NOAA Technical Memorandum NMFS

APRIL 2019

SONOBUOY ACOUSTIC DATA COLLECTION DURING CETACEAN SURVEYS

Shannon Rankin[1], Brian Miller[2], Jessica Crance[3], Taiki Sakai[4], Jennifer L. Keating[5,6]

[1]Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, 8901 La Jolla Shores Dr., La Jolla, CA 92037

[2]Australian Marine Mammal Centre, Australian Antarctic Division, Channel Highway, Kingston, Tasmania, 7050, Australia

[3]Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 7600 Sand Point Way NE, Seattle, WA 98115

[4]Lynker Technologies for Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration, 8901 La Jolla Shores Dr., La Jolla, CA 92037

[5]Joint Institute for Marine and Atmospheric Research, University of Hawaii at Manoa, 1000 Pope Road, Marine Sciences Building 312, Honolulu, Hawaii 96822

[6]NOAA Fisheries, Pacific Islands Fisheries Science Center, National Oceanographic and Atmospheric Administration, 1845 Wasp Blvd., Honolulu, HI, 968188

NOAA-TM-NMFS-SWFSC-614

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

About the NOAA Technical Memorandum series

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency which establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

SWFSC Technical Memorandums are available online at the following websites:

SWFSC: https://swfsc.noaa.gov

NOAA Repository: https://repository.library.noaa.gov/

NTIS National Technical Reports Library: https://ntrl.ntis.gov/NTRL/

Accessibility information

NOAA Fisheries Southwest Fisheries Science Center (SWFSC) is committed to making our publications and supporting electronic documents accessible to individuals of all abilities. The complexity of some of SWFSC's publications, information, data, and products may make access difficult for some. If you encounter material in this document that you cannot access or use, please contact us so that we may assist you.
Phone: 858-546-7000

Recommended citation

Shannon Rankin, Brian Miller, Jessica Crance, Taiki Sakai, Jennifer L. Keating. 2019. Distribution, Sonobuoy Acoustic Data Collection during Cetacean Surveys. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC614

CONTENTS

INTRODUCTION

Sonobuoys are expendable recording devices useful for airborne or shipboard surveys; signals detected by the omnidirectional hydrophone are relayed from the buoy to the vessel via VHF radio signals. DIFAR (Directional Frequency Analysis and Ranging) sonobuoys contain orthogonally oriented vector (pressure) sensors and a magnetic compass that allow for estimation of a bearing angle to sounds of interest. The directional information is multiplexed into a carrier signal and transmitted with the omnidirectional hydrophone signal via VHF.

Sonobuoys are useful for studying sounds produced by whales and have been used for studies in marine mammal research for decades (see McDonald 2004). DIFAR sonobuoys have been used to describe the vocal repertoire of species (Oleson et al. 2003, Rankin et al. 2006, Rankin et al. 2007, Širović et al. 2013) or for real-time tracking of target species (Wade et al. 2006, Rone et al. 2012, Miller et al. 2015). Recent improvements in the quality of sonobuoys provided by the Navy, along with recent software improvements that allow for efficient, user-friendly analysis of sonobuoy data (Miller et al. 2016) allow sonobuoys to be considered for population studies for whales in remote locations (Miller et al. 2015, Rankin et al. 2016).

National Marine Fisheries Service is the largest user of sonobuoys provided by the Navy (Anu Kumar, pers. comm.), where sonobuoys are largely used to study baleen whales during large shipboard cetacean surveys. Data collected during these NMFS cetacean surveys typically fall into one of three categories: (1) opportunistic buoys (in the presence of sighted cetaceans), (2) sonobuoy stations (for larger scale assessment), or (3) real-time tracking of target whale species for focused studies.

Despite the potential, numerous complications particular to sonobuoys can negatively affect the accuracy estimation of bearing angles using the DIFAR signal, the quality of the acoustic data, and the interpretation of the data. This report serves to identify methods for data collection that will alleviate many of the problems associated with marine mammal acoustic studies that rely on sonobuoys for acoustic recording and bearing angle estimation. This includes suggested hardware and software methods for data collection, calibration of the hardware system, and protocols and methods for deploying and calibrating the sonobuoys. These hardware and software methods are expected to change over time and recent technological advancements should be considered prior to implementing a research program involving sonobuoys.

METHODS

Sonobuoys are typically deployed from a large research vessel, and the methods below reflect what might be expected during a large-scale shipboard survey conducted by NMFS. These methods can be scaled to function from a smaller vessel, ship of opportunity, or even a shore-based receiving system. These methods include suggested hardware setup, sonobuoy settings, deployment methods, and suggested protocol for deploying sonobuoys. Methods related to software recording and analyses are not discussed, as these methods are likely to change dramatically in the near future.

Hardware Setup

Working with sonobuoys requires an antenna (to receive radio signals), a cable that will run from the antenna to a receiver, which is connected to the sound card and the computer. Together, this Sonobuoy Acoustic Recording System (SARS) allows for digital recording of sonobuoy signals. We strongly recommend that backups of all equipment as well as copies of all manuals be provided for field personnel. A list of hardware supplies (including make/model) are provided in Table 1. New digital alternatives to the hardware suggested in Table 1 have not yet been tested but may provide a simpler and more cost-effective option.

Table 1. List of components for Sonobuoy Acoustic Recording System (SARS) at the time of this publication (note: components change over).

Equipment	Make	Model	Comments
Antenna	Diamond	X30	2m Dual Band,
Masthead Amplifier	Mini-Circuits	ZX60-33LN+	
Amplifier power			5 v
Coaxial Cable			LMR-400 or LMR-800
Bias-T	Mini-Circuits	ZFBT-4R2G-FT+	10-4200 MHz, powered by 5v plug-in
High Pass Filter	Mini-Circuits	NHP-150+	High Pass Filter/ N-connector
Low Pass Filter	Mini-Circuits	NLP-150+	Low Pass Filter/ N-connector
Coaxial Cable	Mini-Circuits	086-10SM+	Cable w/ SMA connectors
Power Splitter	Mini-Circuits	ZMSC-2-1+	
VHF Receiver	WinRadio	WR-G39WSBE	
USB Hub	Vaunix	LPH-204B	Optically Isolated (no noise)
Sound Card			Multiple Options (e.g. FireFace, NIDAQ, SAILDAQ)
Surge Protector	Tripp Lite	Isobar	

Signal reception relies on VHF radio frequencies, and therefore line-of-sight between the transmitter (sonobuoy) and the antenna. Ideally, the antenna will be mounted as high as possible on the ship, with unobstructed 360° views to the horizon. The antenna should be mounted away from other metal superstructure and from any other transmitting sources (e.g., radar). The shortest distance from the antenna to the receiver should be identified as signal is attenuated over the length the cable. We suggest using high quality (thick & flexible) coaxial cable (LMR-400 or LMR-800). A directional antenna (e.g. YAGI) allows for increased reception; however, the antenna must be tuned (angled) towards the sonobuoy; therefore it can be difficult to use on a maneuvering vessel. Directional antennas are ideal for transiting where the sonobuoy is most often behind the vessel.

If the signal attenuation (AKA insertion losses) along the coaxial cable, connectors, and splitters reduce the local RF noise floor below the lower limit of receiver (e.g. -120 dB for the WinRadio G39WSB in the SARS), then a masthead amplifier may be required. Otherwise, the masthead amplifier is unlikely to provide much of an improvement since it will indiscriminately amplify both the signal and the noise together. Instead, it may be preferable to try to reduce signal attenuation by using a better antenna, cable, or fewer connectors & splitters. Signal attenuation along the cabling and connectors can be roughly estimated from the data sheets (e.g. LMR400 nominally attenuates at 5 dB/100m; a ZMSC-2-1 power splitter has 3-4 dB of insertion loss; N-type connectors have 0.1-0.5 dB insertion loss, etc.). However, where possible we recommend measuring signal losses using a calibrated receiver (e.g. WinRadio G39 WSB) and VHF signal generator (e.g. the relatively affordable RF Explorer Signal Generator [RFE6GEN]). Measurement of signal losses is preferable to estimation as it can allow for identification and replacement of any bad components.

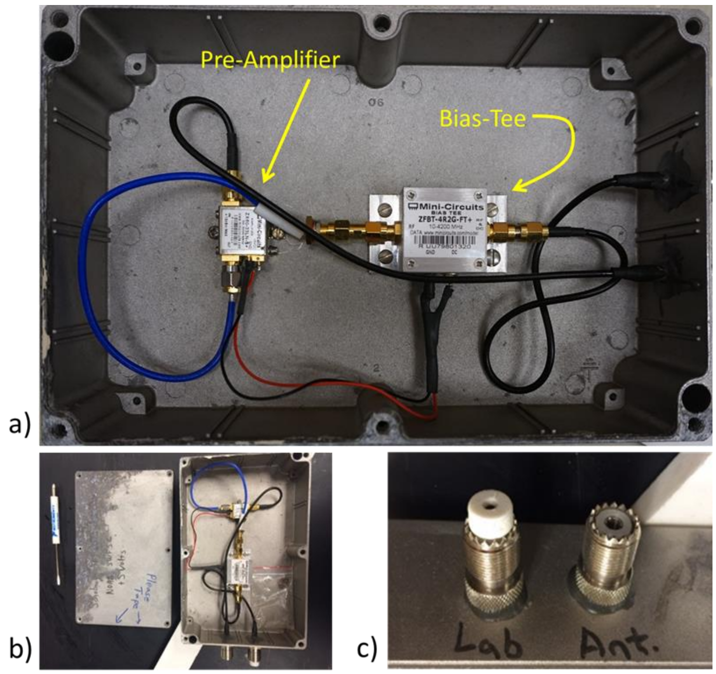
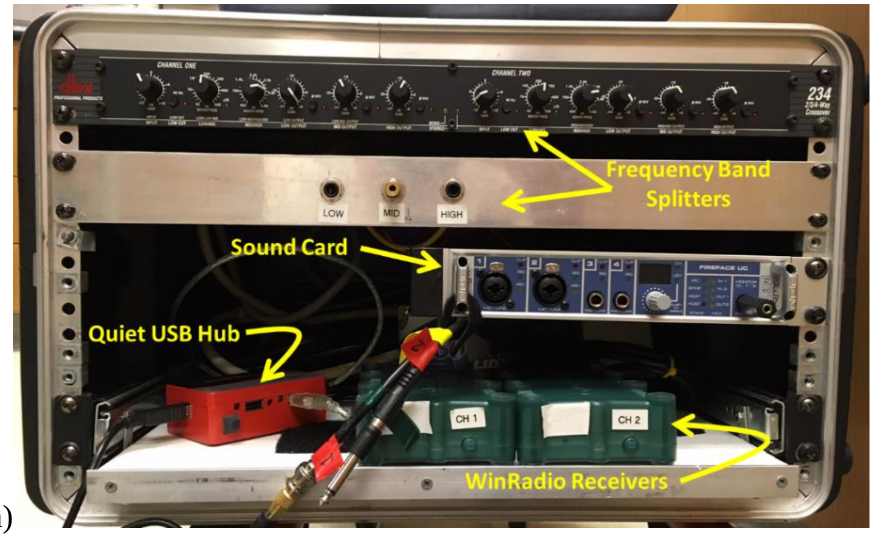
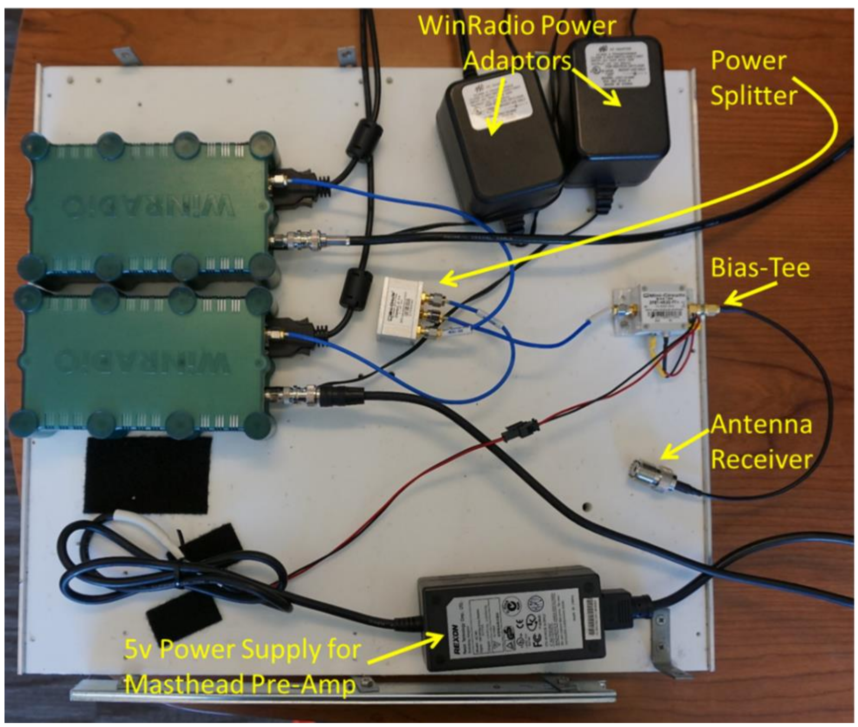


