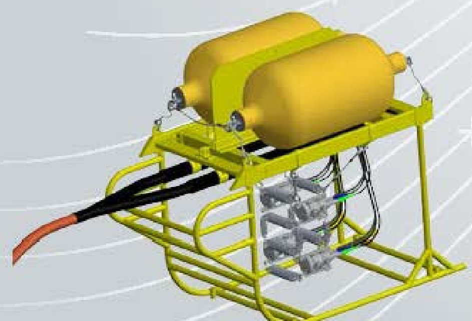
Medium size array

The Tri-Cluster offers high power output thanks to its unique point source design.

The array includes 8 sources, combining concentrated parallel and square clusters for maximized acoustic performances.

The Tri-Cluster can be fitted with an optional cage protecting the sources in hazardous water, such as rivers with heavy debris.





//MINI SLED

High resolution array

The MINI SLED is designed for operating 4 MINI G. GUN for high-resolution surveys.

Light and compact, it benefits from the square cluster powerful output.

//SHALLOW WATER HARNESS

Shallow water array

The USW systems are designed for small arrays or ultra-shallow water operations.

Two versions are available:

- single sources (up to 2 sources)
- parallel cluster sources (up to 4 sources)

Marine Sources

High-performance airguns

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Ahead of the Curve℠

3100

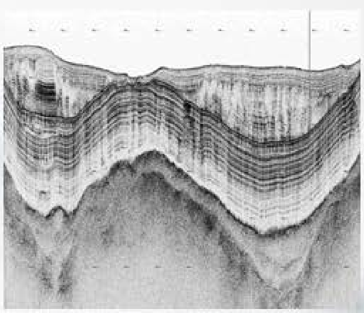
PORTABLE SUB-BOTTOM PROFILING SYSTEM

FEATURES

- Portable
- Low power requirement (runs on AC or DC)
- Choice of towfish depending on the application
- Pole mount option for shallow water surveys
- Easy to setup and operate

APPLICATIONS

- Geological Surveys
- Geohazard Surveys
- Buried Object Location
- Mining/Dredging Surveys
- Bridge/Shoreline Scour Surveys
- Pipeline and Cable Location



The 3100 is EdgeTech's portable version of their highly successful sub-bottom profiler product line. The system utilizes EdgeTech's Full Spectrum CHIRP technology which provides higher resolution imagery of the sub-bottom structure and greater penetration.

The 3100 is ideally suited for use in rivers, lakes, ponds and shallow water ocean applications up to 300m max depth. The system was designed for customers that require a portable system that can be used from smaller boats while not wanting to sacrifice image quality.

A 3100 system comes with a choice of two towfish; either the SB-424 or SB-216S. These towfish operate at different frequency ranges and selection between the two depends on the type of application. The 424 operates at 4-24 kHz and will provide slightly higher resolution but less penetration. The 216S operates at 2-16 kHz and provides slightly less resolution but greater penetration. Along with a towfish, the 3100 system comes with a portable splash-proof topside processor with laptop computer running EdgeTech's DISCOVER software for display of the sonar data. The system comes standard with a 35m tow cable with customer-specified lengths also available.

For more information please visit EdgeTech.com

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EdgeTech

3100

PORTABLE SUB-BOTTOM PROFILING SYSTEM

KEY SPECIFICATIONS

TOWFISH	SB-216S	SB-424
Frequency Range	2-16 kHz	4-24 kHz
Vertical Resolution (depends on pulse selected)	6-10 cm	4-8 cm
Penetration		
In coarse calcareous sand	6m	2m
In clay	80m	40m
Length	105 cm (41")	77 cm (30")
Width	67 cm (26")	50 cm (20")
Height	40 cm (16")	34 cm (13")
Weight in Air	76 kg (167 lbs)	45 kg (100 lbs)
Weight in Water	32 kg (70 lbs)	18 kg (40 lbs)
Max Depth Rating of Towfish	300 meters	
TOPSIDE PROCESSOR		
Hardware	Rugged, portable splashproof enclosure	
Operating System	Windows 7	
Display	Splashproof semi-rugged laptop	
Archive	DVD-R/W	
File Format	JSF, SEG-Y & XTF	
I/O	Ethernet	

SB-216S TOWFISH

SB-424 TOWFISH

For more information please visit EdgeTech.com

info@EdgeTech.com | USA 1.508.291.0057

EdgeTech

3200
SUB-BOTTOM PROFILING SYSTEM

FEATURES

- Choice of 3 towfish depending on the application
- Low frequency for greater penetration
- Pole mount option for shallow water surveys

APPLICATIONS

- Geological Surveys
- Geohazard Surveys
- Sediment Classification
- EEZ Resource Development
- Buried Object Location
- Bridge/Shoreline Scour Surveys
- Mining/Dredging Surveys

The EdgeTech 3200 Sub-bottom Profiling System is a wideband Frequency Modulated (FM) sub-bottom profiler utilizing EdgeTech's proprietary Full Spectrum CHIRP technology. The 3200 generates high resolution images of the sub-bottom stratigraphy in oceans, lakes, and rivers and provides penetration of up to 200m.

The 3200 comes available with a choice of three stable, low drag towfish that operate at different frequencies and can be used at depths of up to 300m. The selection of towfish depends on the sub-bottom characteristics as well as the resolution and penetration requirements.

Along with a towfish, a standard 3200 system comes with a topside processor running EdgeTech's DISCOVER sub-bottom acquisition & processing software as well as a customer-specified length of tow cable. Additional optional sensors are also available.

For more information please visit EdgeTech.com

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EdgeTech

3200

SUB-BOTTOM PROFILING SYSTEM

KEY SPECIFICATIONS

TOWFISH	SB-0512i	SB-216S	SB-424
Frequency Range	500 Hz–12 kHz	2-16 kHz	4-24 kHz
Vertical Resolution (depends on pulse selected)	8–20 cm	6-10 cm	4-8 cm
Penetration (typical)			
In coarse calcareous sand	20 meters	6 meters	2 meters
In clay	200 meters	80 meters	40 meters
Length	160 cm	105 cm	77 cm
Width	124 cm	67 cm	50 cm
Height	47 cm	40 cm	34 cm
Weight in Air	204 kg	76 kg	45 kg
Weight in Water	68 kg	32 kg	18 kg
Depth Rating	300 meters		
TOPSIDE PROCESSOR			
Hardware	Standard 19 inch rack mount with portable aluminum enclosure for transport		
Operating System	Windows® 7		
Display	High resolution 21 inch flat panel display		
Archive	Hard drive and/or DVD-R/W		
File Format	Native JSF or SEG-Y		
Output	Ethernet		
Power Input	120/220 VAC		
SYSTEM OPTIONS			
	Integrated depth sensor, USBL acoustic tracking system		

SB-0512i

SB-216S

SB-424

For more information please visit EdgeTech.com

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KNUDSEN
CHIRP
RACK SERIES
KNUDSEN
SYSTEM
POWER
CHIRP
Proudly Made
In CANADA

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Proudly Made In CANADA

CHIRP RACK SERIES

Knudsen CHIRP Systems are the next benchmark in scientific sub-bottom profiling echosounders. The CHIRP Rack system, a blackbox system which interfaces to your computer via a USB connection, incorporates the latest in digital signal processing technology and includes Knudsen SounderSuite Windows application software and chirp and correlation processing algorithms to enhance sub-bottom capability. The unit, housed in a 3U rackmount case, is ideal for quick installation to a standard equipment rack on your survey platform.

Available in a 2 or 4 channel configuration, the versatile system is particularly well suited to multiple survey roles and includes a wide range of standard bathymetry and sidescan frequencies for both shallow and deeper depths.

Technical Specifications: *(subject to change without notice)*:

Available Channels
- Chirp 3200: 1 channel
- Chirp 3202: 2 channels
- Chirp 3204: up to 4 channels

Frequency
- All channels: 3.5kHz - 210kHz

Output Power
- Up to 2kW on Channels 1 and 2
- Up to 1kW on Channels 3 and 4

Input Power
- 85 - 265 VAC (DC Optional)

Pulse Length
- Up to 64ms

Gain
- Manual, automatic (AGC), and time varied (TVG)
- 96db range of programmable analog gain

Ranges
- 5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000

Phasing
- Manual and automatic (up to 50% overlaps)

Units
- Meters, Feet, or Fathoms

Resolution
- 1cm (0-99.99), 1dm (100-999.9), 1m (>1000)
- 1/100ft (0-99.99), 1/10ft (100-999.9), 1ft (>1000)
- 1/100fm (0-99.99), 1/10fm (100-999.9), 1fm (>1000)

Sound Velocity
- 1300 - 1800 m/s Resolution 1m/s
- 4265 - 5906 ft/s Resolution 1ft/s
- 710 - 984 fm/s Resolution 1 fm/s

Draft
- 0-100m Resolution 1cm
- 0-328ft Resolution 0.01ft
- 0-54fm Resolution 0.01fm

Interface
- USB 2.0 Full Speed (12Mbps)

Output Data
- Full resolution envelope data in KEB binary format and XTF (for sidescan only)
- Industry standard SEG-Y in 16-bit fixed point in user selected raw, filtered, or envelope detected form
- User configurable ASCII digital depth strings

Dimensions
- 533mm (21") x 483mm(19") x 133mm (5.25")

Weight
- Chirp 3200: 11kg (24lbs)
- Chirp 3202: 12kg (26lbs)
- Chirp 3204: 14kg (30lbs)

Installation
- 3U Rackmount case

Operating Temperature
- 0 - 50°C

Additional Features
- Frequency agility on all channels
- Chirp and correlation processing
- **Transmit signal generation control**
- Advanced digital filter control
- Built-in drivers for all popular GPS
- Built-in test signal generator
- Compatible with industry standard dataloggers and processing software (Hypack, QINSy, SonarWiz)
- Heave compensated echogram

Options
- Sidescan option
- Network option for multiple PC operation
- Remote Display Indicators
- EchoSim Sonar Signal Simulator

SounderSuite Software (included)
- Compatible with Windows Vista or higher
- Easy to use Graphical User Interface (GUI)
- Postsurvey Display and Printing Software
- Large Digitized Depth Display
- Print to standard Windows printers and select thermal printers

Printed in Canada
D131 05116 Rev2.0

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MASSA

GENERATIONS AHEAD IN SONAR & ULTRASONIC TECHNOLOGY

Massa TR-1075
Sub-Bottom Profiling Transducers

The Massa Model TR-1075 Family consists of rugged high-power underwater transducers designed to operate in the 2.5 to 10 KHz frequency range. They are ideal for use in bottom mapping and sub-bottom profiling applications.

The transducers are designed to be driven with a maximum input power of 600 Watts using up to a 30% duty cycle, or 200 Watts maximum for continuous operation. In shallow water, the maximum output is cavitation limited. Minimum water depths of approximately 30 and 100 feet are recommended for input power of 200 and 600 Watts respectively to avoid cavitation.

All of the transducers in the family utilize the same resonant structure containing a circular piston for the radiating source that is ½ wavelength in diameter at 4 KHz. The transducers are designed to be bolted directly through their 4-corner integral shock mounts to a simple frame structure. This modular design allows the transducers to easily be assembled into arrays to achieve any desired beam pattern and source level. Each transducer is terminated with a Massa C1F2 Female Underwater Connector and has a locking ring included. Mating C1M2 Male Connectors can be purchased separately.

The TR-1075E consists of the basic resonator with no electrical tuning. Its nominal frequency of resonance is 3.5 KHz. Massa has fabricated TR-1075 Transducers with a wide variety of different internal tuning networks. They have included transformers to produce different output impedance magnitudes. Transducers have been made with both series and parallel tuning to produce a nominal phase angle of 0 at different frequencies. A separate inductor is required for series tuning, while the inductance of the primary windings of the transformer is used for parallel tuning.

In some cases, damping resistors have been connected across the transducer to lower its Q, which allows the use of a short tone burst excitation pulse with reduced sensitivity for operation when very close to the sea floor. These transducers can be driven with greater input power because some of the energy is dissipated by the resistor. Massa can customize a tuning network to meet any requirement, however, one of our standard models will most likely meet the needs of most customers.

FEATURES

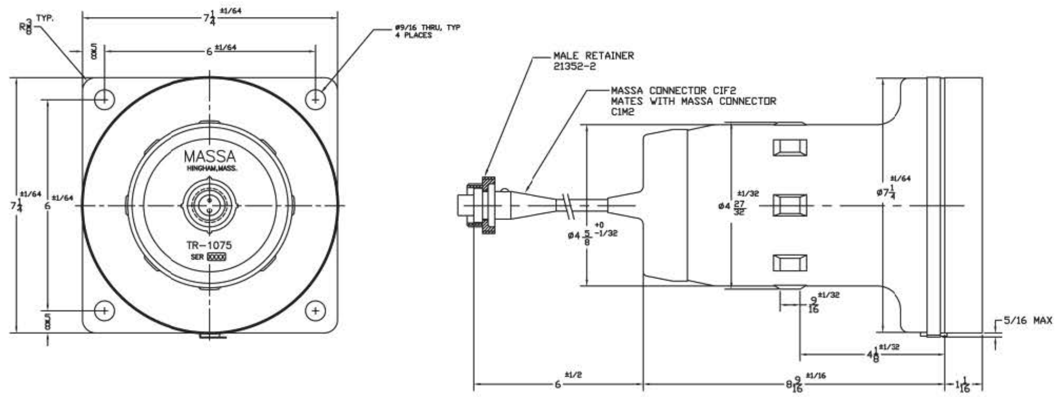
- High Power
  - Up to 600 Watts @ 30% Duty Cycle
  - Up to 200 Watts CW
- Broadband
  - 2.5 to 10 kHz
- MaximumOperating Depth is 600 meters (2,000 ft.)
- True Piston Radiating Source
  - 1/2 Wavelength Diameter at 4 kHz
  - 80° Conical Beam Angle
- Module Design
  - Shock Mounted
  - Easily Assembled into Arrays
- Weight is 25 lbs.
- Terminated with Proven Reliable C1F2 Underwater Connector
- Mates to Massa C1M2 Underwater Connector

APPLICATIONS

- Sub-Bottom Profiling
- Bottom Mapping

MASSA PRODUCTS CORPORATION

Massa TR-1075 Data



TR-1075 Transducer Family Outline Drawing
(Dimensions in Inches)

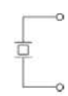
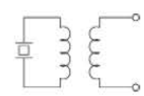
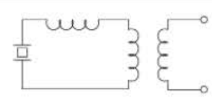
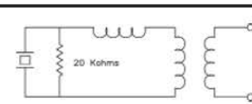
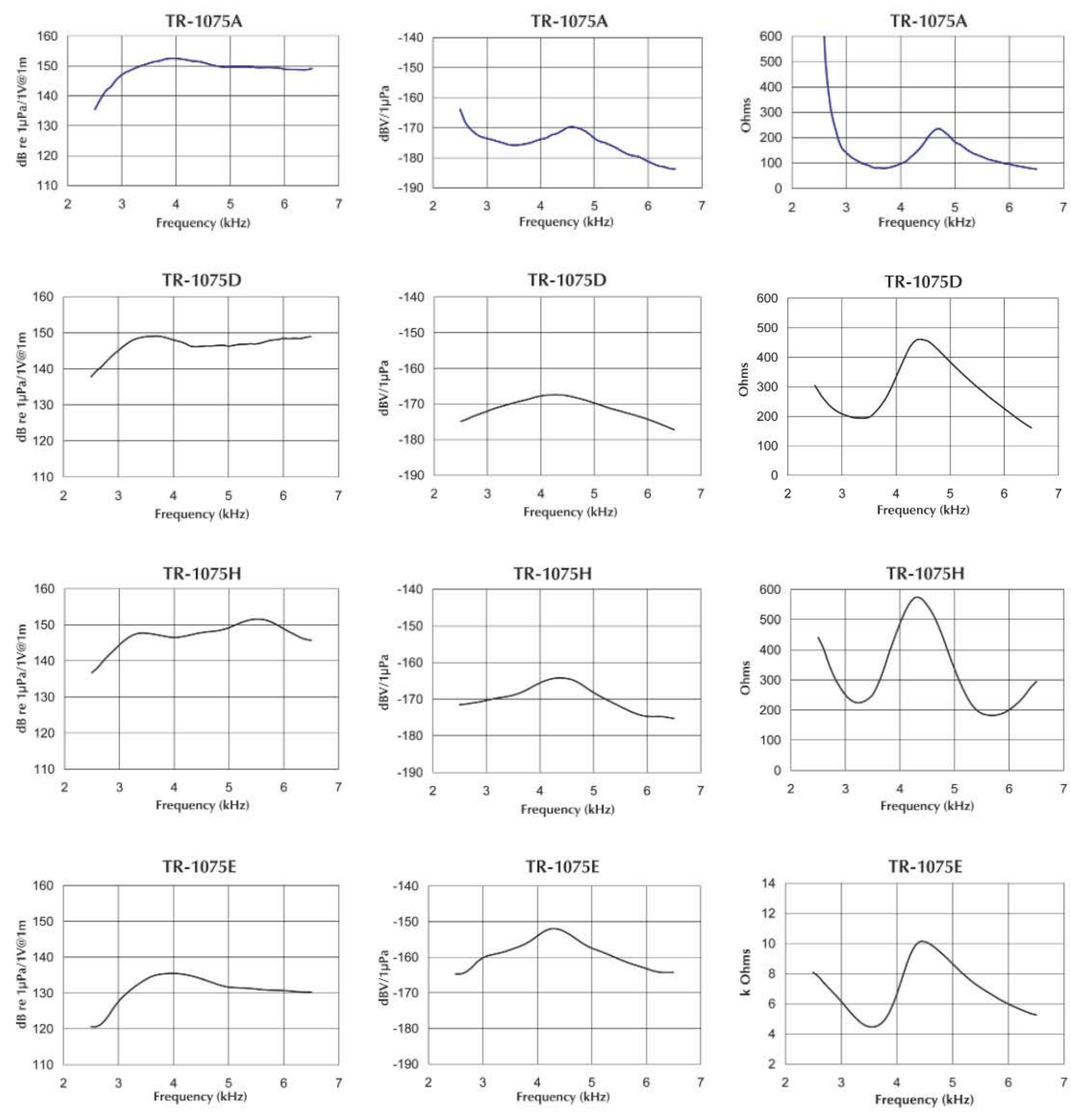
Transducer Model Number	Frequency Tuned for 0° Phase *(nominal)*	Impedance Magnitude *(nominal)*	Power Rating % Duty Cycle	Tuning Circuit
TR-1075E	No Tuning	4,500 Ohms @ 3.5 kHz	600 Watts @ 30% 200 Watts @ 100%	No Tuning 
TR-1075A	4 kHz	100 Ohms @ 4 kHz	600 Watts @ 30% 200 Watts @ 100%	Parallel 
TR-1075H	3.5 kHz	250 Ohms @ 3.5 kHz	600 Watts @ 30% 200 Watts @100%	Series 
TR-1075D	3.5 kHz	200 Ohms @ 3.5 kHz	1,000 Watts @ 30% 335 Watts @ 100%	Series with Shunt Resistor 

Chart Showing the Tuning Circuits for the Standard Models of the TR-1075 Transducer Family

150122

Massa TR-1075 Nominal Response Curves

Transmitting Voltage Responses	Receiving Voltage Sensitivities	Impedance Magnitudes



All Specifications are Subject to Change Without Notice

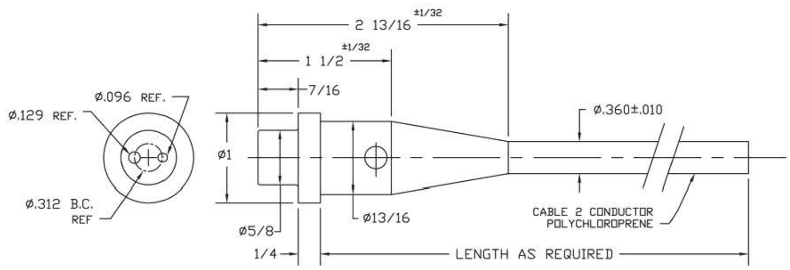
150122

Massa C1M2/C1F2 Underwater Connectors

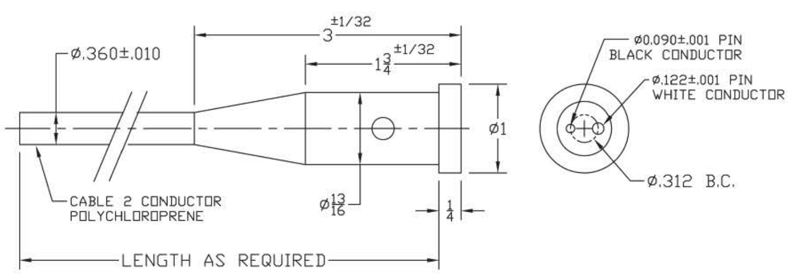
Photograph of C1F2 and C1M2 Connectors with Retaining Rings

Massa C1F2 Female and C1M2 Male 2-conductor in-line Underwater Connectors were developed for the oceanographic community to provide highly reliable underwater connection. Massa has manufactured and sold over 100,000 connector pairs, and some have been successfully used for over 20 years in the ocean. There has never been a failure of a connector reported to Massa.

