

# **Hydrophone Usage and Deployment Collected Methods and Sources**

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**Cornell Bioacoustics Research Program**

## **Preface**

This document is intended to provide a working summary of techniques and methodologies in the use of hydrophones for marine biology research. The document came about as a means of summarizing our own methods in response to the numerous inquiries we receive. We cannot claim that this document espouses the best methods, nor an exhaustive list of all sources. Instead, it is an open document with contributions coming from readers/researchers based on their experience. To that end, we welcome any comments or additions you may be able to provide. Please address them to:

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# Hydrophone Usage and Deployment

## 1. Overview

Research into acoustic emissions of underwater animals is often underfunded, but still requires the best tools and methods. Within this document, collected methods of employing underwater acoustic equipment are addressed in the hopes of providing you with at least one idea to make your work more enjoyable and accurate.

Due to the nature of this collection of ideas and pointers, some of the information may seem obvious or irrelevant to your work. We can only hope that somewhere within this document, a tidbit of new knowledge may lie.

## 2. Hydro-Acoustics

The basic concepts of sound transmission are relatively simple. However, due to the wide variability of the physical properties of sea water, sound transmission in the ocean is quite complex. Temperature, pressure and salinity gradients are the main impediments to a homogeneous view of sound transmission. At such boundaries, even though the speed of sound changes only a relatively small amount, the refraction of the sound transmission path can be quite great. In fact, when such boundaries exist, it is possible for a hydrophone positioned quite close to the sound source to not receive the signal at all. In such cases, the hydrophone is said to lie in a 'shadow zone'.

Fish or other marine organisms are also known to affect sound transmission greatly. One of the more common phenomenon is the so-called 'deep scattering layer' which is composed of a high concentration of plankton and other marine organisms. This layer can serve as a reflector of specific frequencies of sound, a technique the commercial fishing industry readily employs to locate schools of fish.

As sound radiates outward from its source, its intensity decays in proportion to the square of the distance from that source. In addition, some of the radiated acoustic energy is also absorbed by the medium and converted to heat. This absorption of sound in the ocean varies with frequency and is caused by a transition between relaxed and compressed states of the water molecules within the acoustic pressure wave. As the formula is somewhat complex, suffice it to say that there are published tables showing the loss based on frequency (and/or salinity and temperature).

- ☞ The attenuation of sound in water increases with frequency. This means that when working with higher frequency emissions (e.g., dolphin echolocation clicks), you may not be able to record all desired information without being fairly

close to the subject. A good rule of thumb is that you should plan close-in recording for frequencies over 20-25KHz.

In the appendices are several useful formulas (page 17) as well as references for further reading on this subject (page 24).

### 3. Hydrophones

Hydrophones are pressure-sensitive devices, designed to detect the alternating variations of pressure as produced by an underwater sound source and to reproduce these pressure variations as electrical signals. Typically hydrophones are made of piezoelectric materials, although some hydrophones use a magnetic construct called magnetostrictive. Piezoelectric materials have the unique ability of generating an electrical potential when subjected to a mechanical force, and of distorting mechanically when subjected to an electrical stimulus. From this basis, many hydrophones can also be used as underwater projectors (or sound emitters).

To employ hydrophones for research, the basic characteristics of the device and how the element will operate under operating conditions must be known. The characteristics of interest include linear frequency range (usually expressed in +/-dB), sensitivity (typically in dB re 1V/uPa or uV/Pa), directivity, the change of sensitivity over temperature and pressure and finally, maximum operating pressure. For most biological research work, it is the frequency range and sensitivity that is most important<sup>1</sup>.

- ☞ Extreme depths (as little as 1000 meters for some hydrophones) can cause a permanent loss of sensitivity. With certain hydrophone constructions (e.g., oil-filled towed arrays), depths greater than 100 meters may also cause physical damage.
- ☞ Subjecting hydrophones to impacts or shock may permanently damage them. Always wrap your hydrophones in cushioning material when transporting them.

#### 3.1. Hydrophone Calibration

With any work involving marine acoustics, it is important to know the response of your equipment *before* going into the field. There are many methods for calibrating

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<sup>1</sup>Directivity is not much of a concern at frequencies less than ~5KHz for hydrophones due to the length of the pressure wave and the geometry of most hydrophones.

hydrophones, some quite complex. The purpose of this section is to discuss a low-cost and reasonably accurate method of calibrating your hydrophones. For the methods used (and for practical matters), it is assumed that the hydrophone being calibrated has an integral preamp, while the reference does not. Due to the complexities involved, calibration of hydrophone arrays is not covered.

For economic reasons, the 'comparison calibration in a small tank' method is typically used. This involves having a projector (underwater loud speaker) at some distance from both a calibrated hydrophone (herein referred to as the 'reference') and the hydrophone being calibrated (herein referred to as the HBC), while using a low projected level to minimize interfering reflections from the sides of the tank<sup>2</sup>. This method eliminates the need to have a calibrated projector.