Figure 1. Masthead amplifier includes: (a) pre-amplifier with Bias-Tee, in (b) waterproof aluminum box with (c) input/output for coaxial cable. This masthead amplifier should be placed in an easily accessible location for testing and repair.

Placement of a masthead amplifier should be in a secure, weatherproof location that is easily accessible (Fig. 1); it is not unheard of for the masthead pre-amp to require replacement (in fact, they are a known weak point in this system and you may prefer to do without, see Appendix 1 for more information). Power to the amplifier can be inserted at the lab-end of the antenna cable using a small wall charger (5V DC) to inject power into the antenna cable at the lab end of the cable (Fig. 2). The power is added/withdrawn from the cable via a Bias-T adaptor (one at the lab end to insert the voltage, and one at the masthead pre-amp to withdraw the voltage and power the amplifier). The 5v DC current travels up the coaxial cable at the same time the sonobuoy signal is traveling down it. Alternatively, some amplifiers can be powered using D-cell batteries placed within the waterproof box, eliminating the need for a Bias-T (e.g. Advanced Receivers P30-1000 amplifiers).



a)



b)

Figure 2. Recording station for sonobuoys. This is (a) an example rack-mounted recording system, (b) with a detailed view of the components and wiring inside the case. NOTE: We recommend placing the bias-T in a small plastic box (not shown) with a DC socket and shield/pin connector to isolate from power source.

The cable from the antenna or masthead amplifier is then connected to the recording station (Fig. 2 for an example setup). The recording station accepts signals from the antenna and delivers to the WinRadio sonobuoy receiver and then soundcard. Note that each sonobuoy signal requires an independent WinRadio receiver; these receivers use a smaller connector (SMA) and will require an adaptor to connect to the antenna cable. Optional components include pre-amplifier power w/ Bias-Tee (for masthead amplifier), ‘quiet’ surge protecting power supply, ‘quiet’ usb hub, power splitter (to connect multiple WinRadios from a single antenna and coaxial cable). We recommend placing the bias-T in a small plastic box (with a DC socket and shield/pin connector) to protect exposed wiring from 5v power source.

For standard DIFAR sonobuoys, recordings should be digitized at a 48 kHz sampling rate using a high quality sound card (we have had success with FireFace, National Instruments DAQ, SAILDAQ, and MOTU) and recorded to hard drive using Pamguard software (Gillespie et al. 2008). We highly recommend DIFAR analysis using the Pamguard DIFAR module (www.pamguard.org). Newly available GPS sonobuoys (53-G) require a higher sampling rate to accommodate the higher frequency of the GPS carrier signal (suggested 96 kHz sample rate).

System Testing

Testing of the SARS should be conducted immediately after installation. The first test is that the entire system is working, and that each channel on the receiver is connected to the intended channel on the recorder (computer). Confusion between these channels is not uncommon and ensuring proper channel arrangement may require supplying power to the devices in a specific sequence. In fact, some systems will change the order in which the channels are arranged based on which system was powered up first. Ensure that your channel assignment is correct by viewing the spectrogram for all channels and either (1) turn a single WinRadio receiver on/off to confirm channel assignment or (2) tune the WinRadio to the communications channel and use handheld radios, or a calibrated signal generator to produce a signal. After the mapping of connections between receivers sound card (hardware) channels, and software channels has been confirmed, it should be recorded (e.g. written in a table, or documented with a photograph or screenshot) and this should be updated if any connections are changed.

Signal strength may be measured using the power-meter in the WinRadio, which will be less subjective than alternative methods (e.g. audio or visual inspection of the spectrogram). The radio power meter is the faux-analog gauge that reports signal strength in dBm (-120 to -40 dBm or S5-S17). It may be useful to measure the power at regular distances from the sonobuoy (the power measurement and distance to sonobuoy can be logged in the Pamguard User Input). This will allow you to identify buoys with particularly low signal strength, or to assess whether changes you make to the system yield improvements (or otherwise) to the signal strength. We recommend measuring radio signal strength at regular distances from several different sonobuoys at the start of every cruise or after making any substantial changes to the receiving systems. Amplifiers can be tested by bypassing the amplifier and measuring the signal strength, then reconnecting the amplifier and measuring the signal strength again. There should be an increase in signal strength when the amplifier is connected. Sonobuoys may be considered ‘out of range’ when the amplitude of the 7.5 and 15 kHz DIFAR pilot tones are less than 20 dB above the noise floor. This can be easily assessed by viewing the WinRadio audio spectrum as it provides visual information on the pilot tones and noise floor on an amplitude scale with 20 dB gridlines.

Troubleshooting is both an art and a science, and it is impossible to provide a list of all possible problems one might encounter in the field. We have provided a relatively simple list for troubleshooting (Appendix 1); however, we encourage all field personnel to participate in troubleshooting of electronic devices at every opportunity.

Sonobuoy Preparation

Sonobuoys of type 53-F have been developed to be air-launched or hand-deployed over the side of a ship. They employ a seawater battery, which is energized upon saltwater contact. Once energized, a mechanism for inflating a float with CO2 gas is activated, suspending the sonobuoy. The sensors are then released to their specified depths. Data transmission usually begins within 3 minutes after the buoy enters the water. The following information is based on the best of our knowledge, gained from a variety of sources. Specifics may vary by sonobuoy type, manufacturer, age of buoy, etc. You will want to test to ensure these settings and characteristics are appropriate for your specific sonobuoys.

Each component of the sonobuoy has an important role in the deployment process; removal or modification of any of these parts may affect deployment in unintended ways. For example, the parachute helps slow down the sinking of the sonobuoy to ensure that the seawater battery/CO2 cartridge is activated before sinking too deep. If the buoy is too deep when it is activated, the unit may flood (not float). The parachute needs to expand before it hits the water so that it can act as a drogue in the water (rather than just a piece of wet cloth). The plastic parts at the top of the canister maintain cohesion during impact with the water. If these pieces are removed, the depth pin may disengage, which will cause the unit to deploy to the default depth (1000 ft). The metal canister is also critical, as it keeps the sea anchor out of commission until the length of cable is deployed and the hydrophone is at depth. If you deploy without the metal container, the drogue may expand prematurely and slow down the deployment. Not only will this increase the time for full deployment, it will also increase the risk of not deploying in a proper linear/vertical manner and the hydrophone may become entangled. Should the parachute need to be removed for any reason (i.e., replacing dead display batteries) and the depth pin disengages, or if the deployment water depth is shallow (30 m or less), the sonobuoys can be modified to shorten deployment depth. Appendix 2 details how to modify sonobuoys.

Sonobuoys are programmed prior to deployment through an electronic function select circuitry accessed through the side of the sonobuoy. Sonobuoy settings and specifications vary by model and manufacturer; here we describe settings for the AN/SSQ 53-F and AN/SSQ 53-G (e.g., SonobuoyTech Systems, Appendix 3, 4). Frequency sensitivity plots for both sonobuoys are provided in Appendix 5. Settings follow an international standard; the following information should apply to any 53-F type sonobuoy, but may *not* apply towards another model. Preferred selections are provided in Table 2.

The digital readout is an LED located above two buttons positioned next to each other in the horizontal plane; the left button is the “SET” button and the right button is the “VERIFY” button. The SET button is depressed to cycle through the settings. These selections are saved in memory for ~ 48 hours. Once all the settings have been selected, the user should depress the “VERIFY” button to verify the settings are as intended. Selecting VERIFY will restart the 48-hour retention period. Specifications call for buoys to function for a minimum of 50 SET cycles and 100 VERIFY cycles before battery exhaustion.

Table 2. Sonobuoy setting options for AN/SSQ 53-F and 53-G, including preferred selections.

53-F	53-G	Setting	Options	Description	Preferred Selection	Comments
☑	☑	RF Channel	1 - 99	2 digit option	Ch 54	
☑	☑	Life	0.5, 1, 2, 4, 8hrs	time until scuttle	8 hrs	
☑	☑	Depth	90ft, 400ft, 1000ft	hydrophone deployment depth	90 ft	
☑	☑	Sensor	CSO	Constant Shallow Omni	-	Provides acoustic information (30 Hz - 5 kHz) at a fixed depth of 45 ft
☑	☑	Sensor	CO	Calibrated Omni	-	Provides acoustic information (5 Hz to 20 kHz) at a selectable depth
☑	☑	Sensor	DIFAR	low frequency	DIFAR	Provides acoustic information (5 Hz to 2.4 kHz) with directional information at a selectable depth
-	☑	Sensor	XCO	Extended Calibrated Omni	-	Supports uplink of calibrated acoustics signals from the CO hydrophone up to 40 kHz; in this mode the GPS subcarrier is center at 45 kHz.
☑	☑	AGC	on/off	automatic gain control	Off	

Channel. The signals are transmitted from the sonobuoy to the antenna via a small antenna within the sonobuoy float. The sonobuoy transmitting radio frequency (RF) should be selected to match the antenna; the Diamond X30 2m Dual Band Antenna is tuned to 144 MHz (Ch 54). Other antennas may have a different peak frequency. Appendix 6 provides a channel/frequency table and identifies frequencies that should not be used in near-shore deployments. Occasionally, the signal from one channel can 'bleed over' onto nearby channels. This may happen if a sonobuoy is bad and produces extremely loud noise. We suggest that for deployment of multiple buoys, adjacent channels should not be used. A select number of channels interfere with the GPS Operation (Table 3); also, channels 93, 57, and 58 are not available for selection.

Table. 3. Sonobuoy channels that interfere with GPS Operation (only applicable for 53-G GPS sonobuoys).

Transmit Channels			
49	52	87	90
50	53	88	91
51	54	89	92

Upon depressing and releasing the SET button for the first time, the user can select the RF Channel, first by selecting the 'tens' digit, which will be cycled from 0 to 9 in one second intervals. Upon reaching the desired number, the operator depresses and releases the SET button again, freezing the tens digit at its current number, and starting the 'ones' digit (right hand digit). Upon reaching the desired number in the 'ones' digit position, the operator presses and releases the SET button freezing the 'ones' digit at its current number. The RF Channel is now selected.