Massa typically supplies transducers with C1F2 Female Connectors attached. C1M2 Male Connectors can be purchased separately to complete the mating connection. The standard C1M2 is attached to a 5 foot cable with a retaining ring included, but connectors can be fabricated with any length of cable required.



Outline Drawing of a C1F2 Female Connector for Mating to Massa Underwater Transducers
(without retaining ring)



Outline Drawing of a C1M2 Male Connector Supplied on Massa Underwater Transducers
(without retaining ring)

ORDERING INFORMATION

C1F2 Female Underwater Connector P/N 21342-1
Includes Retainer Ring P/N 21352-2

C1M2 Male Underwater Connector P/N 21343-1
Includes Retainer Ring P/N 21352-1

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Teledyne RESON

PLD13774-5

SeaBat® 7111

Multibeam Echosounder System

The SeaBat 7111 produces bathymetry data suitable for the generation of high resolution hydrographic charts exceeding international standards in water depths from 3 to 1000m. Operating at 100kHz, the system forms 101, 201 high-density, equi-angle or 301 equi-distant beams to cover a total receive sector of 150°.

The SeaBat 7111 transducer array is comprised of a cylindrical receive array and a linear transmitter array, mounted together on a support cradle that provides mounting points to the vessel. Lightweight and portable, the array can be installed temporarily over the side of a vessel of opportunity a first for a system in this frequency range.

The SeaBat 7111 is controlled by a high performance sonar processor that manages data flow and signal processing using a state-of-the-art FPGA architecture. The sonar processor provides a Windows®-based GUI user interface, allowing system configuration, control, data output, storage and built-in test environment (BITE) displays to assist the operator.

Equi-distant or equi-angular beam spacing across the entire swath is selectable by the operator to provide uniform sounding density and maximize usable outer swath. Data outputs include bathymetry, sidescan, snippets & beamformed water column data.

FEATURES

INSTALLATION
Unique portable system

MOUNTING
Suitable for vessel over-the-side, bow or hull mounting

FREQUENCY
100kHz frequency

BEAMS
101, 201 EA / 301 ED focused beams
SWATH150° swath coverage (7.5X depth)

BATHYMETRY
Bathymetry & imagery from 3m to 1000m

OPERATION
Automatic operation

STABILISATION
Pitch stabilisation

IHO
IHO compliant

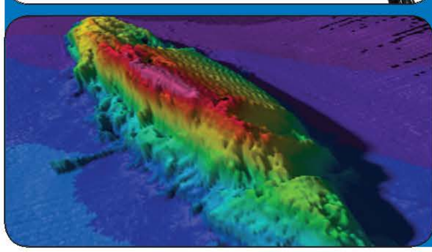
OPTIONS
- 19" marine grade monitor
- 1 TB external RAID drive
- SVP-70 sound velocity profiler with
- 25m cable
- Standard Service Level Agreements (SLA)
-7111 30m transducer cables
-7111 spares kit

TELEDYNE RESON
Everywhereyoulook™

SeaBat® 7111

SEABAT 7111 SYSTEM SPECIFICATIONS

Frequency	100kHz
Pulse length	0.08ms to 3.04ms (selectable)
Typical depth	1m to 900m
Max depth	1000m
Depth resolution, sector coverage,	3cm, 150°
Number of beams	101, 201 EA or 301 ED
Along-track, across-track beamwidth	1.9°, 1.5° ± 0.05° (3.0°, 4.5°, 6.0° operator selectable)
Bottom detection method	Center-of-energy and phase-zero-crossing algorithm
Pitch stabilisation	±10° (motion sensor required)
Max update rate	20Hz (range selection dependent)
System supply	90 to 260 VAC 50/60 Hz, 350 W
System control	Trackball or from ethernet
Temperature: operating, storage	-5°C to +40°C, -30° to 55°C
Data output	Gigabit ethernet
Transducer array: weight	72kg (air), 59 kg (water) with cables
Sonar processor: dimensions, weight	431.4mm x 220.8mm x 559.5mm, 30kg
Transceiver: dimensions &, weight	267mm x 483mm x 489mm, 13.6kg
Hydrophone & projector dimensions	636mm x 118mm (Diameter/ Length), 113mm x 650mm (Diameter/Length)
Cable length	15m, 30m (optional)



WHY CHOOSE A SEABAT 7111 SYSTEM?

- Lightweight and portable system, which can be installed
- Temporarily over the side of a vessel
- Sidescan and snippet, assisting with determination of detected features
- Advanced signal processing and bottom detect routines deliver second-to-none data quality
- Service Level Agreements (SLA)

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TELEDYNE RESON
Everywhereyoulook™

Teledyne RESON PLD15535-4

SeaBat® T20-P

High resolution multibeam echosounder

Superior acoustic quality engineered for the demanding marine environment

The T20-P is a new addition to the leading SeaBat product range engineered from the ground up to evolve with your business. Combined with the Portable Sonar Processor the T20-P provides uncompromised survey data in a highly portable waterproof package designed for small vessel use.

The solution includes a range of powerful software features at an attractive price, with the option for future feature expansions to grow with your needs.

The T20-P can be supplied in ruggedized flight cases with total weight and dimensions suitable for check-in on commercial airlines and can be transported by one person.

T20-P Standard configuration

Portable Sonar Processor:

- Reduced cable connections – fast mobilization
- Single-point, accurate, sensor time-tagging
- Water-resistant IP54 rated
- 24VDC and 100-230VAC for maximum flexibility
- 10m cable to wet-end components

T20 sonar head assembly

- 200 – 400kHz wide-band
- Robust titanium housing
- Less than 8kg in water

FEATURES

Product features

- Snippets & sidescan backscatter
- Full water column backscatter
- Tracker – powerful tool for automated control
- SeaBat User Interface. Runs on separate laptop or PC (not included)
- Selectable Beam Density – you can define what you need to get the job done

Optional extra features

- X-Range - improve range and reduce external noise
- Multi-Detect - Multiple detections for enhanced detail over complex features and water column targets
- FlexMode – increase data density where you need it most
- Pipe Detection & Tracking – unique to SeaBat, optimize detection of pipes
- Full Rate Dual Head
- Max 512 Beams

TELEDYNE RESON
Everywhereyoulook™

SeaBat® T20-P

SEABAT T20-P SYSTEM SPECIFICATIONS

Input voltage	24VDC or 100-230VAC 50/60Hz
Power (typical / max)	200W / 300W
Ingress protection	Water resistant (IP54)
TRANSDUCER CABLE LENGTH	10m (standard), 25m, 50m, 100m (optional)
Temperature (operational / storage)	Portable Sonar Processor: -5°C to +45°C / -30°C to +70°C
	Sonar wet-end: -2°C to +35°C / -30°C to +55°C

	Height [mm]	width [mm]	depth [mm]	weight [kg/air]	weight [kg/water]
T20 Rx (EM7219)	102.0	254.0	123.0	5.0	4.2
T20 Tx (TC2181)	86.6	93.1	280	5.4	3.4
Portable Sonar Processor	131	424	379	14	N/A

T20 Acoustic performance	400kHz (max. frequency)	200kHz(min. frequency)
Across-track receiver beam width (nominal values[1])	1° (center)	2° (center)
Along-track beam width (nominal values [1])	1°	2°
Number of beams	Min 10, Max 256 (Optional 512)	
Swath coverage (up to)	140° Equi distance 165° Equi Angle	
Typical Depth (CW[2])	0.5-150 meters	0.5-375 meters
Max Depth (CW[3])	250 meters	550 meters
Typical Depth (FM[2])	0.5-180 meters	0.5-450 meters
Max Depth (FM[3])	300 meters	575 meters
Ping rate (range dependent)	Up to 50 pings/s	
Pulse length (CW)	30 – 300µs	
Pulse length (FM)	300µs – 10ms	
Depth resolution	6mm	
Depth rating (sonar head)	50meters	

For relevant tolerances for dimensions above and detailed outlined drawings see Product Description
1 All beam widths measured at -3dB, unsteered with a sound velocity of 1480m/s.
2 This is a depth range within which the system is normally operated, from the minimum depth to a depth value corresponding to the max. swath -50%.
3 This is the single value corresponding to the depth at which the swath is reduced to 10%of its max. value. For actual swath performance refer to Product Description.

T20-P Scope of supply

- Receiver EM7219
- Projector TC2181
- Portable Sonar Processor
- 10m Receiver cable
- 10m Projector cable
- Waterproof cable set
- Wet-end bracket

Optional extras

- 25m, 50m, 100m cable
- Fairing
- Dual head bracket
- Motion and positioning sensors
- RESON Sound Velocity Probes
- RESON PDS2000 Survey Package
- RESON Service Level Agreements (SLA)

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TELEDYNE RESON
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Reference	**OD-5001**
Classification	**Unclassified**
Version	**7.04**
Date	**July 2013**
Copy number *(if applicable)*	**N/A**

Bathyswath Technical Information

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VOIDS

Void	Section	Notes
1		
2		
3		
4		
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8		
9		
10		

LIST OF MODIFICATIONS

Version	Date	Modifications	Pages	Writer	Checker
7.00	17/06/13	Bathyswath update	65	DM	MG
7.02	24/06/13	Add of section « surveying at high speed »	72	DM	MG
7.03	25/06/13	Revision of « high speed » section and general review	24-40	MG	DM
7.04	01/07/13	Minor modifications	70	DM	

TABLE OF CONTENTS

1 INTRODUCTION

1.1 REFERENCES

[Ref. 1] International Hydrographic Organisation, "IHO Standards for Hydrographic Surveys, 5th Edition, Special Publication No 44", available at http://www.iho-ohi.net/iho_pubs/standard/S-44_5E.pdf

1.2 GLOSSARY & ACRONYMS

WORDS & ACRONYMS	DEFINITION
AGDS	Acoustic Ground Discrimination Systems
AUV	Autonomous Underwater Vehicle
CW	Continuous Wave
DC	Direct current
DTM	Digital Terrain Model
FGPA	Field-Programmable Gate Array
GNSS	Global Navigation Satellite System
GPS	Global Positioning System: a GNSS, maintained by the USA
IHO	International Hydrographic Organization
LLWS	Lowest Low Water Springs
MBES	Multi-Beam Echo-Sounder ("beamformer")
MRU	Motion Reference Unit
Nadir	The region of the seabed directly below the sonar transducers
NMEA 0183	A standard computer interface for marine equipment, maintained by the US National Marine Electronics Association
OEM	Original Equipment Manufacturer
PC	Personal computer
PDBS	Phase Differencing Bathymetric System ("interferometric sonar system")
PRF	Pulse (or Ping) Repetition Frequency
QA	Quality Assurance
RIB	Rigid Inflatable Boat
ROV	Remotely-operated underwater vehicle
TEM	Transducer Electronics Module
TIU	Transducer Interface Unit
TVG	Time-Varying Gain
USB	Universal Serial Bus: a standard computer interface
USV	Unmanned Surface Vehicle (radio-controlled or autonomous boat)
UUV	Unmanned Underwater Vehicle: includes AUVs and ROVs

1.3 SCOPE

This document describes the technical aspects of the Bathyswath system, its options, components, and capabilities

2 GENERAL DESCRIPTION

2.1 SYSTEM DESCRIPTION

Bathyswath is a wide swath sonar system for surveying underwater surfaces. Its data acquisition abilities are high-density bathymetry and sidescan.

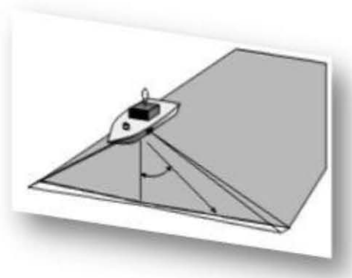
Processed data output includes Digital Terrain Models (DTM) and sidescan. It is equally well suited for use at sea, and for inland waterways and lakes.

Bathyswath is manufactured and marketed by ITER in France from technology originally developed by Systems Engineering & Assessment Ltd. (SEA).

The main components of a Bathyswath system are sonar transducers, Transducer Interface Unit (TIU) and software package (real-time functions for data acquisition, processing functions for the acquired data and quality assurance functions for survey accuracy). The system can easily be integrated into a survey suite to allow the acquisition of all relevant position, orientation and environmental data to enable accurate survey output.

The Bathyswath architecture is very flexible. It can be configured to work on small boats and large ships, AUVs, USVs and ROVs. The system can be operated over long cables and in computer networks. A range of sonar frequencies is available to suit the application: from deep water to high-resolution shallow water surveys.

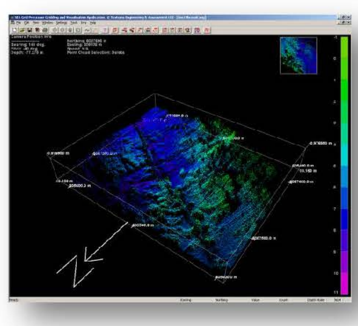
2.2 SYSTEM FUNCTIONALITY



A swath system is one that sends out sonar signals either side of the ship, in a beam that is wide in the vertical direction but narrow in the horizontal direction. These beams form a "footprint" on the seabed that is a narrow strip at right angles to the direction of travel. As the ship moves forwards, a ribbon-shaped swath of seabed measurements is built up.

Bathyswath simultaneously measures two kinds of information: the direction of the echoes from the seabed, and the strength of the signal.

The first is used to measure the depth of the seabed (bathymetry), and the second is used to provide a black-and-white image (sidescan).



For operation from the surface, the transducer(s) may be fixed to the hull of a survey vessel, or to a pole or other portable fixture. By measuring and recording the motion and location of the transducers, the depth information is correctly located with respect to a survey grid system. Displays shown in real time allow the seabed to be inspected while the survey is underway. The post-processing software supplied with the system allows the data recorded during a survey to be processed into a continuous surface for charting in the form of a Digital Terrain Model (DTM).

Additional processing can provide bottom contour charts, individual depth soundings and oblique 3-Dimensional views of the data set. In addition, the attributes of sonar reflectivity may be 'draped' onto these views or used to compute the bottom material encountered. If needed, several third-party post-processing software packages now have interfaces for Bathyswath data sets (QINSy, SonarWiz, Hypack, Caris, etc.)

2.3 ADVANTAGES OF BATHYSWATH

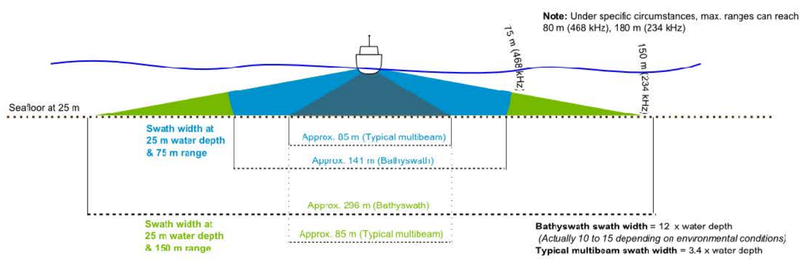
Bathyswath not only provides the benefits associated with other swath bathymetry sonars, but also it has several unique advantages:

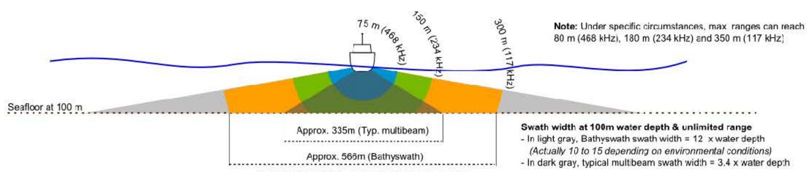
2.3.1 Wide Swath Width

Bathyswath measures depths across a wide track, giving high resolution and accuracy. Both these factors mean that the time taken to survey an area with sufficient coverage for engineering and hydrographic use is greatly reduced, when compared with conventional surveying techniques.

Bathyswath is capable of providing total ensonification of the bottom at practical and efficient survey speeds. The seabed is typically covered at around 500 m² per second.

Refer to section 8.1 for more details





2.3.2 Simultaneous Pinging

Bathyswath provides the option to ping on both port and starboard transducers simultaneously, thus offering the ability to double the productivity and along-track coverage of competing interferometric systems.

2.3.3 Portability

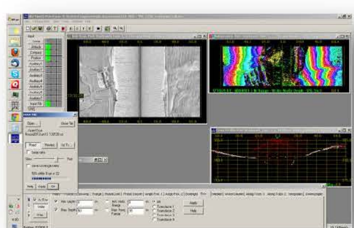
Bathyswath may be configured as a portable system, which means that it may be deployed from almost any vessel. This eliminates the need for expensive modifications to survey vessels, with the associated tying-up of capital investment in a single vessel, and allows the system to be transported anywhere in the world.

Bathyswath can be used with laptop computers, with electronic components weighing a few kilograms and taking power of less than 25 W.

2.3.4 High Resolution and Accuracy

Compared with beamforming swath sounding systems, Bathyswath takes many more depth measurements per hour, thus giving greater resolution and coverage, and allowing greater scope for statistical filtering of the measurements. Furthermore, the angle at which depths may be measured is not limited to a fixed arc, so that much wider coverage can be obtained in shallow water, even allowing measurements to be made of shoreline structures. A beamformer suffers from poor resolution at far range, where the footprint of its beams is very large due to the small strike angle with the seabed. Bathyswath avoids this problem, as the area of the energized patch of seabed does not increase dramatically as it moves away from the transducers.

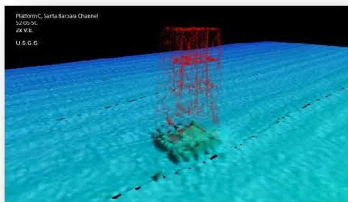
2.3.5 Simultaneous Side Scan



Bathyswath produces high quality side scan data as well as bathymetry. The range of the side scan data is the same as that from sidescan-only systems.

The sidescan information helps with the interpretation and processing of bathymetric data, and the bathymetry enables the sidescan information to be correctly located on the seabed, avoiding the usual “flat seabed” approximation used in sidescan-only systems.

2.3.6 Mid-water Objects and Structures



Courtesy USGS

Bathyswath can detect objects in mid-water and on the surface, as well as the bottom. The Bathyswath processing software allows such objects to be mapped and visualized in 3D. The high resolution of the system makes it ideal for this application. Measuring the amplitude of return as well as bathymetry allows small, hard mid-water targets to be differentiated from “noise”.

Applications of this capability include scanning the hulls of vessels, for example for homeland security and anti-drug enforcement, or for monitoring sub-sea engineering structures, including port facilities, pipelines and oilfields.

2.3.7 Low Cost of Ownership

System simplicity results in a low initial purchase price, high reliability, simple maintenance and long service life. The Bathyswath software runs under Microsoft Windows, with a familiar user interface, or industry-standard data gathering and processing software can be used, which reduces the need for training and refreshing courses.

