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Coastal hydroacoustic surveillance

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Abstract. Coastal hydroacoustic surveillance network is necessary to identify submarines in due time and to have an anti-submarine protection at shores. A solution to detect, localize and track silent submarines in coastal waters is one to build a multi-static sonar network (MSN), which offers a numerous advantage compared to a monostatic network.

1. Introduction

Coastal anti-submarine defence is conducted to protect naval forces, shores economic hot points and also maritime communication routes against enemy submarine actions. In this context one has to take into consideration that procedures and tactics used on high seas against submarines are not the same ones used in coastal waters, due to high Ambiental noise. This high Ambiental noise drops down the efficiency of hydroacoustic systems, which is an advantage for enemy submarines.

Coastal underwater environment is a not a humogen one, it is influenced by waves, sea currents, rivers fresh waters and also by shore bathymetry.

Because passive acoustics systems are not the only mean of underwater detection, it is necessary that non acoustic and active acoustics system to be used.

In order to protect the shores against enemy submarines, naval forces should be able to:[1]

- detect and localize enemy submarine in coastal waters;
- act on time and decisive against enemy underwater contact, which can last only a brief moment;
- utilise integrated antisubmarine warfare (ASW) systems (well-trained operators, sensors, weapon and communication systems) with high detection probability and neutralise the target;
- offer to all commanders an integrated tactical picture of underwater battlefield.

2. Coastal waters characteristics

Coastal waters can be defined as "those regions relating to or existing on a shore or coastal region, within direct control of and vulnerable to the striking power of naval expeditionary forces".[2]

Sensors are a very important asset in coastal antisubmarine warfare, by the way they are adapted to environment, in order to identify underwater propagation conditions and acoustic channels, assuring that ASW missions are conducted with high success rate.

Green water, brown water and blue water (high sea/ocean environments) are the three types of marine environment based on factors that can influence underwater sound propagation.

Green waters are those area of continental shelf characterised by a mixture of waters with different temperatures, salinity and speed of currents, turbulences, wrecks, movements of school of fish, rocky areas, which can reduce the detection range of hydroacoustic systems and also can produce false targets.[3]

Brown waters are those area of confluence between fresh water rivers and salt water of the seas or oceans up to contiguous zone limit.[3] These areas are characterised by sea currents, temperature and salinity variations (fresh water of rivers that meet with salt water of seas produce layers of different temperature which can reduce the detection range of hydroacoustic systems). Also, in these areas rivers can bring an important quantity of mud and different industrial or household debris which influence hydroacoustic systems and also can produce false targets.

Blue waters are those areas which are not included in green or brown waters. In blue water areas the velocity of which the sound it travelling is more predictable, in the way that is mainly influenced by variation of salinity, temperature and pressure.

After all coastal submarine defence means to take into consideration the influence of green and blue water onto hydroacoustic systems when those are being installed and fitted to the environment.

3. Sound propagation in coastal waters

Marine environment is not homogenous and immovable, meaning that the temperature, pressure and salinity changes according to the depth (down to 100 meters temperature distribution in influenced by weather, season, hour of the day, wind speed, tides and so on), the presence of separation layers reflects acoustic waves in the same way as sea surface and sea bottom.

Taking into consideration that sound propagation is determined by coastal bathymetry and by environmental conditions, it is very important to analyse sound propagation in shallow waters. According to bathymetry shallow waters means waters with depth of down to 200 meters, because upper and lower limits in which the sound is travelling, determined by surface and bottom of the sea, influence the spread of acoustic energy through reflection, scattering and absorption. On the receiver end a major role is also played by reverberation.

From the acoustic point of view shallow water conditions exist each time when sound propagation is characterised by reflexions of interference from surface and sea bottom, and are determined by the difference between structure and composition of sea bottom (sand, mud, clay, rock, gravel or a mixture of those) which makes that compression velocity of acoustic wave to be higher of that from upper layers.[4] Figure 1.

Sea bottom is the most important component of underwater environment, which make the difference between shallow and deep-water sound propagation. Incident acoustic energy which hit sea bottom on sufficient bigger angles, it is reflected almost entirely back in the water, which create an acoustic channel with propagation losses almost equals with cylindrical propagation, in frequencies between 100 to 1500 Hz.[4]

Observation about acoustic waves absorption by sediments, made by Hamilton (1980), in wide range of frequencies, shown that attenuation in natural sediments, saturated, is almost equal with $0,25 \cdot f$ (dB m^{-1}), where “f” is expressed in kilohertz. Denser sediments, like sand, have a bigger attenuation that of less dense sediments, like mud.