Life. Life expectancy is the length of time until the sonobuoy scuttles (self-destructs); selections include 0.5, 1, 2, 4, or 8 hours. We recommend selecting the maximum of 8 hours. Depressing the SET button while the desired life is illuminated sets the life.

Depth. Depth relates to the deployment depth of the hydrophone, recorded in feet (U.S.) or meters (U.K.); options include: 90ft (30 m), 200ft (60 m), 400ft (120 m), or 1000 ft (300 m). The LED may read 'd1' for 90 feet, 'd2' for 200 feet, 'd3' for 400 ft, and 'd4' for 1000 ft. Depressing the SET button while the desired depth code is illuminated sets the depth.

The depth selection can dramatically affect the range of detection; however, in our experience our intention is often to focus on animals in close proximity to the deployment location. In fact, detection of sounds from distant whales can complicate the analysis. In most cases, we select a depth of 90ft, which coincides with the approximate calling depth of some baleen whales and will minimize detection of distant calling whales in most situations. If the intention is long-range tracking, then a deeper deployment may be preferred. For example, in the Antarctic, the deep sound channel is relatively shallow, and a sonobuoy depth of 120m (UK) allows for long-range tracking (and there is anecdotal evidence that the suspension may be improved at this depth).

Sensor. The 53F sonobuoys have three options for the hydrophone sensor configuration: CO, CSO, and DIFAR. Frequency responses for the three sensors are provided in Appendix 5. Unless there is a need for broadband recording (> 2.5 kHz), we suggest selection of DIFAR to allow for processing of directional information.

Calibrated Omni (CO) provides capability for high frequency processing, with a response curve calibrated from 5 Hz to 20 kHz (± 1 dB) and minimal frequency roll-off to 25 kHz. The CO hydrophone is physically located ~ 3 ft above the DIFAR package.

Constant Shallow Omni (CSO or CS) is an omni-directional hydrophone deployed to a depth of 45 feet in addition to the regular DIFAR hydrophone.

DIrectional Frequency Analysis and Ranging (DIFAR, or dF) deploys the DIFAR sensors, proving hydrophone sensitivity to ~ 2.5 kHz with orthogonally placed pressure sensors that provide directional information for sound sources.

Recent 53G GPS buoys have an additional sensor option: Extended Calibrated Omni (XCO). The XCO mode supports the uplink of calibrated acoustic signals from the CO hydrophone up to 40 kHz. To support the larger acoustic bandwidth in the XCO mode, the GPS subcarrier is centered at 45 kHz. The subcarrier is centered at 33.5 kHz for all standard acoustic modes (DIFAR, CSO, and CO).

AGC. The automatic gain control (AGC) measures the acoustic energy in the DIFAR omnidirectional channel and uses this information to set the gain of all three DIFAR channels. If high ambient noise is present, the gain in the DIFAR channels is decreased to reduce the probability of saturation. While this may be beneficial for some purposes, it fundamentally changes the gain and therefore the variables associated with the intensity. We suggest selecting AGC = OFF to ensure stable sound measurement.

In some older sonobuoys, the display battery may be dead, resulting in the inability to program the sonobuoy to the desired settings. Although the sonobuoy will still function when deployed, it will use the standard default settings. It is possible on some sonobuoy models to replace this display battery; see Appendix 7 for specific details. Replacing the display battery does require removing the parachute and disabling the depth pin; therefore, it may also require shortening the deployment depth depending on the depth of the water column (see Appendix 2).

GPS Sonobuoys

The 53-G sonobuoys are essentially 53-F with additional GPS capabilities. The GPS Uplink data settings are 1200 baud, 8 bits, no parity, and one stop bit. The subcarrier center frequency is 33.5 kHz in DIFAR, CSO, or CO modes; the subcarrier center frequency is 45 kHz in XCO mode. See the User's Manual for more specifics on these buoys (Undersea Sensor Systems 2011).

Sonobuoy Deployment

Sonobuoys should be fully prepared (see previous section) prior to deployment. We highly recommend that sonobuoys be kept in their intended configuration and that you do **not** remove any parts or otherwise modify them (other than removal of the outer plastic waterproof storage housing). Sonobuoys should be deployed from the same location on deck (to allow for GPS correction).

Proper deployment requires that the parachute be open when it hits the water, to allow it to act as a drogue and slow the sinking of the buoy. Ideally, sonobuoys would be deployed from a drifting vessel and care would be taken to ensure vertical deployment and expansion of the parachute. If the vessel can move slowly or have the engines disengaged—that is also helpful. Unfortunately, most sonobuoy deployments from a NMFS survey must be done at full (or near full) speed. For deployment from a moving vessel, it is advised that the technician deploy from a high platform and/or toss the sonobuoy high (to increase the opportunity for the parachute to open). We also suggest that you do not deploy in the prop wash, if at all possible.

Sonobuoy signals are received on VHF radios; therefore, they are subject to interference by other VHF signals, including shipboard radio communications. This effect is more dramatic when the sonobuoy signal is not strong (increased distance to sonobuoy) or when the radio communications are particularly strong. Shipboard radio communications wired to the masthead antenna are much stronger than the handheld radios. To reduce radio interference, all shipboard communications should use handheld radios, preferably over UHF or CB bands, during the recording.

If the vessel is turning—the sonobuoy should be deployed on the outside of the turn and near the stern of the ship. Deployment off the stern decreases the chances that the wires may get entangled in the propeller; deployment on the outside of a turn decreases the chances it may be hit by the vessel. If the vessel is drifting, the vessel will drift at a faster rate than the sonobuoy in most cases (the hull of the ship acts like a sail). The sonobuoy should be deployed from the windward side of the ship. If the drift is due to currents—this may require specific consideration to avoid entanglement and it may be best to deploy underway to minimize risk.

If you need to retrieve the sonobuoy, be sure not to touch the sea-water ground when holding the metal parts of the buoy. Disable battery power connection to the surface unit by cutting the seater battery ground wire (black wire). Pull the remaining hardware up by pulling on the signal cable.

Compass Calibrations

Bearing angle estimates provided by processing of the DIFAR sensor are subject to several sources of error. The bearing angles provided by the sensor are subject to local magnetic deviation, which varies in time and space. The accuracy and precision of bearing angles show some level of individual buoy variation. Manufacturers' specifications require that bearing angles are accurate within ±10°, and expired buoys may not meet these standards. It is in the best interest of researchers to identify the precision and accuracy of bearing angles for a given sonobuoy and, if possible, to improve the accuracy of these estimates. In addition to individual buoy calibration, sonobuoy drift may lead to inaccurate localization, even if individual bearing angles are accurate. Methods to address these sources of error use sounds produced by a known sound source at a known location (typically the noise produced by the research vessel) to allow for individual buoy calibration and estimation of sonobuoy drift. As there is no one-size-fits-all scenario for calibrating during sonobuoy deployments, we aim to provide some important points to allow you to make the best decision possible.

Initial sonobuoy calibration (to adjust for local magnetic deviation and individual sonobuoy variation) should be conducted soon after the sonobuoy is deployed. Bearing angle estimates have higher variability when the vessel is extremely close (within 500 m) of the deployed sonobuoy, yet the calibration must be completed soon after buoy deployment, before the buoy has had time to drift. Therefore, sonobuoy calibration would begin after the vessel has transited ~ 500m from the buoy and continue while the vessel is transiting in a straight line away from the buoy until a sufficient number of calibration samples have been made (we suggest 10-20 samples), or the vessel noise has decreased to less than 10 dB above ambient. We have found that bearing angle estimates are unreliable for sounds whose signal-to-noise ratio is below 10 dB above ambient.

Drift calibration requires additional calibration sounds from a known sound source with known location (again, typically noise from the research vessel). These noise samples should be obtained sometime after the buoy has been deployed, and ideally at many compass angles. While the newly available GPS sonobuoys (53-G) should provide an accurate reading of the drift, at the writing of this document we do not (yet) have a means of accessing these GPS data. We suggest that drift calibration data be collected whenever possible to allow for estimation, even with the GPS sonobuoy models.

Calibrations require sample sounds from a known source location. Strong tonal components in the noise generated by the vessel can provide an ideal calibration signal, though these will typically vary depending on the operating conditions (engine revs, gearing, propeller pitch, speed, course, etc). At close range, ship noise may saturate the hydrophone and recording chain, making bearing angle measurements unreliable. Likewise, sonobuoys require some time to initialize, and if a vessel is transiting at 10 knots during deployment, it takes ~ 100 sec to move 500 m from the vessel. Increased use of quiet vessels may make it difficult to obtain vessel noise samples beyond 500m. So, the reliability of the calibration bearing angles will vary depending on each specific vessel and situation. You may need to work with your ship officers to identify a means of making noise on the ship. An alternative sound source includes weighted light bulbs (Heard et al. 1997).

Intensity Calibration

Sonobuoys all have hydrophone sensitivity specified to within ±3 dB. This means that it is possible to obtain relatively accurate estimates of the received level of sounds (in µPa) provided that all of the instruments in the recording chain are also calibrated (Maranda 2001). However, unlike cabled hydrophones where the sensitivity is specified in units of V/µPa, the sensitivity of the sonobuoys are specified as a reference pressure and frequency deviation (i.e. in terms of the radio signal in units of kHz/µPa). Thus, the calibration of the radio receivers, specified in units of V/kHz frequency deviation, is also an important part of retrieving absolute sound pressure levels from a sonobuoy. By multiplying the sonobuoy sensitivity with the radio calibration, one can obtain the hydrophone sensitivity in the familiar units of V/µPa.

Measuring the receiver calibration is beyond the scope of this document, but in general it involves measuring the voltage output of the receiver for relevant modulation frequencies as a function of frequency deviation in Hz. If available, the manufacturer's specifications may be used, caveat emptor, if empirical calibration is not possible or practical. For example, the WinRadio G39WSB in the SARS has a flat (±1 dB) modulated frequency response from 0.005 – 20 kHz (i.e. audio band), and an output level (receiver calibration) of:

$$1.0 \pm 0.2\ V_{rms}\ @\ 75\ \text{kHz frequency deviation} = 0.0133$$

This can then be combined with the known voltage limits and gain from the sound card, as well as the reference pressure and frequency response curve of the sonobuoy sensors (APPENDIX 5. Frequency Response Curves) in order to obtain calibrated sound pressure levels re 1 µPa. It is worth noting that different sonobuoys and sensors within (e.g. CO, CXO, CSO, and DIFAR) may have both different reference pressures as well as frequency response curves. For example, in DIFAR mode 122 dB re 1uPa generates 25 kHz frequency deviation. Thus the hydrophone sensitivity, S (in dB re 1 V/uPa), of a WinRadio G39WSB and a DIFAR buoy would be:

$$S = 20 * \log(0.0133\ \text{V/kHz} * 25\ \text{kHz}) - 122\ \text{dB re 1 uPa} = -131.542\ \text{dB re 1 V/uPa}$$

Lastly, the shaped frequency response can be accounted for by transforming digital samples x[t] into the frequency domain, e.g. by taking the FFT of the time series of digitized samples, X = FFT(x[t]). The calibrated amplitude spectrum A, can then be obtained by multiplying or dividing the amplitude of X by each of the calibration factors such that:

$$A = X * V * S / F$$

Where A is in units of µPa/Hz; V_{adc} is the voltage limits of the sound card; S is the combined hydrophone sensitivity above from above; and F is the frequency response curve of the sonobuoy (APPENDIX 5. Frequency Response Curves). NB: This multiplicative equation for A requires linear units (i.e. not dB). If desired, the calibrated spectrum, A, can then be transformed back into the time-domain via inverse FFT.