For portable systems, low system bulk and rapid deployment result in low mobilization and demobilization costs. Bathyswath is robust, reliable and simple, resulting in reduced repair costs and down-time. Each Bathyswath system is delivered complete with all the software necessary for real-time survey work and data post-processing.

Data is recorded in a completely raw state; filter settings applied by the operator only apply to the screen images and processed data files. This reduces the need to re-survey because of operator error. Processed data files can be recorded at the same time, in real time, giving the potential for a quick turn-around of data products.

2.4 VERSIONS AND OPTIONS

The standard Bathyswath system is available in three sonar frequencies: 117, 234 and 468 kHz. The higher frequencies have smaller, lighter transducers and higher resolution, but smaller range and depth capability.

A third, forward-looking, transducer can be supplied. This helps to increase the data density in the region directly below the transducers. See section 10.

Several electronic housing types are available, including a splash-proof one for use on deck or in open boats but limited to 2-transducer systems, and a desktop unit which can be used in a rack or as a stand-alone unit.

The system can be supplied complete, ready to use, or in OEM form, as a kit of parts, to be incorporated into vehicles or vessels. See section 12.

Modular “bottles” can be provided for small AUVs, including Gavia (Teledyne Gavia) and REMUS 100 (Kongsberg). See section 11.

A 40 kHz, 6000-metre pressure-rated, version is available, for full-ocean-depth survey work. See section 13.

3 SYSTEM FUNCTIONS

3.1 SOUNDING REPETITION RATE

The user may set the rate at which soundings are taken, on-line. This has the effect of changing the range of the data collection. Swath width is approximately twice this range when using a twin transducer system. A 300m range corresponds to a ping repetition frequency (PRF) of around 2.5Hz (times per second). A 70m range gives a PRF of 10.7Hz. The time to gather a full swath at a given nominal range depends on the speed of sound. The operator can select the PRF required to maximize along-track coverage for the required swath width.

3.2 MOTION SENSORS AND POSITION

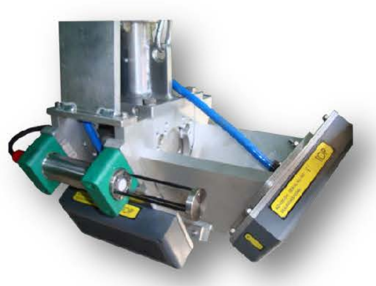
Swath bathymetry requires that the full motion (also known as attitude) of the platform be recorded. The essential parameters are roll, pitch, heave, heading and position. Bathyswath is fully compatible with, amongst others, SMC, Applanix, CodaOctopus, Ixblue, Kongsberg, SBG Systems and TSS motion reference units (MRU).

The position of the sonar sensor also needs to be measured. Bathyswath interfaces to a wide range of position sensors. Most such sensors are based on GNSS. Some sensor systems provide motion (attitude), heading and position as an integrated package.

Positioning information is accepted in both angular (latitude and longitude) format and grid projection (easting and northing). A range of conversion parameters and ellipsoids is available to the operator.

A remote platform will often collect its own attitude and position data and pass it on to the Bathyswath system using an interface port.

3.3 SPEED OF SOUND



A miniSVS and 468 kHz transducers on pole mount

Bathyswath provides interfaces to both a speed of sound profiler and a continuous reading speed of sound meter. The profiler is used by the surveyor at suitable intervals, to measure speed of sound at intervals of depth. This is used by the system software to correct for refraction of the sound as it passes between layers of water with different sound speeds. The continuous reading meter is mounted near the sonar transducers. It ensures that the sound signals are correctly converted to measurements of angle.

The profiler is essential, but the continuous reading meter is only necessary if the speed of sound at the surface changes strongly within the survey area.

3.4 TIDE AND VERTICAL POSITION

In order to relate the depths measured by the sonar system to a chart datum height, for example, LLWS (lowest low water springs) sea level, or position height datum (e.g. WGS-84) the height of the sensor needs to be measured in real time. Bathyswath supports two ways of doing this:

- Tide measurements: the height of the sensors relative to the water surface is measured, using measuring tape or equivalent methods, and entered as an offset in software. The height of the water surface relative to datum, against time, (i.e., a tide table) is recorded and entered into the processing software. This tide information can come either from recording or real-time tide sensors, or from published tide tables. For accurate work in inshore waters, more than one tide sensor is needed, including offshore tide buoys. The Bathyswath software can integrate between such multiple tide sensors in both position and time.
- GNSS (GPS) height measurements: if the positioning system is able to provide height information at the accuracy required by the users' application, then this information can be used in processing instead of tide. However, standard GPS and differential GPS (DGPS) systems do not usually provide height to sufficient accuracy; a system such as real-time kinematic (RTK) is needed.

In either case, heave measurements from the motion sensor are merged with the height measurements in the Swath software.

3.5 OTHER SENSORS

Bathyswath provides interfaces to a range of other sensors and systems. These include:

- An arbitrary data stream, which is time-tagged and logged with the sonar data. The information in this stream can be extracted and used for the operator's own purposes during post-processing.
- Echosounder: serial data outputs from single-beam echosounders can be logged by the Bathyswath software. The depth information from the echosounder can be corrected for motion and position, and placed in the gridded depth model for comparison or inclusion with the swath data.
- Acoustic Ground Discrimination Systems (AGDS)
- Tide: on-line tide information can be logged and used for processing.

Acoustic pulse triggering is possible to and from other sonar systems, in order to minimize acoustic "cross-talk"

3.6 EXTERNAL CONTROL

Bathyswath can be controlled by external systems, either through an RS232 serial line or by TCP/IP, for example through an Ethernet link. This is used in remote systems, such as USVs, AUVs and ROVs.

3.7 SOFTWARE FUNCTIONS

Bathyswath provides all the hardware and software functions needed to produce bathymetric information. In addition, it is provided with links to many industry-standard software packages.

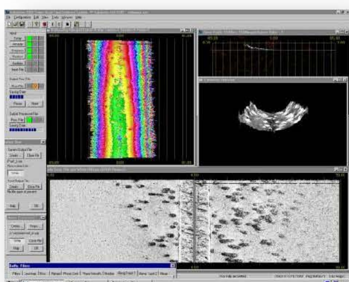
3.8 STANDARDISED RAW DATA OUTPUT

In real-time, Bathyswath data is recorded in both a generic data format, and as 'end product' files. The latter file format is selected to suit the post-processing system chosen.

The Processing/QA off-line software can export data in x,y,z and gridded digital terrain model (DTM) formats, and as depth-and-contour graphics.

These outputs are available in common forms, including ASCII.

3.9 SIDESCAN SEAFLOOR IMAGING

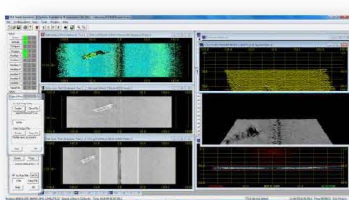


Bathyswath provides sidescan imaging, with bathymetry fully co-registered. Imaging data may be displayed on the computer screen. Bathyswath also provides links to several commercially available sidescan-processing platforms.

3.10 PATCH-TEST CALIBRATION

The system software includes support for automatic patch-test calibration, which uses data from overlapping survey lines to determine the precise mounting angles of the transducers, and other similar correction factors.

3.11 WRECK AND OBJECT DETECTION



The imaging function of Bathyswath allows the operator to detect and identify objects on the seabed, including wrecks. The use of sidescan and colour-coded swath bathymetry displayed coincidently is an extremely powerful tool for this task.

The links to commercial sidescan processors referred to above also provide the opportunity for extended capabilities in this area.

3.12 SEAFLOOR SEDIMENT CLASSIFICATION

The combination of swath bathymetry and sidescan imaging allows the user to identify the type of seabed being surveyed. Automatic seabed classification is available through several 3rd party software suites.

3.13 INTEGRATION WITH SURFACE LASER SCANNERS

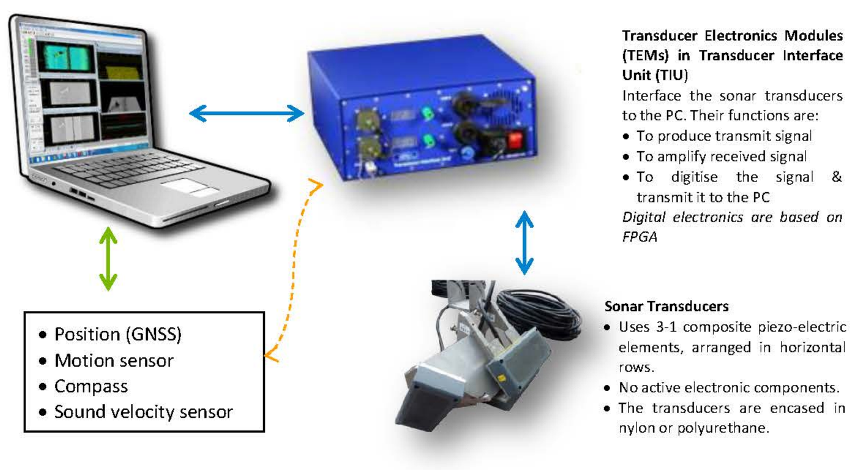
Bathyswath has been successfully integrated with laser scanning systems, with excellent results. Further information can be provided on request.

← *Livorno Castle Moat, subsea data Bathyswath-Standard-2-468, above water OPTECH ILRIS. Image courtesy Codevintec, Srl.*

4 HARDWARE

4.1 GENERAL DESCRIPTION

The main components of the Bathyswath are sonar transducer(s), Transducer Electronics Module(s) (TEM), Bathyswath software and a PC computer (not included in the package). Data is recorded by the PC computer onto disk. Data may be archived onto standard PC media, e.g. USB disk. There is one TEM for each transducer; all TEMs are inside the TIU (Transducer Interface Unit)



4.2 SONAR TRANSDUCERS

Sonar transducers are available in three frequencies: 117, 234 and 468 kHz.

117 kHz

234 kHz

468 kHz

4.3 TRANSDUCER ELECTRONICS MODULES

The Transducer Electronics Modules connect the sonar transducers to the PC computer. One Transducer Electronics Module is used for each sonar transducer, so a typical system is supplied with two TEMs. Each Transducer Electronics Module (TEM) contains a single printed circuit board (PCB), with flexible connections to the computer and sonar transducer. It is thus extremely robust. The TEM on-board data processing is implemented in a large FPGA. The TEM PCB has sub-sections performing the following functions:

- Transmitter, which sends an electrical pulse to the sonar transducers. This makes the sonar pulse.
- Analogue Receiver, which amplifies the returned echo signals, and produces sidescan amplitude data. The Bathyswath analogue circuits provide very high gain and low noise, enabling signals below acoustic sea noise to be measured. The limiting factor to performance is therefore determined only by the external environment.
- Phase Interface, which receives the amplified sonar signals, measures the phase differences between them and converts the sidescan data into digital form.

4.4 USB SYSTEM INTERFACE

Each Transducer Electronics Module (TEM) is connected to the PC computer using an industry-standard USB connection. Up to 15 TEMs can be connected to one PC, with up to four of them being used simultaneously.

If the sonar system needs to be mounted at a distance from the computer, then the USB interface can be extended using a commercial USB extender or USB-to-Ethernet converter. Alternatively, a remote compact computer unit can be installed close to the sonar system and auxiliary sensors, which then acts as a data storage and control unit for the sonar. This remote unit can then be operated over a network link, either cable or Wireless, using standard remote interface software. This latter option is useful for remote systems, such as USVs (unmanned surface vehicles), UUVs (unmanned underwater vehicles) and towed vehicles.

4.5 WORKSTATION

The Bathyswath software operates in Microsoft Windows. Commands may be entered via the mouse and keyboard. A wide range of displays is available, which allow the operator to monitor and control the operation of the sonar system.

4.6 AUXILIARY INTERFACES

The operating software supports ports to allow real time interfaces to other survey suite sensors, including Motion Measurement, Position (DGPS / RTK DGPS) and Heading (NMEA 0183 format). It also supports multiple information streams from integrated systems. Tide height information can be input manually either from a telemetry system or in post processing. Water speed of sound profiles may be input manually after speed of sound dips or in post processing.

4.7 TRANSDUCER CONFIGURATION

4.7.1 Ship Hull Mount Configuration

This configuration is used where Bathyswath is to be permanently mounted on a vessel, and where a pole mount is not required.

4.7.2 Pole mount configuration – Side mounting

This configuration is used when a permanent hull mount is not required. The "wet end", consisting of the transducers and the motion reference unit in a watertight pod, is mounted on a special plate at the end of a rigid pole.

The pole is deployed over the side, or on the bow, of the vessel. The pole can be hinged or retractable, so that the system and the ship are not at risk in shallow water.

Alternatively, Bathyswath can be deployed through a moon pool or gate valve.

For the reasons implied in the advantages of a bow mount, it should ideally be possible to stow a side mount away during transit to site or when coming alongside.

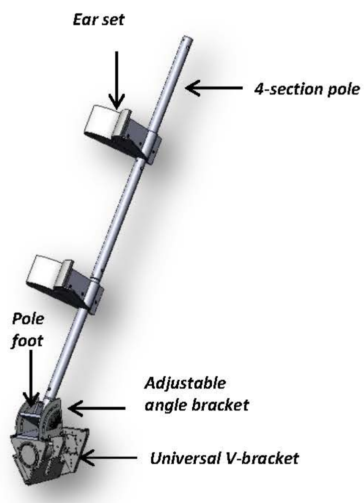
A rigid side mount is usually acceptable for a few days, but after that, the time wasted in slow transits to site, or in mounting and de-mounting a rigid mount at sea, is greater than the time taken to prepare a movable mount.

Another consideration with side-mounts is that good fixing points are often not available along the side of small vessels. It is sometimes possible to use the side rails for the mountings, but this should be discouraged on safety grounds

4.7.3 Pole mount configuration – Bow mounting

For use on small ships of opportunity, the best mounting position is usually on the bow, because:

- It is rigid and mechanically stable, even at speed when making transits to site.
- The transducers have a clear view of both sides of the vessel, and therefore the transducers can be mounted above the bottom of the keel. This means that the transducers do not need to be lifted when coming alongside or operating in shallow water.



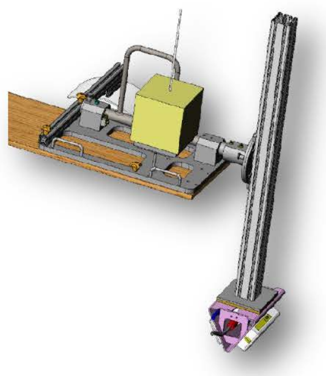
4.7.4 Pole mount configuration – Stern mounting

This needs to be done with caution, as aeration from the propellers severely reduces sonar range. It can sometimes work when outboard motors are used.

4.7.5 Use on Remote Platforms

Bathyswath has been used on a range of remote and underwater platforms, including unmanned surface vehicles (USVs) and unmanned/autonomous underwater vehicles (UUVs/AUVs). It is also ideal for use on remotely operated vehicles (ROVs).

4.7.6 Use on Very Small Boats



Courtesy EDF & Nominal

Bathyswath can be used from very small boats such as rigid-inflatable boats (RIB), and can be configured to use DC power from a battery, rather than mains power. The higher frequency transducers are smaller and lighter than the low frequency ones, and are thus more suitable for this application. A carefully selected system of Bathyswath with laptop and lightweight auxiliary sensors can weigh less than 10kg and consume less than 20 Watts.

The plank is fixed across the inflatable hulls and the pole is rotated out of the water for fast transits

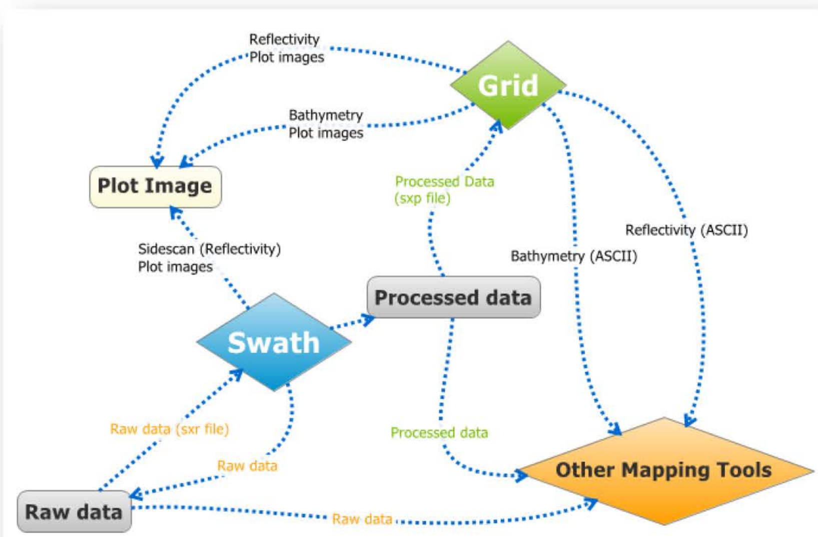
5 SOFTWARE

5.1 INTRODUCTION

Bathyswath acquires, processes and displays data whilst a survey is underway, using a program called “Swath”. This also allows for control and set-up of the system, and gives error diagnostic information. The software stores data in two forms: ‘raw’ and ‘processed’. The raw data is exactly as it was acquired by the system, unfiltered and unprocessed. The processed data is filtered, and then written out in a file format that suits the post processing system being used.

Post processing software converts the data acquired in real-time into Digital Depth Models. These depth models are used to produce displays and plots of the surveyed area. Users may use Bathyswath post processing software, or a third-party program, to suit their application.

The Swath program is used to provide the first pass of post-processing when using the Bathyswath software. It reads its own raw data files, and produces processed data files. The second pass of the post-processing converts the processed swath data files into Digital Terrain Models. This program is called “Grid”. Grid also allows 3D visualization, filtering, data correction and calibration functions.

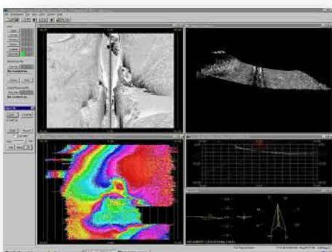


Bathyswath software tool flow

5.2 SWATH SOFTWARE

Swath runs on a PC computer, and performs all the real-time functions. These include

- Controlling the sonar electronics system
- Acquiring data from the sonar electronics system
- Acquiring data from the auxiliary systems, through the PC's serial ports
- Storing all the raw data
- Converting the raw data to depth, position and amplitude [xyza], combining auxiliary data, such as motion, position, heading, tide and speed of sound.
- Filtering the data to remove noise and unwanted targets
- Displaying the data
- Storing processed [xyza] data in a range of formats



Swath screen image and its online help facility

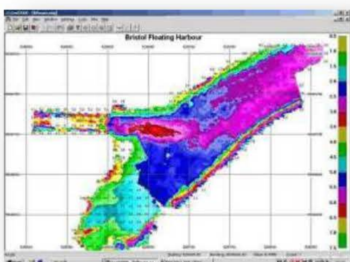
All of these functions are controlled by the operator using parameters that are stored in a "session file". This allows the operator to store the parameters used on a particular project. In addition, the configuration parameters used to generate a particular processed data set are automatically stored in the processed data file. This feature is only available in the Bathyswath processed data file format.

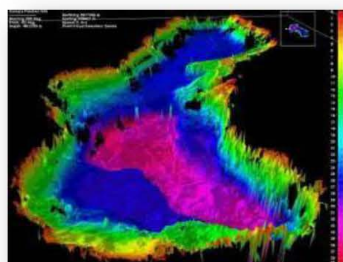
There is an extensive context-sensitive software help system to assist the user with all aspects of using the Bathyswath.

5.3 GRID SOFTWARE

The Grid program runs off-line, either after the survey on the survey PC, or on a separate PC. It performs the following functions:

- Placing all the processed data (depth and amplitude) into a gridded digital terrain model (DTM)
- Displaying depth and amplitude for each node of the grid
- Displaying statistical information about the depths in each node of the grid, including mean, standard deviation, range and data count
- The data for each ping and line of the survey are stored separately in the grid, allowing simple comparison of overlapping data sets.
- The data from overlapping survey lines is compared to provide automatic post processing calibration. This includes derivation of the roll offset between transducers. This calibration information is stored in the session file for subsequent re-processing of the raw data with the swath program.
- Filtering and moving the data in the grid, to enable the operator to quickly and easily clean and correct the processed data.
- 3D views of the data in the grid, allowing the operator to see the seabed in three dimensions and to "fly" across the seabed using the mouse or in pre-defined routes. The grid can be edited in the 3D mode, using the mouse to "lasso" points and groups of points that are not required, for example mid-water targets.





