# Evolving ASW sensor technology

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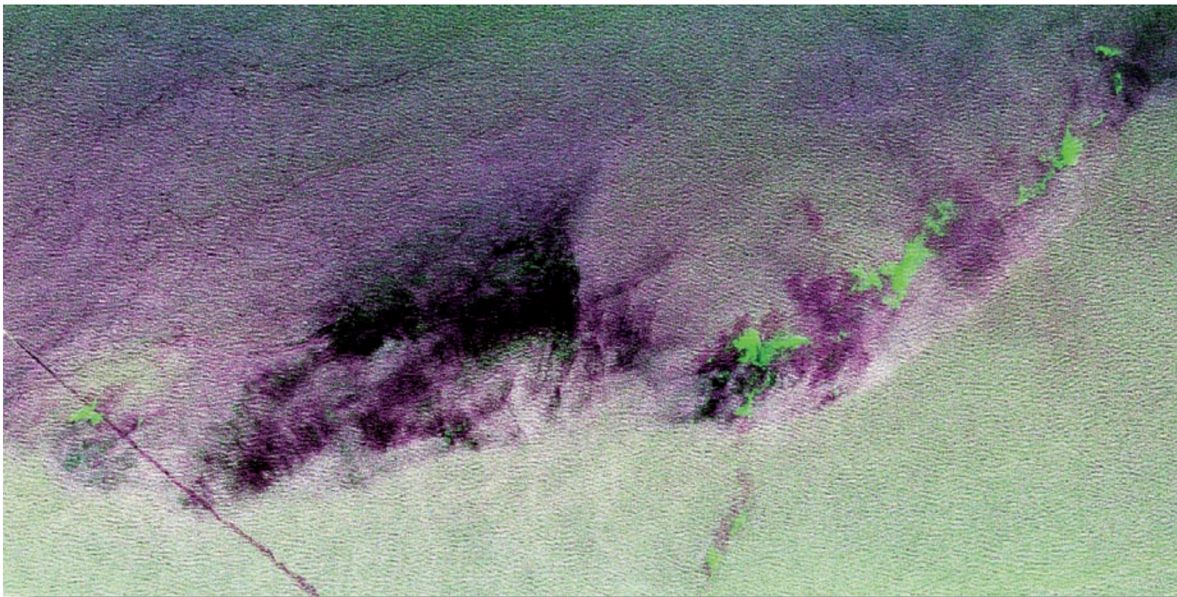
Sensor technology remains the pivotal capability in Anti-Submarine Warfare (ASW), as it has been since the very first 'cat and mouse' engagement between stealthy submarines and the warships and aircraft hunting for them. Submarines have always been elusive and difficult targets, whether the attacker is an aircraft, surface vessel or another submarine.



*Ship wake, lower left, imaged by NASA Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar system from low orbit.*

With well over a century of evolutionary arms race in submarine and ASW technology, many sensor technologies for ASW are now well matured. But this does not necessarily mean long term stagnation, as the drive to digitise all Intelligence Surveillance Reconnaissance (ISR) capabilities and fuse data collected by same using digital networks presents further opportunities: to increase the potency of specific sensors and exploit multiple sensors, to fuse intermittent and/or fragmentary data to find targets below the threshold of individual sensor capabilities.

Sensor fusion has been exploited to great advantage in air defence systems, fusing tracking data from multiple radars, such that the target can be tracked regardless of blind spots, dropouts, adverse clutter, single aspect target stealth or jamming impairing individual radars in the network. The US Navy CEC (Cooperative Engagement Capability) system, and its Russian analogues such as the Poima or Nebo M fusion system are good examples of the potency of such digital technology.

Submarine designers have for decades invested enormous effort in reducing the detectable signatures of submarines, be they acoustic emissions from screws and propulsion and power machinery, acoustic reflections from hulls, as well as radar, visual and infrared signatures of masts and snorkels. Modern submarines are considerably more difficult to detect than their predecessors of even two decades ago.

The task confronted by ASW sensor and system designers is thus more difficult today due to incremental evolutionary gains in submarine signature reduction, but also due to the post Cold War shift from 'blue water' operations to 'littoral' or 'brown water' operations where submarines operate in far more acoustically challenging shallow waters. The proliferation of very quiet modern diesel-electric submarines presents a more complex environment in which many more different submarine designs must be identifiable.

The Asia-Pacific is a region where all of these trends have converged, whether environmental or technological, and thus will remain one of the most challenging regions globally for ASW operations.