Metadata Requirements

Regardless of the type of sonobuoy protocols being followed, there is some core information that should always be collected for each sonobuoy deployment. Some of the information, namely VHF channel, is only required in-situ for operational purposes. The rest of the information is required for meaningful interpretation and post-processing of the acoustic data. At the bare minimum the following should be recorded for every deployment:

- Date & time of deployment recorded as precisely as possible (ideally within a few seconds of the buoy hitting the water)
- Latitude and Longitude of deployment (again as precisely as possible)
- Sonobuoy type and settings (VHF channel. Depth selection, duration, and operational mode)
- Instrument connection and channel map (e.g. table of radio serial number(s), sound card channel(s), software channel(s), and connections amongst them)
- Nature, timing and location of sound source used for compass/drift calibration

Additionally, it may be useful, but not essential to record:

- Whether the buoy had any issues or outright failed
- Results of compass calibration (mean & standard deviation of bearing errors)
- Date and time of the ending of the recording
- Sonobuoy deployment number and recording protocols followed

Opportunistic Sonobuoys

Opportunistic sonobuoys are typically deployed on baleen whale sightings for which at least 15 minutes will be dedicated to the sighting, although criteria for deployment may vary based on species and survey priorities. A sample protocol for opportunistic sonobuoy deployment during baleen whale sightings is provided in Appendix 8; this protocol was used during the HICEAS 2017 survey.

Ideally, at least two buoys will be deployed in the vicinity of the whale(s). Typically, the first buoy will be deployed in transit to the sighting (to allow for ample time for buoy calibration. The second sonobuoy will (ideally) be deployed in close proximity to the whale, but such that there is NOT a straight line between the two buoys and the sighting, as this complicates localization (Fig. 3a). Ideally, the second sonobuoy would be deployed at a small or moderate distance to the sighting, but offset from the line-of-sight between the first sonobuoy and the whale (see Fig. 3b). Alternatively, if the buoys are deployed on either side of the whale (so that the whales and buoys are in a line), this can be effective as long as the vessel remains at a distance and not on the same line. Remember that bearing angles from the vessel noise could override the bearing angles from the whales—so you want to ensure that the bearing angles to whales and vessel are at very different bearing angles. Every effort should be made to provide some straight-line transit away from the second sonobuoy to allow for calibration.

After each buoy is deployed, the vessel should maintain a straight-line transit away from the buoy, ideally until it has transited at least 1 km from the buoy (preferably 1.5 km).

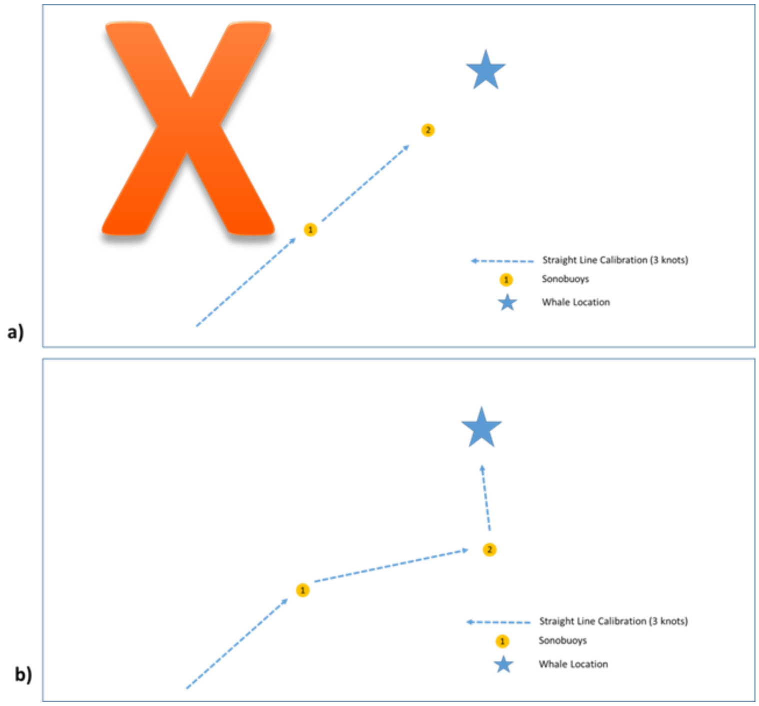


Figure 3. Sonobuoy deployment configuration options for opportunistic sonobuoys. A sub-optimal configuration (3a) where buoys, vessel, and whale are in a line limits localization options. A preferred configuration will provide significantly different DIFAR bearing angles from each buoy to the whale (3b).

Sonobuoy Stations

Sometimes sonobuoys are not deployed specifically in response to a particular sighting, but rather at specific times or specific intervals to acoustically sample an area. We refer to these as 'sonobuoy stations'. Each station may consist of a single sonobuoy or multiples, depending on resources and the research question. Typically station-type data require consistency in deployment and monitoring methods to ensure comparability between stations. To this end, we highly recommend that a consistent plan for calibration and monitoring be determined prior to the survey.

We provide an example of a sonobuoy station protocol, used during the HICEAS 2017 survey. These consisted of paired sonobuoys deployed each afternoon shortly after the end of visual-observer effort. It was critical that stations occur during the same time each day, and that the protocol was strictly adhered to. The data collected during these sonobuoy stations were intended for estimation of call density/whale density, and variation from the protocol would adversely affect the density estimation. A full sample protocol for sonobuoy deployment during sonobuoy stations is provided in Appendix 9.

For these sonobuoy stations, we required a period of straight-line calibration immediately after the sonobuoy is deployed (extending beyond 1 km from deployment location) as well as an angular calibration to provide data to correct for sonobuoy drift. This scenario was developed to allow for the deployment and calibration of buoys to occur between the end of daytime operations and the start of oceanographic (CTD) operations.

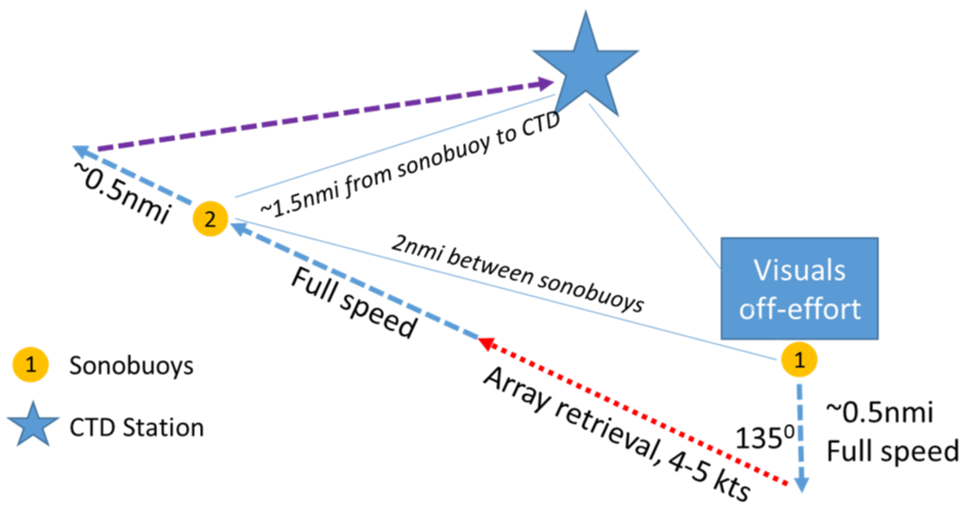


Figure 4. Sonobuoy deployment and vessel course/speed adjustments for sonobuoys stations. Sonobuoy station protocol should begin immediately after cessation of effort; strict adherence to sonobuoy protocol is required for sonobuoy stations.

Real-time tracking

Sonobuoys can also be used in a different manner yet again to assist in locating rarely encountered species (e.g. Crance et al 2017, Miller et al 2015). These real-time tracking sessions/surveys often involve first conducting regularly spaced/timed single- or paired-sonobuoy stations as described above. However, upon detection of sounds from the target species additional sonobuoys would then be deployed in an adaptive manner to locate the calling animal/group. There is no one-size-fits-all protocol for real-time tracking, however, the following general strategy has proven fruitful in practice, and should be relatively straightforward to adapt to a novel situation.

In general, real-time tracking requires the ability to steer the ship in order to home-in on the sound source. In practice, homing-in on sounds involves following bearing lines and continuing to deploy sonobuoys at regular intervals (e.g. every hour). As the ship approaches the calling animal, bearings from successive sonobuoys will eventually start to change as each sonobuoy is deployed closer-to the animal (and will eventually point backwards if visual observations are not made before the ship passes the animal). Additionally, calls from successive sonobuoys will likely show an increase in intensity, though this is often more subtle and less reliable an indicator than changes in bearings. One can continue home-in until a) visual observers see the target animal, or b) the animal stops calling, or c) the ship must enter into another mode of operation.

DISCUSSION

This report serves as a basic introduction to using sonobuoys for cetacean research on NMFS surveys. This document discusses the 53-F sonobuoys (and the closely related 53-G); however, there are a large number of other sonobuoy models that are not discussed here (e.g., 53-D, 77A, etc.). Software analysis is rapidly developing, and any discussion of software will soon be outdated. Many researchers use their own custom designed code (typically in Matlab); we would recommend the Pamguard DIFAR module for others.

Sonobuoys contain lithium batteries and CO2 cartridges, and are therefore considered hazardous materials. They require hazmat labeling on shipping and may be prohibited from being shipped via airplanes (or prohibitively expensive).

ACKNOWLEDGEMENTS

Anke Klueter helped with data collection during the sonobuoy playback experiment. Fieldwork was conducted aboard the M/V *Horizon* during a sea trial to test equipment (funded separately by NOAA's Cooperative Research Program), R/V *Ocean Starr* for CalCurCEAS data collection, and R/V *Oscar Elton Sette* and R/V *Rueben Lasker* for HICEAS data collection. Thanks to lead field acousticians Emily Griffiths and Shannon Coates for their assistance in field data collection. Special thanks to Erin Oleson for modifying the sonobuoy station deployment plan while underway with HICEAS.

REFERENCES

Crance, J.L., Berchok, C.L., and Keating, J.L. (**2017**). "Gunshot call production by the North Pacific right whale *Eubalaena japonica* in the southeastern Bering Sea", Endangered Species Research, 34, 251-267.

Gillespie, D., Gordon, J., McHugh, R., McLaren, D., Mellinger, D. K., Redmond, P., Thode, A., Trinder, P., and Deng, X.-Y. (**2008**). "PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans," J. Acoust. Soc. Am. 30, 54-62.

Heard, G. J., McDonald, M., Chapman, N. R., & Jaschke, L. **(1997)**. Underwater light bulb implosions, a useful acoustic source. *To appear in Proc. IEEE Oceans, 97*, 755-762.

Mc Donald, M. **(2004).** "DIFAR hydrophone usage in whale research," Can. Acoustics, 32(2), 155-160.

Maranda, B. H. (2001). Calibration Factors for DIFAR Processing 1-28 pages. Defence Research Establishment Atlantic Canada

Miller, B.S., Calderan, S., Gillespie, D., Weatherup, G., Leaper, R., Collines, K., and Double, M.C. (**2016**). "Software for real-time localization of baleen whale calls using directional sonobuoys: A case study on Antarctic blue whales," J. Acoust. Soc. Am., 139, EL83-EL89.

Miller, B.S., Barlow, J., Calderan, S., Collins, K., Leaper, R., Olson, P., Ensor, P., Peel, D., Donnelly, D., Andrews-Goff, V. and Olavarria, C. **(2015)**. "Validating the reliability of passive acoustic localisation: a novel method for encountering rare and remote Antarctic blue whales," Endangered Species Research, 26(3), 257-269.