The *proximity criterion* is used to evaluate the calibration tank for near-field<sup>3</sup> effects and reflections as result from the projector and tank dynamics. As such effects can invalidate a calibration effort, it is important that they be minimized, if not eliminated. The method involves driving the projector at a constant level and placing the hydrophone at two or more distances (e.g. desired min and max and some mid-point) from the projector. The output level is monitored from the hydrophone. If the level shows a voltage inversely proportional to the distance from the projector, then the tank configuration is satisfactory. If it does not, one solution is to drive the projector at a lower level.

### 3.1.1. Calibration Aspects

In all cases of calibration, the reference and the HBC are placed side-by-side at the same distance from the projector. The formulae presented herein have been simplified for ease of use.

#### *Hydrophone Linearity (Frequency);*

Defined as the measure of the ratio of free-field pressure input (to the hydrophone by the projector) to the open circuit voltage output (produced by the hydrophone). In simpler terms, and in respect to our comparative calibration method, this is simply how linear a response your HBC has in respect to the reference hydrophone across the frequency band.

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<sup>2</sup>The tank used must also be smaller (at the largest dimension) than the smallest wavelength you will be employing. In some configurations, acoustical damping is also used to reduce reflections but typically effective damping is beyond the reach of small tanks due to the material and physical size of its construction.

<sup>3</sup>Near-field is a condition where a projector's effect is primarily through particle motion (as opposed to far-field where the sound conducted is by pressure waves.

The procedure involves measuring the output<sup>4</sup> of both the reference ( $e_1$ ) and the HBC ( $e_2$ ) across the frequency band. To negate the projector's non-linear response, a multiplying factor is derived for each frequency point measured (the HBC's output divided by the reference's). An average of the response across the frequencies measured is calculated -- and here a calculated gain can be derived -- as well as a minimum and maximum. At each frequency point, the reference's output is multiplied by this average and noted. The difference in decibels (re. 1uPa) between this derived value for the reference and your HBC is then calculated by the formula for the particular frequency:

$$variance(dB) = 20 \log \left[ \frac{e_2}{e_1} \right]$$

This is then plotted as the frequency linearity response curve for your HBC.

#### *Hydrophone Sensitivity;*

Used to determine sensitivity relative to a known output level (i.e., the reference hydrophone). Essentially it involves the measurement of the open circuit voltage of the HBC and the reference at a specific frequency and distance from a projector using a high-impedance device such as an oscilloscope, then applying the formula below. The formula result ( $M_x$ ) and  $M_s$  are in decibels re 1V/uPa.

$$M_x = M_s + 20 \log \left( \frac{e_x}{e_s} \right)$$

- where:

$M_s$  is the free-field voltage sensitivity of the standard

$M_x$  is the " " " " " " HBC

$e_s$  is the open-circuit voltage of the standard

$e_x$  is the " " " " " HBC

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<sup>4</sup>The output being measured is referred to as the 'open circuit voltage'. A high-impedance measurement device must be used to measure this voltage -- the most common being an oscilloscope with a 10M Ohm probe. The drawback being that most scopes are not calibrated therefore giving you only a reasonably close approximation of the output voltage.

### 3.1.2. A Simple Calibration Setup

This information is provided for those who do a lot of work with hydrophones, or wish to build their own, but do not want the cost of using (or purchasing) a calibration lab. The main (creative) goal here is in keeping costs to a minimum.

A University Sound UW-30 speaker serves as a medium-range projector (100Hz-15KHz), while an in-house-designed high-frequency projector extends the range into the ultrasonic region as needed. A Bruel & Kjaer 8103 calibrated hydrophone serves as the calibrated reference. A Crown SA 30-30 amplifier drives the projectors being used, with a Krohn-hite 1000A function generator providing the calibration waveforms. Alternatively, a TEAC DA-P20 DAT recorder/player is used for complex (real-life) waveforms, connected to the Crown amplifier.

For the tank, a large rubber tub is used, measuring approximately 16"w x 20"l x 16"d. Serrated 2" thick packing foam is glued to the sides of the tub to reduce reflections. Surrounding the tank, a 1/2" mesh wire cage is wrapped to keep stray electromagnetic interference from interacting with our measurements. Wooden dowels inserted through this cage over the bath are used to suspend the hydrophone and projector cables. The test equipment consists of an inexpensive 2-channel oscilloscope that is capable of at least 1mV/division. A spreadsheet program is used to calculate and plot the results.

The ultimate enhancement to this setup might be as follows. A PC waveform generator card is used to drive the amplifier/projector. A PC data acquisition card (2-channel) is used to monitor the reference and your HBC. The PC software (e.g. National Instruments LabView) is designed to drive the waveform generator at each frequency, with the acquisition card collecting the results. The software then calculates and plots the results.

## 4. Configuration & Deployment

In general, hydrophone elements are nearly neutral-buoyant. As a result, some form of ballast must be added to the hydrophone cable to ensure it drops to the desired depth. In addition, all hydrophone cables will pass vibrations to the hydrophone elements which will be picked up as noise. Therefore, some form of cable isolation technique is needed.

