*Aquatic Mammals* 2009, *35*(4), 426-434, DOI 10.1578/AM.35.4.2009.426

# A Brief History of Active Sonar

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**Abstract**

As background for this special issue on strandings and mid-frequency active sonar (MFAS), this paper presents a brief history of active sonar, tracing the development of MFAS from its origins in the early 20th century through the development of current tactical MFAS.

**Key Words:** mid-frequency active sonar, MFAS, anti-submarine warfare, ASW, whales

## Introduction

It has been suggested from several fronts in recent years that surface ship mid-frequency active sonar (MFAS) use is responsible for mass strandings of beaked whales (family Ziphiidae) (Frantzis, 1998, 2004; Evans & England, 2001; Martín Martel, 2002; Brownell et al., 2004; Freitas, 2004; Martín et al., 2004). To provide background for this special issue on strandings and MFAS, a brief history of active sonar is presented that traces the development of MFAS from its origins in the early 20th century through the development of current tactical MFAS. An overview of their parameters as well as their use over time is also provided. A glossary defining the terminology used in this paper is presented in the "Appendix."

*Summary History of Active Sonar*

Two events underscore the value of underwater acoustics for the detection of submerged objects: (1) the loss of the *HMS Titanic* to an iceberg during her maiden voyage on 15 April 1912 and (2) Allied shipping losses to U-boat attacks during World War I. In response to the need for enhanced detection of submerged objects and enemies, the first successful underwater transducer developed was a 540-Hz electrodynamically driven circular plate, conceived and designed by Reginald A. Fessenden while he was working for the Submarine Signal Company in Boston, Massachusetts. Work on this system started in 1912, and a patent was awarded in 1913. In 1914, the system demonstrated the power of echo ranging with the detection of a distant iceberg 3.2 km off the coast of Newfoundland, Canada. Work on what was termed the Fessenden oscillator was conducted until 1931, during which time the frequency was increased from 540 Hz to 1,000 Hz (Lasky, 1977; Hackman, 1984; Bjørnø, 2003; Katz, 2005).

The emergence in World War I of the submarine as a weapon of choice of weaker naval powers—an "asymmetrical threat" in today's parlance—stimulated the need to detect submerged submarines that were otherwise invisible (Cote, 2000). The stealthiness of the submarine and the opacity of the oceans profoundly changed naval warfare for the remainder of the 20th century (Keegan, 1990; Cote, 2000). Since sound is the only transmitted energy that penetrates water for any appreciable distance, acoustic echo-ranging had to be exploited to counter this threat.

The most important echo-ranging system to emerge after World War I was the ultrasonic ASDIC, a cooperative effort by the British and French Navies. ASDIC, an acronym for Allied Submarine Detection Investigation Committee, was formed during World War I to conduct research on the detection of submarines. Similar research was undertaken in Italy and more extensively in the United States. In 1918, the first ASDIC system was demonstrated by Paul Langevin, a French physicist, using a transmitter that was designed to mechanically resonate at 38 kHz and was used to estimate target range and bearing (Lasky, 1977; Urick, 1983; Burdic, 1984; Hackman, 1984; Bjørnø, 2003; Proc, 2005).

The first ASDIC shipboard systems, which had a covered dome that allowed the system to operate while the ship was moving, were installed in 1919. Operating frequencies varied from 20 to 50 kHz. During the 1920s and early 1930s, ASDICs were developed for use on destroyers for anti-submarine warfare (ASW). The inter-war period was also a time for basic research in underwater acoustics. One key discovery during this period was that amplitude of higher frequencies of underwater sound are attenuated more than lower frequencies as they pass through seawater. Based on this observation, the frequency range for a new destroyer ASDIC (type 119) was dropped from

21 to 31 kHz to 14 to 26 kHz and stabilized a few years later at 14 to 22 kHz. The typical frequency for ASDIC during that time, and subsequently during World War II, was 20 kHz, with the primary goal of detecting submarines near surface ships that were their potential targets (Hackman, 1984). After World War ll, ships with ASDIC sets were used by the whaling industry for different reasons other than submarine detection (Haslett, 1967; Ellis, 1991; Brownell et al., 2008).

