ENERGY-EFFICIENT TRANSMISSION METHOD FOR UNDERWATER ACOUSTIC MODEMS

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ABSTRACT

In this article we present a transmission method that minimizes the energy used by an underwater acoustic modem (UAM) to send the acquired data from the environment to another UAM or to the surface. This underwater communication device could be placed on the seafloor to monitor the aquatic environment. The energy used to transmit the acquired data is finite because the modem is powered by batteries. Using this finite energy-efficient will enable the modem to monitor a longer time.

If the method described in this article will be used to design an underwater acoustic modem, it can reduce the energy used for transmission and the modem will be adapted to the underwater acoustic channel. Another advantage of this method is that the design and technical maintenance cost will be reduced which will determine a reduction in the total production cost of an UAM.

Keywords: *transmission method, underwater acoustic modem, passive sonar equation.*

1. INTRODUCTION

The ocean acoustic engineers have designed and implemented two types of underwater modems: cabled and acoustic.

A cabled modem transmits the acquired information, to a data center placed near shore, through a fiber optic placed on the ocean or sea floor [1]. Also through this cable the modem is powered and can function a very long time, virtually unlimited. We must emphasis that this method of monitoring has a high cost of implementation and maintenance because a cable is very long and expensive and must be placed on the ocean floor. Furthermore it is not a reliable monitoring method because the cable can break at any time when the weather is bad.

An acoustic modem is an underwater communication device used to acquire scientific data from the marine environment through the use of a sensor module and to transmit acoustically the data to another modem or to the surface. Afterwards the data are saved on a server placed near shore for immediate or later processing [2]. We must emphasize that a big shortcoming of this monitoring method is that the modem will operate a short period of time because it is powered by batteries.

Even if this is an important disadvantage at the present time the underwater acoustic modems are widely used due to the fact that they have smaller manufacturing cost than cabled modems, but the costs are still high [3].

A big advantage is that an acoustic modem can be recovered easily. It is provided with an acoustic release, which can be operated remotely. The acoustic release opens and the modem comes to the surface. Afterwards the communication device is recovered, fixed and placed in the water again [4].

Although this operation is quite fast, it is expensive because it involves at least one marine research platform, trained personnel and numerous sophisticated devices. It can be repeated several times in a year because most of the time the energy from the batteries is depleted quite fast. This is due to the fact that the modem uses a lot of power to transmit the data at shorter or medium distances. Efficient use of this energy, for data transmission, will increase the life of the underwater acoustic modem.

This will be possible if we adapt the modem to the transmission channel. It means that we have to know the variations of the underwater acoustic channel ahead of time or to estimate them [5].

The energy-efficient transmission method described in this article is based on the idea of estimating the variations of the underwater acoustic channel in a particular region. The area of interest is located in the north-western part of the Black Sea belonging to Romania. We split this area in two important regions. In figure 1 we highlight the Danube Delta region and in figure 2 we show Constanta region.

If the method described in this article will be used to design an underwater acoustic modem, it can reduce the energy used for transmission and the modem will be adapted to the underwater acoustic channel. Another advantage of this method is that the design and technical maintenance cost will be reduced which will determine a reduction in the total production cost of an UAM.

In the next section we will present the energy-efficient transmission method and we will highlight its use and performance with an example. In section 3 we will present the results obtained using this method for the variations of the underwater channel in the considered regions. In section 4 we present the conclusions of this article.

2. ENERGY-EFFICIENT TRANSMISSION METHOD

The method presented in this article is based on the passive sonar equation which is shown in equation 1.

$$SNR = SL - TL - NL \quad (1)$$

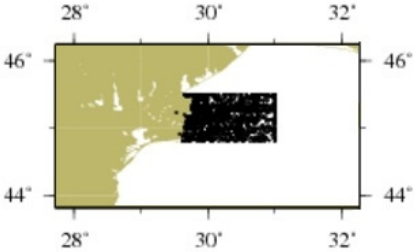


Figure 1 Danube Delta region.