- ☞ Hydrophones are like microphones -- they will pick up everything in the environment, including equipment on your boat as well as the cable being handled. Cables are not 'microphonic' -- it is the hydrophone's sensitivity that forces us to take measures to isolate its cable from the boat or your handling it!

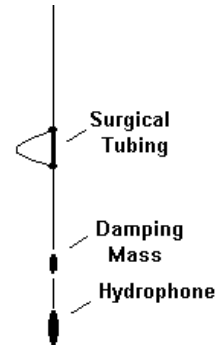


To address both of these issues at once, a combination of mass loading and vibration damping is employed as is discussed in the following subsections.

#### 4.1. Vibration damping

In any hydrophone (or microphone) application where the deployment platform is moving you will pick up cable noise -- unless special precautions are taken. The industry's term is 'acceleration noise' and the phenomenon is similar to that of dangling a microphone by its cable. This effect can be minimized by a variety of methods.

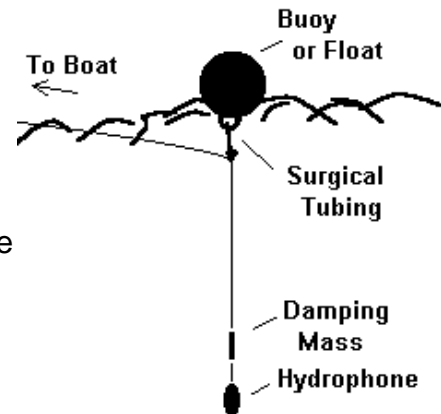
The best and least expensive method is to employ surgical tubing<sup>5</sup> near the hydrophone to dampen any cable noise. The addition of mass damping (such as a small lead weight) completes the modification. The weight of this damping mass should only be enough to keep the tubing taut and take the element to the desired depth. **Figure 1** illustrates this technique.



**Figure 1.** Vertical Cable Damping.

The elastic damping does not necessarily need to be within the cable itself. Often a small buoy or float is used as illustrated in **Figure 2**. Again, the mass is required near the end of the hydrophone itself.

- ☞ The damping mass's weight should only be as much as will bring the hydrophone element to the desired depth. If a heavier anchor is needed (i.e. to prevent drift in a stationary deployment), ensure that the cable can support the load under whatever sea states might be expected.
- ☞ When deploying a buoyed array from a boat, always deploy to windward so the boat is carried away from the buoy.
- ☞ Note: attaching the weight to the hydrophone itself may create noise by the physical distortion induced.



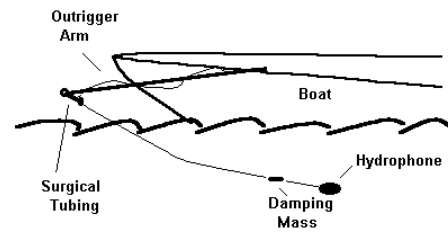
**Figure 2.** Buoy-damped System.

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<sup>5</sup>Available at your local medical supply or by mail order through McMaster-Carr or a similar industrial supply house.

## 4.2. Towed Element Considerations

With shallow deployment from the bow of a moving boat, another potential problem results -- that of the boat's bow wave movement. This will cause the hydrophone to bounce through the water and possibly against the boat. A commonly-used solution is to employ an outrigger to hold the hydrophone well away from the boat and its wake. Again, a shock cord and damping mass arrangement is critical as illustrated in **Figure 3**. The same basic principles would apply for other towed arrangements as well.



**Figure 3.** Damping a Towed System.

## 4.3. Binaural Configurations

Occasionally there is the need to use 2 hydrophones in a stereo-listening or binaural configuration. When doing so, the most important consideration is that the distance between the two hydrophones should be approximately five times the distance between your ears<sup>6</sup>. This typically translates to a hydrophone separation of roughly 25".

There is a second consideration to be made in binaural deployment -- that of knowing the hydrophone orientation once deployed. In a towed arrangement this can be resolved by placing the hydrophone elements at the tips of a towed underwater wing. Since the wing 'flies' in the water towards the towing vessel, the left-right orientation of the hydrophones is always known (provided the wing stays horizontal). If the binaural listening device is deployed statically, the problem is slightly more complicated and (typically) requires a bar supported by two individual control lines widely separated to prevent the assembly from rotating in the water column. Alternatively, a pair of hydrophones can be mounted on a towed cable approximately 25" apart.

- ☞ Always be sure to test your equipment completely *before* going into the field. The costs saved with a successful deployment will more than justify the time expended.

## 5. Interface Equipment

Hydrophones can be deployed either directly or remotely. Direct deployment implies that the observer deploys the hydrophone directly and the hydrophone is physically wired to the applicable monitoring and/or recording equipment. In a remote deployment, hydrophones are connected to a power source and a transmitter. The

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<sup>6</sup>As the speed of sound in sea water is roughly 5 times that of its speed in air.

acoustic signal is sent, via transmitter, to a receiver which is then connected to the monitoring and/or recording equipment. This approach is most often used with large arrays or installations on buoys.

