TECHNICAL REPORT 3273
April 2022

Standardized Unclassified Nomenclature to Describe Navy Sonar Signals

E. Elizabeth Henderson
Tyler A. Helble
NIWC Pacific

Susan Jarvis
Stephanie Watwood
NUWC Newport

Naval Information Warfare Center Pacific (NIWC Pacific)
San Diego, CA 92152-5001

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Administrative Notes:
This report was approved through the Release of Scientific and Technical Information (RSTI) process in April 2022 and formally published in the Defense Technical Information Center (DTIC) in April 2022.
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NIWC Pacific
San Diego, CA 92152-5001

NIWC Pacific
San Diego, California 92152-5001

A. D. Gainer, CAPT, USN
Commanding Officer

W. R. Bonwit
Executive Director

ADMINISTRATIVE INFORMATION

The work described in this report was performed by the Environmental Readiness Branch of the Intelligence, Surveillance, and Reconnaissance Department, Naval Information Warfare Center Pacific (NIWC Pacific), San Diego, CA. Funding was provided by the Navy's Living Marine Resources (LMR) Program.

Released by
Mark Xitco, Division Head
Reconnaissance and Interdiction

Under authority of
Mike McMillan, Department Head
ISR Department

ACKNOWLEDGMENTS

We would like to acknowledge Anu Kumar and Mandy Shoemaker at LMR for their support in this work, and Christy Cowan at Fleet Forces for her invaluable assistance in facilitating communications with sonar operators to inform this report.

Editor: RJP

EXECUTIVE SUMMARY

This report presents an unclassified vocabulary for describing sonar signals in public documents and presentations. The development of a unified nomenclature system is crucial as navy-funded research into the impacts of sonar on marine species advances and non-navy researchers without access to classified information are analyzing these signals. The terminology presented here provides specific ways to describe sonar signals and their components, including how to recognize and interpret artifacts arising from how a signal may interact with the environment or with the recording device.

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FIGURES

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1. INTRODUCTION

The classification of various aspects of Navy sonar creates barriers to open public discussion and non-Navy scientific studies that deal with Navy sonar. Navy researchers often have access to classified information regarding the sonar (e.g. the source type, beam pattern, source level, ship distance, etc.) that are not available to non-Navy researchers. This tends to create a disparity when these communities come together to discuss the impacts of Navy sonar on marine life. Furthermore, gathering data on the impact of Navy sonar activity on marine species is currently a requirement of Navy environmental compliance; this research is actively conducted by both Navy and non-Navy researchers. However, due to the lack of access to information about sources that may be present, non-Navy bioacousticians that assess the impact of sonars on marine species have developed their own individual terminologies to describe sonar signals. These terminologies may lead to confusion when interpreting results from different organizations – e.g., are they looking at the same signal with different descriptions, or are they seeing different signals altogether? For example, the individual components of a sonar signal have been described as a ping or pulse, but those terms have also been used to describe the whole combined sonar signal. There have also been various terms used to describe a bout or series of sonar signals, and the period between signals. Unified terminology is important for comparing impact determinations to sonar use requests in Navy letters of authorization.

To facilitate the use of unified terminology, the Navy has developed the following unclassified terminology and rulebook to describe sonar signals that can be used by all researchers to describe sonar in a similar manner. This should assist with reporting results back to Navy sponsors, as well as provide a common language for peer-reviewed publications such that readers will clearly understand what signals are present.

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2. DESCRIPTORS

The following terminology and description guidance have been developed using unclassified standard Navy terminology where possible, and includes methods to describe signals where underlying specific details may be classified.

