Hardened Sonobuoy Design

Cornell Bioacoustics Research Program
October 30, 1996

Related Documents:

Buoy Usage and Deployment
Hydrophone Usage and Deployment
Hydrophone Fabrication

1. Overview

The purpose of this document is to present the design notes for the construction of a hardened sparbuoy-style sonobuoy. This buoy is intended as a platform for remote acoustical monitoring, although it can be easily retrofitted to perform other activities as well.

In principle, the design follows that of a sparbuoy in which conventional wave-induced bobbing is minimized. This is the result of placing the majority of the mass and surface area below the water.

The design has been tested in swells ranging to 18 feet and winds reaching over 30 knots (B7), and has a battery life of over 100 hours continuous. Range of operation (RF transmission) depends on the sea state and receive station but easily exceeds conventional sonobuoy equipment (several kilometers), with the added feature that the buoy is reusable.

2. Construction

The overall length of the buoy was derived as a combination between performance, material strength, and shipping constraints. The material (PVC) was chosen because of its low cost, resilience, and ease of fabrication. An overview of the completed buoy is presented in **Figure 1**.

Important: If you have not worked with PVC before, get assistance. It is very important that all joints are fully prepared (cut, sanded, and primed) before assembly or mechanical integrity will not be obtained.

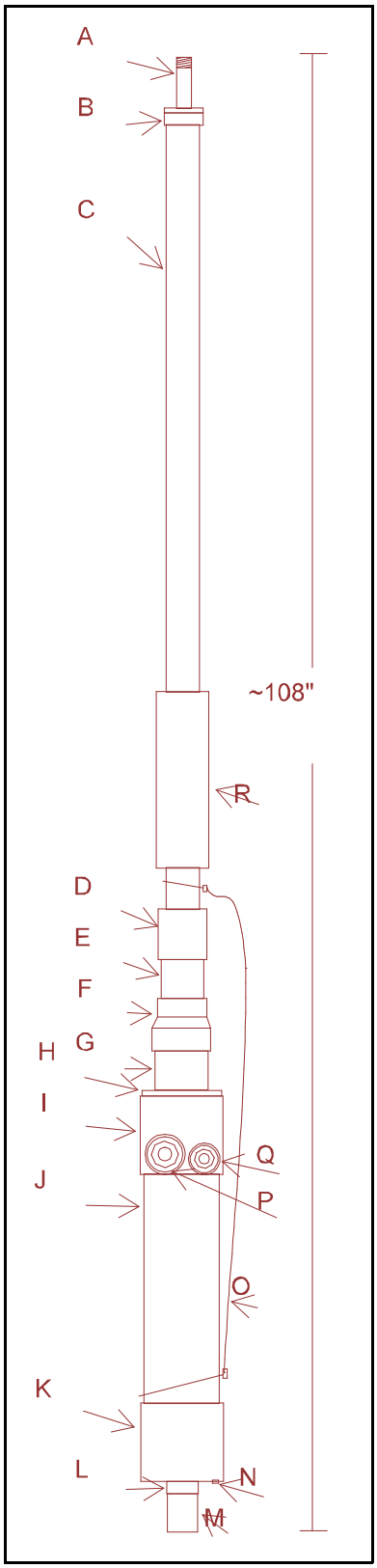

Figure 1. Finished View.

Key to **Figure 1**:

A. Antenna mount
B. 2" PVC cap
C. 2" PVC pipe (~75" total)
D. 2x3 PVC bushing and 3" PVC coupling
E. 3" PVC pipe (~5" total)
F. 3x4 PVC reducer
G. 4" PVC pipe (~5" total)
H. 4x6 PVC bushing
I. 6" PVC coupling
J. 6" PVC pipe (~25" total)
K. 6" PVC threaded cap
L. 6" PVC screw cap
M. 2" PVC connector protector (~2" total) & hydrophone connector
N. Stainless bolt (seawater ground)
O. 1/8" aircraft cable bridle, with plastic tubing to protect body
P. 2" PVC connector protector (~2" total) and power connector
Q. 1-1/2" PVC connector protector (~2" total) and antenna connector
R. 2-3/8" ID polyethylene buoyancy foam

2.1. The Mast Section

Begin assembly of the mast by first fabricating the antenna mount assemblies (ref. **Figure 2**). The aluminum plate is drilled with 3 holes to match the antenna mount's hole placement. The PVC cap is then drilled so that the 3 pieces align. Next, silicon RTV is applied to the back of the aluminum plate to provide a seal when mated. The antenna mount, PVC cap and the aluminum plate are then assembled and the screws tightened down. Care must be taken to ensure the plate is centered so that it lies inside the 2" PVC mast when assembled and that all residual silicon is removed.

