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A characteristic evaluation of signals generated by combining multiple linear chirp signals and M-sequence

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1. Introduction

Conventional multi-static sonars (MSS) consist of one transmission array and multiple receive arrays. Compared to conventional MSS, a multi-source MSS, consists of multiple transmission and reception arrays, enables to expand detection volume. To make a multi-source MSS, a multiplexing technique is needed. In communication field, Time Division Multiplexing (TDM), Frequency Division Multiplexing (FDM) and Code Division Multiplexing (CDM) are used1). However, considering application to continuous active sonar in the future, TDM and CDM cannot be applied for a multi-source MSS. FDM can be applied to a multi-source MSS, but frequency band of underwater acoustic is not so wide that the number of channels is limited.

Therefore, the authors proposed Varying Frequency Modulation Division Multiplexing (VFMDM)2), proved that VFMDM signals enables sources to be identified3), revealed the number of channels in frequency band that we plan to use3) and the affection of LFM-combination on characteristics of a multi-source MSS4,5). This report shows results to evaluate the affection of the M-sequence shift value on characteristic of a multi-source MSS.

2. VFMDM

Figure 1 shows the outline of VFMDM. Here, we suppose two transmission systems and one reception system. Each transmitted signal consists with a pair of the up-chirp LFM signal (LFM-up) and the down-chirp LFM signal (LFM-up) of which chirp rates are different for each transmission system. As transmitted signals correspond 1 of M-sequence to LFM-up and -1 of that to LFM-down, it is possible to identify the sources from the received signals by cross correlation.

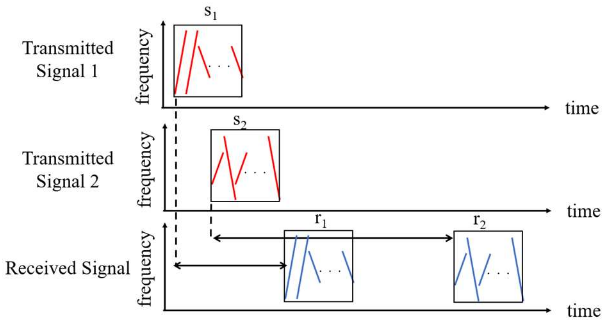

Fig.1 Transmitted and received VFMDM signals.

Figure 2 shows an image of spectrum of transmitted signals. A i-th LFM signal of n-th transmission system $s_{n,i}(t)$ $(i = 1, 2, \dots, L)$ is described as below.

when $m_i = 1$

$$s_{n,i}(t) = \sin\left\{2\pi t\left(f_c - \frac{k_{up_n}T}{2}\right) + \pi k_{up_n} t^2\right\},$$

when $m_i = -1$

$$s_{n,i}(t) = \sin\left\{2\pi t\left(f_c - \frac{k_{down_n}T}{2}\right) + \pi k_{down_n} t^2\right\},$$

where L is the length of M-sequence, t is time, f_c is the central frequency, k_{up} (>0) is the chirp rate of LFM-up, k_{down} (<0) is the chirp rate of LFM-down, T is the symbol length, and m_i is the i-th symbol of M-sequence. As described above, transmitted signals are generated by combination of multiple LFM signals and M-sequence. In this report, every channel uses 3rd-order M-sequence as shown in **Table I**. 13 pairs of LFM signals were selected so that each absolute value of chirp rate has large difference. For each combination, 13 (the number of channels) times 7 (the number of M-sequence shift value), that is, a total of 91 types of signals were

Table I M-sequence for simulation.

Shift Value	M-sequence
0	-1, -1, 1, -1, 1, 1, 1
1	-1, 1, -1, 1, 1, 1, -1
2	1, -1, 1, 1, 1, -1, -1
3	-1, 1, 1, 1, -1, -1, 1
4	1, 1, 1, -1, -1, 1, -1
5	1, 1, -1, -1, 1, -1, 1
6	1, -1, -1, 1, -1, 1, 1

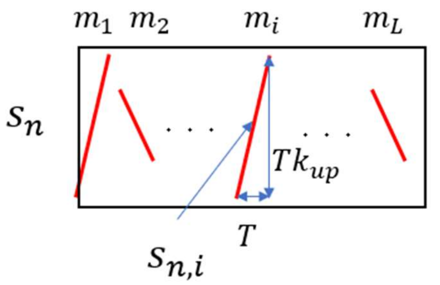

Fig. 2 A transmitted VFMDM signal of n-th

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transmission system.

generated, and their ambiguity function characteristics were evaluated.