2.1 BASIC COMPONENTS

1. Each individual component of a sonar signal is a ***Pulse***. The combined components are a ***Waveform***.
2. The **pulses** can be described as either ***Frequency-Modulated (FM)*** or a ***Continuous Wave (CW)***.
    a. A **continuous wave waveform** is a single frequency tone, while a **frequency-modulated waveform** is a tone that changes in frequency over its duration.
    b. The sweep direction of an FM Pulse can also be noted if important (e.g. upsweep FM-CW-CW)
3. The duration of the signal is called the ***Waveform Duration***
4. When describing a waveform, characterize it by each pulse type plus the overall minimum and maximum frequency (***bandwidth***) and ***duration of the signal*** (e.g. FM-CW-CW with 1 kHz bandwidth from 3 to 4 kHz and waveform duration of 2.5 sec, see Figure 1).
    a. The preference is to describe the whole waveform, rather than each individual component
    b. However, if components need to be described, follow these same guidelines (pulse type plus minimum/maximum frequency and duration)

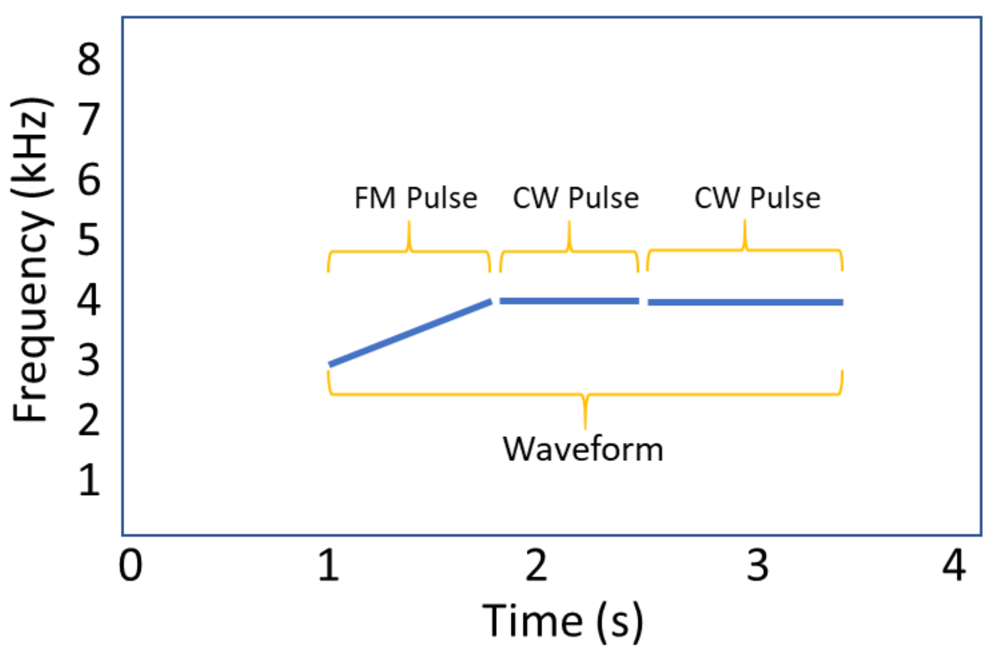


Figure 1. An FM-CW-CW waveform with a 1 kHz bandwidth from 3 to 4 kHz and duration 2.5 sec.

2.2 MULTIPLE SIGNALS

1. The ***inter-waveform interval*** can be described by the ***interval period*** (e.g. the **repetition rate**) and the percentage of time during the interval period that the signal is on (e.g. **duty cycle**).
2. An entire group of recurring waveforms may last for minutes to hours; these are called ***Bouts***. A **Bout** is defined as a group of waveforms with ***less than a 5-minute interval between individual signals***. If there has been a 5-minute interval or longer, then it would be considered a new Bout (Figure 2).
3. Within each Bout, each waveform type is unlikely to change (e.g. FM-CW-FM will not change to FM-CW-CW and then back), but additional waveforms could start and stop within a bout.