Key to **Figure 2**:

A. Shakespeare 4" Stainless antenna mount
B. 8-32 x 1" stainless screws (3)
C. 2" PVC cap
D. 0.09" Aluminum plate, 1-15/16" diameter (fits inside 2" PVC mast)
E. 8-32 stainless locking nut

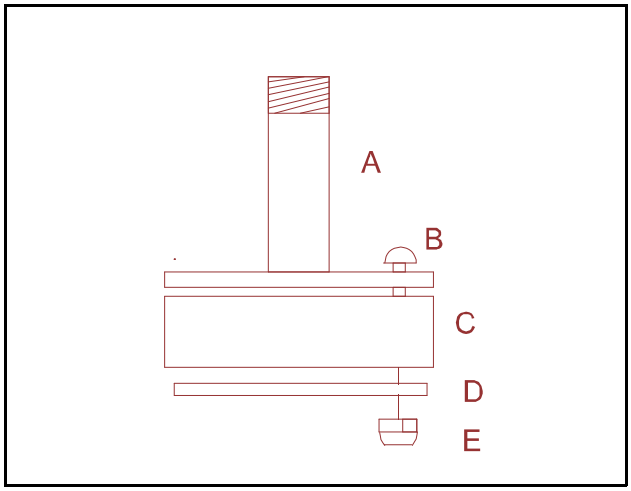

Figure 2. Antenna Mount Assembly

Next, the 2x3 bushing that fits into the 3" coupling must be cored out. Use a 2-3/8" hole saw and core the bushing out, removing any residual burring. A 2" PVC pipe should fit snugly through the bushing when complete.

Clean, Assemble and Glue (CAG) the cored

2x3 bushing and 3" coupling. When complete, CAG the 5" long section of 3" PVC pipe into the assembly. After it has set, repeat with the 3x4 reducer, etc. until your assembly includes all components up to the 6" PVC pipe section (i.e. up to the 6" PVC coupling).

When the PVC glue has had time to fully set, take 1/4" PVC sheet material and cut a 6" diameter disk that will fit in the bottom of the 6" coupling. This disk then needs to have a 2-3/8" hole cut out of its center (confirm proper dimension with a section of 2" PVC pipe -- it should slide through snugly). This disk will provide the support for the other end of the antenna mast. It should be glued into the bottom of the 6" coupling section of the assembly completed so far (against the 4x6 bushing).

Now cut a length of 2" PVC pipe 75" long and debur the edges. On one end, glue the antenna mount assembly previously prepared. When that has set, slide the other end through the prepared upper body assembly just prepared, starting at the 2x3 bushing. Slide it through the entire assembly until it emerges through the 6" disk at the other end far enough for you to be able to work the end. Glue a 2" PVC cap to this end and allow it to set. Once set, pull the mast so that the cap is nearly against the disk. Cover the capped end (contact edges and surfaces) with PVC cement and quickly pull the mast so that the cap is flush against the disk. Hold until set. The total exposed length of the 2" mast should now be ~60.5"

Finally, recheck all joints for integrity. If available, it is recommended that a PVC welder be used to further strengthen / seal the joint between the mast and the 2x3 bushing, as well as the point where the capped mast is glued to the 6" disk inside the 6" coupling.

2.2. Buoy Base & Endcap

Cut a 25" section of 6" PVC pipe. CAG the 6" threaded cap to one end of the section. Once set, CAG this assembly into the mast section already prepared.

