The Research on the Coverage Area of Multistatic Sonar under Various Work Modes

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***Abstract*—Absorption loss which is an important characteristic in the field of underwater acoustic, caused by sea water is often neglected in the research on the coverage area of bistatic sonar, in this article, the coverage area of bistatic sonar considering absorption loss is studied. When multistatic sonar works in different modes, detection criterion varies, so the coverage area can't be considered as the direct sum of coverage area of each bistatic sonar unit. This article discussed the coverage area respect to the most relaxed criterion and the most strict criterion.**

Keywords-multistatic sonar; bistatic sonar; coverage area; absorption loss; various work modes

I. INTRODUCTION

Multistatic technology originated in radar field. Recently, multistatic technology becomes a research hot spot in the field of underwater acoustic along with the development of sonar technology. Compared to monostatic, the receiving station of multistatic sonar systems has better concealment and anti-jamming capability. Multistatic sonar systems can consist of shore-based sonar, ship-based sonar and bouy according to application situation and assigned tasks because of its flexible configuration. Besides, multistatic sonar systems have more freedom in overall design, parameter selection and the design of transmitting waveform, and is easy to realize the optimization of system design.[1,2]

II. STUDY ON BISTATIC COVERAGE AREA

Presently, the research on the coverage area of bistatic sonar always doesn't consider the impact of absorption loss and draws the conclusion that the shape of bistatic sonar's coverage area (cassini oval) is the same as bistatic radar's and the coverage area of multistatic sonar is regarded as the direct sum of the coverage area of each bistatic sonar unit [3-5].The approximation brings two shortcomings. First, absorption loss in the sea water which is a characteristic of underwater acoustic as distinguish radar can't be neglected except for low-frequency and short distance transmission. Next, when multistatic sonar works in different modes, different information fusion algorithms are applied and coverage area differs. If, for instance , multistatic sonar works in searching mode, it is enough that only one receiver detects the target, as multistatic sonar works in tracking mode which need high positioning accuracy, it demands that several receivers detect the target at the same time.

A. Coverage Area under Geometrical Spreading Loss

Bistaic sonar equation is

$$SL+TS-(NL_B-DI)-DT=TL_T+TL_R\,. \tag{1}$$

In (1):*SL* is transmitting source level, *TS* is target strength, NL_B is noise level at the receiving end, *DI* is directivity function, *DT* is detection threshold, TL_T is transmission loss form transmitting terminal to the target , TL_R is transmission loss form the target to the receiver.

To various applications, the maximum transmission loss can be computed when *SL* and other parameters are given. The relationship between the maximum transmission loss and coverage area can be got by studying the relationship between transmission loss and target location. And we can know the bistatic coverage area according to the various sonar systems and various applications.

Transmission loss can be expressed as

$$TL=10K\lg(r)+\alpha r\,. \tag{2}$$

When according to spherical attenuation law, $K=2$, α is absorption coefficient which is the function of frequency f , empirical formula under 10kHz is

$$\alpha=0.007f^2+\frac{0.263f^2}{2.9+f^2}(\mathrm{dB/km})\cdot \tag{3}$$

Here, we term *10K lg(r)* geometrical spreading loss and name αr absorption loss.

Bistaic transmission loss shows in the formula below

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$$TL_T+TL_R=20\lg(r_Tr_R)+\alpha(r_T+r_R). \quad (4)$$

Neglecting absorption loss, transmission loss equals to geometrical spreading loss which is all about the product of the distance from the target to the transmitting terminal and receiving terminal, namely $TL_T+TL_R=20\lg(r_Tr_R)$. Plug it into the bistatic sonar equation,

$$20\lg(r_Tr_R)=TL_T+TL_R=SL+TS-(NL_B-DI)-DT. \quad (5)$$

Set $r_Tr_R=A^2$, $A^2=10^{(SL+TS-(NL_B-DI)-DT)/2}$. The coverage area and boundary equation of bistatic sonar can be estimated according to $r_Tr_R\leq A^2$, when *SL*, *TS* and other parameters are identified. The boundary is cassini oval which is the loci of moving points with constant products of distances from two focus, two focus are transmitting terminal and receiving terminal. According to $TL_T+TL_R=20\lg(r_Tr_R)$, and baseline length, we can get contour map of bistatic geometrical spreading loss.