In either configuration, there may also be the need for an additional preamplifier beyond that which may be built into the hydrophone itself. This is discussed further in the next subsection.

### 5.1. Preamplifiers

Most single-polarity pre-amplified hydrophones (i.e., running from a single battery) exhibit a DC response upon which the acoustic signal rides. In addition, the output impedance of such hydrophones varies widely by manufacturer. Some recorders may not be able to handle the impedance or the DC offset<sup>7</sup> of your hydrophone directly so an additional preamp is required for such recording devices. In cases where a preamp is required, one will note the recorder's level meters appear to have a constant signal even when none is present to the hydrophones. Preamplifiers may also be necessary where the hydrophone has been deployed quite deeply and the signal has degenerated over the long length of cable required. In such cases, our group employs a Shure FP-11 preamplifier.

- ☞ An inexpensive preamplifier can be had by using a Radio Shack pocket amplifier (9V battery power), p/n 277-1008. Use this type of amplifier with headphones when you are simply listening to the sounds and don't expect frequencies below 100Hz or above 10KHz. When employing this amplifier, use the lowest volume setting you can set it for and still hear as a pre-amplified hydrophone will easily overdrive it.
- ☞ On occasion, a simple load resistor may be all that is needed to stabilize the hydrophone signal sufficiently for your recorder. Use a 100 Ohm resistor between the signal output and the ground. The effect of this addition is to stabilize the DC level change caused by wave-induced pressure changes.

### 5.2. Remote Monitoring (Transmitting Data)

Remote monitoring of hydrophones requires some (potentially) unfamiliar pieces of equipment. These include alternative energy sources (e.g., solar), low-power

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<sup>7</sup> If the recorder has the capability to record frequencies to DC, a preamplifier is required to ensure that the DC offset of the single supply hydrophone preamp is not recorded.

transmitters, antennae, and receivers. The level of complexity is relatively small and the potential of remote recording should not be ignored.

The main consideration in remote monitoring is that the transmitter/receiver have a wide enough bandwidth to support the frequency range you will be broadcasting *and* that the broadcast band is not one that is controlled or allocated to some other group. The reason for the latter concern is two-fold; 1) you don't want to get in trouble with the FCC, 2) you don't want to have their transmissions picked up as data by your receiver, and 3) you don't want your transmission to interfere with their radio use.

The best approach is to employ the U.S. Navy's sonobuoy broadcast band. This is a group of 32 channels stretching from ~166Mhz to ~173Mhz allocated specifically to monitoring hydrophone listening devices at sea. Each channel is capable of carrying a full spectrum audio signal (<10Hz to >20KHz). Incidentally, sonobuoys themselves, complete with a transmitter, antenna, battery and hydrophone (ready for deployment) are available from several manufacturers -- often for less than the cost of a hydrophone by itself. Some minor modifications may be required for your application but it is a viable option. See the appendix listing equipment sources for sonobuoy listings (page 20) -- receiver and antennae sources are also listed in the same appendix.

- ☞ When purchasing a transmit antenna, be aware that the higher the antenna's gain, the more likely you will encounter signal fade on rolling sea. This is because a higher gain means a more narrowly-focussed (oblong) beam.
- ☞ Should you be planning reception over extended distances, you may want to consider purchasing an antenna signal booster for your receive antenna. Mini-Circuits has one (p/n 15542), but your local Radio Shack may carry one as well.

The most difficult part of remote monitoring is the authorization and fabrication of the deployment platform (typically a buoy). Because sea conditions vary so widely from location to location, this document will not attempt to cover this topic. Instead it is advised that a professional buoy builder be contacted who has had experience in this area. Be forewarned that the hydrophone cable and anchoring system, as well as the buoy must be designed to withstand the *worst* sea state envisioned for the area of deployment. Of course if your needs are for short-term use (i.e. < 8 hours), you may want to consider simply dropping a complete navy sonobuoy in the water and save yourself the trouble and expense!

- ☞ Before you go out in the field, the audio signal gain of every component in your system should be known, from the hydrophone to the recorder (including the transmitter, receiver, preamplifiers, etc.). This information is very important in proper post-analysis of your data.

## 6. Data Collection and Analysis

### 6.1. Recording

There are several types of recorders that can be used to record the audio data your hydrophones will pick up. Again, the main concern is the bandwidth and frequency range of the recorder. With the advent of DAT (Digital Audio Tape), such recorders have become quite compact -- in fact Sony even produces a DAT WalkMan with a respectable frequency range and a 4 hour record time. Other formats include video tape -- typically used when your range of frequencies extend beyond the conventional audio band of 20Hz to 20KHz. With modern analysis tools, one should always use digital recording equipment to gain the full benefit of analysis.