Another major development in active echo-ranging systems occurred when the U.S. Naval Research Laboratory developed the first "QA" sonar, which was to become the first destroyer-mounted, echo-ranging sonar in the U.S. Navy, operating at 15 to 20 kHz. By 1933, the QA sonar was installed on eight destroyers. Subsequent improvements in transducer technology yielded the QC series, which was installed as a standard ASW active sonar on all U.S destroyers at the outbreak of World War II (Friedman, 1988). When two-letter designators were used for U.S. Navy equipment, the first letter indicated the type of equipment (Q represented Sonar Echo Ranging Listening equipment) and the second letter indicated the subtype of the equipment (Parsch, 2008).

Use of the word *sonar* for these systems, defined as Sounding Navigation and Ranging, was coined in 1942 by F. V. Ted Hunt, director of the Harvard Underwater Sound Laboratory (Hackman, 1984). All of the World War II sonars had transducers consisting of a flat-faced array of elements in spherical or tear-shaped housings that were mechanically lowered below the hull and also mechanically trained (turned) in azimuth. A Naval Sonar Operator's manual published just after World War II (Bureau of Naval Personnel, 1953) provides a diagram of the traditional sonar dome (Figure 1). Between the late 1940s and 1960, in response to improvements in submarine technology and the increased threat this represented, surface ship active sonars were developed for the U.S. Navy. The major Cold War active sonar technology development was the advent of scanning sonar to compensate for faster submarine speeds and the need to switch rapidly from long-range to short-range detection of an attacking submarine. In a scanning sonar, the transducer becomes an array of elements arranged in a vertically oriented cylinder. This permits omnidirectional transmission and reception. Scanning sonar provides directional search capability via sending and receiving focused sound energy in multiple directions simultaneously with different ping intervals. Longer ping intervals allow longer-range detections, which are derived from the time it takes for the ping to reach a target and for the echo to return (Hackman, 1984; Friedman, 1988). The QHBa series was the first scanning active sonar, and it operated at 28 kHz (Friedman, 1988; Cote, 2000). Figures 2 and 3 show a cut-away of a scanning sonar and a diagram of the QCB system, respectively.

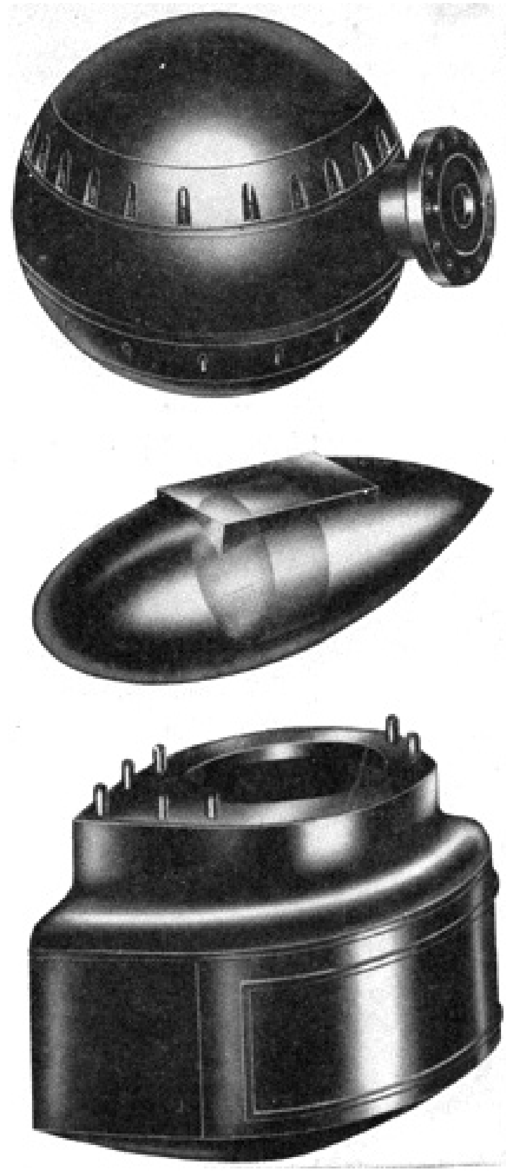

**Figure 1.** Standard World War II sonar domes (Bureau of Naval Personnel, 1953); reproduced with permission from the Historic Naval Ships Association.