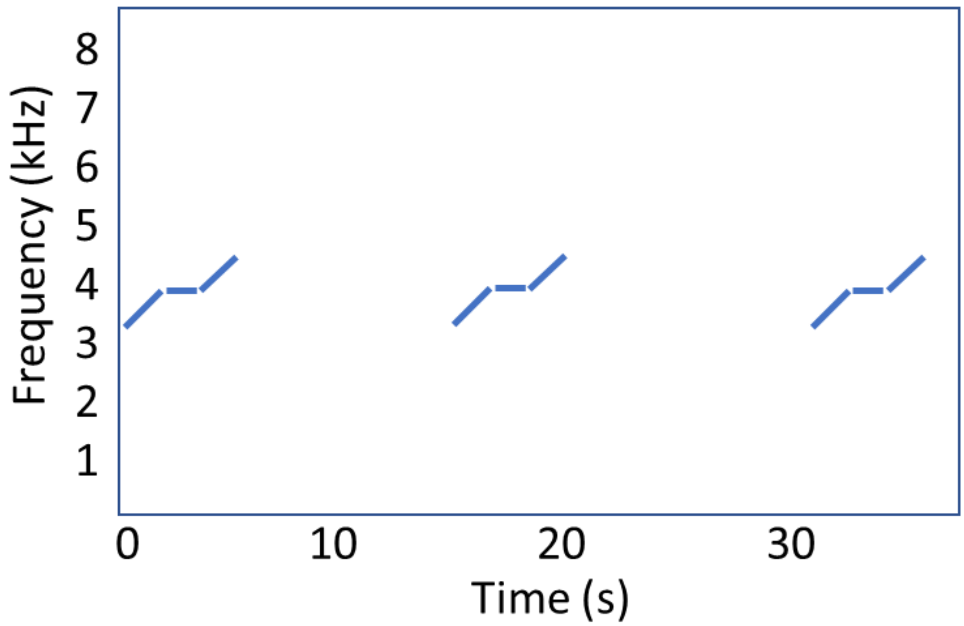
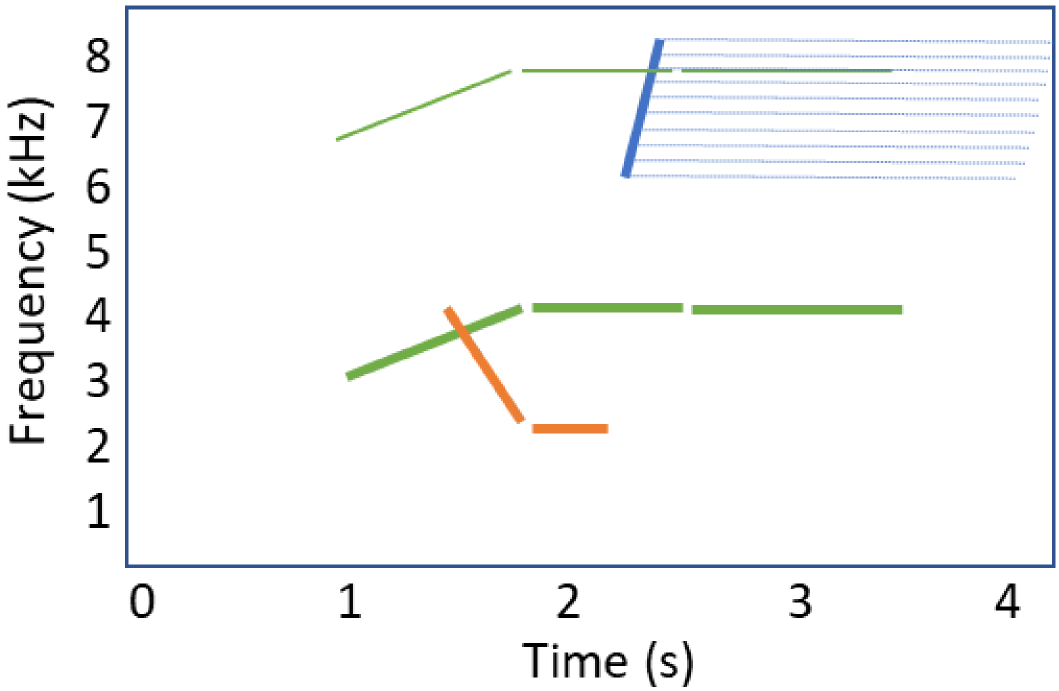


Figure 2. An FM-CW-FM waveform with a 2 kHz bandwidth from 3 to 5 kHz, a duration of 6 sec, and a repetition rate of 15 sec (duty cycle 40%). This example is a 38-sec duration bout.