Read the specifications for the recorder of interest before agreeing to take it into the field. You may want to ask others of their opinion and choice based on their experience.

- ☞ When using a pre-amplified hydrophone directly into a recording device such as a DAT, use the unbalanced setting and line input, with a low gain recording level (e.g. 3). The unbalanced configuration typically also means that you will require a special wiring configuration for the connector. Typically, with an XLR connector, this means that the hydrophone's signal comes in on pin 3, while pins 1 & 2 are jumpered and connect to the hydrophone's ground.
- ☞ When recording with a single hydrophone, consider recording on both channels but at different gains. This will effectively increase the dynamic range of the final data.

### 6.2. Signal Level Analysis

Once the data has been recorded, one often needs to examine animal sounds to determine how far the subject was from the hydrophone. When using a single hydrophone, one can generally only estimate this information. When an array of hydrophones is used, the process is more exact and can be handled in software (see the next section).

To determine distance with a single hydrophone, three pieces of information are needed: 1) The 'sensitivity' of your hydrophone (including the integral preamp) in  $\mu\text{V}/\text{Pa}$ , 2) The gain provided by any additional preamplifiers and the recorder, and 3) the vocalization level of the subject (again, in dB). The gain from item 2 is used to multiply the  $\mu\text{V}$  factor in item number 1. Since 1Pa equals 120dB, the factor derived (item #1 times item #2, in  $\mu\text{V}/\text{Pa}$ ) represents the signal level (peak-to-peak) one can

expect for a 120dB acoustic output. To extrapolate to other levels (in dB), use the formula:

$$120+20\log\left[\frac{e_1}{e_0}\right]$$

-- where  $e_0$  is your base factor (re 120dB) and  $e_1$  is the recorded level in question. The result is in dB.

This formula also shows us the relationships: 20dB is a gain of 10 and 6dB is a gain of 2.

Once you know the recorded level (in dB), you can then extrapolate the distance. Since the loss over distance is subject to the frequency of the subject's recorded call and to the temperature of the seawater, it therefore best to employ a standard 'sound absorption' table (see references, page 24) for this final step.

### 6.3. Monitoring and Analysis Software

With more powerful computers sitting in our labs, the ability to inexpensively analyze recordings with software has become a reality. Although inexpensive Digital Signal Processing (DSP) libraries are available, it is often more convenient to purchase software written and maintained by someone else. A couple of the more popular are briefly discussed below.

- |               |  |
|---------------|--|
| <b>QuikVu</b> | Distributed by TEAC for their DAT recorders, this product can be used to perform signal-level analysis of the recordings on a IBM-PC style computer. Contact your local TEAC product distributor for more information.   |
| <b>Canary</b> | One of the most powerful products available is a package called Canary produced by the Cornell University Bioacoustics Research Program. Canary runs on the <i>Apple Macintosh</i> and allows full frequency analysis and the ability to 'browse' a tape in real-time. Potential future enhancements include automatic locations of the sound source (when 3 or more hydrophones were used) and direct DAT interfaces. Call or write the lab for additional information. |
| <b>WAVES</b>  | Available for workstations (e.g. SUN, etc.) -- a powerful analysis package but expensive and requires a good knowledge of the math behind the analysis.  |

**SpectraPlus** SpectraPlus is put out by Sound Technologies, Inc. and is available through many software distributors. It runs on a *PC under Windows* and employs standard Windows sound cards. It is a very powerful package, offering several different ways of viewing your signals, including an interesting 3-D spectrogram. One caution -- a good quality sound card is necessary as most of the less expensive ones have sharp rolloffs below 300 Hz. We recommend you use a Turtle Beach sound card.

## 7. Noise

### 7.1. Noise Sources

In recording underwater, there are a multitude of noise sources to consider -- some you can do something about, others you will have to live with. For discussion purposes, a partial list of potential noise sources follows.

#### 7.1.1. Natural Noise Sources

Natural noise sources are virtually impossible to deal with but the possibility of their presence must be considered before tearing your equipment apart looking for electrical noise sources. The following is a partial list of the more common, but less obvious ones you might expect to come across. Typically these are continuous (non-periodic) noise sources.

- ! **Snapping shrimp** Hissing & crackling, typically 2KHz and above. Other types of marine organisms also produce noise (fish, etc.) and a good knowledge of your research area's biology is always helpful.
- ! **Surface waves** Rumbling, typically 500Hz and above, but storms may show up as low as 50Hz.
- ! **Shipping traffic** Constant background, typically around 100Hz, but ranging from 4Hz to 400Hz..
- ! **Rain** Constant white noise, 10KHz and above.
- ! **Turbulence & currents** Rumbling or constant background, 1-10Hz.
- ! **Ice, land and air-borne noise** Frequency is based on the source (e.g. snowmobiles, wind, aircraft, etc.)