The AN/SQS-4 sonar was proposed in 1948 as a 14 kHz equivalent of the QH sonar. The AN/SQS-4 was first tested in 1951 and entered fleet service in 1954, primarily on surface ships

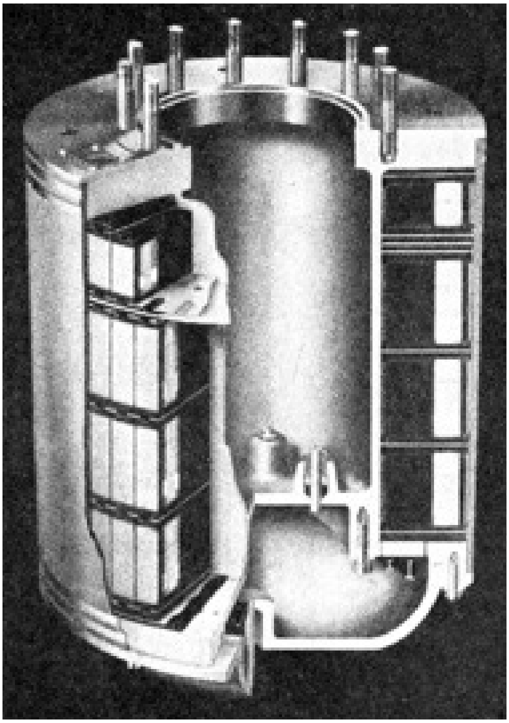

**Figure 2.** Cut-away view of the first scanning sonar transducer (Bureau of Naval Personnel, 1953); reproduced with permission from the Historic Naval Ships Association.

and some submarines. System designators were originally called the Army-Navy Nomenclatures System (the prefix "AN"). There is a three letter and a number designator for the surface ship sonars. "SQS" signifies "S" – Surface ship, "Q" – Sonar, and "S" – Search. The number represents the series (Cowden, 2005).

The detection range of these sonars was limited by their operating frequency, leading to the development of lower frequency active sonars to minimize attenuation loss and thus increase detection ranges. Later versions of the AN/SQS-4 reduced the typical operating mode to four variants: (1) 8 kHz, (2) 10 kHz, (3) 12 kHz, and (4) the original 14 kHz (Hackman, 1984; Friedman, 1988, 1989; Cote, 2000; Watter, 2004). The next improvement in surface sonars was RDT (Rotational Directional Transmission), which permitted increased transmitted power by pulsing groups of hydrophones in sectors sequentially. This feature was back-fitted into the existing AN/SQS-4 series sonars, which were then redesignated AN/SQS-29 through AN/SQS-32 (for AN/SQS-4, mod 1, 2, 3, 4, respectively) (Friedman, 1989). RDT was also utilized in new follow-on sonars.

The U.S. Navy also continued its quest for lower-frequency sonars through the development of the AN/SQS-23 sonar with a frequency of 4.5 to 5.5 kHz. The AN/SQS-23 replaced AN/SQS-4 on some older destroyers under the Fleet Rehabilitation and Modernization (FRAM I) program and was installed in new construction ships. Many of the replaced AN/SQS-4 versions were transferred to Allied navies during the 1950s and 1960s (Hackman, 1984; Friedman, 1988, 1989; Cote, 2000; Watter, 2004). The goal of the AN/SQS-23 sonar was to provide a standoff engagement capability to its ship, which was then being equipped with the ASROC (anti-submarine rocket) system with a nominal range of about 5 nmi, which was introduced in 1961. ASROC could deliver payloads consisting of either homing torpedoes or nuclear depth charges. Prior to the advent of the ASROC ASW weapon, weapon delivery was very short range. The AN/SQS-23 was installed in all DDG-2, DLG-6, and FRAM I-class destroyers (Hackman, 1984; Watter, 2004).

Up to this point, all surface sonars were capable of using only the direct acoustic path (DP) data that limited sonar detection ranges to 5 nmi or less. However, Dr. Maurice Ewing of the Woods Hole Oceanographic Institution, working closely with the U.S. Navy, demonstrated the existence of much longer-range acoustic paths (Ewing & Worzel, 1945). These were the bottom bounce (BB) path, the convergence zone (CZ) path, and the deep sound channel. Ewing's discoveries were instrumental to all subsequent sonar development. In particular, the sound channel has been exploited by the U.S. Navy's Sound Surveillance System (SOSUS) (Whitman, 2005).

Exploitation of the BB and CZ paths constituted the largest U.S. Navy investment in sonar development in the Cold War. Cox (1974), Urick (1983), and Payne (2006) discuss the application of these underwater sound paths to sonar. Using these acoustic paths drove sonar frequencies even lower and required more power, better pulse shapes, and more processing. The results of these efforts were the AN/SQS-26 and AN/SQS-53 sonars (commonly referred to now as MFAS).