Grid 2D & 3D displays

Grid data can be stored in "point cloud" format. In this mode, every data point from the Swath program is retained in the grid. Although memory-intensive, this allows for high-resolution views. In this mode, the views are not restricted to a single surface, and so complex objects and mid-water targets can be imaged.

5.4 DATA POSTPROCESSING TIME

Given an experienced operator and available secondary data, the processing time requirement for Bathyswath does not exceed 100% of acquisition time for a normal survey. At no stage in data manipulation is the raw data file modified. An audit file is available to quickly indicate which processing and calibration parameters have been applied in order to create the processed file.

5.5 CALIBRATION AND OFFSET CORRECTION FUNCTIONS

Bathyswath provides facilities to calculate instrumental and positioning offsets and alignments. Such calibrations use surveyed data, and provide accuracy of calibration to allow the survey system to meet the overall accuracy requirements. All calibration parameters are available for changing and can be reapplied at the processing stage. The changing of calibration parameters does not change the raw stored data file.

5.6 DATA FORMATS

The Bathyswath data file format description is open and described in the Bathyswath File Formats document. In addition, source code fragments, example programs and technical advice are provided to developers and users who wish to exploit the Bathyswath data in their own software tools.

5.7 SIDESCAN AMPLITUDE DATA

Sidescan sonar data is stored in the Bathyswath raw data before any normalization or time-varying gain (TVG) is applied. The sonar raw data includes the full time series of amplitudes and phases from each ping at a user selectable sample rate. All the data is recorded for each shot (i.e. everything from the trigger to the end of the swath) to allow for full reprocessing of the data. The system applies software normalization (TVG) to the data and displays the results (as well as recording the raw data) in real-time, and the sidescan can be replayed and reprocessed during post processing.

This feature, together with the angular measurements and auxiliary sensor data, allows the full sonar equation to be solved, thus permitting the acoustic properties of the seabed to be analysed for research and mapping purposes.

5.8 OTHER SOFTWARE SYSTEMS

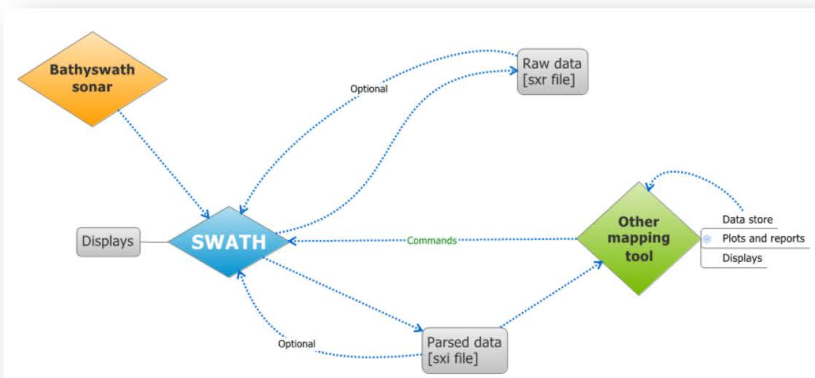
The community of Bathyswath sonar users encompasses a very wide range of operational requirements. Although the Bathyswath software provides a comprehensive set of functions, it naturally cannot exactly match the needs of every one of these users. Therefore, Bathyswath has provided links to many of the industry-standard software packages available today. The following list gives some of the systems that have been used with Bathyswath sonars. The list of systems that are supported is growing. Many systems not on this list will also read in one or more of the standard file formats that the software provides.

Software	Vendor	Notes
ARC	ESRI	GIS (Geographic Information System)
AutoCAD	Autodesk	Producing CAD-type plots. Integrate other survey data, such as coastlines obtained from land surveys.
CARIS HIPS & SIPS	CARIS	Comprehensive bathymetric, seafloor imagery and water column data processing software.
Cfloor	Cfloor	A long-standing bathymetry processing system.
Fledermaus	QPS	Interactive 3D geo-spatial processing and analysis tool
GeoSurvey	CodaOctopus	Sidescan processing and mosaicing software
HydroPro Navigation	Trimble	Navigation and survey planning/ survey processing/ charting package.
Hypack	Coastal Oceanographics	Navigation and survey planning/ survey processing/ charting package.
PDS2000	Reson	Survey planning, data acquisition, editing, chart production, volume calculations
QINSy	QPS	Navigation, positioning and surveying package
SeeTrack	SeeByte	AUV mission planning and data processing tool
SonarWiz	Chesapeake Technologies	A complete sidescan data acquisition and survey management system
Surfer Pro	Golden Software	A low cost utility with many very good display abilities.

5.8.1 Using other software systems in real time

Bathyswath can be used with "fully-functioned" third-party sonar processing and control systems, allowing the user to perform all data acquisition and processing functions in the third-party system. In this mode, the Bathyswath Swath processor application acts as the interface to the Bathyswath hardware, and performs some initial processing and filtering before sending the data to the third-party process. The data that results from this process is as raw as possible whilst maintaining a consistent range-and-angle data format. This format is known as the "Parsed Data" format.

The user can elect to use the Swath processor with minimal processing and displays, just passing the Parsed data to the third-party system or alongside the third-party system, with all displays enabled. Swath and third-party application can be run on the same computer, or on different computers, connected by Ethernet.



5.9 NAVIGATION SOFTWARE

Bathyswath software provides a coverage chart, showing which areas have been covered in the survey. Tasks such as planning the survey route and giving the helmsman a display to steer from are provided by third-party software, integrated with the Bathyswath system.

5.10 SOFTWARE LICENSING

The standard Bathyswath software, that is, Swath and Grid, are supplied with unlimited licenses to run on the real-time computer used for surveying, and also on a single office-based PC, for post-processing.

Licenses for third-party software can be obtained either direct from the suppliers of such software or via Bathyswath team and agents.

6 MANUALS, TRAINING AND SUPPORT

6.1 MANUALS

Each Bathyswath system is supplied with a full set of manuals, describing the use of the system for surveying applications, how to install and maintain it, and how to operate the software. The software includes an on-line, context-sensitive help tool.

6.2 TRAINING

Bathyswath team offers a training course. This generally takes place at the client's location. It takes about a week, and is a mixture of classroom training, surveying on the client's boat, and then processing back in the office. The idea is to get the customer's operators working with their own equipment in their own environment. An emphasis is placed on hands-on use of the system and software, including:

- Description of the system
- Deployment
- Real-time and post-processing software
- Maintenance and trouble-shooting

6.3 SUPPORT

The warranty package that is included in the initial sale price includes replacement of faulty equipment and software upgrades. Major and minor software upgrades are distributed approximately every six months, although specific user issues may be addressed in interim releases. Extended maintenance arrangements are available and renewable on a yearly basis.

6.4 QUALITY AND CERTIFICATION

Bathyswath systems are provided with certificates of quality and calibration.

6.5 MAINTENANCE AND CALIBRATION

Bathyswath requires very little maintenance and calibration. The transducers are extremely robust, and maintenance generally consists of a regular inspection for damage and fouling by marine life (cleaning if necessary).

The TEM units include an in-built calibration function, which measures and compensates for any phase drift of the analogue circuits. This calibration is simply initiated and logged in the software with the click of a single on-screen button.

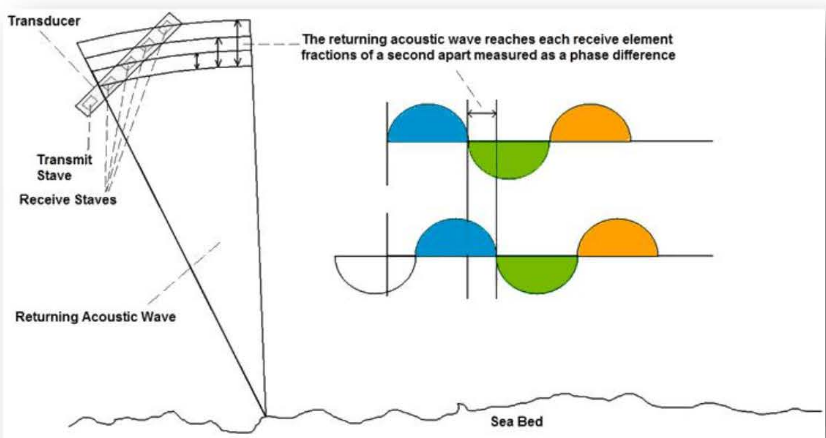
6.6 SPARES

System spares can be supplied with Bathyswath. The system electronics is contained on two or three circuit boards (the TEM). Therefore, spares holding for most systems can consist of a single TEM unit. The transducers are passive components, and so have very long mean time before failure.

7 INTERFEROMETRY

A "swath-sounding" sonar system is one that is used to measure the water depth in a line extending outwards from the sonar transducer. Such systems are generally arranged so that the line of depths, or "profile", lies at right angles to the direction of motion of the transducer. A series of these profiles are known as a swath.

The term "interferometry" is generally used to describe swath-sounding sonar techniques that use the phase content of the sonar signal to measure the angle of a wave front returned from a sonar target. Systems using this technique are also known as Phase Differencing Bathymetric Systems, or PDBS. This technique may be contrasted with "beamforming" multi-beam echosounder sonars (MBES).



These generate a set of receive beams, and look for an amplitude peak on each beam in order to detect the sea-bed (or other targets) across the swath. See below for a comparison between beamformers and Bathyswath.

Interferometers themselves fall into several categories. All of these use similar transducer geometry: two or more horizontal arrays (or "staves") arranged one above the other. Each array is equivalent to a "normal" sidescan array, producing a beam that is narrow in azimuth (that is, viewed from above), and wide in elevation (viewed from the side). One of these arrays is supplied with a pulse of electrical energy at the sonar frequency, producing a narrow "shell" of sound that moves outwards from the transducer. Where this shell meets the seabed there is a small "ensonified" patch, which moves across the seabed as the sound travels outwards. The ensonified patch scatters sound energy in all directions. When this scattered sound is detected back at the interferometric transducers, the angle it makes with the transducer is measured. The range is calculated from the travel time there-and-back. The range and angle pair enables the location of the ensonified seabed patch to be known relative to the sonar transducer.

Bathyswath measures the phase of the measured signal at each of the transducer staves relative to a reference signal at the system's sonar frequency. The phase difference between the staves is derived by subtracting these phase measurements from each other. The phase is derived from a simple and robust electronic method, which directly provides a digital measurement of phase. The electronics are thus kept simple and therefore small and reliable. Wavefront angle is calculated from a simple formula relating phase and transducer spacing measured in wavelengths.

In order to measure the angle accurately, more than one pair of staves must be used. Narrow spacings give an unambiguous measurement of angle, but are more susceptible to noise and give poor resolution. Wide spacings give good resolution and noise immunity, but any one-phase measurement from them can decode to several elevation angles. To overcome these restrictions Bathyswath uses a range of spacings to obtain the best results. The combinations of spacings are used in a manner similar to that used by a mechanical vernier measuring device.

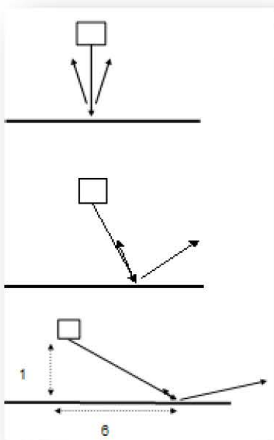
8 SYSTEM CAPABILITIES

This section describes the performance and capabilities of Bathyswath in various survey situations.

8.1 RANGES, SWATH WIDTHS & COVERAGE ANGLES

8.1.1 Grazing angle and spreading loss

Line spacing is the distance between adjacent survey lines. The spacing is determined by the sonar horizontal range expected at that depth, and the amount of overlap required. The horizontal range expected depends on the water depth under the sonar-head, as well as the seabed type and the sea state.



The term "Horizontal range" is used to describe the sonar coverage from one transducer. For a twin transducer configuration, the total swath width, from port edge to starboard edge, is therefore twice this range.

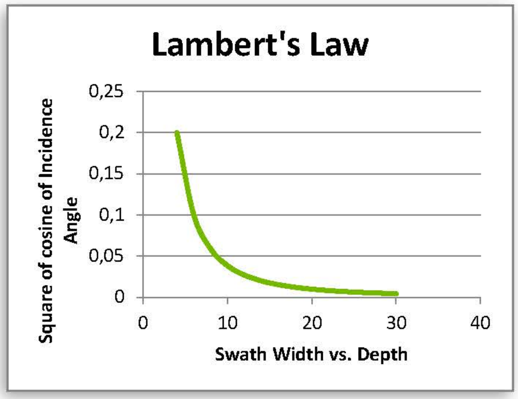
The horizontal range is limited by two factors: grazing-angle and spreading loss. The grazing angle limit is related to the angle that the sound 'beam' makes with the seabed.

Directly under the transducers, sound is reflected directly, and there is little loss when sound is scattered by the seabed.

Moving away from the transducers, much of the sound is reflected away from the transducers, but enough sound is scattered back for the seabed to be properly detected.

At the grazing-angle limit, the sound makes a very small angle with the seabed. Most of the sound is reflected away, and the signal scattered back from the seabed is too small to be detected. Actually, the configuration of the Bathyswath transducers is similar to sidescan sonars: the swath width ends at the point where the backscattered signal is not sufficiently above noise to enable detection of the angle of the backscattered wave.

Backscattered acoustic signals from a seabed generally follow "Lambert's Rule"; that is, the backscattered signal falls with the square of the cosine of the angle of incidence of the acoustic "ray".



Plotting this rule, we can see that the Lambert's Law function is low at depth to swath width ratios above about 15:1.

In poor seabed conditions or turbid waters, this ratio can be reduced to about 10:1 or even less. Bottom types such as soft mud or peat can indeed reduce the expected range by as much as 30%. Sand, rock and shingle all give good sonar backscattering.

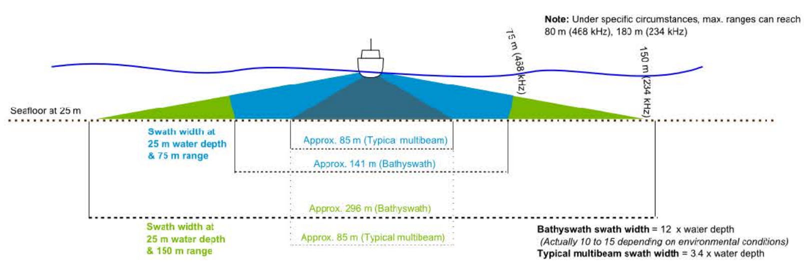
The spreading loss limit is simply caused by the sound spreading outwards, and being absorbed by seawater. The rate of absorption is related to the frequency of the sonar signal. The spreading loss limit is thus determined by the distance from the transducers to the farthest point on the seabed (the slant range).

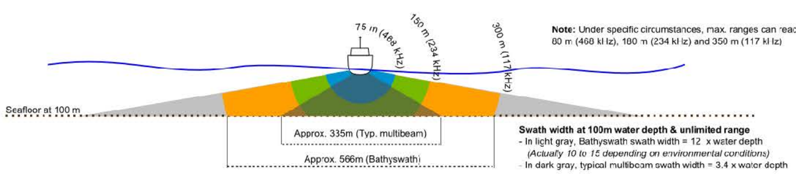
8.1.2 Ranges

	117 kHz	234 kHz	468 kHz
Minimum depth (1)	0.3 m	0.2 m	0.1 m
Operational slant range (2)	300 m	150 m	75 m
Maximum slant range (2)	350 m	200 m	80 m
Swath width vs. water depth ratio	Typically between 10:1 to 15:1		

(1) There is no real physical limit to the depth at which measurements can be made by an interferometric system. Close to the transducer, the sonar system is operating in the near-field domain, where sound rays are not yet fully formed. This means that the accuracy of the angle measurement is not as good as a fraction of the sonar range as it is in the far field zone, but the very small ranges (within the 15-times depth limit) means that the depth measurement accuracy remains easily within that specified. A practical limit is close to that of the size of the transducer itself.

(2) The operational slant range is the one you should get in most cases. The maximum slant range is the one you should get in the best environmental conditions.

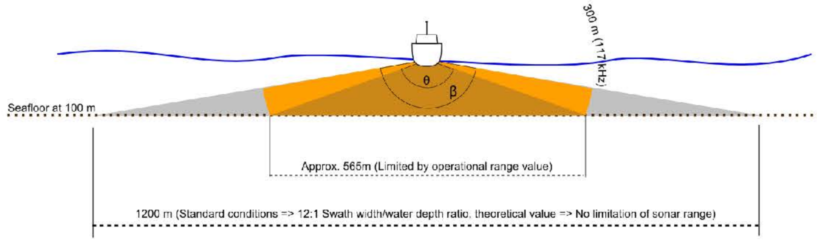




8.1.3 Swath width and coverage angle

Environmental conditions	Poor	Standard	Good
Swath width vs. water depth ratio [1]	10:1	12:1	15:1
Max. swath coverage angle - β angle [1]	157°	161°	165°

[1] *Theoretical value → Not limited by sonar range (θ angle)*



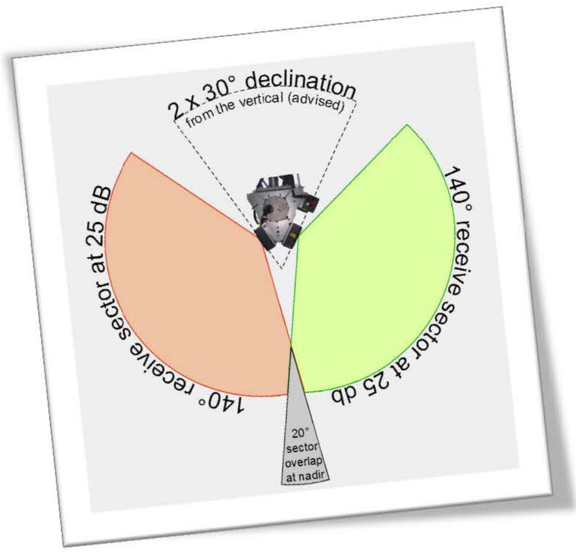
The following table shows the optimum water depth for which the maximum swath coverage angle and width are reached without being limited by the operational sonar range.

Environmental conditions		Poor		Standard		Good	
Swath width vs. water depth ratio		10:1		12:1		15:1	
	Operational slant range	Water depth (Optimum)	Swath width (max.)	Water depth (Optimum)	Swath width (max.)	Water depth (Optimum)	Swath width (max.)
468 kHz	75	14.7 m	147.1 m	12.3 m	148.0 m	9.9 m	148.7 m
234 kHz	150	29.4 m	294.2 m	24.7 m	295.9 m	19.8 m	297.4 m
117 kHz	300	58.8 m	588.3 m	49.3 m	591.8 m	39.6 m	594.7 m

8.1.4 Elevation angle

Bathyswath is typically configured with two transducers, one facing port and the other starboard, and with both transducers pointing downwards at 30° from vertical (recommended). Each of the two transducers can, in principle, measure the angle of any sonar wavefront that approaches its front face, from -90° to +90° of its normal. If the two transducers were pointing horizontally, the angle of coverage would be a complete 360°.

The 30° elevation angle means that the top 30° is not covered on each of the port and starboard sides. In addition, the shape of the transducer beam in elevation means that the signal is weak for the last 20° of the -90° to +90° coverage. Therefore, we calculate the angular coverage range to be (360° - 2 x 30° - 2 x 20° =) 260°. This configuration also gives 20° overlap in the nadir region between coverage of the 2 transducers.