In ASW operations, diverse sensor suites have been and will continue to be used. This reflects the variable detection performance and accuracy of these sensors, with variations in submarine signatures and sea state conditions. Typically less accurate sensors may be used to establish the presence of a contact, and more accurate sensors establishing exact position and identity, to prosecute an attack.

*Sonobouys remain a mainstay of ASW operations.*

## Passive Sonar Technology

Passive sonar techniques remain a mainstay of ASW systems, and have benefitted strongly from advances in digital processing and advances in array beamforming techniques over the last two decades.

The preferred passive sonar configuration for surface warships and submarines is a towed array sonar, where a cable carrying an array of hydrophones is towed behind the vessel. With digital beamforming techniques, a towed array can produce high sensitivity but also highly accurate bearing tracks. If a series of accurate bearing measurements are made, the location of a submarine emitting screw and machinery noise can be determined.

In airborne ASW operations, sonobuoys remain the technology of choice. The most important current advances in technology are the introduction of satellite navigation receivers on sonobuoys, and advanced digital beamforming techniques to exploit the improvements in sonobuoy position measurement.

With exact three-dimensional positioning data for every sonobuoy in an array dropped in the water, range measurement accuracy to a contact is improved. More importantly though, the ability to use beamforming techniques which aggregate data collected by all dropped buoys, if in close proximity, permit accurate bearing measurements and increased sensitivity as the array of hydrophones is in effect acting as a single large steerable hydrophone.

Current technology research and development effort appears mostly focused on beamforming research, with Capon and Bartlett beamforming algorithms preferred. Given the enormous potential in the use of tomographic algorithms for this purpose, there is considerable long term growth potential in satellite navigation receiver equipped sonobuoys, combined with high power digital processing.

## Active Sonar Technology

Like passive sonar techniques, active sonar techniques have a long and colourful history, and active sonars are carried by surface warships, submarines, helicopters on dunking tethers, but also used in active-passive sonobuoys.

The most important developments in active sonar are high power digital signal processing, and at the sensor end of the system the shift to Low Frequency Active (LFA) sonar technology operating in the 100 Hz to 1 kHz bands. There are two imperatives, one being the prodigious range performance of LFAs less affected by propagation mechanisms that scatter high frequency signals, but also its ability to defeat thin anechoic coatings or cladding on target submarines. The technology is best known for the controversy surrounding claimed injuries to marine mammals resulting from exposure to high powered LFA emissions.

LFA technology is now utilised in other platforms, with contracts recently awarded for the AN/AQS-22 Airborne Low Frequency Sonar (ALFS) to be fitted as a dunking sonar on the US Navy MH-60R Seahawk. AN/BQQ-5D/E LFAs have been installed in Los Angeles and Ohio class SSNs, and a number of types are now available for surface warships, including the SQS-53 on the DDG-51.

## Radar Technology

Radar has been a key sensor in ASW operations since the 1940s, initially used to detect surfaced diesel-electric subs recharging batteries, and following the invention of the snorkel, used for the detection of snorkels, periscopes and other masts of shallow running subs. As submarine designers applied radar absorbent materials and shaping to masts, radar designers progressively increased peak power ratings of their radars. A typical contemporary ASW search radar operates in the centimetre X-band and delivers very high peak power levels, compared with fighter or bomber radars with similar antenna sizes. Digital processing technology introduced into such radars since the 1980s has improved detection and range performance, but this class of radar remains largely limited to direct detection of exposed submarine components on the surface.

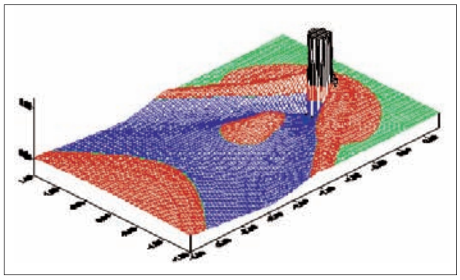
A more important long term development that has produced much research effort over the last two decades is the use of Synthetic Aperture Radar (SAR) techniques, carried by RORSATS (satellites), manned aircraft for radars carried by RPVs, and intended to detect the wakes of submerged submarines.

Submerged submarines, no differently than surface vessels, produce a wake of disturbed water when running, produced by vortices in the water excited by the motion of the submarine hull and screw. This wake expands in a roughly conical shape behind the submarine, as it dissipates in intensity with distance and time. When the front of the wake impinges on the surface of the water above and behind the submarine it produces a surface disturbance in the shape of a non-linear paraboloid curve. In non-technical terms, the wake pattern looks like a blunt arrowhead pointing in the direction the submarine was travelling minutes ago.