In 1955, technology was developed to further lower active sonar frequencies, leading to the 3.5-kHz AN/SQS-26, which represented the culmination of U.S. tactical MFAS development. Feasibility studies for the AN/SQS-26 began in 1955, and the prototype model was installed in 1961 on the *USS Wilkinson*. Since larger transducers are required to produce lower frequencies, a special class of ASW frigates was commissioned specifically to accommodate the new sonar. Starting in 1960, 58 frigates were authorized to be equipped with the AN/SQS-26 sonars. The U.S. Navy accepted the AN/SQS-26 for service in 1968. Concurrently, the U.S. Navy also modernized its

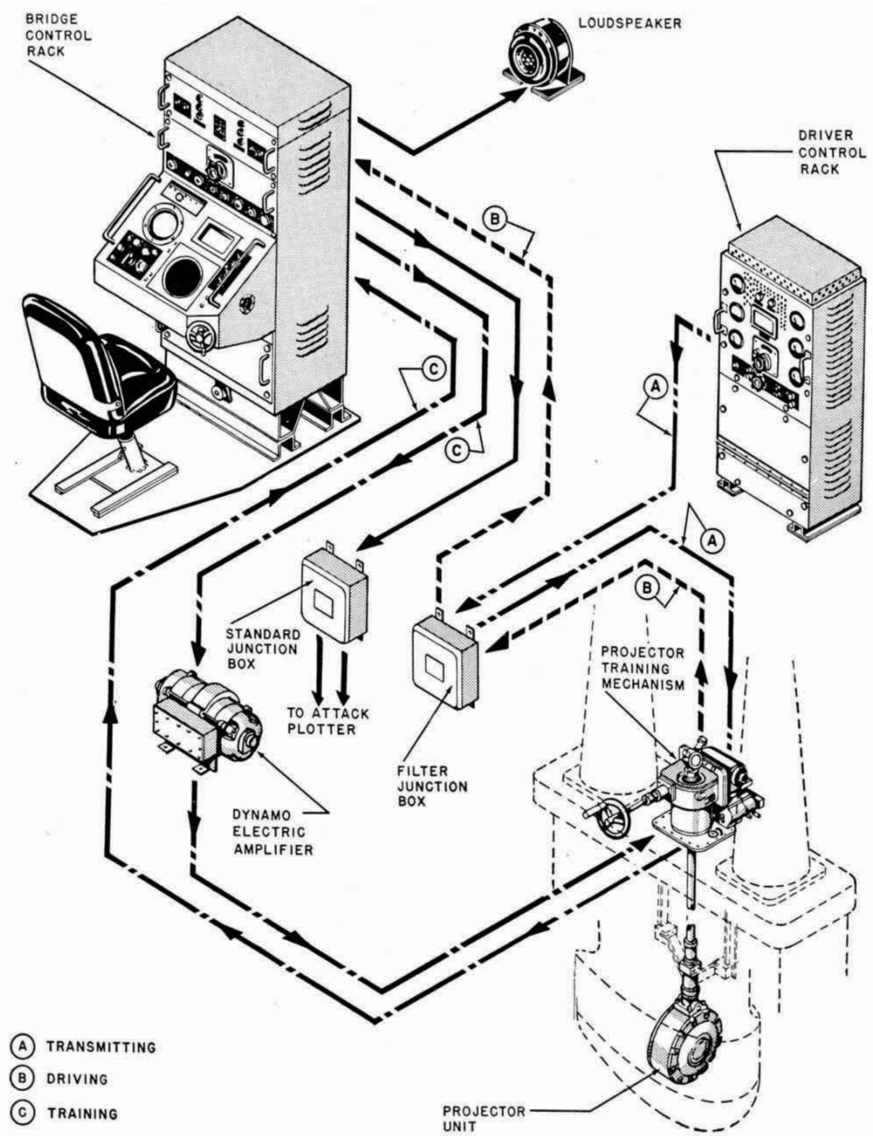


**Figure 3.** Pictorial diagram of the QGB System (Bureau of Naval Personnel, 1953); reproduced with permission from the Historic Naval Ships Association.

existing World War II-era destroyers (a total of 79 Gearing class destroyers) with hull-mounted AN/SQS-23 sonars (Hackman, 1984; Friedman, 1988, 1989; Cote, 2000; Watter, 2004).