8.3 ACCURACY AND RESOLUTION

8.3.1 Context

Consideration must also be given to the accuracy required from the survey. Bathyswath is essentially an angle-measuring instrument, so that depth accuracy reduces with horizontal range. The angular accuracy of both the Bathyswath sonar and commonly available MRUs is better than 0.05 degrees. The accuracy of the combined system is thus better than 0.1 degrees. The maximum range required for a given depth accuracy can easily be calculated. One accuracy specification is that of the International Hydrographic Organisation (IHO) S44 specification [Ref. 1]. Bathyswath has been used, and quality checked, in surveys at all IHO S44 accuracy orders, including Special Order.

This section considers the accuracy and resolution of Bathyswath; these two parameters are closely related, and can be selected for, against each other, using statistical methods in data processing. It is derived from a model of the accuracy of Bathyswath, related to resolution. This model has been validated using data collected and published for the 2008 Shallow Survey conference. Bathyswath can output pulses down to 2 cycles (A single-wavelength pulse will not have sufficient transfer efficiency into the water), so the physical limit of measurement resolution is as per the following table.

	117 kHz	234 kHz	468 kHz
Actual Frequency[1] *Divisor [1] – f*	117.1875 kHz *512 (or 2^9)*	234.3750 kHz *256 (or 2^8)*	468.7500 kHz *128 (or 2^7)*
Period *$T=1.f^1$*	8.55 µs	4.27 µs	2.14 µs
Wavelength *λ=c.T*	12 mm	6 mm	3 mm
Resolution detection limit[2] *½.λ – Half wavelength*	6 mm	3 mm	1.5 mm
Min. pulse time *2 cycles = 2.T*	17.09 µs	8.55 µs	4.27 µs
Max. pulse time *1000 cycles = 1000.T*	8.55 ms	4.27 ms	2.14 ms
Pulse length *2. λ*	2.5 cm	1.2 cm	0.6 cm
Measurement resolution limit[3] *½ pulse length*	1.2 cm	0.6 cm	0.3 cm
Resolution Across Track	7.5 cm	5cm	3cm
Beam Width, Azimuth	1.7°	1.1°	1.1°
Beam Width, Azimuth (2-way)	0.85°	0.55°	0.55°
Transmit Pulse Length	17µs to 1 ms	8.5µs to 500µs	4.3µs to 250µs
Source level *1µPa @ 1m*	224 dB	220 dB	222 dB

(1) Bathyswath is a single frequency (also known as Continuous Wave – CW) system; the sonar frequency is built into the electronics systems. The frequencies are derived by dividing a 60 MHz base frequency in powers of two (i.e. 60000 kHz / 2^9 = 117.1875 kHz)

(2) Any sonar system can detect objects that are larger than half of its wavelength. The limit to measurement resolution is determined by the sonar pulse:

$$\Delta y = \frac{c.\tau}{2} \times \frac{1}{\cos\beta}$$

Where

c is the speed of sound

τ is the pulse time

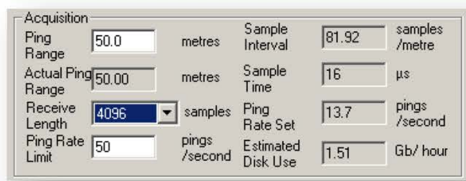
c.τ is the pulse length in meters

β is the grazing angle. In the best case, cosβ is 1

(3) These are theoretical values, but practically there is no way <u>any</u> sonar could tell the difference between a seabed at 20.000 metres and another one at 20.003m.

8.3.2 Sampling

The software allows the user to select between 2^8 to $(2^{15} + 2^{14})$ samples



For a 234 kHz system, at 50m with 4096 samples, we get 12 mm sample interval (so 6 mm at 8192, 3mm at 16384 and 2mm at 24576; halve these values for a 468 kHz system).

However getting a very low interval by collecting huge amounts of data is meaningless and would in some cases reach USB buffer limits

8.3.3 Filtering, Accuracy and Resolution

Interferometric swath bathymetry systems give many data points per side, typically 2000 to 8000. However, the spread (standard deviation) of raw data points is usually greater than that of beam-forming multibeams, which typically produce 100 – 200 points per side.

Software filtering can be used to reduce this standard deviation to internationally acceptable survey limits. However, this filtering also reduces the resolution of the filtered data.

The International Hydrographic Organisation (IHO) Special Publication number 44 [Ref. 1], sets out standards for both accuracy (termed "uncertainty") and resolution. These are defined in a set of "Orders", of which "Special Order" is the most stringent, followed by Order 1.

Accuracy is specified in terms of the depth uncertainty to 95% confidence.

Resolution is specified in terms of the size of objects that must be detected, and the number of acceptable data points per square meter.

8.3.4 Beam Width, Azimuth

The beam width of the transmit and receive elements of Bathyswath, for the three sonar frequencies available, is given in "Beam Width, Azimuth" below. These figures are for both the transmit and receive elements. The effective width of the sonar "footprint" on the seabed is found by combining the "footprint" of both the transmit and receive staves, which is done by halving the beam width of the separate staves, to get a "two-way" azimuth angle.

	117 kHz	**234 kHz**	**468 kHz**
Beam Width, Azimuth	1.7°	1.1°	1.1°
Beam Width, Azimuth (2-way)	0.85°	0.55°	0.55°

Azimuth Angle (Stave and 2-way Footprint)

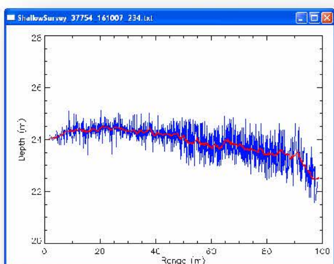
8.3.5 Total Propagated Error

This analysis is concerned only with the depth error component of the sonar system. Other error components include position, attitude, heading and height relative to datum. The last of these is usually measured using GPS height or tide height, and is often the largest component. This discussion concerns itself only with the contribution of the interferometric sonar.

8.3.6 Estimating Depth Uncertainty

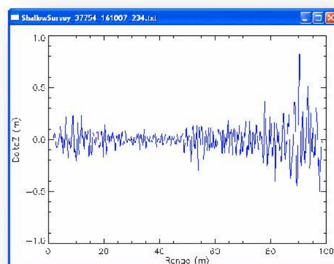
This analysis uses Bathyswath sonar depth profiles extracted from the data sets that were submitted to the 2008 Shallow Water data set. Profiles are analysed at two Bathyswath frequencies: 468 and 234 kHz.

Depth error is first estimated by comparing raw data points with an averaged profile.



234 kHz profile

(Blue: raw data, red: average)

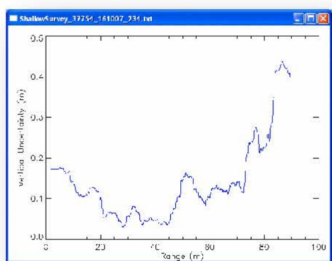


Estimated error of raw data

8.3.7 Data Smoothing

The Bathyswath software includes a range of data filters. These include averaging filters, which smooth the data, thereby reducing the statistical spread (and thus the uncertainty) of the depth data, but at the expense of resolution.

This smoothing filtering is mathematically modelled using a Gaussian sliding window filter.

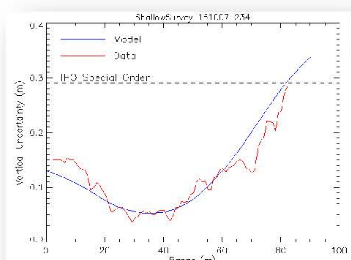


The width of this window is selected to satisfy the S44 requirement for a given number of accepted data points per square meter. Both across-track (along the profile) and along-track (profile separation, from vessel speed and ping repetition frequency) are used.

The smoothed points are converted to 95% uncertainty, using the statistical method recommended in IHO S44.

← 95% Uncertainty of smoothed data

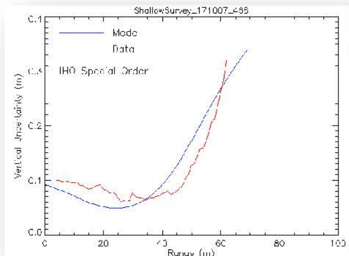
8.3.8 Error Modelling



The data smoothing procedure is repeated for a number of "pings" in the data set, and averaged by range.

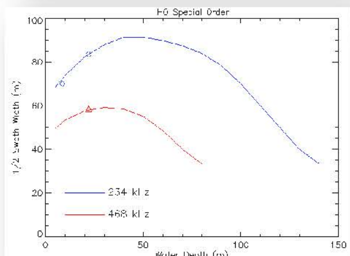
A mathematical model of phase error in Bathyswath is created, and validated against the observed uncertainty; see the blue line on the left

← Data uncertainty at 234 kHz



The process is repeated for all three Bathyswath sonar frequencies

🡐 Data uncertainty at 468 kHz



Finally, the models are used to graph the maximum range (half swath width) at which the IHO S44 Special Order is met (Shapes are measured data)

🡐 Horizontal range at which IHO S44 Special order is met

8.3.9 Conclusion

Error modelling, validated with data from the Shallow Survey 2008 data set, shows that Bathyswath is capable of providing survey depth accuracy within the requirements of IHO S44, Special Order, at good ranges. Longer ranges are achieved with the lower-accuracy Orders.

8.4 SURVEY PRODUCTIVITY

The time in which a given seabed area can be surveyed depends on the distance between the survey lines and the forward speed of the survey vessel.

8.4.1 Line Spacing

The spacing between survey lines is determined by a combination of range limit and accuracy required. There must also be some overlap allowed to account for variations in the survey line followed. Otherwise, any small helmsman's errors will cause gaps in coverage of the seabed.

8.4.2 Pulse Repetition Frequency

The time taken for a ping cycle is that for a round trip from the transducers, to the farthest range, and back again. The speed of sound in water is about 1500 meters per second. For example, a 150 meter ping takes 0.2 seconds. This gives a pulse (or ping) repetition frequency (PRF) of 1 / 0.2 = 5 per second (or Hertz).

The software allows the nominal sonar range to be set in meters. The corresponding PRF is calculated in software and used in data acquisition.

8.4.3 Platform Speed and Along-Track Coverage

Bathyswath is capable of providing total ensonification of the bottom at practical and efficient survey speeds

The distance between pings along the track of the vessel is determined by the pulse repetition frequency (PRF) and platform speed. In order to minimize cross talk between the two sides, the system can be used with alternating sonar transmissions, port and starboard. Thus, in the alternating mode, this distance is doubled:

d = 2 . V . PRF

where:

d is along-track distance between pings, in meters

V is platform speed in meters per second.
Halving the speed in knots gives a good estimate

PRF is the pulse repetition frequency, in seconds.

Bathyswath also provides the option of firing both transducers simultaneously. This doubles the coverage rate, so that the along-track ping spacing reduces to (V.PRF). However, this mode should be used with caution in surveys with a requirement for high bathymetry accuracy, because some cross-talk between the channels is likely. That is, the signals from one side can affect the other side.

Coverage is also determined by the width of the sonar beam. A narrower beam gives better resolution, but carries a greater risk of missing targets between beams. See section 8.3.4. At 50 metres, the 234kHz and 468kHz beams cover 0.43m, and the 117kHz beam covers 0.74m.

Increasing the speed over the ground will reduce survey time, but will also reduce the along-track coverage. Five or six knots is generally a good compromise. At 5 knots, with a 100m range, giving 6.7 pings per second, each side is covered every 75cm along-track. At 10 knots, this spacing doubles. In the 5 knot example, ground is covered at 500 square metres per second, or 1.8 square kilometres per hour.

When using the system in simultaneous pinging mode, on a typically flat seabed, the directionality of the two transducers is sufficient to prevent the signals from one side appearing on the other. However, if one side contains a very strong reflector (e.g. a harbour wall), or is very weak (e.g. contains acoustic shadows), then there can be “cross-talk” between the sides. The operator needs to be aware of the risks and priorities. Typically, it may be safest to use alternating mode where bathymetric accuracy is paramount, and simultaneous mode when using the system to detect small objects on the seabed. When high coverage is required in a limited area, and channel cross-talk is a problem, it may be beneficial to ping on one side only, thus doubling the along-track coverage on that side.

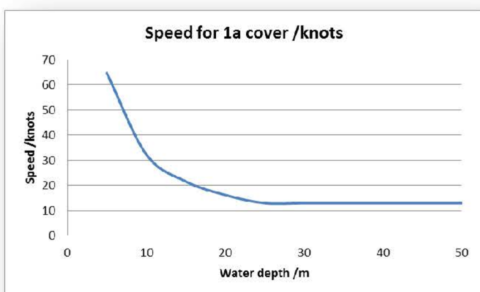
8.5 SURVEYING AT HIGH SPEED

8.5.1 Introduction

Some users have a requirement to survey at relatively high speeds, 8 knots or more. At excessive speeds, along-track coverage is reduced, and data density could fall below specification or the sidescan imagery might not fully cover the seabed.
This section shows the options for meeting this specification with Bathyswath.

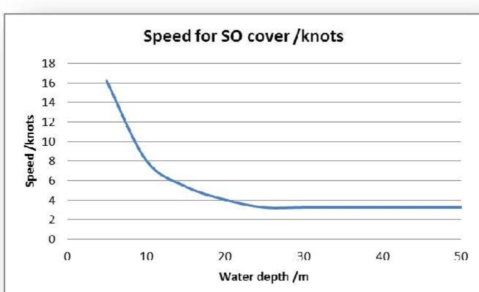
8.5.2 Data Density

Survey data specifications such as IHO S44 [Ref 1] define a minimum detection resolution, which is often interpreted by hydrographic organisation in terms of sounding density. For example S44 Special Order surveys require around 9 soundings per square metre, and Order 1a requires round 9 soundings in a 2x2 metre patch, so 2.25 soundings per square metre. Special Order is reserved for limited areas such as docksides, where high vessel speeds are not usually allowed. Therefore, we use the Order 1a requirement for this analysis. Bathyswath can provide S44 accuracy at around 3 soundings per metre across-track (see section 8.3), so it is necessary to achieve no fewer than (2.25 / 3 =) 0.75 pings per metre along-track.



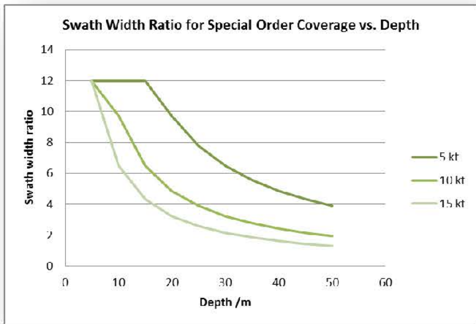
For typical 234 kHz Bathyswath swath widths (12 times water depth up to a maximum of 300 m), the speed at which Order 1a data density is just met can be calculated; this is 13 knots at depths below 25 metres.

← The speed in knots at which Order 1a data density is just met



For Special Order data density, the maximum speed falls to 3.2 knots with 12 times water depth swath widths for depths below 25 m.

← The speed in knots at which Special Order data density is just met

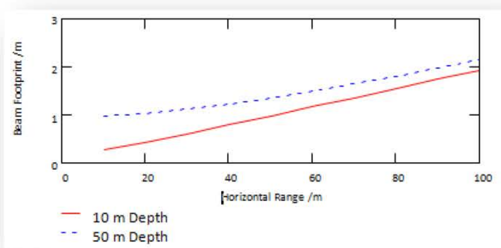


To achieve Special Order data density at high speed in depths below 10 metres, the swath width must be reduced.

🡐 The swath width ratio at which Special Order data density is just met for various speeds

8.5.3 Complete Bottom Coverage

If it is necessary to find all sonar targets, no matter how small, then full bottom coverage is needed. This is determined by the area covered by the sonar beam on the seabed, called the "sonar footprint". A sonar beam is generally taken to extend to the angle at which the power at the centre of the beam falls to half its power, or 3 decibels (dB). For resolution purposes, a "two-way" angular resolution is quoted; see section 8.3.4 below. In this analysis we assume that detection of seabed targets of interest is achieved within the "one-way" azimuth angle.

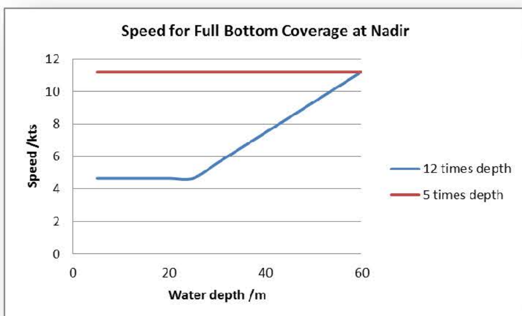


The footprint is narrowest under the transducers, and widest at far range. Under the transducers it is wider in deeper water.

🡐 Beam Footprint vs. Horizontal Range, at 10m and 50m water depth

8.5.4 Maximum Speed for Full Coverage

The maximum speed for full coverage can be calculated for a given water depth using the ping rate for that depth, and the footprint of the beam below the vessel. The maximum speed is that at which the vessel moves forwards by the width of the footprint within the ping period. Bathyswath is usually operated in simultaneous ping mode, in which both transducers fire at the same time. This doubles the along-track coverage at a given forward speed compared to systems that work in alternating mode (port-starboard-port-starboard etc.).



This graph shows the maximum speed at which full coverage is achieved immediately below the boat, operating in simultaneous ping mode.

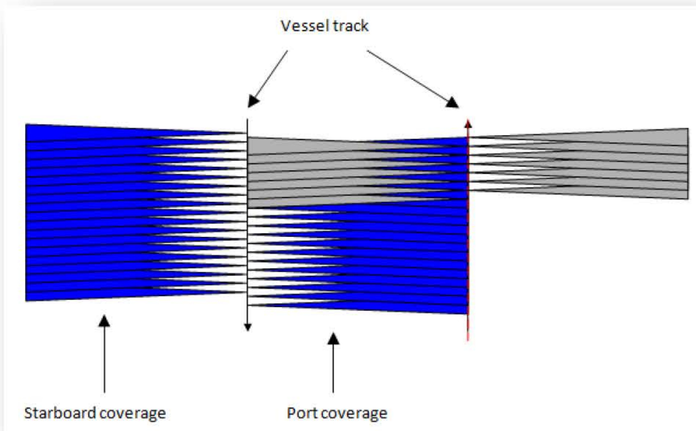
← Max. speed for full coverage below boat

It can be seen from these graphs that full coverage under the boat can be achieved at ten knots water depth if:

- The swath widths are kept to five to six times water depth
- The sonar is operated in simultaneous mode

8.5.5 Sidescan Search Mode

Most sidescan systems are run with every other line spaced for 100% overlap, so that the nadir of each swath is covered by the far range of at least one adjacent line. Bathyswath can be run in this way to give full bottom coverage with both bathymetry and sidescan.



The maximum speed is given by the footprint at far range and the ping period:

$$v = \frac{f}{t}$$

Where the footprint is a function of range and beam angle: $f = r.tan\theta$ and time is a function of range and sound speed $t = \frac{2.r}{c_{sound}}$

… so the speed is independent of range, and for a beamwidth of 1.1° is 28 knots.

8.5.6 Conclusion

These calculations show that the Bathyswath sonars can easily provide both IHO S44 data density and 100% bottom coverage at relatively high survey speeds. Bottom coverage depends on the along-track and across-track beam patterns. Bathyswath provides very high data density across-track, so that coverage is complete in this dimension. The along-track coverage depends on ping rate, beam width, and speed of sound.

There are several options for obtaining 100% coverage:

- Operate the system with minimal overlap, limit swath widths to approximately seven times water depth, or
- Operate the system with 100% overlap between adjacent survey lines. In this case, 100% coverage is obtained in 10 metres of water at 15 knots.
- Add a third, forward-facing transducer to boost data coverage in the nadir region; see section 10.

There is a range of options lying between these solutions, so that the system can easily fit in with the operational practices of the user.

8.6 NEAR-RANGE SEABED COVERAGE: THE 'NADIR' REGION

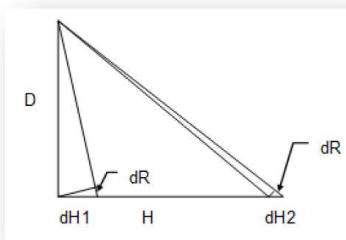
8.6.1 The Nadir Region

The region of the seabed directly below the sonar transducers is called the "nadir region".