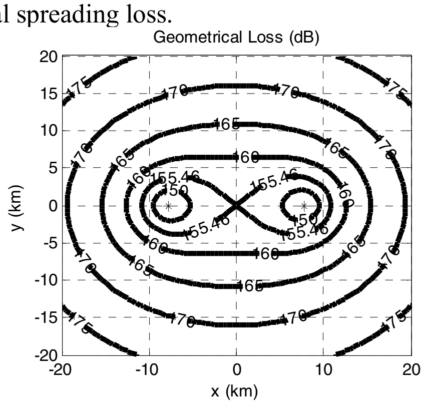

Figure 1. Bistatic geometrical spreading loss

The properties of cassini oval studied thoroughly, the result can be used directly.

Set bistatic baseline length as *2L*，set *B* equals *A/L* and $A=\sqrt{r_Tr_R}$.

When B<1, coverage area is divided in two parts,

When B=1, the shape of coverage area is ∞ and the boundary is lemniscate.

When 1<B<√2, coverage area boundary is a smooth curve without intersections and the middle part is concave,

When B=√2, the middle part of coverage area boundary flattens.

When B>√2, the middle part of coverage area boundary is convex.

It can be seen from the Fig. 1, when *B* is large, bistatic coverage area is similar to concentric circles, as *B* decreases, bistatic coverage area becomes flat , when B<1, bistatic coverage area is divided into two regions which respectively surround the transmitter and the receiver and don't connect.

According to the equation and properties of cassini oval, when baseline length is identified, we can know the bistatic coverage area under the maximum transmission loss allowed quickly and also can get the important indicators such as the maximum transmission loss when keeping coverage area connected.

B. The Relationship between Absorption Loss and Distance

The cassini oval coverage area considers only the geometrical spreading loss, so cassini oval coverage area is merely a useful approximation.

Then, we do study on absorption loss caused by sea water. Fig. 2 are the bistatic absorption loss in the area of 40km × 40km when frequency equals 1kHz and 8kHz. According to Fig. 1, for every 5dB swing in transmission loss has a big effect on the bistatic coverage area. This is a simple and imprecise conclusion which is aimed at providing the basis for discussing impacts of absorption on geometrical spreading loss approximate method. From Fig. 2, absorption loss in the study area is relatively low and the maximum absorption loss is lower than 5dB only when fc=1kHz. It shows a significant increase of absorption loss as central frequency increases, when fc=8kHz, absorption loss in the study area is almost higher than 10dB and the maximum absorption loss exceeds 35dB, in this case, estimating the coverage area of bistatic sonar used geometrical spreading loss approximate method no longer works.

C. Bistatic Coverage Area

Below, we will give the contour map of bistatic transmission loss considered geometrical spreading loss and absorption loss at different central frequency. It has been shown that every transmission loss isoline corresponds to the bistatic coverage area when that transmission loss is the maximum allowable transmission loss.

Compared Fig. 3 to Fig. 1, the real bistatic coverage area has a marked change from coverage area considering geometrical spreading loss at 1kHz only, when coverage area equals, the real transmission loss has about 5dB higher than transmission loss in geometrical spreading loss approximate method that can verify the conclusion above. When central frequency is 8kHz, the real bistatic coverage area is far smaller than that in geometrical spreading loss approximate method.

The variation law of coverage area under real transmission loss is similar to that in geometrical spreading loss approximate method.

So, we can draw the conclusion: it is inapplicable that we estimates the bistatic coverage area used geometrical spreading loss instead of real transmission loss when central frequency exceeds 1kHz, but we can make use of geometrical spreading loss approximate method to study the variation trend of coverage area with distance and transmission loss.

III. MULSTITAC COVERAGE AREA UNDER VARIOUS WORK MODES

The same multistatic systems could have various coverage areas for various information fusion algorithms and information fusion algorithms are decided by the tasks which are performed by multistatic systems. For example, it is enough that only one receiver detects the target when multistatic sonar works in searching mode and, to ensure location accuracy, it is necessary that several receivers detect the target at the same time multistatic sonar works in tracking mode. In this way, coverage area in searching mode is always larger than that in tracking mode and it should be pointed out that the coverage area now can't be considered as the direct sum of coverage area of each bistatic sonar unit.