After the joints are fully hardened, we now want to place and drill the locations for the power and antenna connector. These are placed in the area where the upper 6" PVC coupling overlies the 6" pipe below it to give the greatest surface area for threading. Based on the connectors you employ, drill the proper hole diameter for the taps needed. Next, taking a power sander, grind a flat are of ~1-1/2" diameter around these holes to provide a sealing surface for the connector gaskets. Now carefully tap the holes for the connectors, and test the fit. If the connector's o'ring gaskets do not fit flush, continue to sand until they do.

Now, cut 2 to 3" sections of both 2" and 1-1/2" PVC pipe to serve as connector protectors. Using a file (or grinder), shape one end of each to fit as nearly flush as possible when centered over the tapped holes. These pieces can then be glued in place. Once set, they will need to be welded to provide the greatest strength. Do not mount the connectors as of yet.

Take the 6" screw cap (the one that screws into the bottom of the buoy), and drill and tap it for the hydrophone connector. Prepare a connector protector for it and affix as above.

Lastly, take a 5/16" stainless carriage bolt and drill a hole for it in the screw cap (you will need a file to cut the square key slot). You will also need to cut a piece of rubber to use as a gasket for the bolt. Mount the bolt into the hole, with the rubber piece under the bolt head and the threads and rubber coated with silicon RTV. For the time being, place a flat and a lock washer on the other side and tighten securely (to allow the silicon to set). Again, leave the connector out for the time being.

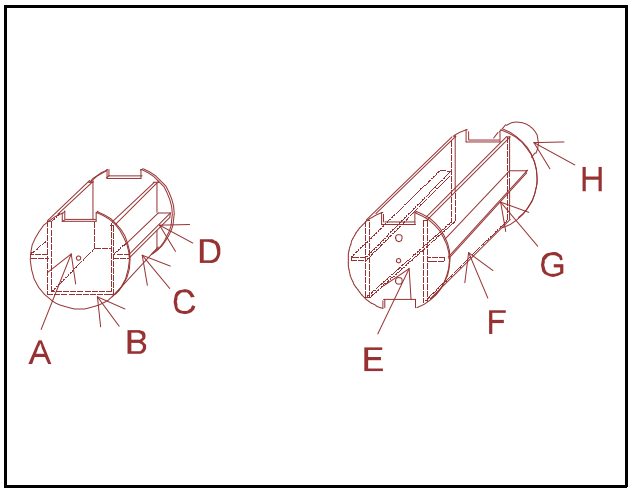

Figure 3. Carrier Construction

2.3. Carrier Assemblies

There are two internal carriers in the buoy as-designed. They serve the purpose of providing a means of packaging the transmitter (or other electronic assembly) and the battery in a fashion for easy access and replacement. **Figure 3** provides an idea of how these carriers appear and are constructed.

Key for **Figure 3**:

[All pieces are constructed from 1/4" PVC (gray) sheet]

A. 5-7/8" diameter battery endcap (2)
B. 5-15/16"x3-13/16" bottom piece
C. 5-15/16"x3-15/16" side pieces (2)
D. 5-15/16"x3/4" side supports (2)
E. 5-7/8" diameter transmitter endcap (2)
F. 7"x5" transmitter protectors (2)
G. 7"x3/4" side supports
H. 3" section of 1-1/2" PVC

In the illustration, you will note that there are cutouts on either end of each of the carriers -- these are for cable routing. There is also a center-drilled hole on the endcaps -- these are for adding a piece of string for ease of removal of the carriers during usage. In addition, there are two offset holes on the transmitter carrier which are used to mount the transmitter electronics (they mate with the pre-drilled holes on the Sparton transmitter units). Exact dimensions are not give here due to differing equipment you may be using.

Assemble all by the CAG process used to this point. For the battery carriers, the fit should be tight and a weld bead may be desired to provide additional integrity due to the same.

In **Figure 4**, the small-weight carrier is shown. This unit is used as a carrier for the smaller 20 oz. weights that are used to fine tune buoy ballasting during usage.

1-by pine is used, glued to 5/16" plywood to form a 1-1/16" laminate. This laminate is then cut into the form shown (5-7/8" primary diameter), and then heavily polyurethaned. The polyurethane provides additional strength as well as endurance from the saltwater exposure. Total capacity is 3.75lbs.