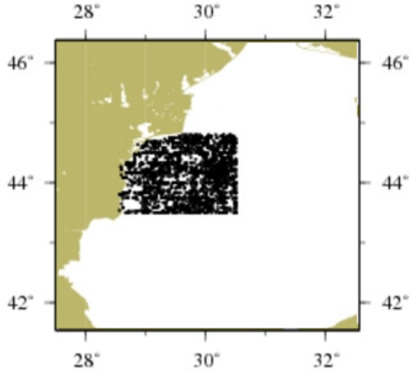


Figure 2 Constanta region.

where SNR is the expected signal-to-noise ratio at the receiver, SL is the source level of the projector, TL is the transmission loss experienced by an underwater sound wave when travels from the transmitter to the receiver, NL is the noise level in the underwater acoustic channel produced by various sources. These four parameters are expressed in decibels relative to the intensity of a plane wave of rms pressure 1μPa and are functions of frequency.

We must emphasize that the parameters of the left side of equation 1 are characterized by positive values only.

The single parameter in equation 1 that can be modeled by an underwater modem designer is the SL. The parameters TL and NL depend on the specific characteristics of the underwater acoustic channel and can only be measured or estimated.

The transmission loss will be estimated for each link configuration in the underwater acoustic channel. The noise level is presented in equation 2 for the frequency range 0.1-100 kHz

$$NL = 50 + 7.5w^{0.5} + 20\log_{10}(f) - 40\log_{10}(f+0.4) \quad (2)$$

where w is the wind speed in m/s.

Next we define the parameter total frequency response (TFR) that is shown in equation 3 and represents the cumulative effect of transmission loss and ambient noise.

$$TFR = TL + NL \quad (3)$$

We will use the above notation and rewrite equation 1. This is highlighted in equation 4.

$$SNR = SL - TFR \quad (4)$$

The relationship that defines the parameter SL is shown in equation 5

$$SL = TVR + 20\log_{10}(k) \quad (5)$$

where TVR is the transmitting voltage response and k is the amplification. We must emphasize that the TVR is defined as the output sound intensity level generated at 1 m range by a transducer for an input voltage of 1 V. The TVR profile for various transducers could be obtained from different manufacturers [6]-[8].

In equation 6 we show the new form of the passive sonar equation.

$$SNR = TVR + 20\log_{10}(k) - TFR \quad (6)$$

From equation 6 we observe that for a given SNR at the receiver we could find the optimum amplification k. Then for this amplification we can find the optimum transmission frequency. This method will offer good results if one could estimate accurately the transmission loss in the region of interest [9].

The amplification k, as a function of frequency, can be computed using the equation 7.

$$k = 10^{((SNR-TVR+TFR)/20)} \quad (7)$$

Next for a given transmission bandwidth (ΔB) around the optimum frequency we can find the amplification that will ensure the chosen SNR for the entire band of frequencies.

2.1 UAM design example

We propose to ensure at the receiver a SNR equal to 60 dB re 1μPa. In figure 3 we present an estimate of the parameter TL for the frequency range 0.1-100 kHz that was computed for a specific Tx-Rx configuration with real acoustic data acquired in the region of Constanta.

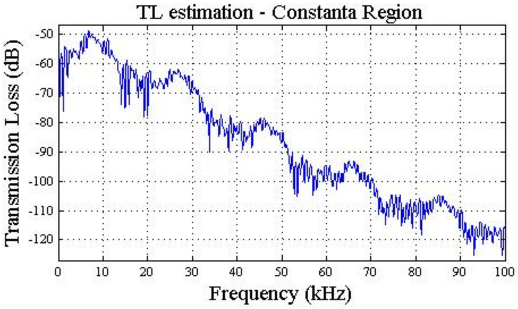


Figure 3 Transmission loss estimated using real acoustic data acquired in the Constanta region.

For the estimation of the parameter TL was used an underwater acoustic propagation modelling software named AcTUP (Acoustic Toolbox User interface and Post processor) [10]. This software runs under Matlab and is a guide user interface written by Amos Maggi and Alec Duncan which facilitates the rapid application of different acoustic propagation codes from Acoustic Toolbox which was written by Mike Porter [11].

In figure 4 we present the parameter total frequency response and in figure 5 we show the TVR of an underwater transducer. This profile was obtained from [6].

Using the equation 7 and the information described above we computed the amplification in the frequency range 0.1-100 kHz. The amplification in the region of the optimum frequency is shown in figure 6.

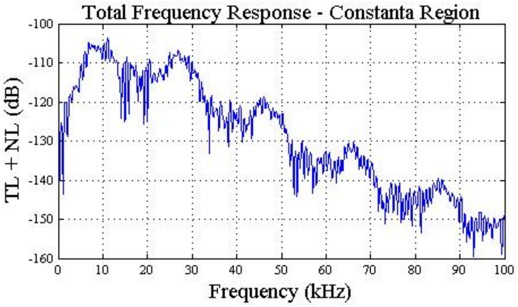


Figure 4 Total frequency response for Constanta region.