4. Important: Sonars might have multiple modes of operation; however, these are often classified, and so should not be referred to in open literature even if known (or presumed). It is always preferred for researchers to use the pulse descriptors and waveform frequency and duration information.
5. In the case of multiple, sometimes overlapping **waveforms**, each **waveform** can be described separately using this terminology, if that is of interest/importance. Alternatively, the description can simply state that multiple waveforms are present, with an estimate of the number, and the overall bandwidth (minimum and maximum frequency inclusive of all the waveforms). Because the repetition rates can vary across waveforms, when there are multiple overlapped signals the repetition rate does not need to be described, unless it is important to do so, and then should be described for each individual waveform (Figure 3).



This could be described as three separate signals (orange, green and blue):

1. An FM-CW waveform with a bandwidth of 2 kHz from 2 to 4 kHz and duration of 0.7 sec (orange).
2. An FM-CW-CW waveform with a bandwidth of 1 kHz from 3 to 4 kHz and duration of 2.5 sec with a single harmonic (green).
3. An FM waveform with a bandwidth of 2 kHz from 6 to 8 kHz and duration of 0.2 sec with reverberation (blue).

Alternately, and more simply, this could be described as three multiple overlapping waveforms with a 6 kHz bandwidth (from 2 to 8 kHz).

Figure 3. Depiction of multiple overlapping waveforms..

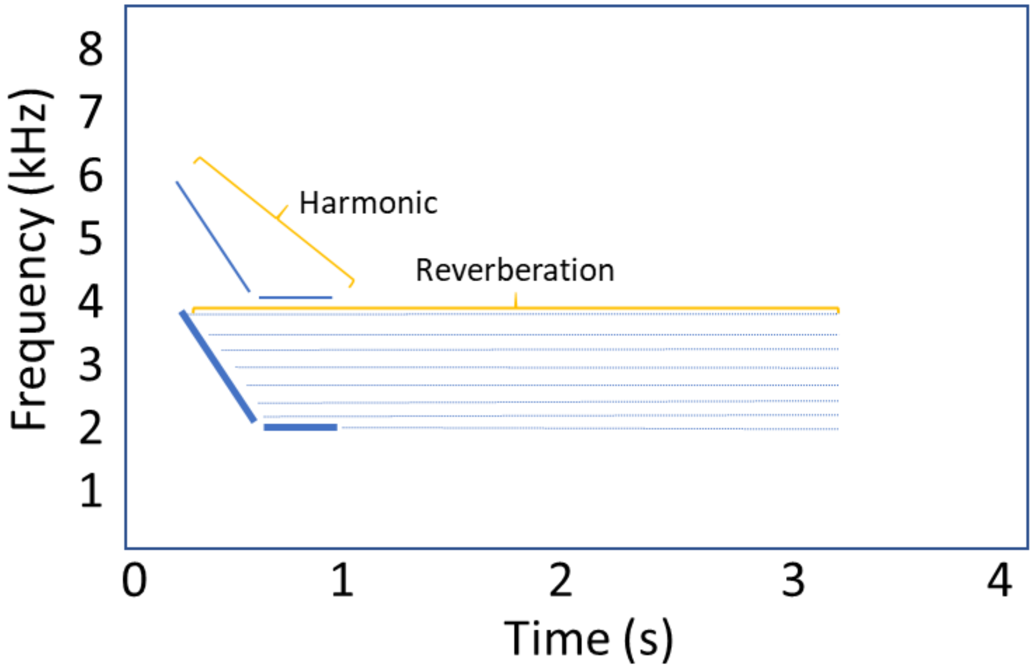
See next Section for definitions of harmonics and reverberation.

2.3 ENVIRONMENTAL/PROPAGATION EFFECTS ON SIGNALS

As sound propagates, the signal is affected by the environment through which it travels such that the received signal is actually a modified version of the transmitted signal. Three common propagation effects are ***Harmonics, Reverberation,*** and ***Multipaths***.