Miller, B.S., Gedamke, J.A., Calderan, S.U., Collins, K., Johnson, C.A., Miller, E., Samaran, F., Smith, J., Double, M.C. (**2014*a***). "Accuracy and precision of DIFAR localisation systems: Calibrations and comparative measurements from three SORP voyages," SC/65b/SH08 presented to the IWC Scientific Committee, Bled, Slovenia, 13 pp.

Miller, B. S., Wotherspoon, S., Rankin, S., Calderan, S., Leaper, R., and Keating, J. L. (2018). "Estimating drift of directional sonobuoys from acoustic bearings," J. Acoust. Soc. Am., 143, EL25-EL30. doi:10.1121/1.5020621

Oleson, E. M., Barlow, J., Gordon, J., Rankin, S., & Hildebrand, J. A. **(2003)**. "Low frequency calls of Bryde's whales," Marine Mammal Sci., 19(2), 407-419.

Rankin, S., & Barlow, J. **(2007)**. "Vocalizations of the sei whale *Balaenoptera borealis* off the Hawaiian Islands. *Bioacoustics*," Bioacoustics 16(2), 137-145.

Rankin, S., Barlow, J., and Keating, J. (**2016**). "Passive acoustic density estimation of baleen whales: Using sonobuoys to estimate call-rate correction factors," Report to Navy Living Marine Resources, 19 pp.

Rankin, S., Barlow, J., and Stafford, K. **(2006)**. "Blue whale (*Balaenoptera musculus*) sightings and recordings south of the Aleutian Islands," Marine Mammal Sci., 22(3), 708-713.

Rone, B. K., Berchok, C. L., Crance, J. L., and Clapham, P. J. **(2012)**. "Using air-deployed passive sonobuoys to detect and locate critically endangered North Pacific right whales," Marine Mammal Sci., 28, E528-E538.

Širović, A., Bassett, H. R., Johnson, S. C., Wiggins, S. M., Hildebrand, J. A. **(2013)**. "Bryde's whale calls recorded in the Gulf of Mexico," Marine Mammal Sci., 30, 399-409.

Undersea Sensor Systems, Inc. **(2011)**. "User's manual for SSQ-53F/GPS Sonobuoy". Report for Contract No. N00164-08-C-GP08 Mod P00009.

Wade, P., Heide-Jørgenesen, M. P., Shelden, K., Barlow, J., Carretta, J., Durban, J., LeDuc, R., Munger, L., Rankin, S., Sauter, A., and Stinchcomb, C. **(2006)**. "Acoustic detection and satellite-tracking leads to discovery of rare concentration of endangered North Pacific right whales," Biological Letters, 2, 417-419.

APPENDIX 1. Field Data Collection Troubleshooting

1. No Reception on Receivers

Did the sonobuoy float inflate? If not, it could be a bad buoy. Give it 10-15 minutes and ask if anyone else saw the float inflate.

Double-check that the receiver channel matches the sonobuoy channel. If you are not sure of the sonobuoy channel, then scan all channels to see if you get reception elsewhere.

Do the 'channels' on the WinRadio receivers match the frequencies they are supposed to? (check the chart)

2. I sometimes hear loud interference.

Does it coincide with radio communication? If so, ask the observers/crew to minimize radio communication and ask the bridge to switch to handheld radios, if possible.

Is the sonobuoy far away? As the signal gets weaker, it takes less and less to 'interfere' with the signal. You may need to move closer to the sonobuoy.

3. Everything was fine for a while, then the sound from the buoy turned to bad noise.

Check the WinRadio receivers…. Are they still getting reception? If no, then there is a good chance your buoy has died a sudden death (although they have been known to come back from the dead).

4. Poor Reception

Reception problems are related to one (or more) of the following: (1) Signal attenuation/losses on the receiving system, (2) Radio noise on nearby radio bands, (3) Line of sight between antenna and transmitter, and (4) Low transmitter signal strength (bad buoy).

- **Signal Attenuation/Loss on Receiving System.** Signal attenuation is probably the most straightforward thing to test while at sea. It is not unheard of for the masthead amplifier to die, creating a disconnect between the antenna and the coaxial cable (and therefore poor reception). A fully functioning amplifier should add 20dB gain to the signal. While monitoring the WinRadio power meter, completely disconnect the masthead amplifier and Bias-tee from the coaxial cable to test whether or not it's actually working. If the amp is working, then you should notice an increase a 20 dB increase in power when it's plugged in vs. when it's not. This 20 dB difference when the amp is used should be apparent even when viewing the background radio levels (e.g. background radio power level of -100 dBm when the amp is plugged in, vs background radio power level of -120 dBm without the amp, so you can do this test without deploying a sonobuoy. If the masthead amplifier fails, replace or remove completely (do not leave a malfunctioning amplifier in place). It is also possible that a masthead amplifier can make VHF reception worse (especially when radio signals are weak). Local transmitting devices on the ship (e.g. AIS transmitters, wifi, handheld VHF comms, satellite broadband) can cause the masthead amp to saturate, and thus degrade the reception from sonobuoys.

If replacing/removing the masthead amplifier doesn't solve the problem, then you next check the antenna, coaxial cable, splitter, and connectors. Cuts, nicks, and corrosion on the coaxial cable and connectors can definitely degrade the signal. In addition to visual inspection of the cable, you'll probably want to swap out each of the cables, splitter, connectors, and antenna one at a time with known-to-be-good replacement parts (while continuing to record radio power & distance for each new combination of components) in order to rule them out as the culprit.

- **Radio noise on nearby radio bands.** Similar to the masthead amplifier, the frontend of the WinRadio may become desensitized by local transmitters (even with the masthead amp disconnected). To test for desensitization, request that the bridge crew turn off each transmitting device (including broadband internet, wifi, SSB, VHF, radar, AIS, and anything else that might use a radio) for the duration of one sonobuoy deployment (while of course measuring radio power as a function of distance). If full shipboard radio blackout solves your reception issues, then you can work with the bridge to turn on instruments one at a time in order to locate the worst interference sources. It is likely that many of these transmitting devices serve critical safety function. The intention is to identify offensive devices and relocate the sonobuoy antenna away from these interfering devices.

Consideration of inline passive low-pass and high-pass filters to reject signals outside the sonobuoy band may guard against desensitization (Mini-circuits NHP-150+ (HIGH PASS FLTR / N-connector), NLP-150+ (LOW PASS FLTR / N-connector). While use of these filters will result in overall signal loss (of a few dB), this additional attenuation may be preferred to a desensitized receiver (although, initial tests did not see much difference with use of filters).

- **Line of Sight for Sonobuoy Antenna.** The placement of the antenna is critically important for good radio reception. But ideally you want the antenna to be placed: a) as high as possible, b) away from other metal superstructure with clear views to the horizon 360° around, c) away from any transmitting sources, and d) not too far from the WinRadios (to minimize the length of cable required). If you are using a dual antenna system (i.e., omnidirectional and directional antenna), ensure that you are on the correct antenna. If using the directional antenna and the vessel turns, the sonobuoy will no longer be in line with the antenna, resulting in signal loss.

- **Low transmitter signal strength (Bad Buoy).** There is little you can do to remedy a situation of poor buoy signal strength. Problematic buoys tend to be rare, but an entire lot can be problematic (especially with very old sonobuoys). Many researchers have identified ways to replace batteries, seal for leaks, and otherwise modify sonobuoys to address these issues. These modifications are beyond the scope of this document and we advise you demand newer buoys! (Good luck on that, by the way!)

APPENDIX 2. Sonobuoy Depth Modifications

In the event the parachute needs to be removed and the depth pin disengages, or if the deployment water depth is shallow (30 m or less), the sonobuoys can be modified to shorten deployment depth. The following details how to shorten the sonobuoys. It is important to note that the depth of the hydrophones on modified sonobuoys may not be at the same depth as a sonobuoy deployed with the parachute intact. Thus, modifying sonobuoy depths should be avoided in situations where precise hydrophone depth is required.

In every sonobuoy there is a main spool of 1000 ft of wire – this is the spool that will unwind to the depth setting selected. If the depth pin is disengaged, the entire spool will deploy, resulting in a deployment depth of 1000 ft. To shorten the depth to ~90 ft, this main spool of wire must be bypassed in some manner. The following steps will describe this process.

Shortening an AN/SSQ 53F sonobuoy:

Equipment needed: Scissors, waxed thread (or twine)

1. There are four main internal components inside the metal tube: the first is the top component containing the float. The second plastic housing keeps the first section of bungee and wire contained. The third plastic housing usually contains the main spool of wire and the drogue. At the bottom of the sonobuoy is the metal DiFAR housing.
2. After removing the parachute, pour out the interior components of the sonobuoy only until the top of the third plastic component is accessible, taking care to keep everything as intact as possible (Figure 2a). Locate the section of sonobuoy that contains the main spool of wire. In the 53F, the main spool is in the third plastic housing compartment, with the wire deploying from the top (see Figure 2b).

Figure 2a. Carefully pour out the sonobuoy until the top of the third component is accessible (yellow arrow), trying to keep everything else intact. Note: this is a different type of sonobuoy, but the plastic housing of the inner components look similar.

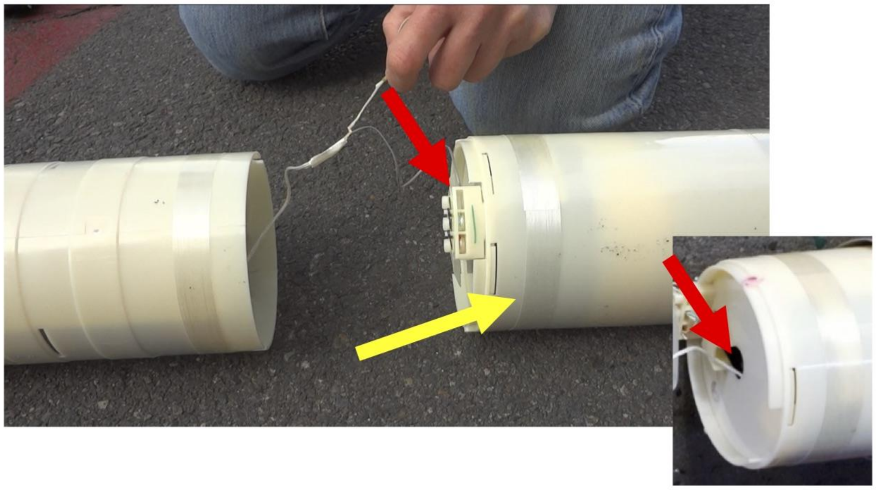


Figure 2b. Locate the section where the main spool of wire comes out, indicated by red arrows. Yellow arrow shows location of main spool.

3. Using waxed thread, twine, or some other string that will not slip, loop the waxed thread through a secure part of each housing, then tie a knot to connect the two housings (Figure 2c). Ensure there is enough space between the two housings to avoid them bumping into each other during deployment (usually ~1-1.5 ft spacing is sufficient unless in high sea states). This should now prevent the main spool of wire from deploying, resulting in a deployment depth of approximately 90 ft.
4. Carefully slide all components back into the metal tube. The sonobuoy is ready for deployment.