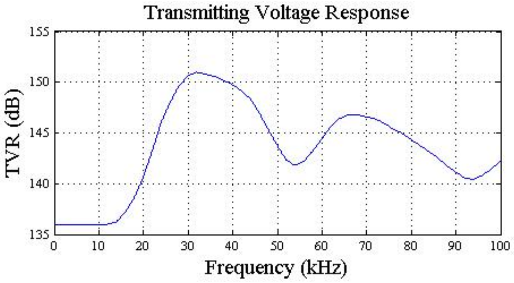


Figure 5 Transmitting voltage response.

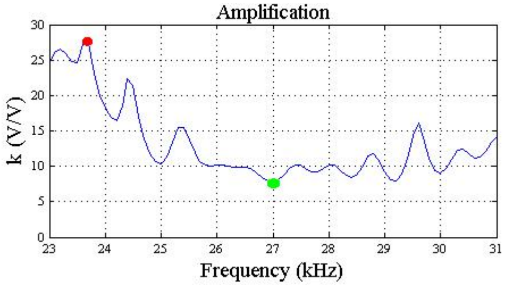


Figure 6 The amplification in the region of the optimum frequency for a given transmission bandwidth.

We obtained an amplification of 27 V/V (red dot) for an 8 kHz transmission bandwidth. The optimum transmission frequency is 27 kHz (light green dot).

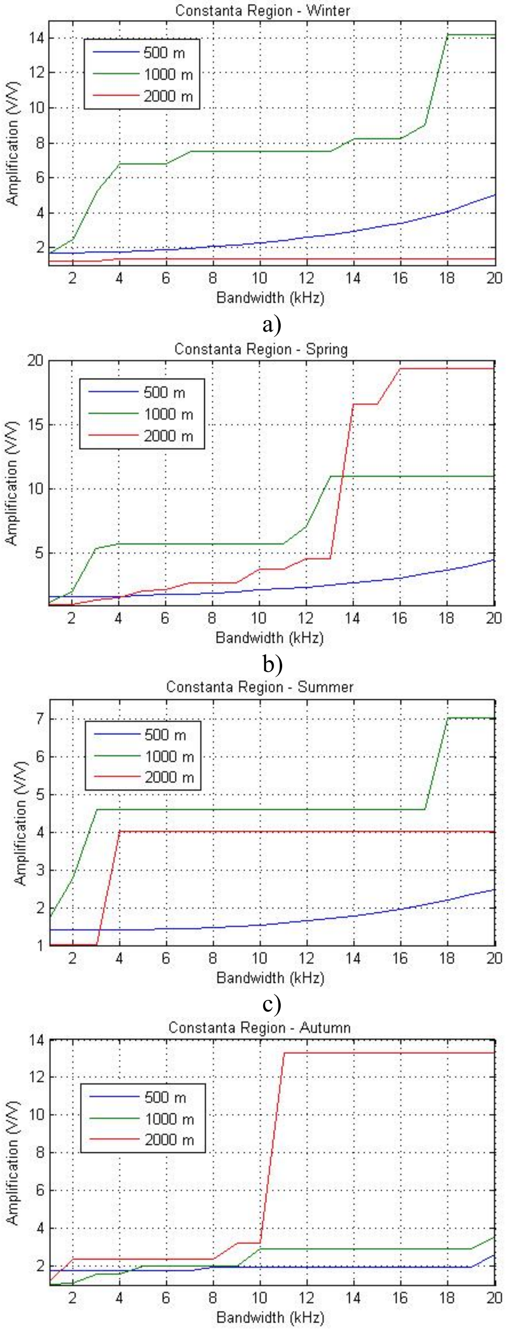
3. TRANSMISSION METHOD RESULTS

In this section we present the results obtained using the transmission method described in section 2. We computed the amplification for transmission bandwidths between 1 kHz and 20 kHz. In figure 7 we show the results for the region of Constanta and in figure 8 we show the results for the Danube Delta region.

For the computation of optimum amplification we used the transmission voltage response shown in figure 5, the noise level described mathematically in equation 2 and estimated transmission losses from the considered regions.

The parameter TL was estimated for three transmission distances, 500, 1000, 2000 meters and for the four seasons of the year using the AcTUP simulation software. In this software we introduced information about the seasonal mean sound speed profile (SSP), mean bathymetry profile, sedimentary composition and speed profile and wind speed at the sea surface.