1. A **harmonic** has the same spectral shape as the fundamental signal but appears in the spectrogram at twice (or more) the frequency as the fundamental. **Reverberation** is caused by reflection of the sound within the environment and can sound like a ringing effect.
2. In the case of signals with reverberation or harmonics, the presence of those artifacts can be mentioned, but the frequency and duration information should be confined to the main (or fundamental) waveform. Only the original signal should be used in computations of duty cycle, bandwidth, and duration (e.g. don't include the reverberation "tail" in the estimate of duration, see Figure 4).
3. **Multipaths** are a fainter second copy of the signal that is an echo of the first arrival of the pulse which occurs when the signal is reflected off the surface of the water or the seafloor (or

both) before arriving at the recorder. This is often more evident in FM pulses than CW pulses (e.g. Figure 5).



- Note that the harmonic and reverberation are not included in bandwidth or duration estimation.

Figure 4. A downsweep FM-CW waveform with a 2 kHz bandwidth from 2 to 4 kHz and duration of 0.7 sec with a harmonic and reverberation.

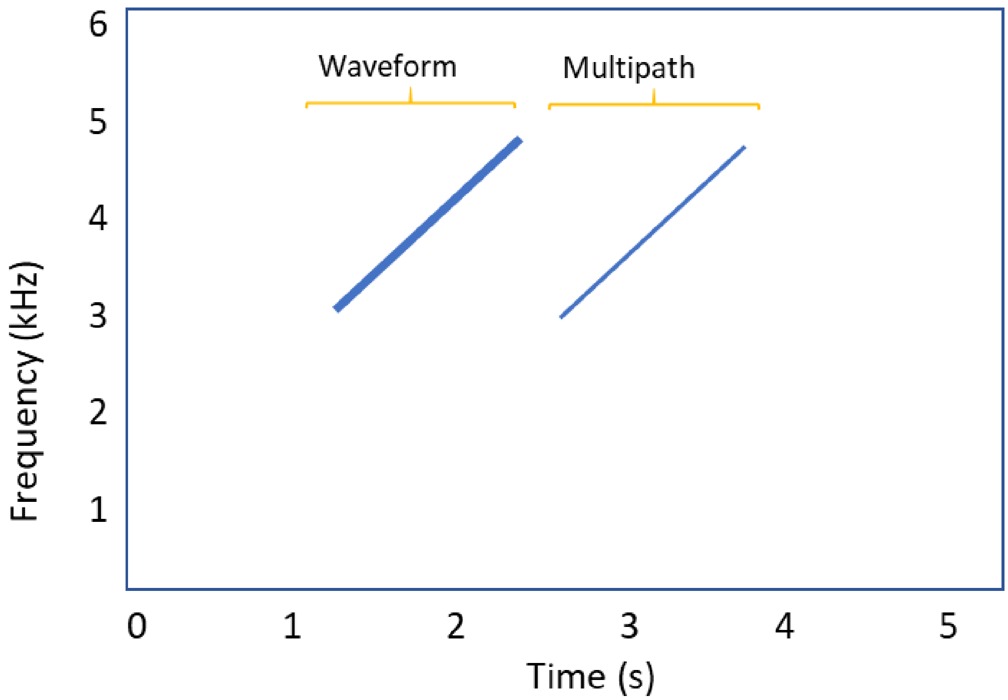
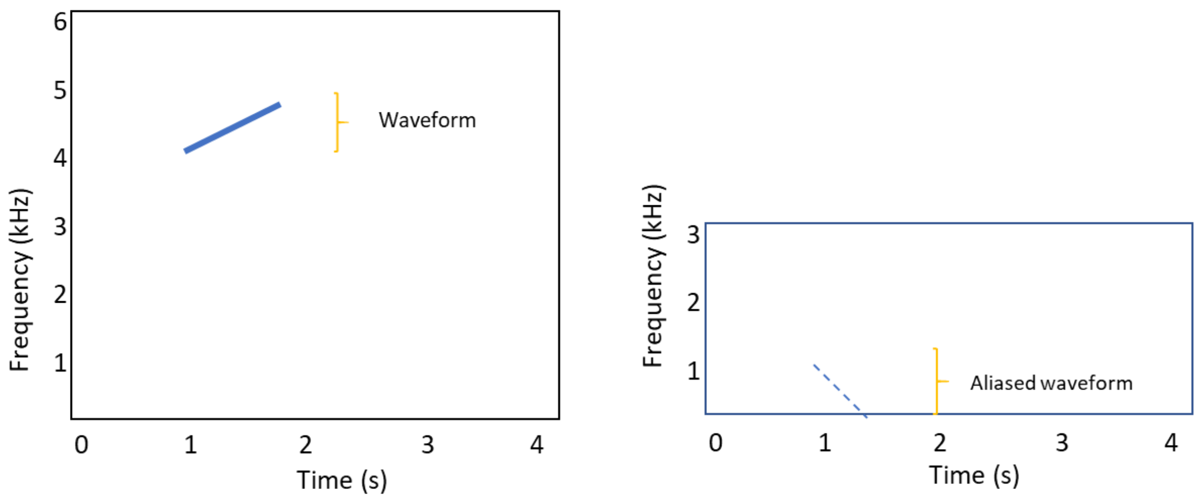