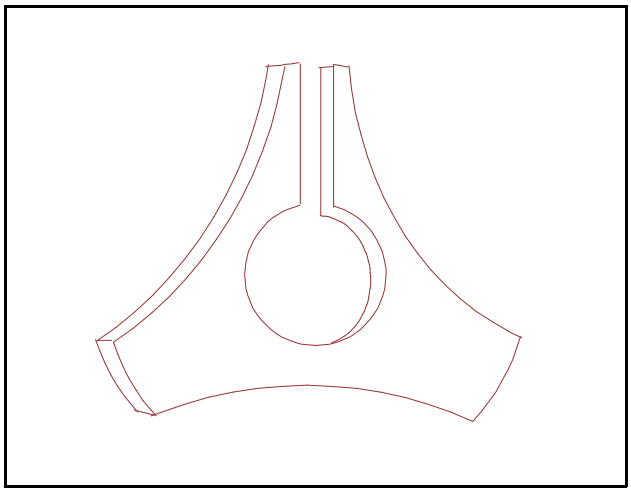

Figure 4. Weight Disk

2.4. Bulkhead Preparation

Due to the screwcap end piece of the buoy, the bottom section has the potential to get flooded. Coupled with the need to be able to change ballasting in the field (thereby exposing the bottom section to additional flooding), a bulkhead is included in the design to keep the upper (electronics) section dry and water tight.

The bulkhead consists of a 6" pressure tester as manufactured by Cherne Industries ('The Gripper'). It is constructed of two plates of high-impact plastic, a rubber ring between, and a bolt used to pull the two plates together, thereby expanding the rubber to form a water-tight seal. The buoy is designed so that only one cable needs to pass through the bulkhead -- that of the hydrophone cable (which also includes a link to the seawater ground). The cable passes through the bulkhead by way of 'liquitite' fittings mounted into the modified unit.

The first step in preparing the bulkhead is to dissemble the 'gripper'. You will find one plate wider in diameter than the other. This plate needs to be ground down to the same size as the smaller. Ensure all burrs are removed and the final surface is smooth. Next, a hole must be drilled through each plate and a 3/8" NPT thread tapped in. This is for the liquitite connectors. In preparation for fitting, grind 1/4" off of the liquitite connector threads.

Mount the liquitite connectors into the prepared holes in the plates, using a thin coating of silicon RTV before screwing them in. Next, reassemble the bulkhead assembly, this time, replacing the w3/4" wingnut that comes with it with a 3/4" nut. This allows the use of a standard deep-dish socket for access. Note that the two plates (with reference to the liquitite fittings) should be rotated 1/3 to 1/2" to allow room for the cable during the bulkhead expansion at installation.

Finally, take a 48" length of the Belden hydrophone cable and pass it through the bulkhead's liquitite fittings. 12" of this cable should protrude from the side where the nut is (this is the bottom, going to the hydrophone connector). Tighten the liquitite fittings fully to complete the

seal.

To complete the bulkhead assembly, we need to wire in the buoy's screw cap. First, mount the hydrophone connector into the threaded hole you made earlier. As always, use a bead of silicon RTV on the threads. When secure, add the low-profile nut to the other (solder) side and secure firmly. Using 18AWG wire, secure and solder a crimp ring lug to one end, then tighten it to the seawater ground bolt. Cut the wire to route into the connector ground pin and solder. Next, strip back and tin the hydrophone cable wire extending from the bottom side of the bulkhead and solder this into the connector (ref. **Figure 5** for pin numbers).

The screw cap is completed by filling the connector cavity with 3-M 2130 Scotchcast compound. Once the compound is set, a foam cushioning disk is prepared from the 1" construction foam and cut to fit within the screw cap lip. It is then secured using silicon RTV. Lastly, wrap a length of protective helical wire wrap around the hydrophone cable to provide protection against the ballast weights.

2.5. Wiring Harness

Figure 5 provides a wiring schematic. Based on your approach to the design, the cable lengths will vary. It is critical however that all cable groups be water blocked and that as little flux be used as possible as both of these will cause premature corrosion and (potentially) failure.