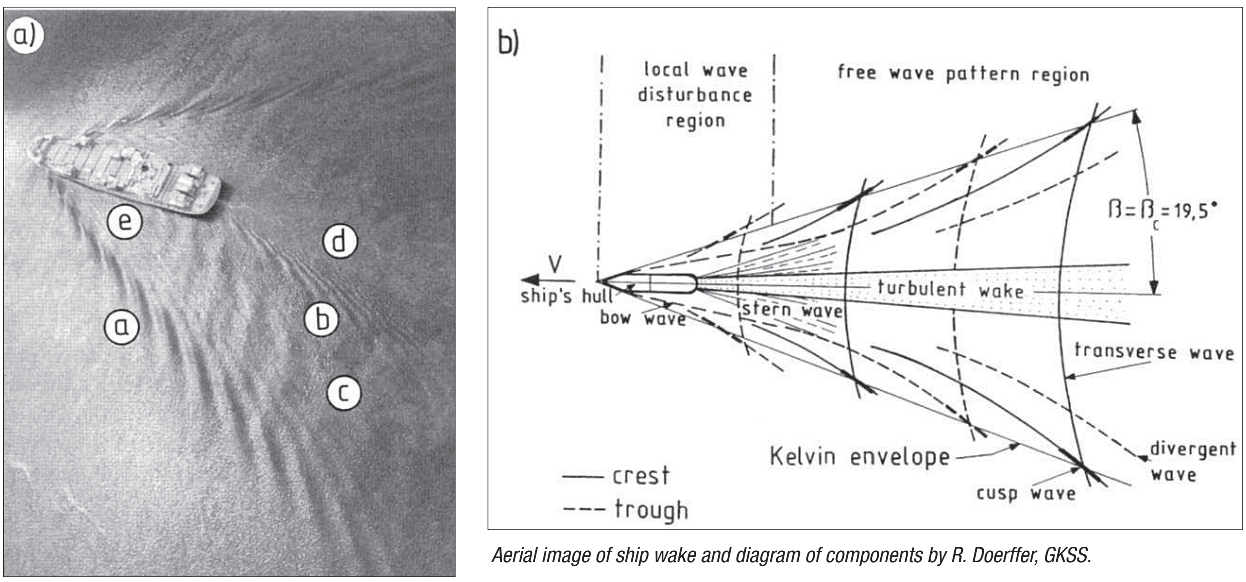
Reliable and repeatable submerged submarine wake detection is a challenging task, primarily due to the enormous variability of ocean surface conditions. With increasingly high sea states, a radar attempting to image from a shallow grazing angle will have to confront wave troughs and

*Raytheon AN/AQS-22 ALFS carried by an MH-60R Seahawk.*

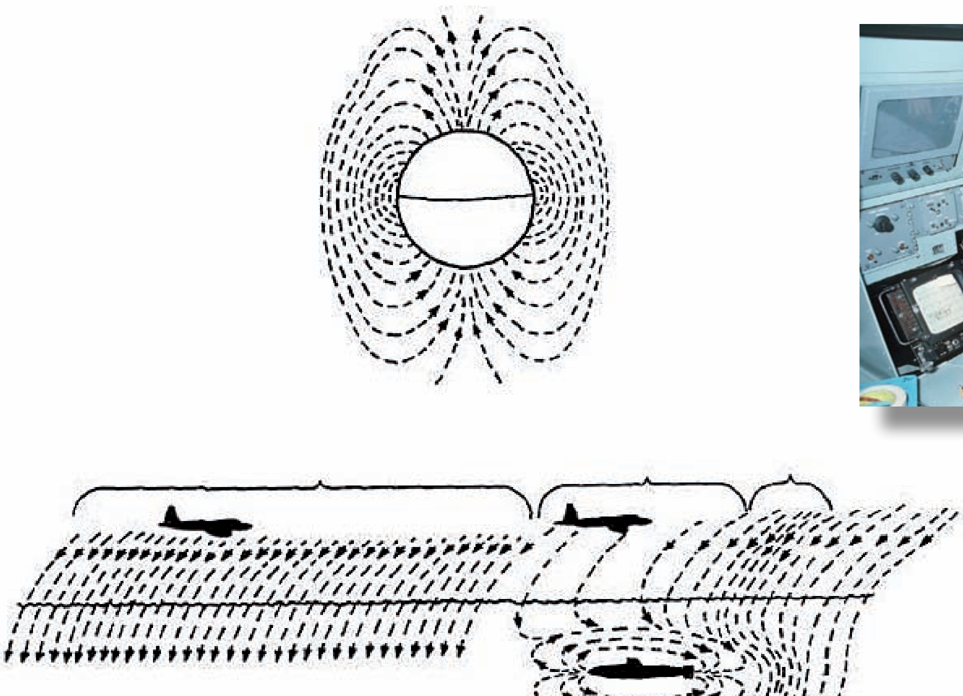
*Late build Arleigh Burke class destroyer bow active sonar array.*



*Computer simulation of periscope mast at 6 knots, including Bernoulli hump and Kelvin wake.*




*Aerial image of ship wake and diagram of components by R. Doerffer, GKSS.*



Magnetic Anomaly Detection.