Figure 5. An upsweep FM waveform with a 2 kHz bandwidth from 3 to 5 kHz and a duration of one sec, with a multipath signal following it.

2.4 EFFECTS OF RECORDING DEVICES

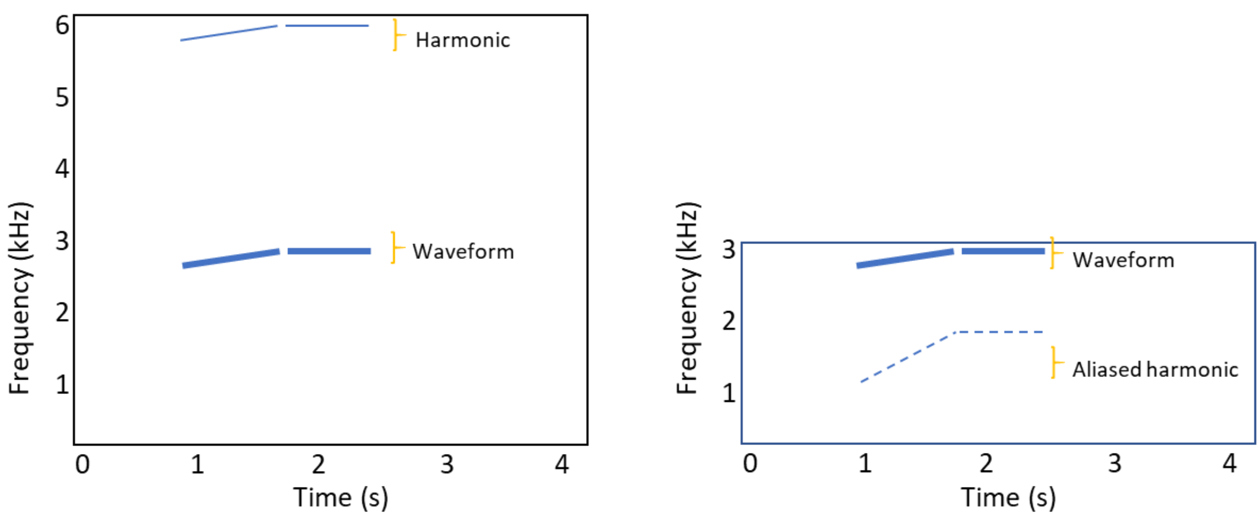
The appearance of signals under analysis can also be impacted by the device on which they were recorded. Different recorders will filter and digitize data in different ways and at different sampling rates, all of which impact the appearance of the signal. Recorder characteristics must be considered when performing acoustic analysis.

1. If an instrument has a sampling frequency such that the signal of interest is a higher frequency than the ***Nyquist frequency*** (i.e. half the sampling frequency), the signal can become ***aliased***. This aliased signal could be mis-interpreted as a real signal, and so caution must be taken to sample at a minimum of twice the highest signal frequency to ensure the full waveforms of interest are captured. The frequency of an aliased signal will be the Nyquist frequency minus the difference between the original signal and the Nyquist frequency (Figure 6). For example, a 10 kHz sampling rate will have a Nyquist frequency of 5 kHz. A 6 kHz signal recorded at this sampling rate will have an aliased frequency of 5 – (6 - 5) = 4 kHz. Frequency modulated signals may also appear distorted. For example, they may appear to be of shorter duration and therefore have a steeper sweep rate. They may also appear to be mirrored or flipped so they sweep in the opposite direction. Even when data are sampled appropriately for the original signals of interest, strong harmonics (above the Nyquist frequency) can also be aliased and appear as a lower frequency than the fundamental signal (Figure 7).