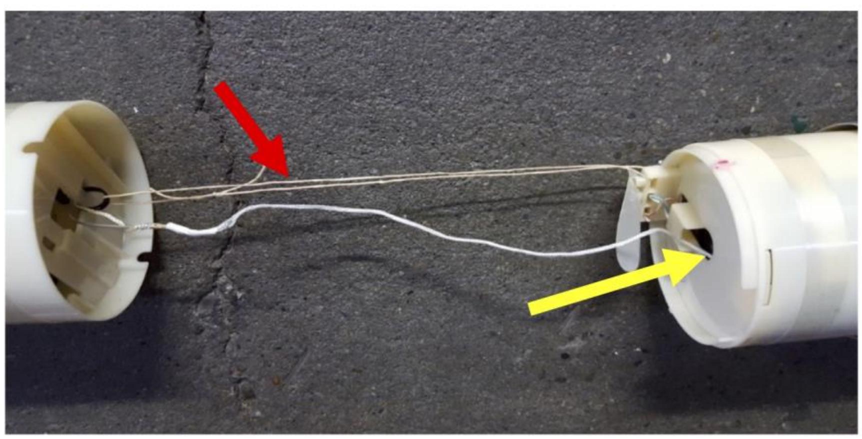


Figure 2c. Waxed thread tied in a knot connecting the two plastic housings (red arrow). This prevents the main spool of wire from deploying out the top of the third component (yellow arrow).

APPENDIX 3. 53-F Specifications

SonobuoyTech Systems

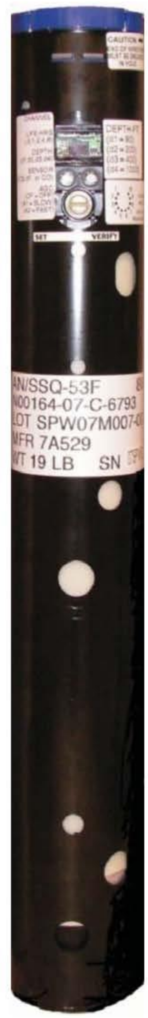
AN/SSQ-53F DIFAR Sonobuoy

Passive Directional

The AN/SSQ-53F is a NATO A-size sonobuoy manufactured for the U.S. Navy which combines a passive directional and calibrated wide band omni capability into a single multi-functional sonobuoy. This advanced sonobuoy combines the capabilities of both the AN/SSQ-53D and AN/SSQ-57 sonobuoys.

The Q-53F can operate in three available acoustic sensor modes that are selectable via EFS or CFS. A Constant Shallow Omni (CSO) provides acoustic information at a fixed depth of 45 ft (13.7 m) while a Calibrated Omni (CO) co-located with a DIFAR sensor provides acoustic information at a selectable operational depth. The buoy amplifies the underwater acoustics and provides directional data necessary to establish bearing to the source of the acoustic energy.

This sonobuoy features both Electronic Function Select (EFS) for use prior to loading and launching, and Command Function Select (CFS) to allow the operator to modify the sonobuoy's mode of operation after it has been deployed in the water. These functions allow the operator to select operating mode (sensor selection), buoy life, depth setting, AGC level and RF channel.



- Acoustic Sensor Selection
  - *CSO, CO, or DIFAR*
- EFS Selectable
  - *RF Channel, Life, Depth, Sensor, AGC level*
- CFS Commandable
  - *RF Channel, Life, Sensor, AGC Level*
- 1 Watt 96-channel RF transmitter
- Factory configurable to AN/SSQ-53D standard
  - *Single Sensor (DIFAR)*
  - *3 Depths (90 ft, 400 ft, 1000 ft)*
  - *No CFS*

Sonobuoy Tech Systems supplies U.S.-specified sonobuoy products and support to the international market.
Phone: 260.248.3503 ◆ Fax: 260.248.3510 ◆ Website: www.sonobuoytechsystems.com

SPECIFICATIONS

Sonobuoy Tech Systems

NSN 5845-01-475-9870

PHYSICAL CHARACTERISTICS

Weight ....8.6 kg (19 lbs)

Sonobuoy Launch Container...LAU-126/A

PERFORMANCE DATA

RF Command Receiver...UHF – single channel

RF Transmitter Power Output..1 W minimum

RF Transmitter Operating Frequency .... 96 Channel Selectable
....(136.000 to 173.500 MHz)

Sensors/Audio Frequencies..CSO (30 to 5000 Hz)
CO (5 to 20 kHz)
DIFAR (5 to 2400 Hz)

Operating Life..0.5, 1.0, 2.0, 4.0, or 8.0 hours

Operating Depth...d1: 27 meters (90 ft)
d2: 61 meters (200 ft)
d3: 122 meters (400 ft)
d4: 305 meters (1000 ft)

EFS selections..RF, Life, Depth, Sensor, and AGC

CFS selections...RF, Life, Sensor, and AGC

Launch Altitude...12 to 9144 meters (40 to 30000 ft)

Launch Speed.. 0 to 370 KIAS

Shelf Life .... 5 years in sealed container

Ultra Electronics USSI
4578 East Park 30 Drive
Columbia City, IN 46725

Sparton Electronics
Government Business Systems
5612 Johnson Lake Road
Deleon Springs, FL 32130

Sonobuoy Tech Systems, is a joint venture between Undersea Sensor Systems Incorporated and Sparton Electronics Florida, Inc.

APPENDIX 4. 53-G Specifications

SonobuoyTech Systems

AN/SSQ-53G DIFAR Sonobuoy

Passive Directional

The AN/SSQ-53G DIFAR US Navy A-size sonobuoy combines a passive directional and calibrated wide-band omni capability into a single multi-functional sonobuoy. This DIFAR sonobuoy has a GPS capability that requires Command function Select (CFS) for GPS operation. GPS is initially off at splash.

This sonobuoy features both Electronic Function Select (EFS) for use prior to loading and launching and Command Function Select (CFS) to allow the operator to modify the sonobuoy's modes of operation after it has been deployed in the water. These functions allow the operator to select operating mode (sensor selection), buoy life, depth setting, AGC level and RF channel.

The AN/SSQ-53G can operate in four acoustic sensor modes that are selectable via EFS or CFS. A Constant Shallow Omni (CSO) provides acoustic information at a fixed depth of 45 ft (13.7 m) while a Calibrated Omni (CO) co-located with the DIFAR sensor provides acoustic information at a selectable operational depth. The Calibrated Omni sensor can operate with acoustic bandwidths of 20 KHz (CO) or 40 KHz (XCO). The buoy amplifies the underwater acoustics and provides directional data necessary to establish bearing to the energy source.

The AN/SSQ-53G has GPS location reporting capabilities to transmit formatted messages. The Sonobuoy transmits the GPS messages per CFS commands on a subcarrier centered at 33.5 KHz for CSO, CO, and DIFAR modes or centered at 45 KHz for XCO mode.

The AN/SSQ-53G is air launchable from fixed or rotary-wing aircraft or can be deployed from the deck of a surface vessel. Descent of the sonobuoy is stabilized and slowed by a parachute.

- Acoustic Sensor Selections
  - *CSO, CO, XCO, or DIFAR*
- EFS Selectable
  - *RF Channel, Life, Depth, Sensor, AGC level*
- CFS Commandable
  - *RF Channel, Life, Sensor, GPS, AGC Level*

SonobuoyTechSystems supplies U.S.- specified sonobuoy products and support to the international market.

Phone: 260.248.3503 • Fax: 260.248.3510 • Website: www.sonobuoytechsystems.com

Sonobuoys are subject to the International Traffic in Arms Regulations (ITAR)

Sonobuoy Tech Systems

SPECIFICATIONS

NSN 5845-01-630-5313

PHYSICAL CHARACTERISTICS

Weight	9.5 kg (21 lbs)
Sonobuoy Launch Container	LAU-126/A

PERFORMANCE DATA

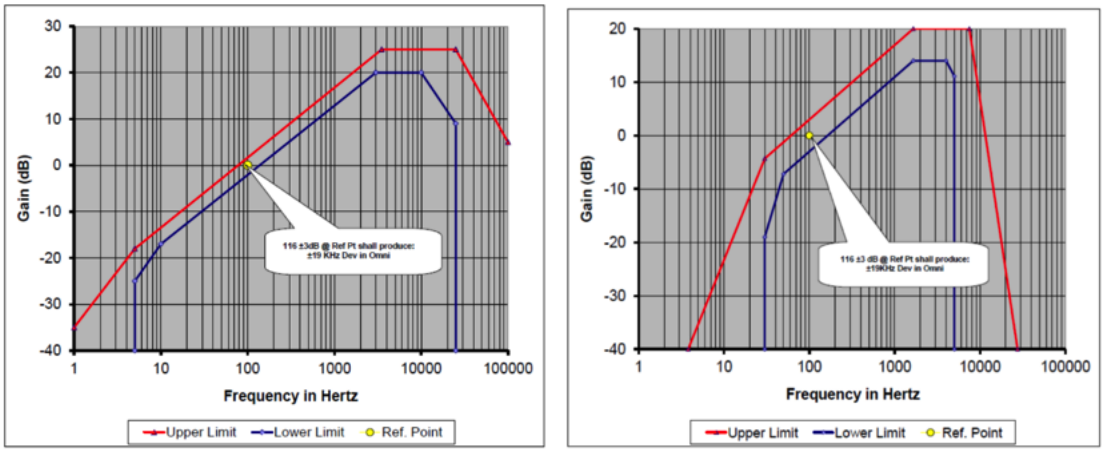
RF Command Receiver	UHF – single channel
RF Transmitter Power Output	1 W minimum
RF Transmitter Operating Frequency	97 Channel Selectable (136.000 to 173.500 MHz)
Sensors/Audio Frequencies	CSO (30 to 5000 Hz) CO (5 to 20 KHz) DIFAR (5 to 2400 Hz) XCO (5 to 40 KHz)
Operating Life	0.5, 1.0, 2.0, 4.0, or 8.0 hours
Operating Depth	d1: 27 meters (90 ft) d2: 61 meters (200 ft) d3: 122 meters (400 ft) d4: 305 meters (1000 ft)
EFS selections	RF, Life, Depth, Sensor, and AGC
CFS selections	RF, Life, Sensor, GPS and AGC
Launch Altitude	12 to 9144 meters (40 to 30000 ft)
Launch Speed	0 to 370 KIAS
Shelf Life	5 years in sealed container

Ultra Electronics USSI
4868 East Park 30 Drive
Columbia City, IN 46725

Sparton Deleon Springs LLC
5612 Johnson Lake Road
Deleon Springs, FL 32130

APPENDIX 5. Frequency Response Curves and Intensity Calibration

.



a) b)

Figure 1. Frequency response for 53-F (a) Calibrated Omni-directional (CO) Sensor and (b) Constant Shallow Omni-directional (CSO) sensor.

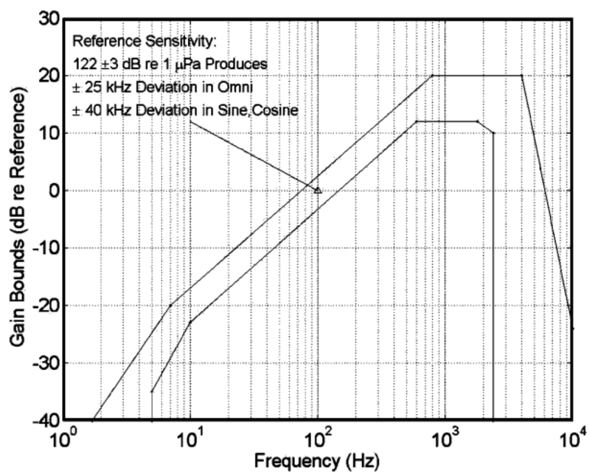


Figure 2. Frequency response for 53-G standard and extended CO.