Sea surface act as a reflector and also like an element of diffusion for the hydroacoustic wave. When the sea surface is perfectly flat it is acting like a near perfect reflector for the acoustic wave, due to the non-adaptation of the acoustic impedance of the water-air separation zone. Wind movement over sea surface cause the appearance of the waves and bubbles, resulting in a growth in acoustic energy losses.

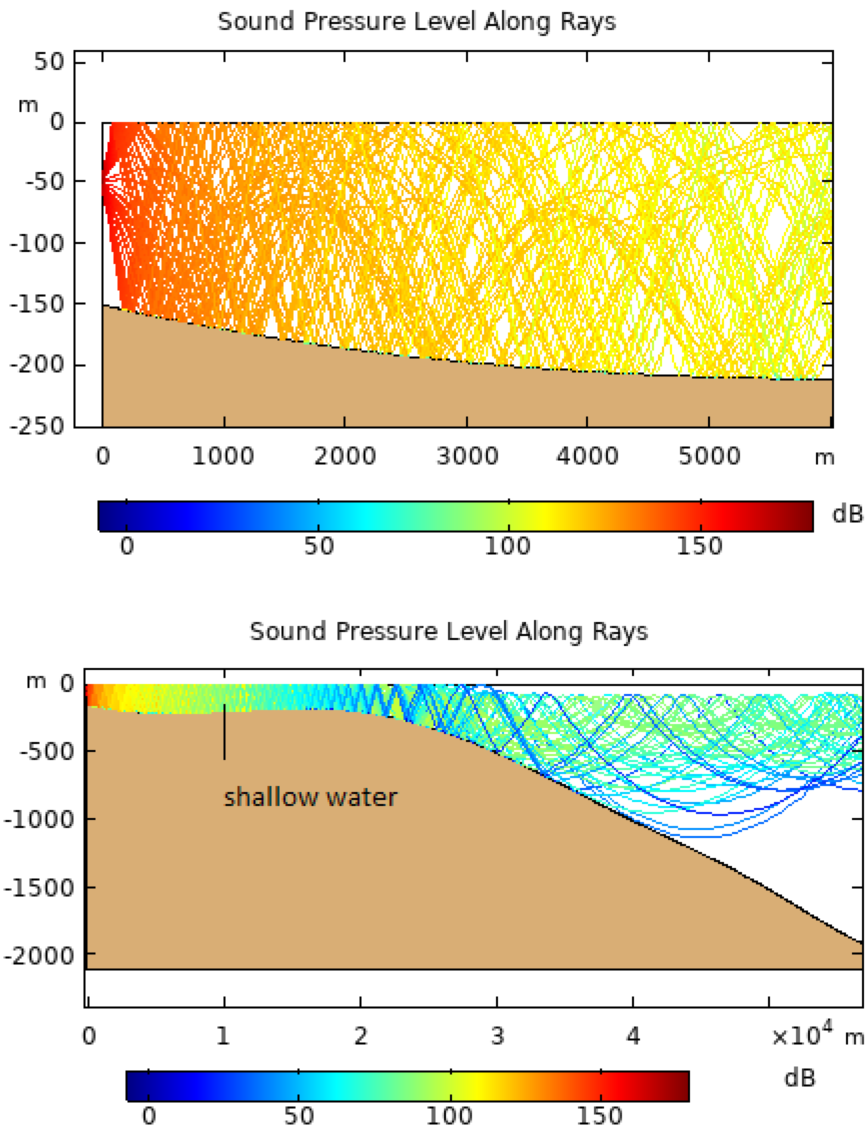

Figure 1. Acoustic waves propagation in marine environment (h_{sonar} = 50m)

When the sonar is working in the active mode one must consider reverberations produced by sea surface and sea bottom in shallow waters.

Sea surface reverberations have a major effect on the operation of the sonar installed on the ship or deployed at a shallow depth. This reverberation is extremely important in the propagation of surface channels. Sea-surface back scattering varies with incident angle of the wave, acoustic frequency and surface roughness. In addition to the actual reflection and diffusion that takes place at the air-water interface, there is also a diffusion due to surface bubbles.