The AN/SQS-26 and its solid-state successor, the AN/SQS-53, are the current standards for U.S. tactical MFAS. The AN/SQS-53 began delivery in 1972. The latest version is the AN/SQS-53C, which was evaluated and tested from 1986 to 1989. Evans & England (2001) documented AN/SQS-53C center frequencies at 2.6 and 3.3 kHz. Several foreign navies employ the AN/SQS-26 (Friedman, 1989; Watter, 2004). Another commonly used surface ship active sonar is the AN/SQS-56 and the export version, the DE 1160B, which operates at 5.6, 7.5, and 8.4 kHz (Friedman, 1989). The AN/SQS-56 was approved for service use in 1980. By 2003, 33 systems were in use by the U.S. Navy, and approximately 63 systems were in use in foreign navies (Watter, 2004). Table 1 summarizes this evolution of surface ship sonar. Surface ship echo-ranging systems have evolved since World War I with systems that have lower operating frequencies, higher transmitted

**Table 1.** Evolution of surface ship sonars from the end of World War I until the present time; surface ship echo-ranging systems have evolved since World War I with systems that have lower operating frequencies, higher transmitted power, and longer pulse lengths. Source levels for the QHBa, AN/SQS 10, AN/SQS 4 series, and AN/SQS 29-32 that were estimated assumed values reported in references 2 and 3 are the acoustic power, not the input electrical power. If the reported values are electrical power, then the calculated source levels would be low. The calculation for source level is SL (dB re 1µPa at 1 m) = 171.5 dB + 10log (Pwr).

| | Inter War | | World War II | Post World War II/ Cold War | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sonar type | ASDIC 111/112 | ASDIC 119 | QHBa | AN/SQS10 | AN/SQS 4/1<br>AN/SQS 4/2<br>AN/SQS 4/3<br>AN/SQS 4/4 | AN/SQS 29<br>AN/SQS 30<br>AN/SQS 31<br>AN/SQS 32 | AN/SQS 23 | AN/SQS 26 | AN/SQS 53A-C | AN/SQS 56 |
| Frequency (kHz) | 20-50 | 14-26 | 28 | 20 | 8, 10, 12, 14 | 8, 10, 12, 14 | 4.5, 5, 5.5 | 3.5 | 2.6, 3.3 | 6.8, 7.5, 8.2 |
| Power (kW) | | | 6 | 4-50 | 10-50 | 4-50 | 60 | | | |
| Source level (dB re 1µPa at 1 m) | | | 209 | 208 - 218 | 212-218 | 208 - 218 | 219 | | 235 | 223 |
| Pulse length (msec) | | | | 6,30,80 | 6,30,80 | 2,7,30,120 | 2,5,30,120 | | 1000-2000 | 1000-2000 |
| Reference | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 4 | 4 |

1. Hackman (1984); 2. Bureau of Naval Personnel (1953); 3. Friedman (1989); 4. Evans & England (2001)

**Table 2.** Number of U.S. Navy combatants ASW platforms from the end of World War II to the present time; derived from U.S. Naval History and Heritage Command (2009).

| Date | Era | Destroyers | Frigates | Patrol | Totals |
|---|---|---|---|---|---|
| August 1945 | End of WW ll | 377 | 361 | 1,204 | 1,942 |
| June 1957 | Pre Sputnik | 253 | 84 | 12 | 349 |
| June 1963 | MFAS in service | 222 | 40 | 0 | 262 |
| June 1975 | End Vietnam | 102 | 64 | 13 | 179 |
| September 1990 | End Cold War | 57 | 99 | 6 | 162 |
| 2009 | Present | 54 | 30 | 0 | 84 |

power, and longer pulse lengths. Table 2 lists the distribution of vessels capable of sonar use in each major era.

Although advances in passive acoustics during the Cold War promulgated the increased use of passive sonar technologies, MFAS has remained standard equipment on almost all frigates and destroyers with ASW missions. In the 1970s, as submarines were equipped with intercontinental ballistic missiles, the development of long-range passive sensors was accelerated (Hackman, 1984). However, as both nuclear and diesel-electric submarines operating on batteries became progressively and simultaneously quieter and faster, and thus more difficult to detect in a timely manner, the U.S. and its NATO allies also began to pursue alternatives to passive acoustics, resulting in the development of low-frequency active sonars (LFAS) systems in the 1990s through to the first decade of the 21st century to achieve greater submarine detection ranges. Tyler (1992) and Pengelley & Scott (2004) provide summaries of the current LFAS systems being developed by various nations.