APPENDIX 6. Sonobuoy Channel-Frequency

Channel	Freq	Channel	Freq
1*	162.250	52	143.500
2	163.000	53	143.875
3	163.750	54	144.250
4	164.500	55	144.625
5*	165.250	56	145.000
6	166.000	57	145.375
7	166.750	58	145.750
8	167.500	59	146.125
9	168.250	60	146.500
10	169.000	61	146.875
11	169.750	62	147.250
12*	170.500	63	147.625
13	171.250	64	148.000
14	172.000	65	148.375
15	172.750	66	148.750
16	173.500	67	149.125
17*	162.625	68	149.500
18	163.375	69	149.875
19*	164.125	70	150.250
20	164.875	71	150.625
21	165.625	72	151.000
22	166.375	73	151.375
23	167.125	74	151.750
24	167.875	75	152.125
25*	168.625	76	152.500
26	169.375	77	152.875
27	170.125	78	153.250
28	170.875	79	153.625
29	171.625	80	154.000
30	172.375	81	154.375
31	173.125	82	159.750
32	136.000	83	155.125
33	136.375	84	155.500
34	136.750	85	155.875
35	137.125	86	156.250
36	137.500	87	156.625
37	137.875	88	157.000
38	138.250	89	157.375
39	138.625	90	157.750
40	139.000	91	158.125
41	139.375	92	158.500
42	139.750	93	158.875
43	140.125	94	159.250
44	140.500	95	159.625
45	140.875	96	160.000
46	141.250	97	160.375
47	141.625	98	160.750
48	142.000	99	161.125
49	142.375		
50	142.750		
51	143.125		

(* these channels prohibited within 200 miles of the coast)

APPENDIX 7. Replacing a dead display battery

Some of the older sonobuoys may have a dead display battery, meaning when pushing the set or verify buttons, nothing happens and nothing appears on the LED display. Note: this does not mean the sonobuoy will not function, but rather it will deploy using the factory default settings. In order to set the sonobuoy to the desired settings, the battery must be replaced. Some sonobuoys have a 9V alkaline battery, while others contain a 6V lithium. The lithium battery can be replaced with a 9V alkaline, though it involves additional steps. The following steps detail how to replace both a 9V alkaline and a 6V lithium battery. Additionally, sometimes the 9V alkaline battery snap connector is corroded. The following steps will also detail how to replace the snap connector. Sonobuoys manufactured by Sparton (SPW) cannot have the battery replaced, as the internal electronics cannot be accessed in the top component (though it is rarely needed with SPW sonobuoys). Note: when replacing the display battery, the parachute must be removed and the top component extracted from the sonobuoy. This will disable the depth pin, causing the sonobuoy to deploy to the full 1000 ft.

How to replace the display battery in an AN/SSQ-53E or 53F:

Equipment needed: For all sonobuoys: thin standard screwdriver, large standard screwdriver, 9V alkaline battery. For sonobuoys with lithium batteries or corroded snap connectors you will also need a 9V alkaline battery snap connector, electrical tape, wire strippers, scissors or precision dikes.

1. Remove the parachute from the sonobuoy by using a large standard screwdriver to pry up the plastic bar in the horizontal plane and pull out the top gray piece (Figure 7a). Then pull out the top housing component (containing the float).

Figure 7a. Remove parachute to access the top component with the float.

2. On each side of the housing is a silver metal bar that must be removed. Using the thin standard screwdriver, carefully pry up the corner of this silver bar and remove the bar from the housing (Figure 7b). Use caution as sometimes the bar will spring off the housing unexpectedly.

Figure 7b. Use a small thin standard screwdriver to pry up the silver bars on either side of the top component.

3. Once the two bars are removed, set them aside. Using the screwdriver, place the end near the top of the housing near the o-ring and gently pry the top piece away from the rest of the housing (Figure 7c).

Figure 7c. Use the screwdriver to pry the lid off the top of the component.

4. Lift the top piece completely out of the housing and leave it hanging off to the side. Locate the dead display battery along the side of the internal compartment and pull it out (Figure 7d).

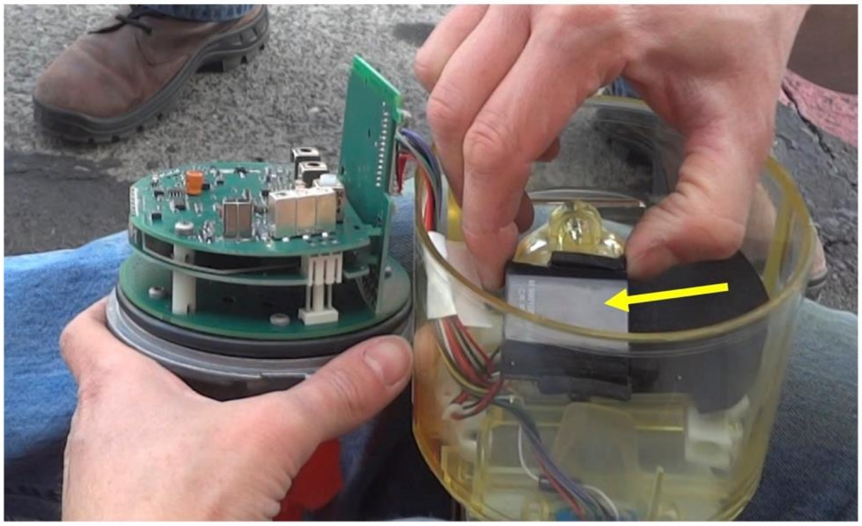


Figure 7d. Locate the dead display battery (in this case, a 6V Lithium battery, yellow arrow).

5. If the dead display battery is a 9V alkaline, and the snap connector is good, simply replace the old 9V with a new one. Then skip to step 7. If the dead battery is a 6V lithium, or if the snap connector is corroded and needs to be replaced, use either scissors or precision dikes to cut the dead battery wires just above the connector (Figure 7e).

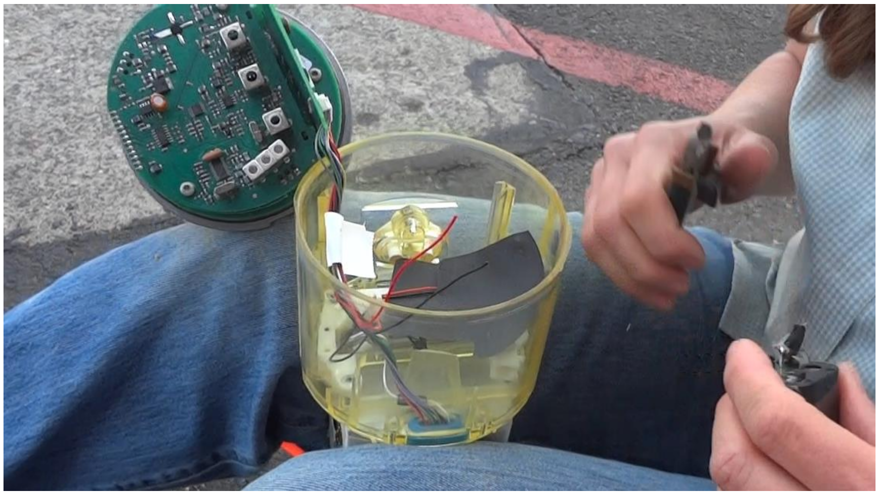


Figure 7e. Cut battery wires just above the connector using scissors or precision dikes.

6. Strip the ends of the display battery wires, leaving approximately 0.5” of exposed wire. Take a new snap connector and splice the ends of the new snap connector onto the exposed ends of the display battery connectors, connecting red to red, and black to black (Figure 7f). Place a small piece of electrical tape over the exposed splices for protection. Insert a new 9V battery.

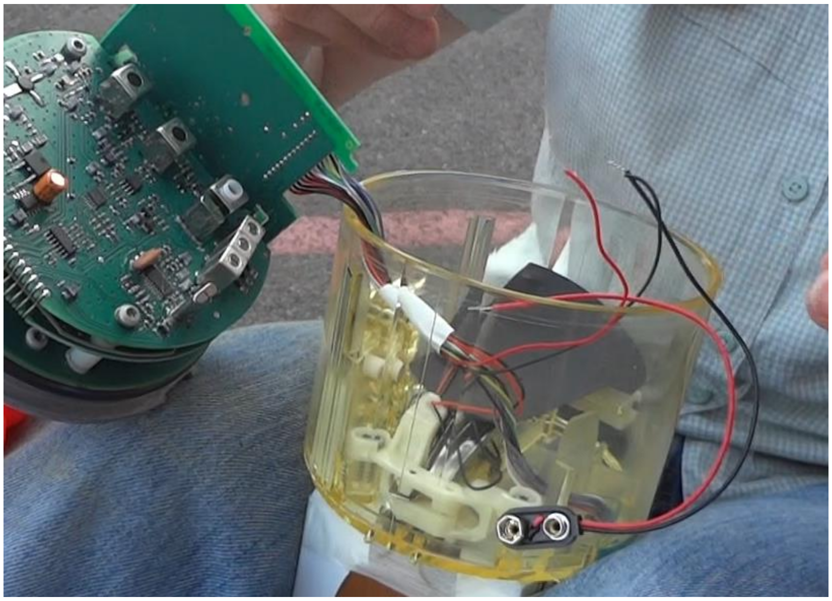


Figure 7f. Strip the ends of the battery wires and splice on the new 9V snap connector, connecting red to red and black to black. Wrap splices in electrical tape for protection. Insert a new 9V alkaline battery.

7. Slide the new 9V battery back into the battery space within the internal compartment. Then slide the top piece back into place by lining up the sides of the top piece into the designated grooves on the inside of the compartment (Figure 7g). Press the top gently but firmly all the way back into place.

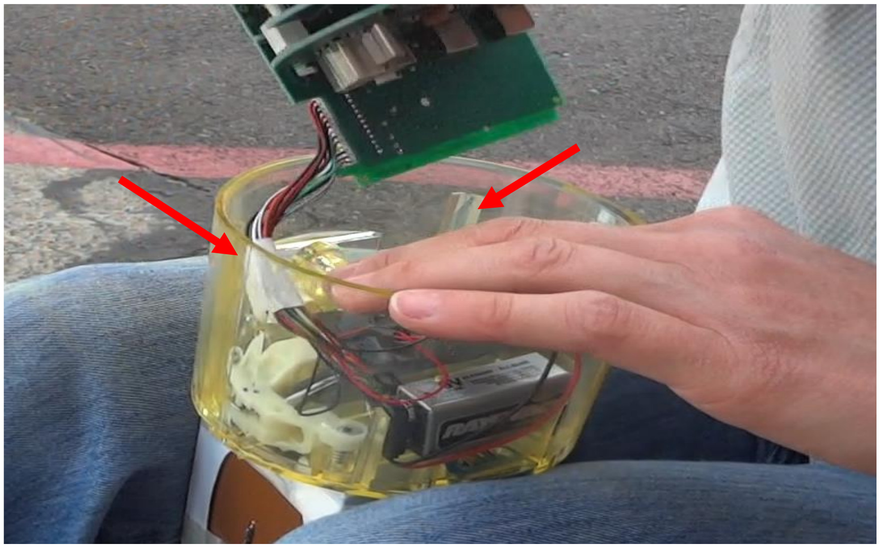


Figure 7g. Put the new 9V battery back into place, then re-insert the top component lid by sliding the green PCB back into the grooves on the side, indicated by red arrows.

8. Test the new battery before reinstalling the metal bars. Press the verify button on the display. The display should now light up. If it does not, remove the top piece and check the splicing, or try placing a new 9V battery in the snap connector. Note: the top piece must be firmly back in place before pressing the verify button.
9. Replace the metal bars on each side of the top compartment. Start by placing one end of the bar into place, then using the back end of the screwdriver, hitting the other end of the bar until it snaps into place (Figure 7h). This may take some force.