In shallow water the reflections produced by sea bottom represents the most important part of the observed reverberation. Values of volume reverberations, of surface and bottom reverberations, for shallow waters are generally of - 80dB, - 40dB and -25dB.[7]

4. Sensor installation for coastal/shore antisubmarine defence

Detection and localisation of silent submarines (diesel-electric) which are conducting activities in coastal areas represent a challenge for antisubmarine warfare (ASW).

One solution for detection, localization and tracking silent submarines from coastal areas is offered by a multi-static sonar network (MSN), which is constructed with several entities or knots, which are communicating between them and are transmitting survey signals, receive echo signals in a coordinated system (these are also processing received signals), in order to get detailed information about the target.

The development of a multi-static sonar network for ASW includes usage of fixed hydroacoustic buoys (active or passive, active and passive in the same time), mobile sonars, AUV's (Autonomous Underwater Vehicle) and a communication network which allows all that equipment to communicate between them. Regarding AUV's, U.S. Navy identified 9 missions for them:[6]

- intelligence, surveillance and reconnaissance;
- mine countermeasures;
- anti-submarine warfare;
- inspection and identification;
- oceanography;
- communication and navigation network nodes;
- payload delivery;
- information operations;
- time-critical strike.

A multi-static sonar network (MSN) is composed of hydroacoustic energy emitters and receivers deployed in different areas (not in the same place). The concept of the operation of such a network is that the transmitters radiate sound energy into the water, this energy is afterwards reflected by nearby object/targets and the echo signals are captured by the receiver's antennas and processed to obtain information about objects/targets in the marine environment.

Advantages of such network compared to a monostatic network having similar dimensions/detection capability are:[5]

- higher detection distance (area of coverage is bigger);
- higher number of detection opportunities per ping – probability of target detection is increased;
- a smaller error in target bearing;
- availability of higher repetition frequencies on emission;
- location of hydroacoustic receivers is difficult to find, compared to location of the emitters, which complicates the tactical situation for submarines;
- lower costs;
- noise pollution of the marine environment is reduced;
- facilitates interoperability between different platforms (active sonar from surface ships or those immersed from helicopters can be used as emitters and hydroacoustic buoys used as receivers).

When installing MSN, one must analyse the different scenarios of enemy submarine operations according to coastal bathymetry (geographic configuration) which means surveillance of a wide area, of an interdiction/access area or a point of interest.

Considering the operation of a monostatic sonar, maximum detection distance is $D_{max} = \frac{C \cdot T_r}{2}$, where T_r represents repetition period of detection pulses in which the detection pulse and the echo signal (signal reflected by target) travel twice the maximum detection distance, being influenced by attenuation and by propagation conditions from marine environment.

The bistatic system consisting of a transmitter and a receiver can be made so that its detection feature is in the form of an ellipse, which is characterized by the fact that the sum of the emitter-target distances D_{ET} (sounding impulse) and target-receiver D_{TR} (echo signal/reflected by target) to be constant.

By making several transmission-reception ellipses, a hydroacoustic or radio-hydroacoustic surveillance network (depending on the type of receivers) of an area is created, thus resulting in a multi-static system.