*Magnetic anomaly detection (MAD) equipment in the P-3 Orion.*

*A rear view of the ASQ-81 Magnetic Anomaly Detection (MAD) boom on an S-3A Viking.*

peaks, which will disrupt the wake pattern and shadow, on average, half of the pattern.

Not only must the radar do a good job of capturing the surface image but the post-processing demands of finding the specific shape of a wake pattern in a very noisy radar image of the sea surface are quite difficult, typically using a Hough transform or Radon transform algorithm, both of which require a lot of computing power.

While wake detection using SAR even under optimal conditions may result in a highly accurate track of the wake, the delay between the production of the wake and its contact with the surface adds considerable uncertainty as to the immediate position of the submarine being tracked, unless it is running very shallow. While the shape of the wake front could be used to infer the distance and the depth of the submarine, for submarines running deep wake detection radars may well become primarily a 'tripwire' sensor, not unlike MAD used for initial detection and tracking rather than prosecution of an attack.

Ultimately, once SAR wake detection technology matures, it will provide a potent capability to detect submarines from orbital and high flying airborne platforms. This will drive submarines to greater depths and lower transit speeds, and result in further design changes in hull shaping to produce the least detectable wake patterns.

## Magnetic Anomaly Detection

MAD (Magnetic Anomaly Detection) sensors were introduced during the 1940s and until the P-8A Poseidon have generally been a standard sensor on all airborne ASW platforms. Typically, fixed wing aircraft carry their MAD sensor in a non-magnetic tail boom while helicopters tow it on a drogue equipped non-magnetic tether. MAD was sufficiently effective that the Soviets constructed some submarines with non-ferrous Titanium hulls to defeat MAD sensors.

MAD sensors are in technical language, termed 'Magnetic Gradiometers' as they measure variations in the local magnetic field of the earth. A large object made of a ferrous metal, such as steel, will distort the local shape of that magnetic field, an effect which can be detected and localised, if the aircraft flies a systematic search pattern. These sensors have generally performed best in 'blue water' operations, in littorals sunken wrecks and variable magnetic properties of the seabed can generate false alarms.

Legacy MAD sensors used 1930s fluxgate technology, with electrical coils wrapped around a magnetic core. More recent MAD sensors such as the ASQ-81 and derived ASQ-208 use an optically pumped helium atom detector device.

The most important advancement has been the development and trialling of SQUID (Superconducting Quantum Interference Device) MAD sensors, which remain amongst the most sensitive magnetometers ever devised. They are however more challenging to operate as they require liquid nitrogen cooling, not unlike thermal imagers. SQUID MAD sensors are considered sensitive enough to locate seabed mines.

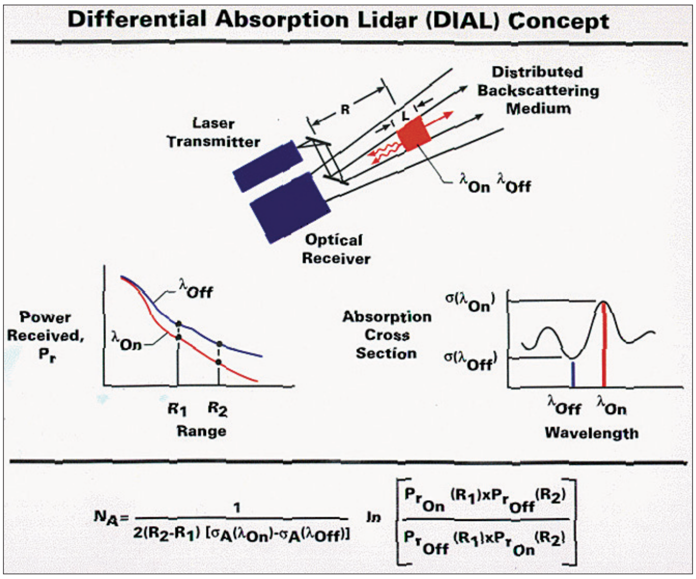
The full potential of MAD techniques remains to be exploited in operational systems. With detail digital mapping of the earth's magnetic field in progress, and newer and more sensitive detectors, much better false alarms rates and detection performance can be expected.