Figure 7h. After ensuring that the display battery now works (by hitting the Verify button), replace the metal bars on the side of the housing. Place one end in the groove, then using the end of the screwdriver, tap the other end until the bar snaps in place. This may take some force.

10. Place the top compartment back into the metal tube. If the sonobuoy deployment depth needs to be shortened (because the depth pin was disengaged), you may now begin the steps necessary to shorten the sonobuoy (see Appendix 2).

APPENDIX 8. Opportunistic Sonobuoy Protocol Example

Opportunistic sonobuoys will be deployed on all baleen whale sightings for which we spend > 15 minutes in the area. Successful implementation will require an initial meeting with all acousticians and any officers/crew that may participate in sonobuoy stations.

REQUIREMENTS

Opportunistic sonobuoys will be deployed on baleen whale sightings where photo and/or biopsy attempts are made (or, where the vessel spends > 15 minutes in the area).

To reduce radio interference, all shipboard communications should use handheld radios during all sonobuoy recordings.

METHODS

1. **Preparation:** There should always be 3 sonobuoys (minimum) prepared for opportunistic deployment according to the channels shown in Table 1 (only two will be used, the third is a prepared backup). Note that these channels are different than the channels for sonobuoy stations, so that if there is an overlap in time/space, the station can be conducted in systematic fashion without radio interference. Channel selection is dependent upon the frequency at which the antenna is tuned; each antenna may be tuned differently and as a result may require different channel selections. Confirm that there are no other sources of interference. Acoustician will open and prepare Pamguard software according to channel designation shown in Table 1 and following detailed instructions.

Table 1. Channel configuration for opportunistic sonobuoy deployments.

Sonobuoy #	Sonobuoy Channel	WinRadio Channel	FireFace Channel	Pamguard Channel
1	62	1	1	0
2	64	2	2	1
3	54	TBD	TBD	TBD

** TBD = To Be Determined; backup sonobuoy will use the WinRadio/ FireFace/Pamguard channel it is replacing.*

2. **Deployment:** Deployment of the first buoy will occur in transit to the sighting (so there is ample time to calibrate before reaching the immediate area). The second sonobuoy will (ideally) be deployed in closer proximity to the detection, but such that there is **NOT** a straight line between the two buoys and the sighting, as this complicates localization (Fig. 1a). Ideally the second sonobuoy would be deployed at a small distance to the sighting, but not between the first sonobuoy and the second sonobuoy; an example of an ideal

deployment configuration is shown in Fig. 1b. Every effort should be made to provide some straight-line transit away from the second sonobuoy to allow for calibration.

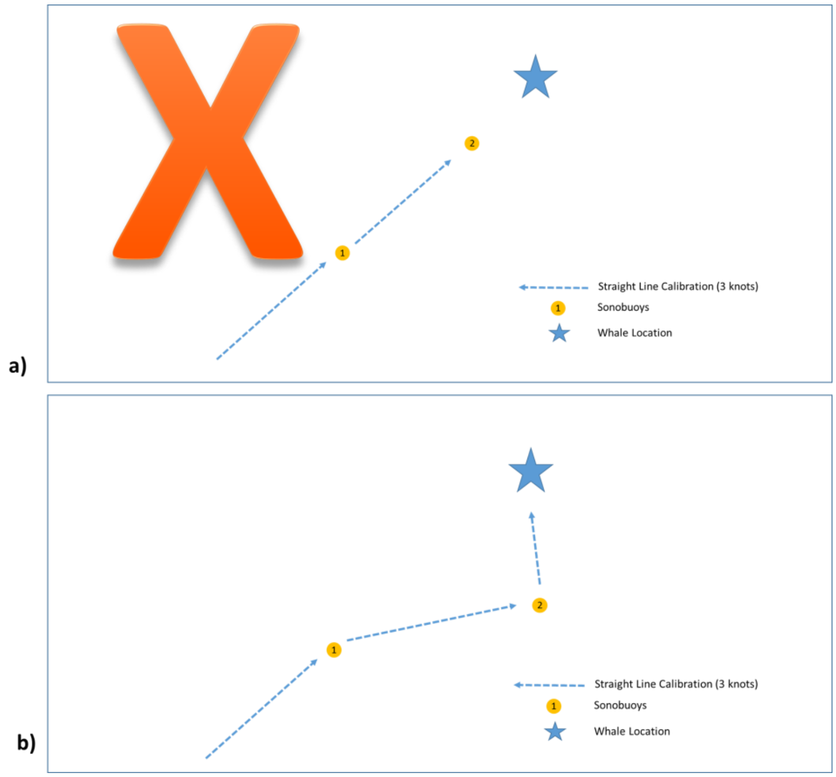


Figure 1. Sonobuoy deployment configuration options for opportunistic sonobuoys. A sub-optimal configuration (1a) where the buoys, vessel, and whale are in a line limits localization options. A preferred configuration will provide significantly different DIFAR bearing angles from each buoy to the whale (1b).

3. **Straight Line Calibration:** Real-time calibration will begin shortly after deployment for each sonobuoy (see detailed instructions). If variation in bearing angles varies by > 20 degrees while the vessel is traveling on a straight course, then the buoy will be considered to be poor quality. If time/opportunity allows, the third (backup) sonobuoy will be deployed in the location of the poor quality buoy. In this case, the straight line calibration must be completed in full.

4. **Recording:** Continue recording until sonobuoy reception is lost on both sonobuoys.

APPENDIX 9. Sonobuoy Station Protocol Example

Sonobuoy stations will be conducted during evening CTD operations; data will be used for call density estimation. It is imperative that the protocol is strictly applied. Sonobuoy deployment and calibration will begin when the visual survey team goes off effort at the end of the day, will continue while the towed array is being retrieved, and be completed prior to stopping for the evening CTD station. Successful implementation will require an initial meeting with all acousticians and any officers/crew that may participate in sonobuoy stations. The movements of the ship are important as the ship is acting as a sound source to calibrate the bearing angles derived from the sonobuoy sensors.

REQUIREMENTS

There are insufficient sonobuoys to conduct stations *every* night; station dates will be pre-selected (to avoid sampling bias). Sonobuoy station protocol will be followed for each evening in which the sonobuoy station is assigned unless cancelled by Cruise Leader or OOD.

To reduce radio interference, all shipboard communications should use handheld radios during all sonobuoy recordings.

METHODS

1. **Schedule:** Confirm that it is a Sonobuoy Station Positive date (see schedule, at end).
2. **Preparation:** Prepare 3 sonobuoys set to the channels shown in Table 1 (only two will be used, the third is a prepared backup). Confirm that there are no other sources of interference. Acoustician will open and prepare Pamguard software according to channel designation shown in Table 1 and following detailed instructions.

Table 1. Channel configuration for sonobuoy stations.

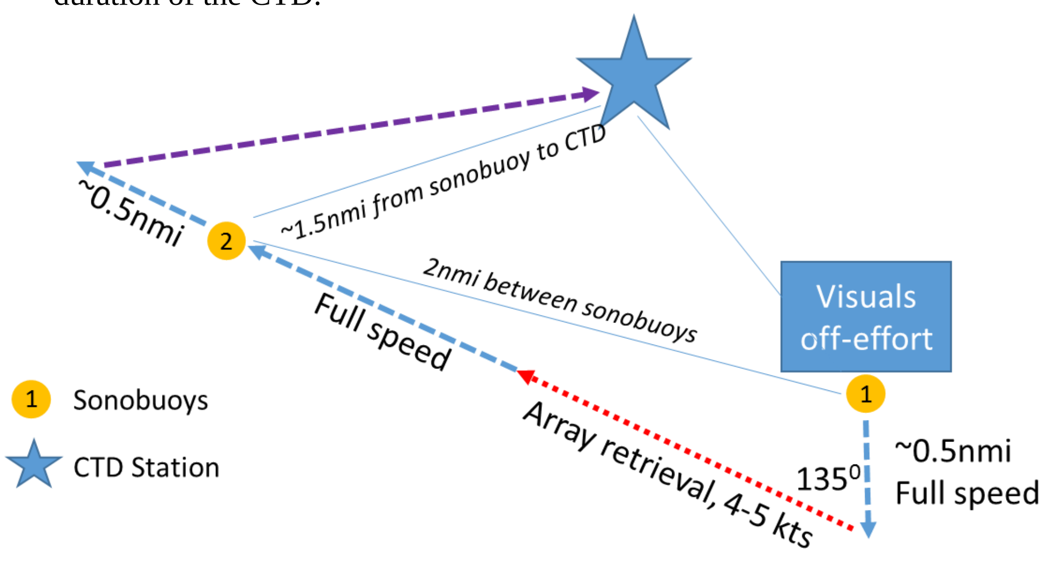
Sonobuoy #	Sonobuoy Channel	WinRadio Channel	FireFace Channel	Pamguard Channel
1	56	1	1	0
2	60	2	2	1
3	54	TBD	TBD	TBD

** TBD = To Be Determined; backup sonobuoy will use the WinRadio/ FireFace/Pamguard channel it is replacing.*

3. **Deployment:** To ensure that calibration is completed before the CTD station, it is imperative that the sonobuoy protocol begin as soon as possible after cessation of daytime effort. All sonobuoys should be deployed at the same location on the vessel. When the Visual Team radios that they are going off effort, the Acoustics Team should be prepared to deploy the first sonobuoy. Deployment of the 2 sonobuoys will proceed as follows:

*If either sonobuoys fail for any reason, then sonobuoy #3 will be deployed as close to the location of the failed sonobuoy as possible. The vessel will then need to repeat the Straight Line Calibration before moving onto the next step.

a. **Visual Team Off-Effort for the day**- Acoustic Team deploy sonobuoy #1. Acoustician in lab will immediately hit the 'DEPLOY' button in the DIFAR interface in Pamguard. OOD on watch will mark the position on the navigation screen.
b. **Straight Line Calibration #1**: Continue in a straight line at full speed (blue line). Acousticians will conduct straight-line calibration in PAMGUARD. When complete (after ~0.5 mi) radio to the Bridge to turn 135^{o} (OOD can choose direction based on prevailing conditions, hazards, etc.) and slow to 4-5 kts.
c. **Angular Calibration #1 & Array Recovery:** Once steadied up on new course and slowed to appropriate speed, begin recovering towed hydrophone array (red line). OOD determine location of sonobuoy #2 along this track to position sonobuoy #2 2 nmi from sonobuoy #1.
d. **Ensure 2 nmi distance between sonobuoys:** Once array recovery is complete return to full speed (blue line). OOD will provide a 2 minute warning to Acoustics Team of upcoming sonobuoy station, and then a countdown to the deployment location. Acoustics Team deploy sonobuoy #2 at location indicated by OOD.
e. **Straight Line Calibration #2**: Continue in a straight line at full speed (blue line). Acousticians will conduct straight-line calibration in PAMGUARD. OOD will determine location of upcoming CTD to ensure it is equidistant to the two deployed sonobuoys at a distance of approximately 1.5 mi to each.
f. **Angular Calibration #2 & positioning for CTD:** When straight-line calibration is complete (after ~0.5 mi) radio to the Bridge to turn toward the CTD station (purple line). Continue to CTD station at full speed. Acoustician should ensure they have adequate sonobuoy radio signal and maintain recordings for the duration of the CTD.



Sonobuoy deployment and vessel course/speed adjustments for sonobuoys stations. Sonobuoy station protocol should begin immediately after cessation of effort; strict adherence to sonobuoy protocol is required for sonobuoy stations.