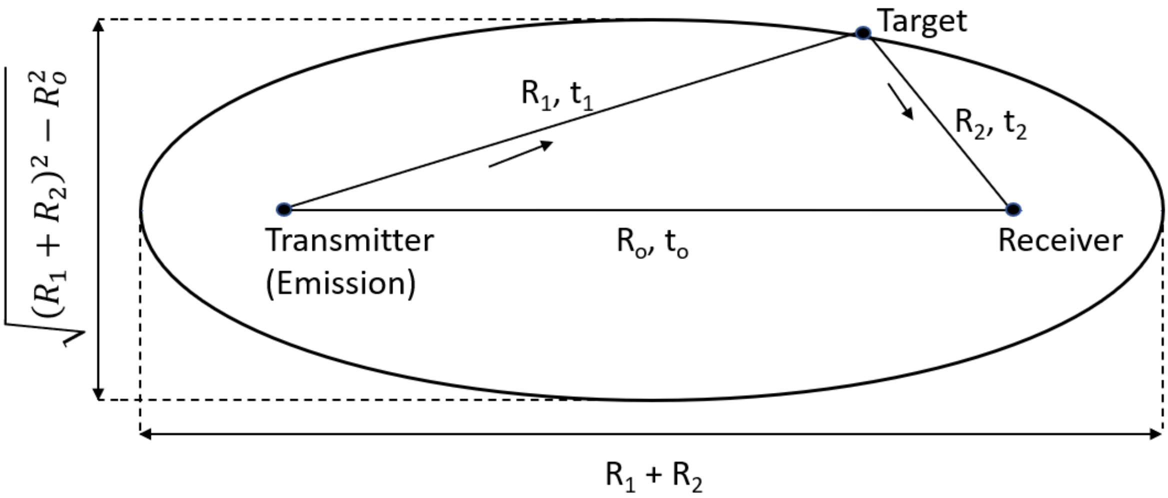

Figure 2. Bistatic system

Detection characteristic of an emission-reception system may be in the shape of Cassini oval, characterised by $|D_{ET}| \cdot |D_{TR}| = D^2$, where D is a constant (multiplication of the distances between the target at the two fixed points transmitter and receiver, is a constant). Considering the constant D equal to the detection distance of the monostatic sonar, the relation is obtained:[5], [8]

$$D_{ET} \cdot D_{TR} = D_{SM}{}^2$$

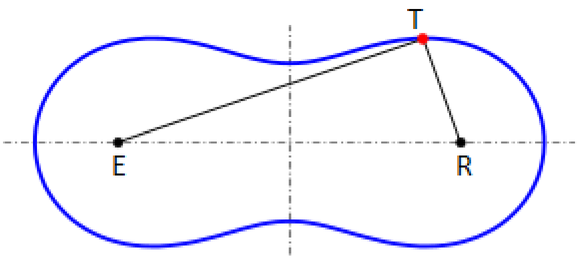

Figure 3. Action area of emitter – receiver system

Depending on the ratio between ($D_{ER}/2$) and D_{SM} detection characteristic of the system thus change (Figure 4):

1. $0 \le D_{ER} < \sqrt{2} D_{SM}$;
2. $\sqrt{2} D_{SM} \le D_{ER} < 2 \cdot D_{SM}$;
3. $D_{ER} = 2 \cdot D_{SM}$;
4. $D_{ER} > 2 \cdot D_{SM}$.

With star-shaped arrangement the receivers around the transmitter, an approximate circular directivity characteristic will be obtained for the surveillance of a certain region.

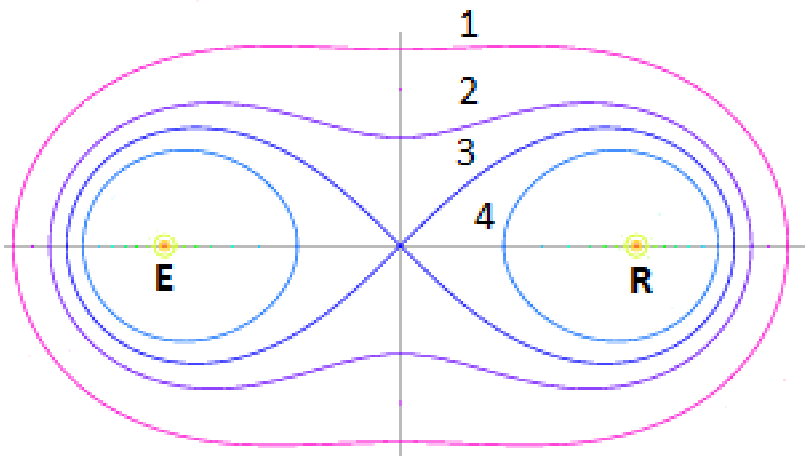

Figure 4. Detection characteristic depending on the ratio between ($D_{ER}/2$) and D_{SM}

5. Conclusions

The hydroacoustic environment corresponding to the coastal area is a complex environment in terms of sound propagation, this being influenced by waves, tides, currents, as well as by the bathymetry of the coastal area. Another important influence, besides the oceanographic characteristics, has the meteorological factors and the size of the naval traffic from surface. All these factors make it difficult to detect and identify underwater targets.

One solution for detection, locating and tracking submarine targets, especially silent submarines in the coastal area, is to construct a multi-static sonar network (MSN) which will cover a larger area, increase the probability of detecting submarines but also lower costs compared to a monostatic network of equivalent size / equivalent detection capacity.

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