- Left - the original signal sampled at 6 kHz.
- Right - the same signal was sampled at 3 kHz and has been aliased. The signal now appears as a downsweep FM waveform from 0 – 1 kHz and a duration of 0.5 sec.

Figure 6. An upsweep FM waveform with a 1 kHz bandwidth from 4 to 5 kHz and duration of 1 sec, sampled at 12 kHz, with an example of aliasing.

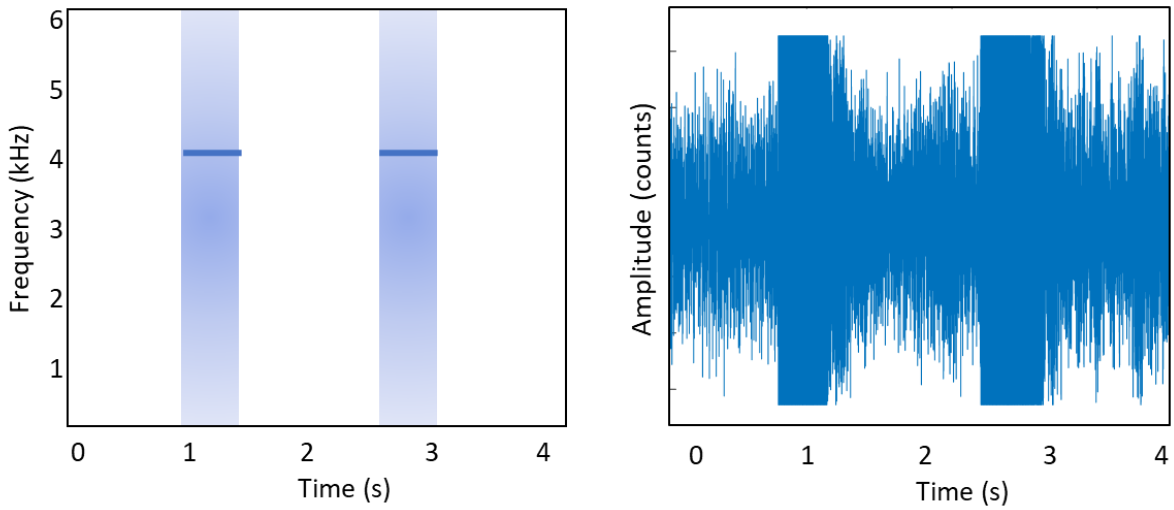


- Left- the original signal was an FM-CW waveform with a 0.5 kHz bandwidth from 2.5 – 3 kHz and duration of 1.5 sec with one harmonic, sampled at 12 kHz.
- Right- when sampled at 6 kHz this signal was still below the Nyquist frequency so the main waveform remains the same, but the harmonic has now aliased.

Figure 7. Examples of aliasing, this time with harmonics.