- ! **Cable & element flow noise -- Towed applications** This varies in frequency based on the shape of the system and the speed of tow. Check for noise in an un-towed state (at the same site). You may want to consider having your cable 'faired' (a fiber airfoil is woven on) to reduce this noise.
- ! **Cable strumming** Similar to that caused by turbulence and currents and is often around 10Hz. However, for this you can calculate the frequency based on your cable as follows:

$$f_{Hz} = \frac{(0.18)(current)}{(diameter)}$$

-- where current is in cm/second (1 knot = 51.5cm/s)  
and diameter is the cable's diameter in cm.

- ! **Physical distortion / Bottom Noise** When using a hydrophone with a damping weight attached to the hydrophone, the physical distortion may cause popping or clipping. The same also occurs if you have an anchor weight that may be shifting along the bottom.

#### 7.1.2. Electrical Noise

- ! **Low voltage to preamplifiers** [clipped levels giving popping and distortion] Check battery voltage and recharge/replace as necessary.
- ! **Hydrophone cable construction** [static-like] Poor construction may result in loose internal layers that cause rustling during movement (check by wiggling cable on land). Improper mass loading of the cable (too little or too much weight) can also cause problems. Inversely, cable mass loading may partially correct the problem of poor cable construction by keeping the cable movement to a minimum.
- ! **Bad electrical connections** [clicking, popping, or static] Check by using headphones and wiggling the cable at each connection point.
- ! **Transmitter or Receiver interference** [static] When using transmitters and receivers to bring signals in from distant hydrophones, try a different channel if available. Otherwise, as time and cost permits, go out to the hydrophone itself -- bypassing the transmitter/receiver combination -- and listen to the hydrophones directly.



- ! **Breaks or exposed shielding in the hydrophone cable** [clicking, popping, static, or faint signals] Always inspect your cable before deploying. Saltwater will quickly damage exposed conductors reducing conductivity, changing line capacitance or shorting them out all together.
- ! **Poor Hydrophone element casting** [low or no line levels, high frequency attenuation] If there are bubbles in the element's casting or the casting pulls away from the cable, it is possible that a seawater may be getting in. Even in minute amounts, this will alter the characteristics of the hydrophone and potentially introduce noise.
- ! **Preamplifier required** [constant level on record meters without input to hydrophones, or a constant noise on tape] Use a preamplifier (see page 8).
- ! **Grounding** See the following section on distributed noise.
- ! **Equipment Noise** See the following section on distributed noise.

## 7.2. Eliminating Distributed Electrical Noise

One of the common errors incurred with the use of hydrophones is to use a power source that is powering other (noisy) equipment. For example, the inverter on some boats may produce noise because of the modified AC waveform it produces. If a battery is being used to power the hydrophone/preamp combination, one of the worst mistakes (and easiest to rectify) is the powering of recording devices or other equipment off of the same battery. This should never be done as the motor noise from a recorder will be passed through the battery into the hydrophone and back to you (the battery acts like a capacitor, passing noise back through the circuit). If you must use the same battery, employ an automotive RF interference filter in line to your hydrophone's power (e.g. Radio Shack's #270-051).

- ☞ A good rule of thumb is to always use a separate battery just for your hydrophones.

With pre-amplified, battery-operated hydrophones, occasionally electrical noise will also be introduced due to a difference in potential between seawater ground and the hydrophone preamp's ground (this type of noise sounds like a hum). One solution to this dilemma may be to run a wire from your battery's *negative* terminal into the seawater.

## 8. Maintenance & Repair

### 8.1. Preventive Maintenance

It goes without saying that the better your equipment is maintained, the longer it will last. Unfortunately, many of us forget the most basic tips that can dramatically prolong the usefulness of our equipment.

Of these, the most important is to always rinse your equipment in fresh water at the end of the day and before packing it away at the end of a research expedition. While you are rinsing the cables and so forth, take a minute to also inspect for nicks in the cable and frayed connections at the terminations. A small nick in your cable will quickly render the cable (and hydrophone) useless through the corroding effect of saltwater on the conductors.

- ☞ Always rinse your equipment with fresh water and inspect for wear at the end of each usage.

Also, when packing cables and other equipment up for shipment, make sure the cables are not kinked and ensure any ballast has been removed. This will prevent any unnecessary stress as well as to reduce permanent kinking of the cable -- especially when the contents reach the high temperatures sometimes experienced in transit.

- ☞ Wiping Armor-All or a similar product into the cable is a good way to preserve the cable's flexibility.

Lastly, when the equipment arrives back home, remember to unpack everything and look over it again. Lay the cable coils out in a relaxed position for long-term storage and try to keep the equipment in a storage area where the temperatures don't fluctuate greatly.

### 8.2. Repairing Cables

When nicks or breaks are discovered in your working cables, they should be repaired immediately.

If you are in the field and don't have cable-working facilities, use some good quality silicon and squeeze it into the exposed cable area and then wrap tightly with electrical or insulating tape (duct tape will suffice in a bind). Let it dry overnight if possible. For more severe cable ruptures, 3-M's ScotchKote and Scotch tape #23 provides a more permanent bond and should be considered a part of your field repair kit.