Multistatic coverage area should be defined before the research of it: the area where the output detection probability is no less than the system requirement under the false alarm probability allowed according to the detection criterion and information fusion algorithms selected[6].

Then we extend from bistatic coverage area to multistatic coverage area.

When multistatic sonar detects target, every unit(we call a bistatic system which is composed of a transmitting terminal and a receiving terminal a unit, if transmitting terminal can receive signal ,it is called a unit too) detects the target independently firstly, the result is recorded as "1", otherwise, recorded as "0". Then do accumulative decision of each unit's result. The decision rules often used by multistatic system is "chose k from m ", namely target is considered to be detected if more than k unit detects the target, when the total number of unit is m.

The allowable final output false alarm probability $P_{fa\ req}$ and the required detection probability $P_{d\ req}$ should be determined in advance when multistatic coverage area is researched. We discuss the coverage area respecting to the rule "chose 1 from m" first. Chernyak.V.K has proven it is appropriate that false alarm probabilities of each unit are considered equivalent, namely $P_{fai}=P_{fa}$, $i=1\sim m$, thus,

$$P_{fa\ i}=1-(1-P_{fa\ req})^{1/m} . \tag{6}$$

Multistatic P_d at a specific point in area is determined by $P_{d\ i}$, $i=1\sim m$ of m units at this point and $P_{d\ i}$ at some point is determined by SNR, detection methods and threshold.

$$P_d=1-\prod_{i=1}^{m}(1-P_{d\ i}) . \tag{7}$$

Multistatic coverage area is composed of all of the points where $P_d \geq P_{d\ req}$.

Compute tristatic system (T/R-R-R) coverage area to take rule "chose 1 from 3" for example. We assume transmit signal is sinusoidal signal and detection method is copy-correlation detection without loss of generality. The allowable final output false alarm probability $P_{fa\ req}=10^{-4}$, and the required detection probability $P_{d\ req}=0.9$. According to the formula above, $P_{fa\ 1}= P_{fa\ 2}= P_{fa\ 3}=3.3\times10^{-5}$ and $P_{d\ i}$ of every unit at some point can be calculated.

The Fig. 4 is the simulation of the coverage area of the each unit and the coverage area of tristatic used rule "chose 1 from 3" with different baseline length. In the figure, dotted line represents coverage area boundary of each unit and full line represents coverage area boundary tristatic used rule "chose 1 from 3".

False alarm probability and detection probability when using rule "chose 3 from 3" are computed by the formula below.

$P_{fa}= P_{fa\ i}$, $i=1\sim m$, tristatic output false alarm probability allowed is

$$P_{fa\ i}=(P_{fa\ req})^{1/m} . \tag{8}$$

The P_d at some point in area is

$$P_d=\prod_{i=1}^{m}(P_{d\ i}) \tag{9}$$

Make simulation on the coverage area under rule "chose 3 from 3" and set $P_{fa\ req}=10^{-4}$, $P_{d\ req}=10^{-5}$. The Fig. 5 shows the coverage area under rule "chose 3 from 3".

The coverage area under rule "chose k from m, $k\neq1$, $k\neq m$" can be computed by Similar methods.

From the result, the coverage area under rule "chose 1 from m" don't equal the union of each unit coverage area, and that under "chose m from m" also don't equal the intersection of each unit coverage area. So, multistatic coverage area under various rules can't be considered as the union or intersection of each unit coverage area.

IV. CONCLUSION

This article studied bistatic sonar system coverage area when absorption loss is considered and compared coverage area under real transmission loss and coverage area considering geometrical spreading loss only. It is inapplicable that we estimates the coverage area used geometrical spreading loss instead of real transmission loss when central frequency exceeds 1kHz. Multistatic coverage area under various working mode is researched. The coverage area varies when multistatic sonar work in different modes, it don't equal the union, intersection or some combination of union and intersection of coverage area of each bistatic sonar unit and must be computed according to the formula above.