This coverage of an interferometer is greatest at medium ranges from the transducers, and is thus less in the area close to the centre than at far range. There are several reasons for this reduced data density in the centre.

8.6.2 Measurement Geometry

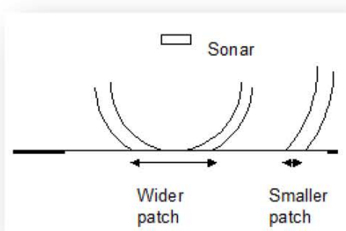
An interferometer samples the angle to the seabed at regular intervals of time. Each angle and time pair is converted to a depth and horizontal range pair. Time is converted to range from the transducer (slant range) using the speed of sound, so regular time steps translate to regular range steps. However, regular steps in slant range do not produce regular steps in horizontal range. Horizontal range is a distance measured along the seabed, starting from a point immediately beneath the transducers.



A simple example illustrates this situation. Consider the system operating in a water depth D. The first depth measurement is taken immediately under the transducers. The next measurement is taken at a range step of dR. Simple trigonometry dictates that the horizontal range step, dH1, is much larger than dR. Now consider the situation further out along the profile, at some horizontal range H. Here, the horizontal range step dH2 is much closer to the range step dR.

8.6.3 Footprint of Transmit Beam

At the start of each ping, the sonar transmits a short pulse of sound. This pulse moves outwards at the speed of sound. Where the pulse hits the seabed, it returns an echo. The echo is picked up by the transducers and the angle of the returning signal is measured.



At any one instant, the pulse of sound will be "illuminating" a patch of seabed. The size of this patch is determined by the length of the pulse and the geometry. Immediately below the transducers, this patch is at its greatest, and thus the resolution is lower than it is further out.

8.6.4 Amplifier Response

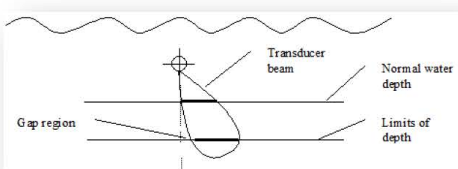
When the sound signal first hits the seabed, the size of the returned echo signal goes from a very low level to a very high one extremely quickly. This fast change in signal level presents a challenge to the amplifier designer. One important part of a successful interferometer like Bathyswath is thus the way in which the amplifier responds to these fast signal changes.

8.6.5 Filter Response

As explained above, an interferometer measures angles to the seabed as a set of samples separated in time, and thus in range. Before the sonar signal reaches the seabed, the angles measured will be discarded due to low signal levels, or random due to noise pick-up or returns from objects in the water. These random signals from the water-column must be discarded before the seabed depths can be recorded. Bathyswath uses a collection of user-settable filters to separate the seabed from objects in the water column.

8.6.6 Deep Water Response

The shape of the sonar transducer beam in elevation has been chosen to maximize the performance for most survey situations. In shallow to medium water depths, the direct reflection from the seabed directly under the transducers is very strong, and can cause the electronics to 'saturate'.



To reduce this, the sonar beam is shaped so that returns from this region are reduced in amplitude. However, at the limits of the depth capabilities of the system, this reduction can cause data-loss in the near-range area. Changing the transducer beam-angle so that the transducer normal makes a greater angle with the horizontal reduces this effect.

8.6.7 Coverage at Nadir

Most users find that the data coverage achieved in the nadir region is sufficient for their purposes. However, if very high data coverage is required at all parts of the survey, and if the sidescan component is also important, then a "sidescan survey" line pattern can be used. Survey lines are run alternately at the sonar range and twice the sonar range, so that the nadir is "filled" from an adjacent swath in every case.

8.6.8 Forward-Looking Transducer

Bathyswath can be supplied with a third, forward-facing transducer to boost the data density at nadir. See section 10 for more information.

8.6.9 Use with MBES Systems

Some users operate Bathyswath at the same time as an MBES system. The MBES provides more data in deeper water and helps to boost the nadir data density, and Bathyswath gives much greater swath width in shallow water and gives true, high-resolution sidescan imagery. Acoustic cross-talk interference between the two systems is usually acceptable, but Bathyswath can provide or accept sonar transmit synchronisation signals if these are required.

8.7 ENVIRONMENTAL IMPACT MITIGATION

The standard Bathyswath systems use sonar frequencies above the limit of hearing of marine mammals. Only Bathyswath-XL uses a sonar frequency and transmitted power levels that are in the range that could disturb or cause injury to marine mammals. Bathyswath is fitted with mitigation features, including:

- Programmable sonar soft-start: this slowly builds up the transmit power levels, allowing any marine mammals in the vicinity to move away before the sonar can cause them injury
- Sonar transmit power linked to pressure depth: for use on deep-operated vehicles, this limits the transmit power until it has reached sufficient depth to be out of the diving range of marine mammals. This also helps to avoid cavitation issues on the transducers.

8.8 MEDIA USAGE

Bathyswath samples a high density of data. It therefore stores data to disk at a high rate. When recording a full set of bathymetry and amplitude points, the recording medium is filled up at a rate of 150 Kb per second (0.54 Gb per hour and 13 Gb per day, so a 1Tb external disk drive can store 11 weeks of continuous recording).

If the data recording rate is a problem, the user may select a lower data sampling rate. This will save recording media but at the expense of resolution. Conversely, very high resolution surveys use more media.

9 COMPARISON BETWEEN INTERFEROMETERS AND BEAMFORMERS

Both interferometric multibeams and beamforming multibeams measure range and angle to a series of points on the seabed. A beamformer mathematically forms a set of "beams", and detects the range to the seabed in each beam. An interferometer measures the angle the incoming sound wave fronts in a time sequence of samples. Slant range is obtained from the time of the sample and speed of sound.

> In summary, beamformers measure range for each of a set of angles,
> and interferometers measure angle for each of a set of ranges.

9.1 ADVANTAGES & DISADVANTAGES OF THE TECHNIQUES

Parameter / Function	Interferometer	Beamformer	Notes
Number of depth measurements	6000+	60-120	Depends on range
Range vs. water depth	10 - 20	3-5	Beamformer footprint becomes unacceptably large at far range.
Amplification / processing channels	4-5	60 +	In a harsh environment, simplicity is important
Outboard transducer electronics	Passive	Active	The outboard component of an interferometer is extremely robust, and cheaper to replace if damage does occur
Outboard transducer size and weight	350x160x60mm 5 kg (air)	120x190x450mm 16 kg (air)	Dimensions for a common portable beamformer. Many beamformers are much larger.
Horizontal resolution at range	Good	Poor	Beamformer footprint becomes unacceptably large at far range.
Angular coverage	260° (including 20° overlap)	90° - 180°	
Co-incident sidescan	True	Partial	An interferometer collects amplitude in the same way as its bathymetry: as a time-series.
Profile data density	Increases with reducing grazing angle	Decreases with reducing grazing angle	Higher complete profile data confidence with an interferometer.
Ability to resolve several targets at the same range	No	Yes	
Ability to resolve several targets at the same angle	Yes	No	
Profile data density	Increases with reducing grazing angle	Decreases with reducing grazing angle	In the first 5 m of horizontal range, a beamformer collects slightly more depth samples. Beyond that, an interferometer collects many more.

9.2 ADVANTAGES OF INTERFEROMETERS

9.2.1 Wide Swath Width

An interferometer produces a swath width of 10 to 15 times water depth, depending on sonar conditions. This advantage is particularly clear in shallow water (less than 30 m).

9.2.2 Coverage

Bathyswath measures thousands of depths along every profile, across a very wide swath. Its coverage of the seabed is thus unparalleled.

9.2.3 Simplicity

A beamformer requires digitized signals from each of dozens of transducer elements, which must then be highly signal-processed. This results in a requirement for many amplifiers, wires, connectors and processors. These components must either be present in the wet-end of the system, or highly complex cabling is required to pass through the hull of the platform. Such complexity must inevitably result in reliability problems.

In contrast, Bathyswath requires only three or four individual signal channels. The innovative use of electronic processing limits the requirement for many processors. Only the transducers need to be placed in the water, and these are entirely passive: they contain no electronic components at all other than the piezo-electric elements and are completely potted in plastic compound. They are thus extremely compact and robust.

9.2.4 Weight and Size

The simplicity of Bathyswath results in a lightweight, portable package with a small footprint and simple cable requirements.

9.2.5 Flexibility

Interferometric systems can similarly be configured to work from a range of platforms, and in a range of configurations.

Interferometer **Multibeam**

9.3 MULTI-BEAM BEAMFORMERS

9.3.1 Effect of Beam Width at Far Range

Beamformers have a finite width of beam, detecting anything within this beam as signal. Their resolution is thus related to the width of beam. At far ranges, where the beams make a small angle with the seabed, horizontal resolution is poor. In contrast, Bathyswath produces a small pulse of sound and measures returns from this pulse across the seabed. The footprint of this pulse thus remains small, and the resolution of an interferometer remains good even at far range.

9.3.2 Angular Restrictions

Beamformers form a limited number of beams, in a limited angular sector. They therefore cannot survey up to the sea surface unless special mounts are used. In contrast, Bathyswath can survey a full 260° sector with 20° overlap in its standard configuration.

9.3.3 Lower Resolution

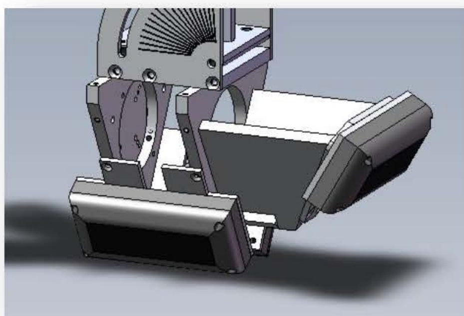
With less than a hundred depth measurements in each sonar cycle, it is often necessary for a beamformer to interpolate between measurements in order to simulate full coverage.

9.3.4 Roll Sensitivity

Beamformer profiles, being a much smaller percentage of water depth than an interferometer, are subject to large movements relative to vessel track. This can lead to unsurveyed areas at the swath edges if the survey vessel is subject to rolling motion from wave encounter.

10 FORWARD-LOOKING TRANSDUCER

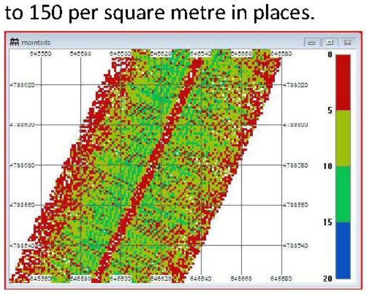
Bathyswath can optionally be provided with a third, forward-looking transducer. This transducer is rotated both downwards and around its own axis. This provides sonar footprints on the seabed that run diagonally across the track in front of the vessel, which builds up to a third swath of measurements, in the central region between the port and starboard swaths.



Although an interferometer such as Bathyswath provides unparalleled data density, the geometry of the sonar means that this data density is relatively low in the region directly under the transducers. This effect can be mitigated by the third transducer.

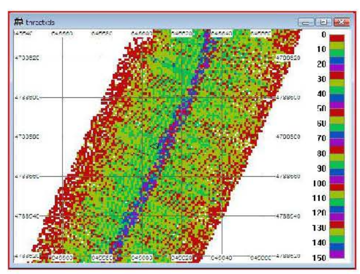
Bathyswath Sonar Head with Forward-Looking Transducer

The results can be seen from Grid Processor data density plots below. These show part of a three-transducer survey, with the third transducer omitted for comparison in the left-hand image. Note that the centre region is well covered, but that there are a few gaps and that the data density in the middle 5 metres is generally less than 5 samples per square metre. In the image on the right, data from the third transducer has been included. The centre region is now covered very well, with data densities greater than 20 samples per square metre, and up to 150 per square metre in places.



Two-transducer data density plot

Scale in samples per 1-metre bin



Three-transducer data density plot

The colour scale is the same as the 2-transducer plot

The forward-looking transducer is also a valuable safety feature when operating in shallow water, as it gives a warning of submerged obstacles ahead.

11 USE ON REMOTE AND UNDERWATER PLATFORMS

11.1 DESCRIPTION

Bathyswath is available as "bottle" modules for small AUVs (autonomous underwater vehicles), including Gavia and REMUS100. It is also ideal for use on ASVs (autonomous surface vehicles), such as remote-controlled survey catamarans.

AUVs provide many advantages, including operation in places that are hazardous for vessels and people, and freeing up personnel and vessels for other tasks.

The low power consumption of Bathyswath compared to similar systems means that the vehicle mission length can be much longer.

The Bathyswath AUV systems are provided with embedded computer systems for data logging, system control, and interfaces to the host vehicle via Ethernet or serial ports. Interconnecting cables and clamps are supplied where necessary.

Hydroid REMUS 100

Teledyne GAVIA

Bathyswath Gavia AUV bottle

Bathyswath on REMUS 100

12 BATHYSWATH-OEM

12.1 DESCRIPTION

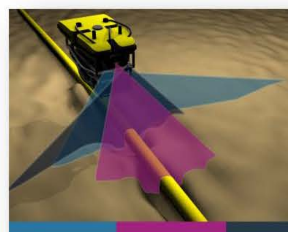
Bathyswath-OEM offers the core components of the Bathyswath swath bathymetry sonar. The purchaser is responsible for integrating these components into the target application.

12.2 TYPICAL APPLICATIONS

Applications for Bathyswath-OEM include:

- Operation on small remotely-operated vehicle (micro-ROV) platforms
- Operation on autonomous underwater (AUV) and surface (ASV) platforms
- Integration into custom-built survey launches
- Any other special application, where the full package of equipment provided by the standard Bathyswath product or its derived platform-specific application products is not required

Bathyswath on a micro-ROV



ROV pipe-scanning configuration

12.3 SYSTEM DESCRIPTION

Bathyswath is a wide-swath bathymetry and sidescan imaging system.

Bathyswath-OEM provides the following components:

- 1, 2 or 3 Transducer Electronics Modules (TEMs). These contain the main system electronics, and connect the sonar transducers to a PC computer.
- 1, 2 or 3 Sonar transducers: typically mounted with one facing port, and one facing starboard.
- The Bathyswath software suite, provided on CD for installation on the Customer's PC computer. The Bathyswath software supports real-time data acquisition, post-processing, and interfaces to most third-party software suites.

See section 14.8 for the system parameters, including sizes and weights.

Technical support and training to assist the purchaser to integrate and operate the system are offered at additional cost.

Bathyswath 468 kHz Transducer
(Standard Format)

468 kHz Transducer
(AUV Format)

12.4 TRANSDUCERS

The standard transducer is fitted with 16 way male Subconn MCIL16M connector, on a 1000 mm tail. This connector could be terminated onto the face of a pressure bottle.

The AUV transducer is supplied with bare-ended cable, for the client to terminate (5 twisted pairs). The cable exits the rear of the transducer directly into the vehicle's hull. Fixing is by one fixing hole at rear, two at the front, M6 holes, counter-bored to take M6 washer. The body is yellow closed-cell foam, and the active face is polyurethane.

12.5 TEMS

The TEMs connect to the software using USB ports.

A boxed TEM has the same form-factor and power requirement as a 5 ¼" PC disk drive. The TEM board can also be supplied without the box. See section 14.8.1 for the TEM dimensions.

🡐 Bathyswath Transducer Electronics Module (TEM), in its box

A suggested configuration when connection is available to the surface (e.g. in an ROV) is to use a USB to Ethernet hub in the pressure bottle, and to connect the Ethernet to the ROV's umbilical. By running the software driver for the USB to Ethernet hub on a PC at the surface, the USB ports are made available to the Bathyswath software running on the PC. The sonar can then be controlled through the software on that PC, and the sonar data viewed on the same platform.

For use on an autonomous vehicle, two USB ports are needed on the vehicle's single-board computer (or a small USB hub may be fitted).

The TEMs require 5V and 12V DC power. Each TEM takes about 6W in total.

To mount the TEMs in a cylindrical pressure housing, they can be placed one on top of the other. In this configuration, they just fit into a 167 mm internal diameter cylinder. If the two TEMs are placed end-to-end, they just fit into a 152 mm cylinder. In either configuration, there is space on top of and below the TEMs to take auxiliary components such as power supply modules and USB hubs.

13 BATHYSWATH-XL

13.1 DESCRIPTION

Bathyswath-XL is a 40 kHz, 6000-metre pressure-rated system. It is provided as an OEM kit of parts for integration into deep-operated platforms, for full-ocean-depth survey work.

13.2 TYPICAL APPLICATIONS

Applications for Bathyswath-XL include:

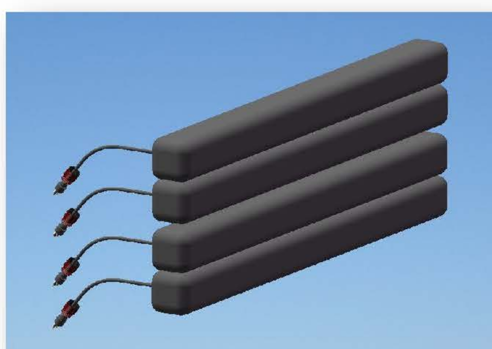
- Operation from very deep-towed platforms and/or scientific research
- Operation on large autonomous underwater vehicles (AUV)
- Surface vessels; with the transducer arrays fitted to the hull of the vessel

13.3 SYSTEM DESCRIPTION

Bathyswath-XL is a wide-swath bathymetry and sidescan imaging system.

The basic sonar system consists of the following components:

- Transducer Bathyswath Electronics Modules (TEMs); these contain the main system electronics, and connect the sonar transducers to the data acquisition system. For use on deep-towed or autonomous platforms, these components can be provided in a 6000m-rated pressure vessel.
- Power amplifiers: these drives the sonar transmit pulses. The power amplifiers are usually provided in a separate housing.
- Sonar transducer arrays: one facing port, and one facing starboard. These are rated to 6000m pressure depth.
- Bathyswath software suite; this supports real-time data acquisition, post-processing, and interfaces to most third-party software suites.



Bathyswath-XL Transducer array

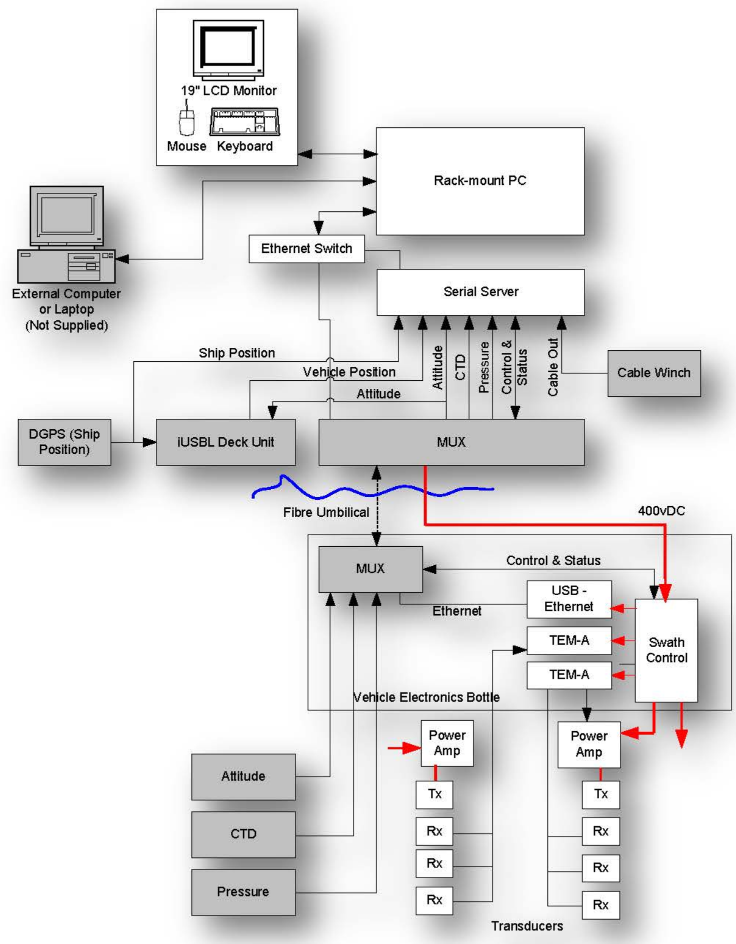
A Bathyswath-XL survey system includes two such arrays, facing port and starboard

Technical support and training to assist the purchaser to integrate and operate the system are offered at additional cost.