When a workbench and tools are available, a full cable repair is a much better long-term solution. One of the easiest methods is to use the 3-M company's pre-measured repair products for cable repair. The 3-M 82-A1 or F1 splice kits containing 2130 ScotchCast are fantastic for quick and permanent repairs. Ask them for a catalog of their electrical products -- it can sometimes mean the difference between being able to continue your research or having to cut it short due to failed equipment.

## Appendix A. Useful Data and Formulae

Decibel relationships:

6dB represents a doubling of acoustic sound pressure, while  
20dB represents a factor of 10 increase.

Hydrophone sensitivity:

Sensitivity of a hydrophone is a figure related to 120dB (1 Pascal). IT can be expressed in terms of decibels (dB re 1V/uPa) or in voltage (uV/Pa). To convert between the two, use the following.

-- If you know the sensitivity in dB, the sensitivity in uV/Pa is found by:

$$\frac{1}{10^{(-(sensitivity)+120)/20}} * 10^6$$

-- If you know the sensitivity in terms of uV/Pa, sensitivity in dB is found by:

$$-120 - (20 \log \frac{1}{Sensitivity})$$

When trying to see the voltage level for a particular received level, start with the voltage sensitivity (in uV). For example, a hydrophone with a sensitivity of -181dB (re 1V/uPa) has a voltage sensitivity of 891uV RMS. This sensitivity figure is the voltage one can expect for a signal of 120dB. Using the relationship that every 6dB represents a doubling and every 20dB represents a factor of 10 increase, the voltage output for 140dB would then be 8.91mV RMS, and so on.

When calculating the power of a signal received as seen on an oscilloscope, the peak-to-peak (pk-pk) voltage must first be converted to a root-mean-square (RMS) value. To convert a pk-pk voltage to RMS:

$$0.707 * (V_{pk-pk} / 2)$$

Relating Sound in Air to Water:

In air, the usual pressure reference is to 20uPa while in-water references are to made to 1uPa -- this converts to a 26dB difference.

With mechanical listening devices (e.g. microphones, hydrophones, or an ear), energy flux must also be considered. Due to the differing acoustic impedance and speed of sound (air vs. sea water), an additional factor of 35.5dB must be added.

The resulting conversion factor is 61.5dB. In other words, hearing a 120dB

sound source in free air is equivalent to a hearing 181.5dB sound source in water.

Sound Pressure Level (SPL) at some distance:

For an ideal spherical projection of sound, if you want to know the loss over distance where  $d_1$  is the ref. point (e.g. 1 meter) and  $d_2$  is the distance from it, use the formula:

$$TransmissionLoss = 20LOG\left[\frac{d_2}{d_1}\right]$$

For a sound channel or bounded (cylindrical) projection, use:

$$TransmissionLoss = 10LOG\left[\frac{d_2}{d_1}\right]$$

Acoustic Intensity at some distance:

The acoustic intensity  $I_0$  at a distance of 1 meter from an omnidirectional (spherical) source radiating a power of  $W$  acoustic watts is given by the formula:

$$I_0 = \frac{W}{4\pi}$$

Attenuation by frequency and temperature (add to any calculated distance loss):

1KHz	loses about 0.01dB per kilometer at 15°C
10KHz	" " 0.6dB " " "
25KHz	" " 4dB " " "

-- See references for published tables of more extensive relationships.

Speed of sound in seawater (15°C) is ~1500m/sec<sup>8</sup>. For varying temperature, salinity and pressure, use the following formula:

$$c = 1449.2 + 4.6t - 5.5 \times 10^{-2}t^2 + 2.9 \times 10^{-4}t^3 + (1.34 \times 10^{-2}t)(s - 35) + 1.6 \times 10^{-2}d$$

where  $c$  = speed of sound,  $t$  = temperature in degrees C,  
 $d$  = depth in meters, and  $s$  = salinity in ppt.

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<sup>8</sup>The speed in air is roughly 343m/sec.

Pressure at depth:

14.7psi per every 10 meters depth descended (1 atmosphere)  
-to convert psi to Pa, multiply psi by  $6.875 \times 10^3$ .

Hydrostatics:

$1 \text{ ft}^3 = 28.316 \text{ litres (7.49 gallons)}$

Weight of 1 gallon:

salt water =  $64 \text{ lb/ft}^3$ , 8.54 lbs/gal ( $, 10053 \text{ N/m}^3$ )

fresh water =  $62.43 \text{ lb/ft}^3$ , 8.33 lbs/gal ( $, 9802 \text{ N/m}^3$ )

lead =  $707.9 \text{ lb/ft}^3$ , 94.5 lbs/gal

$W = Vw$

where  $W$  = weight of floating body, lb (N)

$V$  = volume of displaced liquid,  $\text{ft}^3$  ( $\text{m}^3$ )

$w$  = specific weight of liquid medium,  $\text{lb/ft}^3$  ( $\text{N/m}^3$ )