The underwater speed in the SSP was computed using the sound speed formula obtained from [12] using conductivity, temperature and depth (CTD) information obtained from National Oceanic and Atmospheric Administration (NOAA) [13]. We must emphasize that the CTD data were recorded in a period between February 1890 and September 1998. Information about the sedimentary composition was obtained from [14].



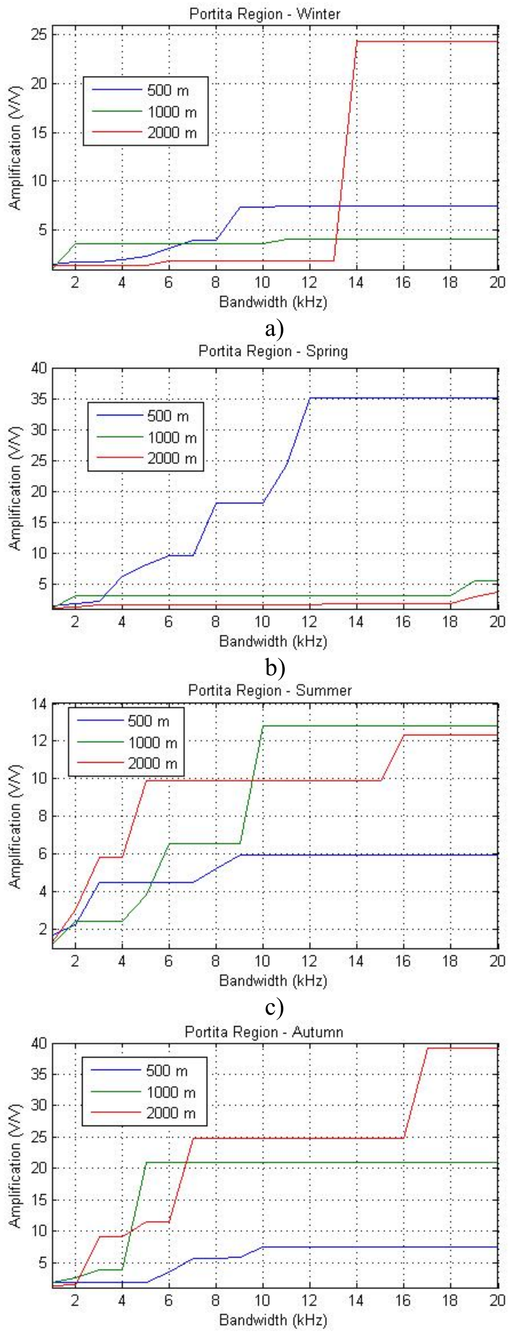
a)

b)

c)

d)

Figure 7 Transmitter amplification as a function of transmission bandwidth in the region of Constanta.



a)

b)

c)

d)

Figure 8 Transmitter amplification as a function of transmission bandwidth in the Danube Delta region.

We wish to specify that these amplifications were computed for a minimum SNR for which the amplification was greater than 1.

We observe in both figures for all the transmission distances that the smallest amplification is obtained in summer. In figure 7 a-c we observe that for a transmission distance of 500 m the amplification increases exponentially with bandwidth, but this growth is slow. In figure 7 d between 1-10 kHz we notice an amplification smaller than 4. For distances 500 and 1000 m this amplification is maintained but for distance 2000 m the amplification is approximately 4 times greater. In figure 8 a, b and d we observe high amplifications. This is due to the fact that the seabed in the Danube Delta region absorbs very well the transmitted underwater signals. In figure 8 b, for the transmission distance 500 m, we notice a rapid increase in amplification, because the values of the estimated transmission loss are smaller. For this region the smallest amplification is obtained in spring for the transmission distances 1000 and 2000 m.

4. CONCLUSIONS

In this article we present an energy-efficient transmission method that could be used by an ocean acoustic engineer in designing an underwater acoustic modem.

This method described in section 2 can reduce the energy used for transmission and we could say that the modem will be adapted to the underwater acoustic channel. This method will offer good results if one could estimate accurately the transmission loss in the region of interest. For the results presented in section 3 we used transmission loss estimates based on acoustic data recorded for 108 years. Another advantage of this method is that the design and technical maintenance cost will be reduced which will determine a reduction in the total production cost of an UAM.

5. REFERENCES

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