13.4 CONFIGURATION

Bathyswath-XL can be mounted on:

- Surface vessels; with the transducer arrays fitted to the hull of the vessel
- Towed platforms and ROVs; operating down to 6000m depth
- Autonomous underwater vehicles (AUVs)



Typical Bathyswath-XL configuration block diagram for a towed vehicle.

Items in grey are not part of the base sonar system (these can be provided on request)

13.5 SOFTWARE

In addition to the standard Bathyswath software, Bathyswath-XL provides specific software functionality for deep-ocean work.

13.5.1 Pilot Displays

With deep-operated vehicles, the vehicle Pilot has responsibility for the safety and operation of the vehicle and its systems. Software functions that support this role include:

- Monitoring vehicle altitude: this can be done using the bathymetry cross-profile display, and an altitude figure written to a text window. The text window will also be capable of displaying a rate-of-climb (or descent) figure
- Monitoring Bathyswath performance: this can be monitored using the standard bathymetric views (waterfalls, cross profiles, etc.), and by specific diagnostic windows (amplitude-range display, angle & phase-range display, text views)
- Tuning the sonar parameters: this is done in the Sonar settings dialog
- Monitoring survey coverage, and modifying the track and/or sonar settings as appropriate: this is done using the Coverage window

The pilot is able to select from all of the displays and controls listed in the previous sections.

Textual parameter outputs provided that are applicable to the pilot are as follows:

- Vehicle attitude: roll, pitch and heading
- Vehicle position (incl. source of position, e.g. IUSBL, calculated from cable out, read from file, fixed value)
- Vehicle depth and Vehicle rate of climb (and descent)
- Vehicle altitude (calculated from a mean of swath profile depths close to nadir)
- Ship Position and Cable Out
- System status, including error conditions

13.5.2 Scientific Displays

For ocean science applications, the end-users of the data from Bathyswath-XL would use views such as:

- Standard bathymetric views (waterfalls, cross profiles, etc.) and text views
- Gridded data 3D and 2D views; these are created by “dropping in” data files as soon as they are available from the main Swath Processor application.
- Outputs to third-party tools

A second SWATH display can be implemented by use of the existing TCP/IP data interface in the Swath Processor application to drive a second instance of the Swath software on another PC at the scientists’ position. This allows the scientists to configure and save their own set of view windows, but not to control the parameters of the Bathyswath sonar. Information and guidance on the use of the SWATH software for a second display and an additional software licence will be provided for this purpose.

13.5.3 Storing and Retrieving Display Layouts

The layout and configuration of display windows in the Bathyswath software can be saved to, and retrieved from, files on disk. Therefore, individual operators (including the Pilot and Scientist roles) may configure the display console to suit their needs.

14 SPECIFICATIONS

14.1 SUMMARY

Bathyswath is a low cost, high performance bathymetry and sidescan system suitable for installation on dedicated vessels, ships of opportunity, and remote platforms, including UUVs and USVs. It is simple to integrate into a full survey suite.

It is intended for mapping the bottom of the sea and inland waterways. The transducers are mounted on pole, hull or underwater platform, and can be used to survey up to about 300 metres water depth (or altitude, for an underwater platform). The end products of the system are images and charts of the depth and strength of reflection of the seabed. These products are known as bathymetry and sidescan respectively.

Bathyswath is available in three frequency versions, 117, 234 and 468 kHz for up to respectively 300, 150 and 75 m slant range. The system accuracy of all versions exceeds the latest IHO specifications, as set out in IHO Standards for Hydrographic Surveys, Special Publication 44, 5th Edition, February 2008.

Operating in Microsoft Windows, and with full on line help and manual, the system is easy to operate and extremely robust.

Data acquisition mode stores all raw data output from the transducers while the real time displays allow processing and/or QA. A coverage plot assists in survey line planning.

Data processing abilities include swath generation with speed of sound profile correction, swath gridding and fairsheet plots. Final data sets consist of correct positional x,y,z & a (amplitude) data. These xyza DTMs can be interrogated, viewed, exchanged and printed by the Bathyswath software and third party charting and DTM display software. Processing may be carried out on the survey workstation or another PC running Windows.

14.2 POWER REQUIREMENTS

Bathyswath requires clean electrical power either of 110-240 Volts, at around 200W (for desktop and industrial computer systems), or 12-25V DC, at around 25W.

When using mains power, the use of an Uninterruptible Power Supply (UPS) or Line Volt Conditioner (LVC) is recommended, in order to ensure a clean and continuous supply. In situations where the survey vessel is unable to supply the required power, a generator should be used. The use of a small generator may also require the use of an UPS or LVC. Alternatively, the output from a choice of generators may be sampled using an oscilloscope or by connecting the Bathyswath system and inspecting the level of noise in the Amplitude window of the Swath program. Inverters can also be used to provide mains power from batteries, but these frequently give a very noisy output.

14.3 ENVIRONMENTAL REQUIREMENTS

	Min	Max
Operating Temperature	0°C	45°C
Storage Temperature	-10°C	65°C

14.4 ADDITIONAL HARDWARE

Bathyswath is used with external computers and sensors, such as the following. These can be supplied with the Bathyswath system, or users may obtain their own.

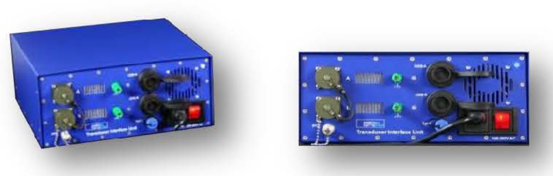
Item	Specification
Computer, minimum specification	Processor P4 3GHz 1 Gb RAM, 128 Mb Graphics Card, 100 Gb HDD
Motion Sensor	Bathyswath accepts input from all standard motion sensors and gyro compasses.
Position Sensor	Bathyswath accepts input from all standard position sensors, including GNSS (global navigation satellite systems, e.g. GPS)
Sound Velocity	Full correction using sound velocity profile for full water depth
Heading	Heading can come from a 2-antenna GNSS receiver, or from magnetic compass, gyrocompass, etc.

14.5 ELECTRONICS HARDWARE

The Transducer Interface Unit (TIU) includes the Transducer Electronic Modules (TEM), a USB hub and a Power Supply Unit (PSU). There is one TEM per transducer

At present, the TIU is either inside a splash enclosure (IP65, 210 x 74 x 461 mm, 5 kg) or a dry one (294 x 125 x 285 mm, 6.4 kg).

Splash TIU



Dry-TIU

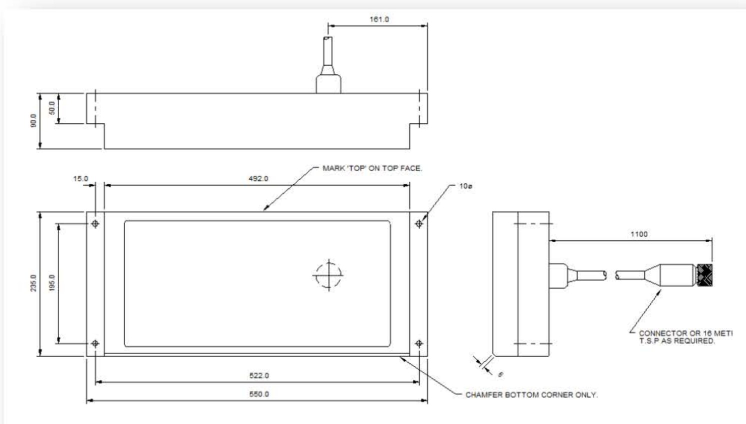
(A new design of the dry enclosure will be disclosed in July 2013, it will be adaptable as desktop unit or 19 inches rack)

14.6 TRANSDUCER DIMENSIONS

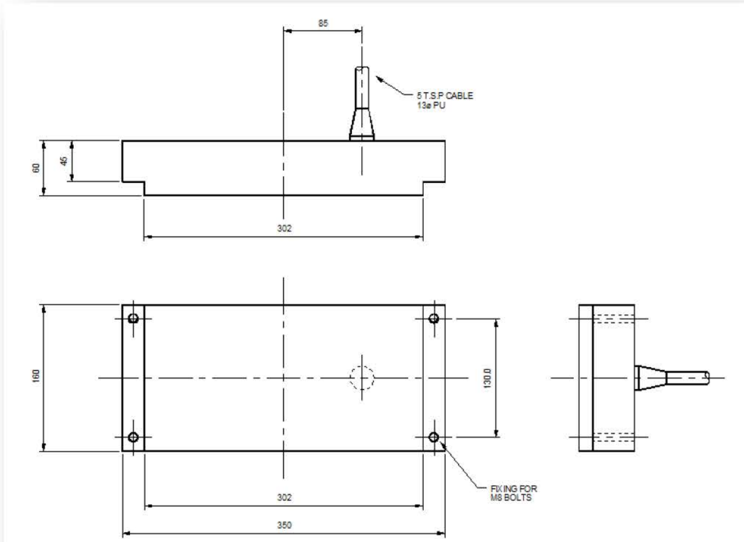
Item	Height (mm)	Width (mm)	Depth (mm)	Weight in air (kg)	Weight in water (kg)
Transducer 117 kHz	235	550	90	13	1.6
Transducer 234 kHz	160	350	60	6	0.9
Transducer 468 kHz	100	215	42	1	0.1
Transducer 468 AUV	88	366	25	1.1	-0.03

Transducers are supplied with 1m short tail and a wet-mate connector. For the 117kHz and 234kHz options, cable extensions are limited to 35m and 15 m only for 468kHz systems. The cable diameter is 13mm. The AUV transducer is positively buoyant.

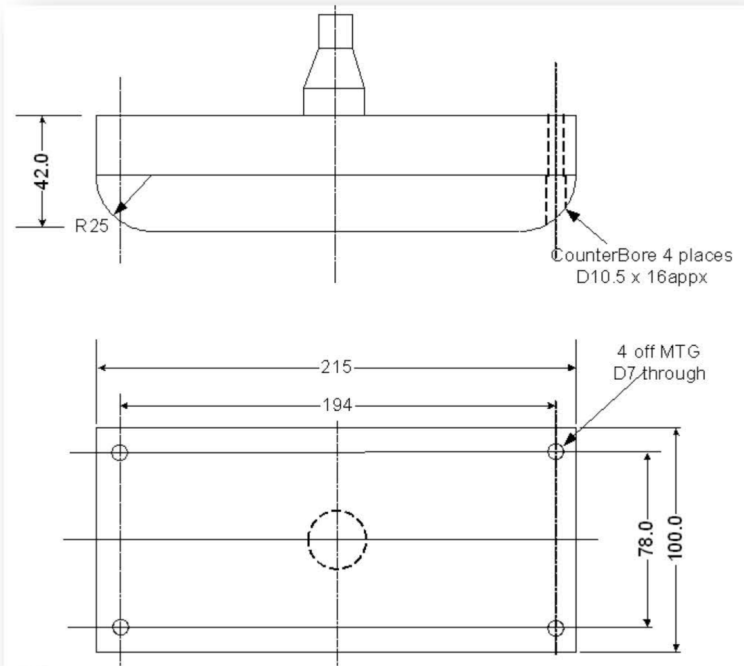
In the diagrams below, dimensions are in millimetres unless otherwise stated.



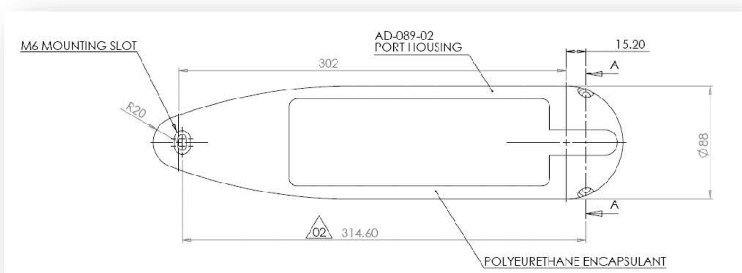
117kHz Transducer dimensions



234kHz Transducer dimensions



468kHz Transducer dimensions

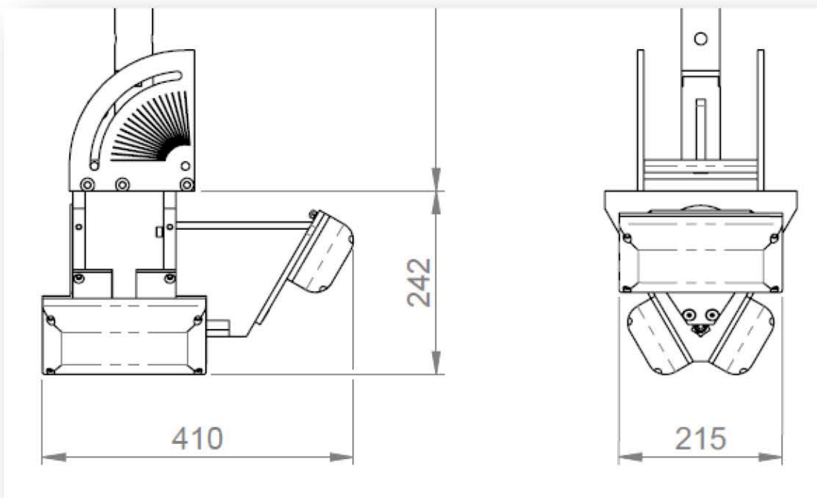


468 kHz AUV-Version Transducer dimensions

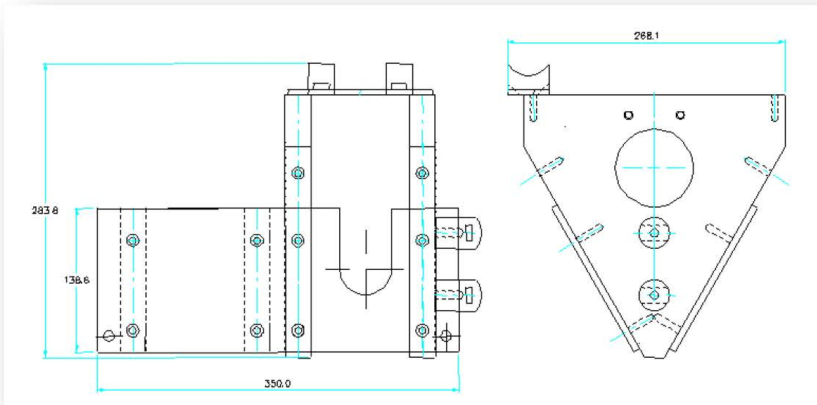
14.7 TRANSDUCER FRAME DIMENSIONS

Bathyswath systems are supplied with a "V"-bracket. The dimensions of the bracket assemblies, fitted with transducers, are as follows:

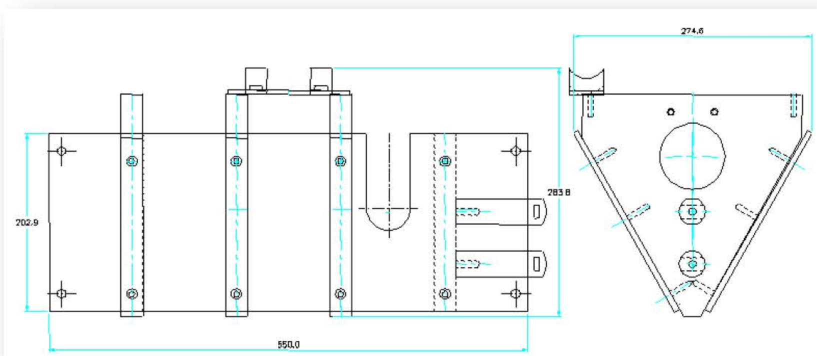
Item	Height (mm)	Width (mm)	Depth (mm)	Fits Through Hole Diameter (mm)
117 kHz assembly	249	411	550	687
234 kHz assembly	169	284	350	451
468 kHz assembly	110	200	215	294



468 kHz V-Bracket with Forward-Look dimensions



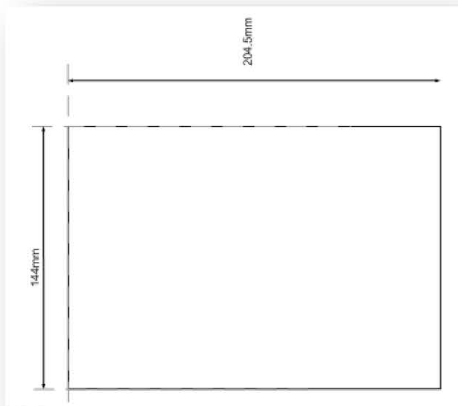
234kHz V-Bracket dimensions



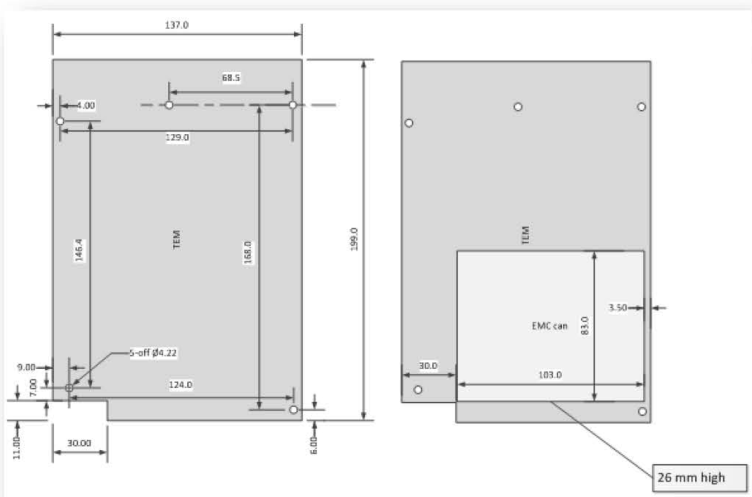
117kHz V-Bracket dimensions

14.8 BATHYSWATH-OEM

14.8.1 TEM DIMENSIONS

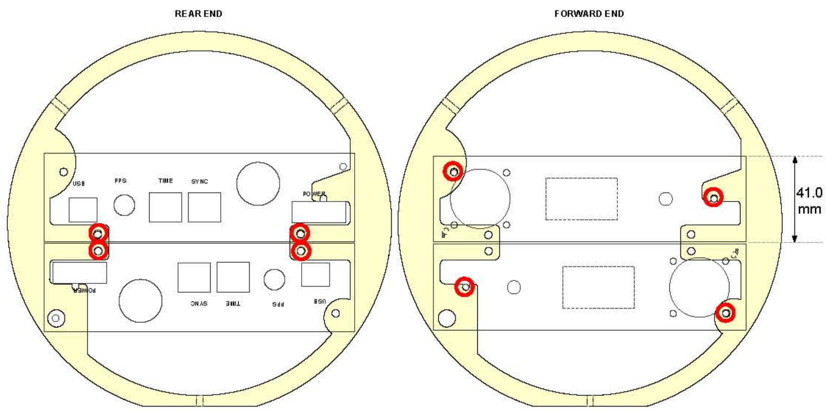


Boxed Bathyswath TEM, top view



TEM Board (un-boxed), showing mounting holes and location of EMC can

The front-end electronics are housed in a metal can for protection from electromagnetic noise (EMC protection)



Bathyswath TEM, end view, showing suggested mounting arrangement for a cylindrical bottle (circular brackets not supplied in standard Bathyswath-OEM)

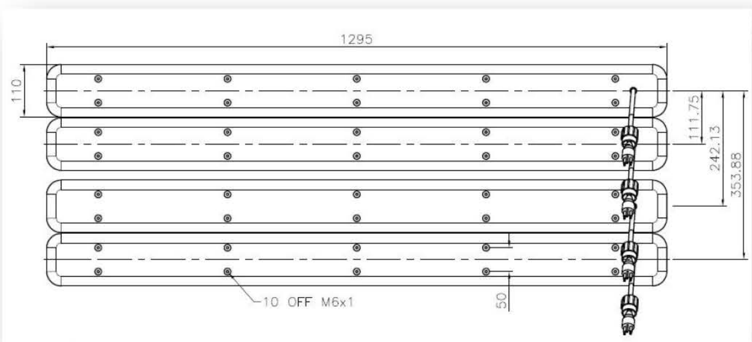
14.9 BATHYSWATH-XL

14.9.1 Bathyswath-XL Technical Parameters

Parameter	Value
Sonar Frequency	40.7609kHz and 39.0625kHz; port and starboard channels respectively
Maximum Altitude	2000 m
Recommended Working Altitude	500 m
Maximum Pressure Depth	6000 m
Azimuth Beam Width (two way)	0.9°
Transmit Pulse Length	0.3 – 30 m
Transducer Dimensions	1290 x 110 x 110 mm
Power requirement (wet end)	400 V DC, 160W (20V DC, 30 W)

14.9.2 Mass and Weight Budget for a Typical Bathyswath-XL Installation

Item	Qty	Mass (kg)		Wet weight (kg)	
Item	Qty	Unit	Total	Unit	Total
Transducer Arrays	8	22.50	180.00	9.40	75.20
Power Amplifier Bottle	1	23.94	23.94	9.45	9.45
Bathyswath electronics (without bottle)	1	3.10	3.10	3.10	3.10
Cabling	1	12.00	12.00	6.00	6.00
Total			**219.04**		**93.75**



Bathyswath-XL Transducer dimensions

Teledyne Odom Hydrographic

Echotrac CV100

Single or Dual Channel Echo Sounder

Compact Survey Solution

Move into the digital age with echo sounders from Teledyne Odom Hydrographic. If your survey does not require traditional paper records, then forget about piles of hard copy – the CV-100 has eliminated all that in favor of digital imaging on a PC-based data acquisition system.