2.6. Transmitter Module Preparation

This procedure is based on the Sparton Electronics AN-57A transmitter modules.

a. Remove scuttle bus wire (E208-E118).
b. Add 3 jumpers to J1 (pins 2-3, 4-5, 7-8).
c. Add a 4.7uF/50V electrolytic capacitor to the E108 terminal (negative side to terminal).
d. Ensure the R119 wiper is glued, with the wiper arm parallel to its closest edge.
e. Using a 2-contact Molex connector and 12" of RG59, configure the antenna connector and affix between terminals E106 (signal) and E107 (ground).
f. Using a 4-contact Molex connector, 12" of RG58 and 12" of 18 AWG Zip, create the power/signal cable. Attach the RG58 between the positive lead of the 4.7uF capacitor and E104 (ground). Place a bead of Silicon RTV over the capacitor and wire leads to insulate and strengthen. Attach the Zip between E112 (positive supply) and E113 (ground).

2.7. Buoyancy Foam

The addition of the section of external buoyancy foam provides an additional level of buoyancy

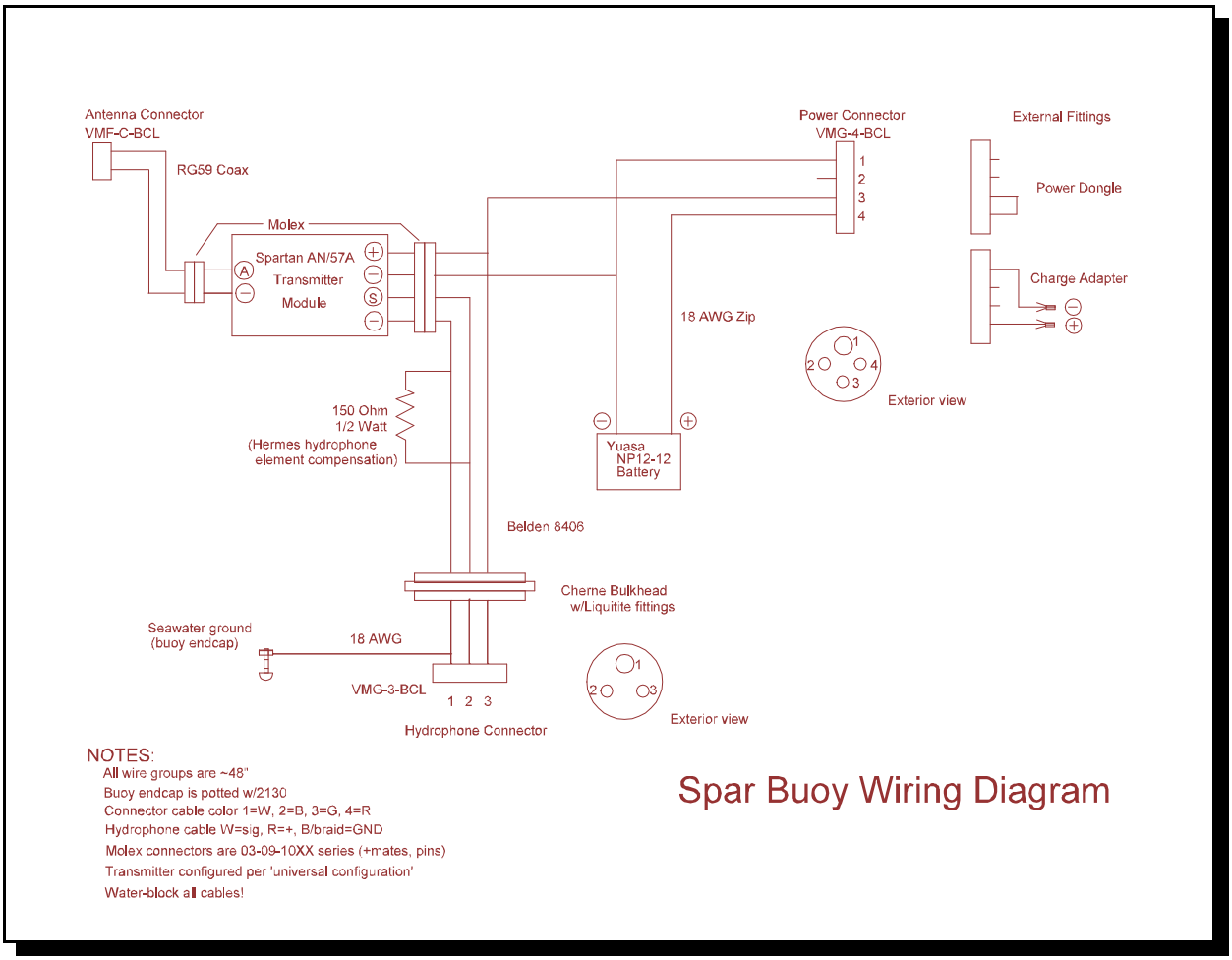

Figure 5. Wiring

and stability to the buoy. A closed-cell polyethylene foam is employed, the type used to wrap hot water pipes. For the as-designed mast (2" PVC), use 2-3/8" ID slit foam in 14" lengths. The foam is first cut and fitted to the mast, then removed and contact cement applied and allowed to set. Upon application, duct tape is used to secure it tightly until the cement is fully set. Originally we employed a UV-screening paint; but in sea trials we found that it did not last and since it is below the water line, the effect of UV is minimal.

2.8. Ballast and Spacer Disks

The ballasting of the buoy is critical to its performance. In order to ensure the buoy rides correctly in the worst seas, this ballast must be the highest mass in the smallest form. In addition, due to this mass, foam spacers must be employed to ensure the ballast does not damage other buoy components or the buoy structure.

The spacer disks are cut (using an electric knife or band saw) from 1" outdoor construction foam. The plastic facing is left on to provide additional integrity. Follow the figures for cutout configurations. A 2" hole saw drill is useful for cutting out the inner area as is required.

The ballast disks should be roughly 7 to 8lbs each and cast of lead. Casting lead is fairly straightforward. Using fine sand (moisten to ensure good impressions), fill a cardboard carton with it, then create the mold using one of the foam disks you have cut. After removing the foam, you may want to use a plant mister to moisten the sand to ensure the form is retained.