Since the end of the Cold War, the U.S. Navy's operational focus has shifted increasingly to littoral warfare (Morgan, 2005). Littoral warfare, as defined in the National Research Council (NRC) (1994) publication, *Coastal Oceanography and Littoral Warfare*, is the use of combined forces designed for coordinated sea-land-air operations. This publication categorizes the littoral regime as consisting of four subdivisions: (1) harbors and approaches, (2) straits and archipelagoes, (3) the surf zone, and (4) the continental shelf. Additional information on littoral warfare can be found in Tyler (1992), U.S. Department of the Navy (U.S. DoN) (1993), Space and Naval Warfare Command (1996), Scott (2000), and Pengelley & Scott (2004).

To give the reader unfamiliar with military exercises some idea of the range and focus of a typical array of U.S. and multinational exercises and the type of equipment used by global navies, information is available at the websites that follow:

*Official U.S. Navy Websites*
- *A Program Guide to the U.S. Navy* (2000 ed.): www.chinfo.navy.mil/navpalib/policy/vision/vis00/contents.html
- National Technical Information Center (NTIS): www.ntis.gov
- U.S. Navy: www.navy.mil
- U.S. Fleet Forces Command: www.cffc.navy.mil

*Non-Official Websites*
- Federation of American Scientists: www.fas.org
- Global Security: www.globalsecurity.org

The U.S. Navy's range complexes provide an environment for U.S. forces to conduct realistic combat-like training. A comprehensive description of the type of training exercises conducted on these range complexes can be found in the *Range Complex Environmental Impact Statements* (EISs) that has recently been published. The text of the EISs for three of the major range complexes can be found at the following sites:
- Southern California: www.socalrangecomplex-eis.com/default.aspx
- Hawaii: www.govsupport.us/navynepahawaii/hawaiirceis.aspx
- Atlantic Fleet Active Sonar Training (AFAST): http://afasteis.gcsaic.com

## Discussion

The advent of the submarine, which was a major threat to Allied security in World War I, World War II, and the Cold War, drove the development of sensors to detect them. Sound uniquely penetrates ocean waters for long ranges, and changes to a sound signal as it propagates were therefore exploited as key cues that could be used to image the otherwise impenetrable depths. Acoustic echo-ranging research led to sonars with increasingly lower frequencies and increased transmitted power. The evolution of surface sonars, shown on a timeline in Table 1, culminated with today's MFAS.

Although each new sonar had more power than previous ones, it can be argued that the U.S. Navy is putting considerably less noise into the water than it did at its peak force levels at the end of World War II. As can be seen in Table 2, the number of U.S. Navy combat ships has been reduced by two magnitudes, almost 96% from its force levels at the end of World War II—that is, 84 ships today compared to 1,942 ships in 1945. Additionally, today's ships are designed and built to be quieter than World War II vintage ships and can regularly employ passive and, when needed, active sonars (Federation of American Scientists [FAS], 2009). In the years between World War II and the early 1970s, surface ships had no passive ASW sensors and had to use active sonar exclusively. Today's ships have improved passive sensors.

When considering the amount of noise put into the seas by U.S. Navy ships, it is useful to consider also that from World War I through the early 1970s, all U.S. Navy ASW combatants and many auxiliary vessels were equipped with depth charges. Dropping depth charges off the stern via a rack or track was standard practice for ASW vessels in both World Wars. The U.S. built over 600,000 depth charges during World War II, and over half of these depth charges were still on hand when hostilities ended. Each Mark 6 (redesigned from the Mark 3) depth charge, commonly used during most of World War II, had nominally the equivalent explosive power of about 136 kg of TNT (*Naval Weapons*, 2008). An operating manual for the Mark 6 and Mark 7 depth charges was published in 1943 (Bureau of Ordinance, 1943). It was standard policy for ships equipped with depth charges to be required to fire a full salvo (up to 30 rounds) every training cycle (yearly). These training evolutions were generally conducted near home ports, especially Norfolk and San Diego. Depth charges were phased out of the U.S. Navy in the early 1970s, having been replaced by homing torpedoes (Captain J. Binford, USN[Ret], pers. comm.; Pittenger, pers. experience as Force ASW Readiness and Training Officer on the Surface Type Commander Staffs, 1971-1976).