With the same technology as the popular Echotrac CV and Echotrac MKIII, including Ethernet communications, Teledyne Odom's CV100 single or dual channel sounder is ready to simplify your transition to the convenience of an all-digital system.

Photo courtesy of David Evans and Associates, Inc.

PRODUCT FEATURES

- Multiple time varied gain (TVG) curves (10, 20, 30, and 40 log)
- DSP digitizer with manual filter control
- Manual or auto scale changes (phasing)
- Calibration menu with controls for transducer draft and index plus sound velocity and bar depth controls
- Rugged and waterproof (IP67)
- Help menus
- Flash memory upgradeable
- Auto Gain and Auto Power Modes for minimal operator input
- Suitable for autonomous vessels

TELEDYNE ODOM HYDROGRAPHIC
Everywhereyoulook™

A Teledyne Marine Company

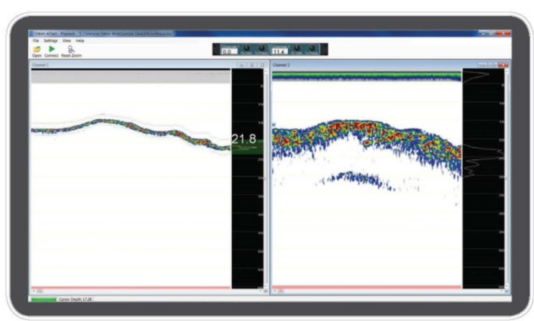
Echotrac CV100

Digital Hydrographic Echo Sounder

TECHNICAL SPECIFICATIONS

Single Channel Configuration[1]	High: 100kHz-750kHz (manual tuning in 1-kHz steps) Low: 3.5kHz-50kHz (manual tuning in 1-kHz steps) variable receiver bandwidth
Dual Channel Configuration	High: 100 kHz-340kHz Low: 24 kHz-50kHz
Resolution	0.01m, 0.1 ft.
Accuracy *(corrected for sound velocity)*	200kHz-0.01 m +/- 0.1% depth 33kHz-0.10 m +/- 0.1% depth
Output Power	Up to 300 watts RMS < 1 watt minimum
Ping Rate	Up to 20Hz in shallow water (10m) range
Depth Range	From <30cm to 600m (depending on frequency and transducer selected)
Input Power Requirement	9-32VDC < 15 watts
Weight	5kg (11lbs)
Dimensions	28cm W (11 in) x 23cm H (9 in) x 11.5cm (4.5 in) D
Mounting	Desktop or bulkhead mount (fixing hardware included)
Ports/Interface	Ethernet (LAN) plus 4 x RS232 or 3 x 232 and 1 x RS422 Inputs from external computer, motion sensor, sound velocity Outputs to external computer or remote display Output string: Odom Echotrac SBT, NMEA DBS, NMEA DBT, DESO 25 Heave Input-TSS1 or "Sounder Sentence" Echotrac Control SW - Simple Windows compatible graphical user interface Storage of full ping to seabed data in DSO format with e-Chart (easily compressed or converted to .XTF for additional processing)
Environmental	Operating 0-50°C Storage -20°-70°C
Options	Heave Sensor
Software Control & Logging Software	Windows based software included: eChart Display

1 Frequency agile in 2 bands (specify band at time of order).



eChart Software.

TELEDYNE ODOM HYDROGRAPHIC
Everywhereyoulook™
www.odomhydrographic.com

Teledyne Odom Hydrographic
1450 Seaboard Avenue, Baton Rouge, Louisiana 70810-6261 USA
Tel. +1-225-769-3051 Fax: +1-225-766-5122 Email: odom@teledyne.com

KLEIN SYSTEM 3000

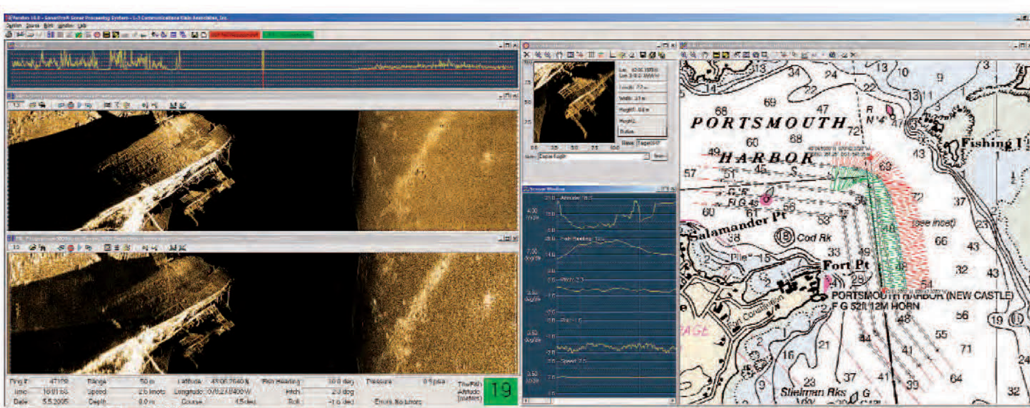
Digital Side Scan Sonar

The Klein System 3000 presents the latest technology in digital side scan sonar imaging. The simultaneous dual-frequency operation is based on new transducer designs, as well as the high-resolution circuitry recently developed for the Klein multi-beam focused sonar. The System 3000 performance and price is directed to the commercial, institutional and governmental markets.

KEY FEATURES

- Advanced signal processing and transducers produce superior imagery
- Cost-effective, affordable
- PC-based operation with SonarPro® software, dedicated to Klein sonars
- Small, lightweight and simple designs — easy to run and maintain
- Easily adapted to ROVs and custom towfish
- Meets IHO & NOAA Survey specifications

The Difference is in the Image



Klein Associates, Inc.

KLEIN SYSTEM 3000

System 3000 Specifications

TOWFISH	
Frequencies	100 kHz (132 kHz ±1% act) 500 kHz (445 kHz, ±1% act)
Transmission Pulse	Tone burst, operator-selectable from 25 to 400 µsecs; Independent pulse controls for each frequency
Beams	Horizontal: 0.7° @ 100 kHz, 0.21° @ 500 kHz Vertical: 40°
Beam Tilt	5, 10, 15, 20, 25° down, adjustable
Range Scales	15 settings — 25 to 1,000 meters
Maximum Range	600 meters @ 100 kHz 150 meters @ 500 kHz
Depth Rating	1,500 meters standard; other options available
Construction	Stainless steel
Body Length	48 in (122cm)
Body Diameter	3.5 in (8.9cm)
Weight	63.9 lbs (29 kg) in air
Standard Sensors	Roll, pitch, heading
Options	Magnetometer, pressure, acoustic positioning, sub-bottom profiler

TRANSCEIVER PROCESSOR UNIT (TPU)	
Operating System	VxWorks® with custom application
Basic Hardware	Standard 19-inch rack or table mount, VME bus structure
Outputs	100 Base-Tx, Ethernet LAN
Navigation Input	NMEA 0183
Power	120 watts @ 120/240 VAC, 50/60 Hz (includes towfish)
Interfacing	Interfaces to all major sonar data processors
Options	Splash-proof packaging option available

TOW CABLE

Klein offers a selection of coaxial, Kevlar® reinforced, lightweight cables, double armored steel cables, and interfaces to fiber optic cables. All cables come fully terminated at the towfish end.

KLEIN SONAR WORKSTATION	
Operating System	Windows
Sonar Software	SonarPro®
Data Format	SDF or XTF or both, selectable
Data Storage	Internal hard drive, CD/DVD-RW
Hardware	Industrial PC
Options	Optional waterproof laptops

SONARPRO® SOFTWARE

Custom-developed software by users and for users of Klein side scan sonar systems operating on Windows XP. Field-proven for many years. SonarPro® is a modular package combining ease of use with advanced sonar features.

Basic Modules	Main program, data display, information, target management, navigation, data recording & playing, and sensor display.
Multiple Display Windows	Permits multiple windows to view different features as well as targets in real time or in playback modes. Multi-windows for sonar channels, navigation, sensors, status monitors, targets, etc.
Survey Design	Quick and easy survey set up with ability to change parameters, set tolerances, monitor actual coverage, and store settings.
Target Management	Independent windows permitting mensuration, logging, comparisons, filing, classification, positioning, time & survey target layers, and feature enhancements. Locates target in navigation window.
Sensor Window	Displays all sensors in several formats (includes some alarms) and responder set up to suit many frequencies and ping rates.
Networking	Permits multiple, real-time processing workstations via a LAN including "master and slave" configurations.
"Wizards"	To help operator set up various manual and default parameters.
Data Comparisons Real Time	Target and route comparisons to historical data.

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Email: Klein.mail@L-3com.com
www.L-3Klein.com

Klein Associates, Inc.

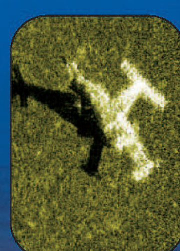
SYSTEM 3900

Dual-Frequency Side Scan Sonar for Search and Recovery

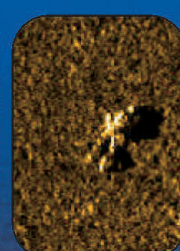
The System 3900 is an extremely high-resolution digital sonar for use in Search and Recovery missions which require a portable side scan system. The model is a selectable dual-frequency system with 445 kHz, which offers excellent range and resolution, and 900 kHz, which offers higher resolution of identified targets. The system is competitively priced and configured to be operated by one man from a small boat in shallow water. The standard system configuration comes complete with a splash-proof Transceiver Processing Unit (TPU), custom-configured laptop and 50m of lightweight tow cable. The Model 3900 Towfish electronics are housed in a stainless steel body with a phosphorescent finish.

KEY FEATURES

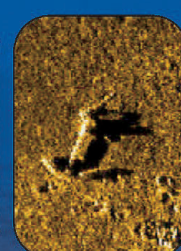
- Very high resolution and long range images
- Lightweight, one-man portable — ideal for small open boat operations
- Special software features for target analysis
- Complete turnkey system ready for field use
- Cost-effective
- Selectable dual-frequency operation (445 kHz and 900 kHz)
- Phosphorescent finish
- Laptop and wireless LAN compatible



Plane



Drowning Victim



Anchor

THE DIFFERENCE IS IN THE IMAGE

L3

C³ISR > GOVERNMENT SERVICES > AM&M > ELECTRONIC SYSTEMS

Klein Associates, Inc.

SYSTEM 3900

Dual-Frequency Side Scan Sonar for Search and Recovery

SonarPro® SOFTWARE

Custom-developed software by users and for users of Klein side-scan sonar systems operating on Windows XP®. Field-proven for many years. SonarPro® is a modular package combining ease of use with advanced sonar features.

- Basic Modules: Main Program, Data Display, Target Management, Navigation, Data Recording & Playback, and Sensor Display
- Multiple Display Windows: Permits multiple windows to view different features as well as targets in real time or in playback modes. Multi-windows for sonar channels, navigation, sensors, status monitors, targets, etc.
- Navigation: Permits underlay of electronic charts
- Survey Design: Quick & easy survey setup with ability to change parameters, set tolerances, monitor actual coverage and store settings
- Target Management: Independent windows permitting mensuration, logging, comparisons, filing, classification, positioning, time & survey target layers, and feature enhancements. Locates target in navigation window.
- Sensor Window: Displays all sensors in several formats (includes some alarms) and responder set up to suit many frequencies and ping rates
- Networking: Permits multiple, real-time processing workstations via a LAN including "master and slave" configurations
- "Wizards": To help operator set up various manual and default parameters
- Data Comparisons Real Time: Target and route comparisons to historical data

SPECIFICATIONS

Towfish	
Frequencies	445 kHz, 900 kHz
Beam width	Horizontal: 0.21° @ 900 kHz, 0.21° @ 445 kHz; Vertical: 40°
Range scales	11 settings: 10 to 200 meters
Maximum range	150 meters @ 445 kHz; 50 meters @ 900 kHz
Depth rating	200 meters standard
Construction	Stainless steel / fluorescent powder coat
Size	122 cm long, 8.9 cm diameter
Weight	29 kg in air
Standard sensors	Roll, pitch, heading
Options	Pressure sensor
Splash-proof Transceiver Processor Unit (TPU)	
Operating system	VxWorks® with custom application
Outputs	100BaseTx, Ethernet LAN, optional wireless LAN
Navigation input	NMEA 0183
Power	120 watts @ 120/240 VAC, 50/60 Hz (includes towfish)
Interfacing	Interfaces to all major sonar data processors
Splash-proof	To IP 65 with waterproof connectors
Klein Sonar Workstation	
Basic operating system	Windows XP®
Sonar software	SonarPro®
Data format	SDF or XTF or both, selectable
Hardware	Laptop
Options	Optional ruggedized laptop
Tow Cables	Lightweight 50m cable; optional armored steel cables

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Klein Associates, Inc.

L-3. Headquartered in New York City, L-3 Communications employs over 66,000 people worldwide and is a prime contractor in aircraft modernization and maintenance, C³ISR (Command, Control, Communications, Intelligence, Surveillance and Reconnaissance) systems and government services. L-3 is also a leading provider of high technology products, subsystems and systems.

EdgeTech

4200 SERIES

SIDE SCAN SONAR SYSTEM

FEATURES

- Optional Multi-Pulse (MP) technology for high speed surveys
- Crisp, high resolution CHIRP images
- Multiple dual simultaneous frequency sets to choose from
- Stainless steel towfish
- Easily integrates to other 3rd party sensors
- Meets IHO & NOAA Survey Specifications

APPLICATIONS

- Cable & Pipeline Surveys
- Geological/Geophysical Surveys
- Mine Countermeasures (MCM)
- Geohazard Surveys
- Channel Clearance
- Search and Recovery
- Archeological Surveys

The 4200 Series is a versatile side scan sonar system that can be configured for almost any survey application from shallow to deep water operations. The 4200 utilizes EdgeTech's Full Spectrum® CHIRP technology to provide crisp, high resolution imagery at ranges up to 50% greater than non-CHIRP systems; thus allowing customers to cover larger areas and save money spent on costly surveys.

One of the unique features of the 4200 is the optional Multi-Pulse (MP) technology, which places two sound pulses in the water rather than one pulse like conventional side scan sonar systems. This allows the 4200 to be towed at speeds of up to 10 knots while still maintaining 100% bottom coverage. In addition, the MP technology will provide twice the resolution when operating at normal tow speeds, thus allowing for better target detection and classification ability. The addition of the optional MP technology provides the operator with two modes of operation; either High Definition Mode (HDM) or High Speed Mode (HSM). This software-selectable mode of operation provides the operator the ability to select the best configuration for the specific job type.

All EdgeTech 4200 systems are comprised of a topside system and a reliable stainless steel towfish. A choice of dual simultaneous frequency sets are available to the user and topside processors come in a choice of configurations from portable to rack mounted units. In addition, an easy-to-use GUI software is supplied with every unit.

For more information please visit EdgeTech.com

info@EdgeTech.com | USA 1.508.291.0057

EdgeTech

4200 SERIES

SIDE SCAN SONAR SYSTEM

KEY SPECIFICATIONS

SONAR SPECIFICATIONS	STANDARD	WITH OPTIONAL MP TECHNOLOGY	
Frequency	Choice of either 100/400, 300/600 or 300/900 kHz dual simultaneous		
Operating Range (meters/side)	100 kHz: 500m, 300 kHz: 230m, 400 kHz: 150m, 600 kHz: 120m, 900 kHz: 75m		
Horizontal Beam Width:	100 kHz: 1.5°, 300 kHz: 0.5°, 400 kHz: 0.4°, 600 kHz: 0.26°, 900 kHz: 0.2°	In High Speed Mode: 100 kHz: 1.26°, 300 kHz: 0.54°, 400 kHz: 0.4°, 600 kHz: 0.34°, 900 kHz: 0.3° In High Definition Mode: 100 kHz: 0.64°, 300 kHz: 0.28°, 400 kHz: 0.3°, 600 kHz: 0.26°, 900 kHz: 0.2°	
Resolution Along Track	100 kHz: 5 m @ 200 m 300 kHz: 1.3 m @ 150 m 400 kHz: 0.6 m @ 100 m 600 kHz: 0.45 m @ 100 m 900 kHz: 18 cm @ 50 m	High Definition Mode: 100 kHz: 2.5m @ 200m 300 kHz: 1.0m @ 200m 400 kHz: 0.5m @ 100m 600 kHz: 0.45m @ 100m 900 kHz: 18 cm @ 50m	High Speed Mode: 100 kHz: 4.4m @ 200m 300 kHz: 1.9m @ 200m 400 kHz: 0.7m @ 100m 600 kHz: 0.6m @ 100m 900 kHz: 26 cm @ 50m
Resolution Across Track	100 kHz: 8 cm, 300 kHz: 3 cm, 400 kHz: 2 cm, 600 kHz: 1.5 cm, 900 kHz: 1 cm		
Vertical Beam Width	50°		
Depression Angle	Tilted down 20°		

TOW FISH	STAINLESS STEEL
Diameter	11.4 cm (4.5 inches)
Length	125.6 cm (49.5 inches)
Weight in Air/Saltwater	48 / 36 kg (106 / 80 pounds)
Depth Rating (Max)	2,000m
Standard Sensors	Heading, pitch & roll
Optional Sensor Port	(1) Serial – RS 232C, 9600 Baud, Bi-directional & 27 VDC
Options	Pressure Sensor, Magnetometer, Integrated USBL Acoustic Tracking System, Built-in Responder Nose, Depressor, Power Loss Pinger and Custom Sensors

TOPSIDE PROCESSOR	4200-P	4200	701-DL INTERFACE
Hardware	Portable splash-proof case	19" rackmount computer	19" rackmount interface
Display & Interface	Splash-proof laptop	21" flat panel monitor, keyboard & trackball	Customer-supplied
Power Input	20-36 VDC or 115/230 VAC	115/230 VAC	115/230 VAC
Operating System	Windows® 7		
File Format	Native JSF or XTF		
Output	Ethernet		

TOW CABLE	
	Coaxial Kevlar or double-armored up to 6,000m, winches available

For more information please visit EdgeTech.com

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