To melt the lead, you will need a cast iron skillet and a small BBQ grill (e.g. a hibachi). Start the grill up using charcoal. Once ready, you will need a good supply of oak or other hard wood to get it hot enough to melt the lead. Fill your skillet[1] with lead shot and set it on the fire. When melted, pour it into the mold you have made in the sand with the foam disk.

Once the cast lead has cooled, remove it from the sand. You will then need to grind or file it to ensure it fits into the buoy smoothly and without gaps between the plates. Finally, weigh the disk (a 25lb spring scale is fine) and engrave the weight into the disk.

Note: use safety glasses, a face mask (or respirator) and good ventilation when performing this procedure.

2.9. Buoy Bridle

The purpose of the buoy bridle is to provide a means to secure the buoy to a tether rope during usage, and to facilitate ease of deployment and retrieval. The bridle is designed so that the securing clip will find the center of gravity based on the way handled. Specifically, during retrieval and deployment, the securing line will ride to a position on the bridle in which the buoy always remains upright. During usage, the tether rope will ride in an unrestraining position depending on the sea state.

The bridle is constructed as illustrated in 1, using 1/8" aircraft cable, crimp ferrules, 3/16" ID plastic tubing, and a set of bolt cutters (for cutting and crimping).

2.10. Mechanical Integrity Testing

Before final assembly, it is necessary to test the mechanical integrity (water-tightness) of the buoy shell. This is done before the electronic carriers or ballast is inserted, but after the wiring and connectors are in place.

---

[1] A 6" cast-iron skillet holds just enough lead to cast a 7-9lb weight.

We performed the procedure by hoisting the buoy (upside down), using the bridle and securing them off of the ground in a vertical position. Next, the interior was filled from above, using water dyed darkly with food coloring. The buoy was allowed to hang for 3 (or more days) with the screw cap lightly threaded to reduce evaporation. Periodically, the buoy was examined for signs of leakage as was the water level for changes. If leakage was noted, a grease pencil was used to mark it for later repair.

After the period had elapsed, the buoys were brought down and drained. The empty buoys were then shaken (while listening) to see if internal compartments had been flooded as well. Any leakage or weaknesses were then touched up with a plastics welder.