Commercial active sonars, designed for detecting underwater objects, are a source of anthropogenic noise. Typically, they operate at higher frequencies, project lower power, and have significant spatial resolution with narrower beam patterns and short pulses. Richardson et al. (1995) and the NRC (2003) provide a discussion of anthropogenic noise provided by commercial sonars and pingers.

MFAS is the primary ASW sensor on U.S. Navy combatants today. The frequency range of these sonars is low to exploit lower propagation loss than at higher frequencies, and the transmitted power is higher to exploit longer ranges. They are ubiquitous, employed by virtually every navy in the world. Data for U.S. Navy ships suggest that while current MFAS are broadly employed or, rather, deployed and have higher source levels than the original sonars in the first half of the last century, fleet sizes of major navies have been steadily decreasing. Thus, while MFAS are clearly a continuing and important technology for these navies, their contribution to the total sound budget of the oceans is likely to have declined over the last 70 years. To fully understand the implications of the fleet size and technologies involved as they evolve over time will require more explicit analyses than this basic history provides. However, it does give a perspective for how sonar and its sound parameters have evolved during a time period in which we have also become increasingly aware of marine mammal populations, strandings, and a potential role of human sound impacts in those events.

### Acknowledgments

The authors would like to thank F. Martin and E. Harland for their assistance in documenting the history of active sonar. The authors appreciate the assistance of P. Tyack, D. R. Ketten, and R. Gisiner for their input, and they appreciate the helpful comments of the reviewers. The authors acknowledge the Office of Naval Research and OPNAV Environmental Readiness Division (CNO N45) for funding portions of this work.

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## Appendix

*Glossary of terms*

| | |
|---|---|
| ASDIC | Allied Submarine Detection Investigation Committee – Echo-ranging system named for the international committee that invented it |
| ASROC | Anti-submarine rocket |
| ASW | Anti-submarine warfare |
| Acoustic Paths (as defined in Cox, 1974) | |
| Direct Path (DP) | Straight line path direct from source to detector |
| Bottom Bounce (BB) | Sound path utilizing sound energy either beamed or bent toward the ocean bottom that results in energy reflected off the ocean bottom |
| Convergence Zone (CZ) | Sound path in deep water through which the sound energy for the source is refracted or bent downward from the source as a result of decreasing temperature until the increase in pressure bends the sound rays upward |
| Active (Sonar) | Echo-ranging system that transmits sound waves and receives reflections |
| Bi-static | Active sonar system in which the transmitter/source is separate from the receiver |
| FRAM | Fleet Rehabilitation And Modernization |
| Hull Mounted | Sonar transducers attached to the underwater hull of surface ships |
| LFAS | Low-Frequency Active Sonar |
| kHz | Kilo Hertz – Frequency measured in thousands of cycles per second |
| MFAS | Mid-Frequency Active Sonar |
| MFA | Same as MFAS |
| NURC | NATO Underwater Research Center |
| NUSC | Naval Undersea Systems Center |
| NUWC | Naval Underwater Weapons Center |
| NRL | Naval Research Laboratory |
| Passive (Sonar) | Acoustic system that senses noise/signals emanating from targets |
| Pulse Length | Duration of individual sonar transmissions |
| RDT | Rotational Directional Transmissions |
| SONAR | SOund Navigation and Ranging |
| SOSUS | SOund SUrveillance System |
| Source Level | Pressure level of the radiated sound that would be measured from the acoustic center from an ideal source radiating the same amount of sound as the actual source being measured – In water, this is measured in dB re 1μPa at 1 m (Ross, 1976). |
| SURTASS | Surveillance Towed Array Sensor System |
| SURTASS LFA | Surveillance Towed Array Sensor System Low Frequency Active |
| AN/SQS | Army Navy S (surface ship) Q (underwater) S (search and track) |
| The Third Battle | The name for the bloodless Allied ASW effort against the Soviet submarine fleet; also refers to previous battles of the Atlantic in which the German U-boat raised havoc with Allies during World War I and World War II |
| TNT | Tri-nitro-toluene – Explosive |
| Transducer | The part of a sonar system that converts electrical signals to acoustic signals and the reverse |
| VDS | Variable Depth Sonar |