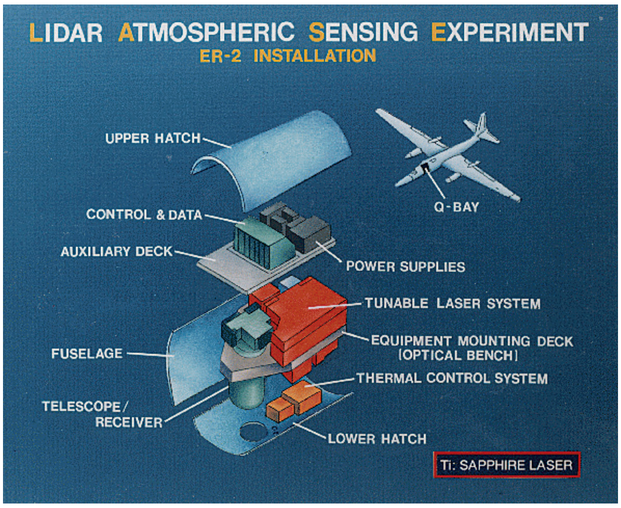
## Diesel Exhaust Sniffers

The diesel exhaust gas 'sniffer' was introduced during the 1940s, and uses techniques similar to contemporary household smoke detectors to locate the exhaust plume residues from snorkelling diesel-electric submarines. The AN/ASR-3 Diesel Submarine Exhaust Gas Detection System was introduced during the 1950s and widely installed on NATO LRMP aircraft, including the P-2, P-3, S-2 and Canadian Lancaster. As the Soviets replaced blue water diesel-electric submarines with nuclear powered replacements, the usefulness of the sniffer declined and they were not replaced when newer LRMP aircraft were built. In operation sniffer equipped aircraft would fly a meandering search pattern to establish the direction of the exhaust trail, and then follow it until they found the submarine. In littorals and heavily trafficked shipping lanes, false alarm rates were high.

Diesel exhaust sniffers have not featured in any recent high visibility ASW programs yet their utility is much higher today than at any time since the 1940s.

A new generation sniffer would be based on DIAL (Differential Absorption LIDAR), a form of laser radar in which the laser colour is tuned to excite specific chemical species in the exhaust gas. A LIDAR based design could sweep a circular footprint of hundreds of square kilometres around an aircraft in a matter of tens of seconds, generating a radar like image of all exhaust trails in reach.




*DIAL LIDAR.*

## LIDAR Sensors

LIDAR (laser radar) technology has been used successfully in depth sounding systems for seabed mapping, and has also been very effectively employed for the detection of seabed and tethered mines in the US Navy Airborne Laser Mine Detection System (ALMDS). It has also been raised at various times since the 1970s as a potential ASW sensor but to date no such device has been disclosed as part of any operational ASW suite.

## Electro-Optical Sensors

Thermal imagers and stabilised high definition television telescopes have been widely integrated on LRMP aircraft and ASW helicopters but have mostly been used for the identification and tracking of surface vessels. The technology has been proposed for use in tracking submarines by bioluminescence in surface wakes, or to track minute temperature increases in a surface wake. Both applications would be more suitable for an infrared hyperspectral imaging sensor but to date there have been no public disclosures on the development of such.

## Emitter Locating Systems

Like electro-optical sensors, ELS/ESM (Emitter Locating System / Electronic Support Measures) have been widely integrated on LRMP aircraft and ASW helicopters, but have mostly been used for the identification and tracking of surface vessels, as surfaced submarines seldom employ radar. However, satellite uplink antennas may produce sufficient sidelobe emissions to render them detectable to more sensitive ELS/ESM type equipment.

## Conclusions

The digitisation of ASW systems continues, and has yielded important capability gains in sensor signal processing and digital post-processing of sensor data. While most sensor technologies used in ASW have long evolutionary histories there have been important developments in sonar, radar and other areas in recent years. As they mature, this will further increase the effectiveness of ASW sensor suites, especially airborne systems. Developments in radar are especially promising, while the full potential of sensor fusion remains to be exploited.

Many contemporary sensors are accurate enough that with digital recording they can be employed to 'fingerprint' the specific acoustic or other signatures of specific submarines.

Significant improvements to ASW sensor suites will be essential over the coming decade in the Asia-Pacific region, given the proliferation of very quiet diesel-electric boats, the growth in China's fleet of nuclear powered boats, and the archipelagic and littoral geography of much of the region. Submarines proved to be a pivotal weapon in Pacific naval warfare during the 1940s, and geo-strategic reality shows that in any future conflicts, submarines will play a no less important role.