2.11. Assembly and Finishing Touches

Following the diagram in **Figure 1** and **Figure 6**, insert the carriers and connect the transmitter connectors. Ensure that all connectors are flushed with a silicon-based contact cleaner and protectant, and that the battery terminals have a liberal coating of grease on them. After the carrier units are inside, check (by sliding the carriers back and forth slightly) to ensure the transmitter top tube has not caught part the cables.

Add the first spacer disk, and then insert the bulkhead firmly against the disk ensuring no cables will be caught when it is expanded[2]. Using a deep socket and ratchet with extension, tighten the bulkhead bolt securely while checking to ensure it remains perpendicular to the sides.

Add the remaining components per the figures. In our final testing (using the components as listed), we ended up using ~15.75lbs of lead ballast in the form of the disks, leaving the weight disk empty so that additional ballasting could be added in the field using the weight disk and 20 oz (or smaller) weights[3][4].

Finally, the PVC endcap is screwed onto the end using a specially-fabricated *buoy wrench*[5]. Before screwing this endcap in, you may want to put a thin bead of silicon RTV on the threads to further enhance the seal. Also, ensure the excess hydrophone cable is tucked into the foam disk

---

[2]It is advisable to ensure the bulkhead rubber seal is clean and has a light coat of plumber's grease to provide a good seal.

[3]Based on a mast length of 72" (above 6" section) and a base of 32" (6" section).

[4]Commercial 20 oz weights have wire loops on the ends that need to be cutoff first.

[5]The buoy wrench is a plywood construct (2 layers of 3/4" plywood, cross-grained) with a cutout at one end to fit over the square projection of the threaded PVC endcap. Ensure that it is liberally protected with polyurethane so that it will last under sea-water conditions.

to prevent it being pinched by the lead ballast disks.

Once the buoy has been fully assembled all external connectors should be lubricated with a non-petroleum grease (e.g. plumber's grease), and then the contacts flushed with a silicon-based contact cleaner and protectant. This protects the contacts and makes the mating of the connectors much easier (it should also be performed on a regular basis throughout the life of the buoy). A quick check of the battery voltage will verify proper connection (pins 1 and 4 of the power connector).

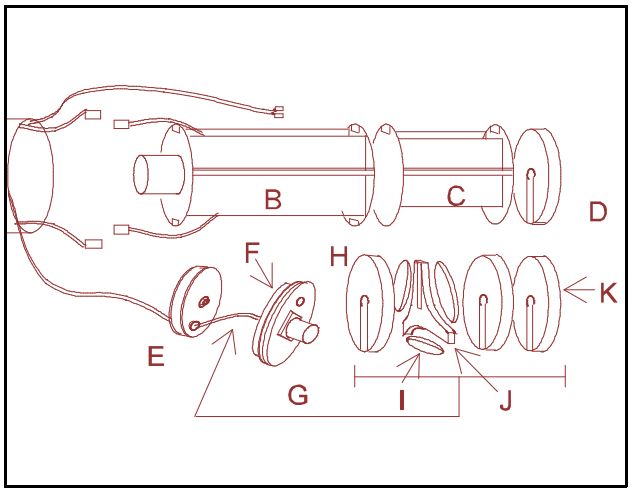

Figure 6. Internal Component Assembly

Key to **Figure 6**:

A. Buoy housing (6" section)
B. Transmitter carrier
C. Battery carrier
D. 1" Foam disk
E. Bulkhead
F. Screwcap foam disk
G. Screw cap with mounted connector and seawater ground
H. 1/2" to 1" foam disk
I. 20 oz Pb trimmed fishing weights
J. Weight disk
K. Pb ballast weights (2)

3. Calibration

Calibration of a completed buoy takes two forms: 1) the calibration of the hydrophone in use, and 2) the calibration of the buoy transmit / receive chain. Hydrophone calibration will not be covered here.

Buoy Tx/Rx calibration requires that you setup the entire system as you would in the field, including buoy, buoy antenna, receiver, filtering, and recording and monitoring equipment. Due to the differing configurations of usage, only general details will be presented here. Note that in this procedure, the buoy does not need to be in water -- leave it in the shipping case you may have constructed and simply lean the antenna up and connect it to the buoy.