Newtons, Pascals, and Microbars to decibels (relation to 1uPa):

$120 \text{ dB} = 1 \text{ N/m}^2$

$100 \text{ dB} = 1 \text{ ubar}$

$26 \text{ dB} = 20 \text{ uN/m}^2 = 20 \text{ uPa}$

$0 \text{ dB} = 1 \text{ uN/m}^2$

$1 \text{ Pa} = 1 \text{ N/m}^2 = 10 \text{ ubar} = 120 \text{ dB}$

Visual Observations

Horizon = 13 miles per 6' above surface

## Appendix B. Equipment Types & Sources

This listing is not intended to be a representation of all equipment or manufacturers available for use, nor an advertisement for those listed. It is only a list of items or sources that we have personally worked with and relate to the information presented in this document.

One of the best listings for a diverse array of manufacturers can be found in the "Sea Technology Buyers Guide / Directory" It is published by Compass Publications in Virginia (phone 703-524-3136) and the price is approximately \$25. If you intend to do much marine work, it is an invaluable resource. They also publish a monthly magazine.

### Data Collection

Transmitters; 162-173MHz Naval sonobuoy band	
Spartan Electronics, DeLeon Springs FL (Jerry Martin)	904-985-4631
electronic assembly -- you add connectors and package and a DC-blocking capacitor at the hydrophone connection point (unless you use their hydrophone), ~\$200 (min order req'd)	
Receivers; 162-173MHz	
L-tronics, Santa Barbara CA (Bruce Gordon)	805-967-4859
2-channel sonobuoy receiver, ~\$500	
IComm	
tunable, single-channel receivers IC-R100, 7100	206-454-8155
Antennae	
Cushcraft	800-258-3860
Models P170,174 or PLC-1669 for 162-173MHz (high-gain Yagi-style directional, used for <b>receive</b> ).	
Boat U.S.	800-365-9283
Shakespeare Professionals (8' fiberglass) or Metz 34" steel; used for <b>transmit</b> .	

### Data Processing Equipment

Hydrophone Preamps	
Shure (FP-11)	Local Audio Dealer

Data Recorders	
Purchase; Sony, Teac	Local Audio Dealer
Lease source: AT&T Instrument Services	800-874-7123
DAT: Teac RD-130T (8ch), etc. [10Hz-20KHz]	
BETA/VHS: Kyowa 650A [DC-40KHz]	
Filters	
Frequency Devices	508-374-0761
Single channel low pass (#900) ~\$900	
Dual channel programmable, low or high-pass (#9002) ~\$2900	
Turtle Beach Sound Cards	
Tracer	717-843-5833
General	
Mineroff Electronics (ask for Natural Sounds Recording catalog	516-775-1370
 <u>Hydrophones</u>	
Hydrophones; Off-the Shelf	
Innovative Transducers Inc, Haltom City TX (Eric Boyer)	817-656-9396
elements (~\$500), arrays, including towed	
Spartan Electronics, DeLeon Springs FL (Jerry Martin)	904-985-4631
Sonobuoys, w/calibrated 10-20KHz hydrophones and a transmitter	
built in, ~\$350 for #57A sonobuoy. (min. order req'd)	
Benthos	800-446-1227
 <u>Hydrophone, Calibration</u>	
Hydrophones, Calibrated	
Bruel & Kjaer type 8103	508-481-7737
 Waveform generation and acquisition system (PC)	
RC Electronics	805-685-7770
 Underwater speakers	
University Sound (e.g. UW-30)	
-- carried by Newark Electronics	800-462-3153



## Hydrophone Components

### Hydrophones; Components & Fabrication

Benthos 800-446-1227  
Hermes 902-466-7491

### Cable; Custom Design & Fabrication

Cortland Cable Company, Cortland NY (Doug Bentley) 607-753-8276  
-- they also do cable 'fairing' and fiber-optic.

### Cable; Standard

Newark Electronics supplies Belden cable. 800-462-3153  
-- We use Belden Brilliance Microphone cable, type 8406 for single hydrophone cables (call for local rep).

### Potting epoxy

Conap; type EN-7 is acoustically transparent (min. order = \$200) 716-372-9650

## Repair Components

### Cable repair

3-M Electro-Products Division (call for local rep) 800-245-3573  
-- We use the 82-XX ScotchCast cable splice kits w/2130 compound

## **Appendix C. Other Technical Notes Available**

The following Technical Articles may be requested from Cornell Bioacoustics. Availability may be limited to researchers in the field. A small fee may be requested to cover printing and postage costs.

- 1) Casting hydrophones
- 2) A 'pocket hydrophone' design
- 3) A Low-cost HF Projector Design
- 4) A PVC sparbuoy-style reusable sonobuoy design

## **Appendix D. References**

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Washington DC 1970.

Tucker, D. G. Applied Underwater Acoustics Pergamon Press, Oxford 1966.

Urick, Robert J. Principles of Underwater Sound McGraw-Hill, NY, 3rd ed. 1983.