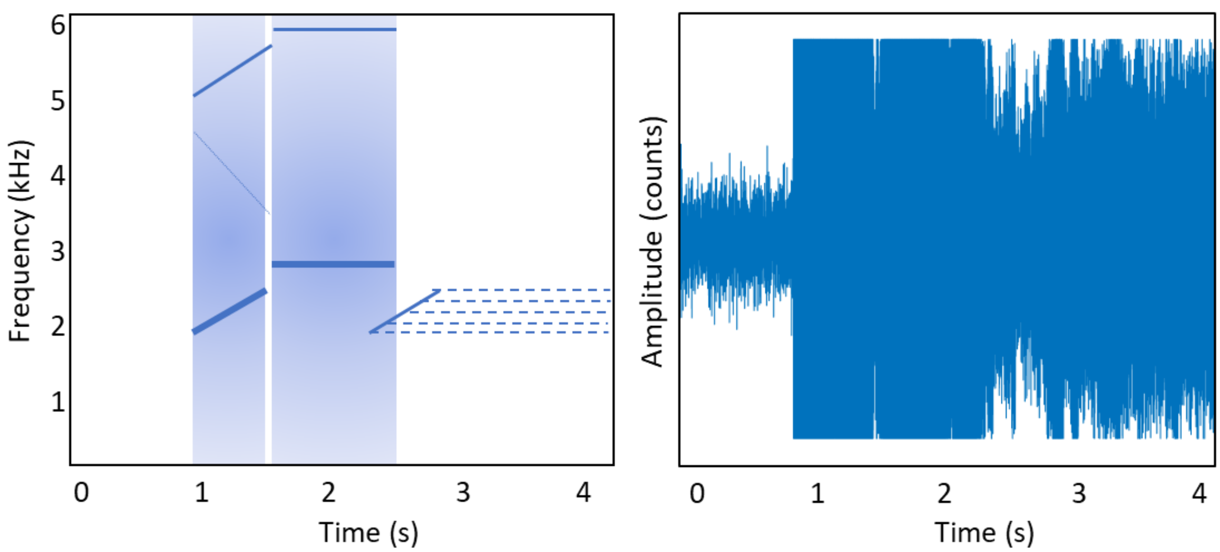
2. If the intensity of the received signal is greater than the sensitivity of the hydrophone or voltage capacity of the analog-to-digital converter, the time series of the signal will be ***clipped*** and the spectrogram of the signal will be distorted. This distortion can look different depending on the waveform (see Figure 8 for an example). There may also be harmonics present as an artifact of the clipping as in Figure 9. Although the clipped signal will have energy spread across the band, the fundamental waveform will still be distinguishable and

should still be described following the above methods, disregarding any of these additional artifacts. The analyst should mention that clipping or aliasing occurred (or environmental effects) but should limit their description to core feature the signal of interest as discussed above.



- Left- depicts the spectrogram with distortion from the clipping.
- Right- shows the time series of the clipped signal.
- The energy present between the signals on the time series represents ambient noise levels.

Figure 8. Two CW waveforms at 4 kHz and 30 sec duration, with a repetition rate of 1 sec, whose signals have been clipped by the analog to digital recorder.



- There is a second faint harmonic on the FM upsweep pulse resulting from the clipping, along with an echo of the FM pulse with reverberation that could result from clipping or as a reflection off the bottom or surface of the water.
- The plot on the right is the clipped time series. Note that even the echoed multipath signal and reverberation are clipped.

Figure 9. A clipped FM-CW waveform with a 1 kHz bandwidth from 2 – 3 kHz and duration of 1.5 sec with one harmonic.

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3. SUMMARY

The unclassified descriptive nomenclature of Navy sonars provided herein are intended to provide a uniform vocabulary to Navy and non-Navy bioacousticians alike. By describing sonar signals using this terminology in reports and peer-reviewed publications, readers from the general public to Navy sponsors will be able to readily understand the signals being described and compare them across publications. In addition, Navy scientists and engineers with classified knowledge of sonar signals will be able to discuss collaborative efforts with non-Navy scientists without concerns of spillage. This nomenclature will thus facilitate research efforts across the bioacoustics community on the analysis of intentional and incidental sonar signals in passive acoustic data.

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-01-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
April 2022	Final	

4. TITLE AND SUBTITLE

Standardized Unclassified Nomenclature to Describe Navy Sonar Signals.

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHORS

E. Elizabeth Henderson
Tyler A. Helble
NIWC Pacific

Susan Jarvis
Stephanie Watwood
NUWC Newport

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NIWC Pacific
53560 Hull Street
San Diego, CA 92152–5001

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-3273

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Living Marine Resources, NAVFAC Engineering and Expeditionary Warfare Center
1000 23rd Avenue
Port Hueneme, CA 93041-4370

10. SPONSOR/MONITOR'S ACRONYM(S)

LMR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A:
Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

unified nomenclature system; pulse; continuous wave; frequency modulated; harmonics; reverberation; multipaths; Nyquist frequency; bioacoustics community

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Elizabeth Henderson
					19B. TELEPHONE NUMBER *(Include area code)*
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