Using a signal generator and an oscilloscope, hook the output of the signal generator to both the hydrophone input connector and to the oscilloscope. This will allow you to monitor and record the signal level being applied. Set the signal generator output level to ~100mV peak-to-peak. From the end of the receive chain, also connect this to the oscilloscope (the other channel) -- or use a program such as SpectraPlus (which will give you received levels in dB).

Finally, power the buoy and then monitor (plot) the input versus the output levels across the frequency range of interest.

Appendix A. Parts List & Sources

General Tools
Drill press
PVC welder
Grinder
Sander
Table saw (w/PVC blade)

PVC Needs
PVC cement
PVC cleaner and primer
6" PVC pipe
4" PVC pipe
3" PVC pipe
2" PVC pipe
1-1/2" PVC pipe
2" PVC caps
2x3 bushing
3" PVC coupling
3x4 PVC reducer
4x6 PVC bushing
6" PVC coupling
6" PVC threaded coupling
6" PVC screw cap

Note: Purchase screwcaps that have the same (~2") square projection. This will allow you to easily design a universal buoy wrench to use with your units.

General Hardware
1/8" aircraft cable
1/8" aircraft cable crimp ferrules
Polyethylene tubing, 3/16" ID (for aircraft cable protector)
Bolt cutter (for cutting and crimping aircraft cable harnesses)
Contact cement (flotation foam)
Stainless steel carriage bolt, 5/16"x3/4" with nut, washer, and locknut (sea water ground)
3/4"-16 low profile nuts (hydrophone and power connectors)
Lead shot
Cast-iron skillet (for melting and casting lead)
Casting sand (as above)
2-3/8 hole saw (coring PVC couplings for mast)
Taps and drills for connectors (3/4"-16NF [11/16" drill], 1/2"-20NF [29/64" drill])
Rubber sheeting for gaskets (1/16")

3/4" nuts (bulkhead)
tap and drill for liquitite bulkhead fittings (3/8" NPT)
1" pink construction foam (exterior rated, used for spacer/cushioning disks)
20 oz elliptical lead fishing weights (hydrophone and weight disk / ballasting)

General Electrical
150 Ohm, 1/2 watt resistors
RG59 antenna cable (internal)
18 AWG Red/Black Zip wire [Radio Shack]
Molex series 03-09-10XX connectors (mating pairs and pins)
Battery spade lugs
Seawater ring lug

Boat America, phone 800-365-9283
Shakespeare Model 5202 8' VHF transmit antenna (p/n 307035-10)
Antenna mount, stainless (p/n 307109-10)

Sparton Electronics, phone 904-985-4631
Sparton AN/57A sonobuoy transmitters

Cushcraft, phone 800-258-3860
Cushcraft #P170-4 Yagi receive antenna

Seacon/Bratner, phone 619-562-7071
hydrophone bulkhead, #VMG-3-BCL
hydrophone connector, #VMG-3-FS
power bulkhead, #VMG-4-BCL
power connector, #VMG-4-FS
locking sleeves, #G-FLS-X-S
antenna bulkhead, #VMF-C-BCL
antenna connector, #VMF-C-FS
locking sleeves, #VSF-FLS-S

McMaster-Carr, phone 908-329-3000
Latex surgical tubing, 1/4" OD (p/n 5234K41)
Lead shot, 25lb bags (p/n 9030K32)
1/4" PVC sheet (p/n 8747K194)
Polyethylene insulation (flotation) for 2-3/8" ID, 3/4" thick (p/n 4530K28)
6" bulkhead plug, Cherne Industry 'Gripper' (p/n 2645K45)
Liquid-tite fittings, Hummel (p/n 69915K52)

Newark Electronics, phone 800-462-3153
Yuasa 12volt/12Amp-hour sealed gel cell battery type NP12-12 (p/n 87F638)

Belden type 8406 hydrophone cable (p/n 36F202WF)
AMP Spirap plastic cable wrap #500030-1 (p/n 95F1136)

Hermes Electronics, phone 902-466-7491
Sippican-style hydrophone elements

3-M Products, phone 800-245-3573
82-A1 splice cast kits
2130 casting and potting compound

Conap Epoxies, phone 716-372-9650
Hydrophone potting; type EN-7 is acoustically transparent

.end