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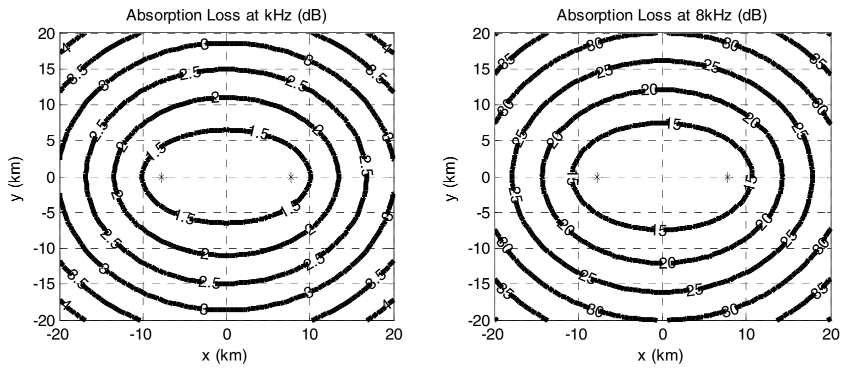

Figure 2. Bistatic absorption loss

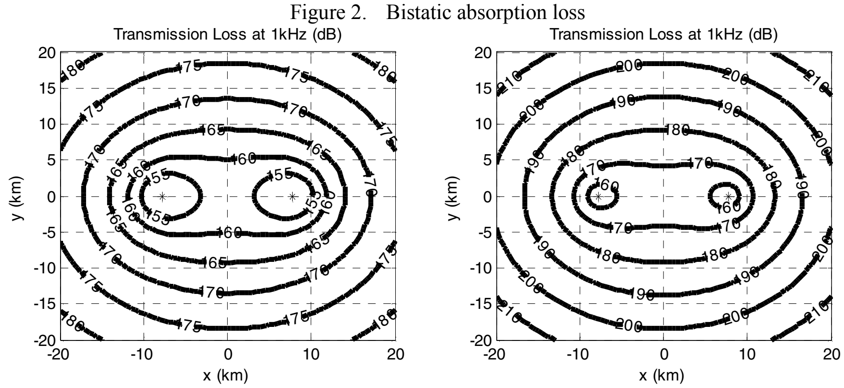

Figure 2. Bistatic transmission loss

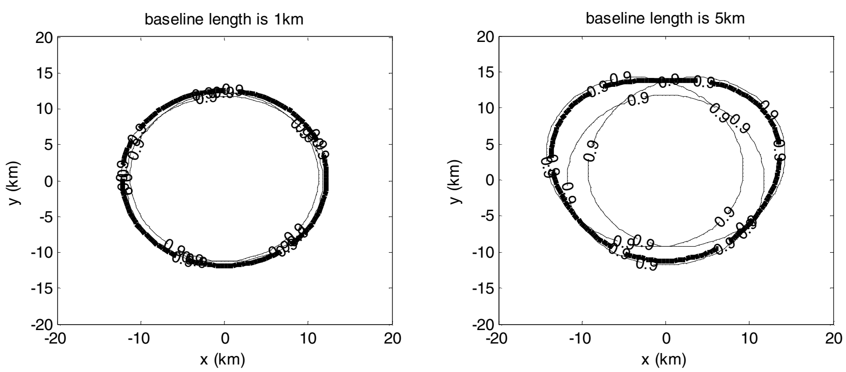

Figure 4. tristatic coverage area under rule “chose 1 from 3”

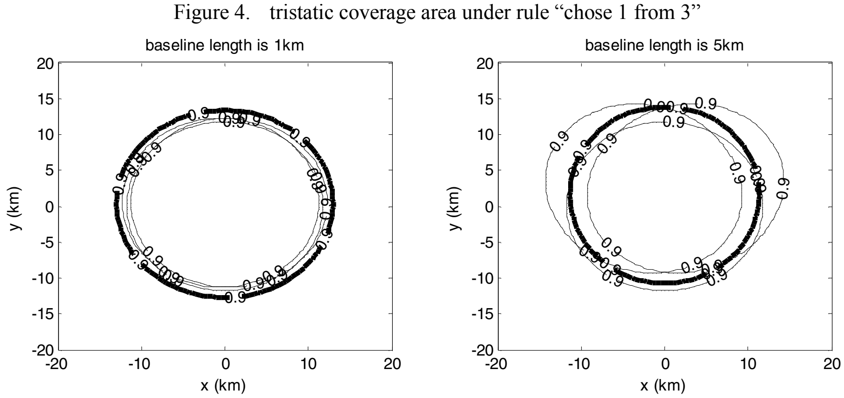

Figure 5. tristatic coverage area under rule “chose 3 from 3”