3. Evaluation

The ambiguity function is expressed as below.

$$Q(\tau, f_d) = \left| \int_{-\infty}^{\infty} s_n(t) s_n^*(t+\tau) e^{j2\pi f_d t} dt \right|^2$$

where s_n is a transmitted signal of n -th transmission system, s_n^* is a complex conjugate of s_n, τ and f_d is delay time and doppler frequency, respectively. **Figure 3** shows an example of an ambiguity function and the resolution of main-lobe width at -6dB and the maximum sidelobe level (MSL). Resolution at $Q(\tau, 0)$ and $Q(0, f_d)$ is evaluated.

4. Evaluation Results

Figure 4 and **5** show results of evaluation. There is no difference of MSL and resolution between each shift cases except for the case that shift value is 5 of which has the best MSL at $f_d = 0$. That might be caused by characteristics of truncation noise of M-sequence, so its characteristics (peak value, average and variance) are calculated and showed in **Table II**. However, the case, in which the shift value is 5, is not special from any point of truncation noise characteristics.

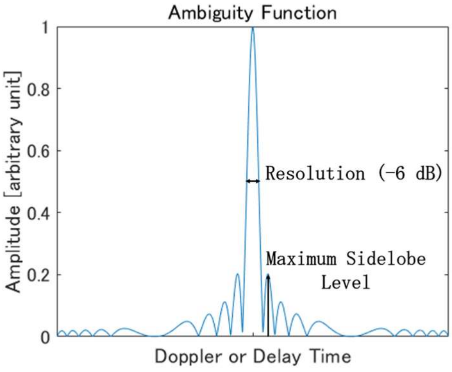

Fig. 3 An example of an ambiguity function.

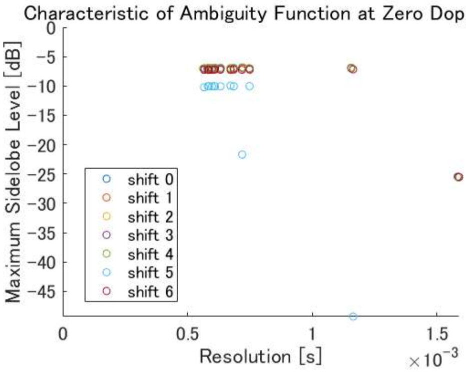

Fig. 4 Characteristics of Ambiguity Function at $f_d = 0$

5. Conclusion

In this report, the affection of the M-sequence shift value on characteristic of a multi-source MSS was evaluated. As a result, in almost case there is no difference MSL and resolution, but when the shift value is 5, MSL is smaller than other cases.

In the future, we will continue to evaluate characteristics by using different third-order M-sequences and other M-sequences that have different lengths.

References

1. N. Kikuchi and K. Kitayama, *Hikari henpukucho hoshiki* (Optical modulation/demodulation method) (IEICE, 2017) Section 3, Chap 3 [in Japanese].
2. S. Urakawa, H. Ogasawara, E. Sato, and K. Mori, Proc. Symp. USE2021 (2021) 3Pa6-4.
3. S. Urakawa, E. Sato, T. Kuroyama, H. Ogasawara, and K. Mori, Proc. Meet. MASJ (2022) 22-12.
4. S. Urakawa, E. Sato, T. Kuroyama H. Ogasawara, and K. Mori, Proc. 2022 Autumn Meet. of Acous. Soc. Jpn. (2022) 2-6-3 (in Japanese).
5. S. Urakawa, E. Sato, T. Kuroyama H. Ogasawara, and K. Mori, IEICE Technical Report **122** (2022) (in Japanese).

Table II Characteristics of truncation noise of M-sequence.

Shift Value	Peak	Average	Variance
0	-2	-0.5	1.00
1	-2	-0.5	2.45
2	-2	-0.5	1.00
3	-3	-0.5	3.18
4	-1	-0.5	0.272
5	-2	-0.5	1.00
6	-3	-0.5	3.18

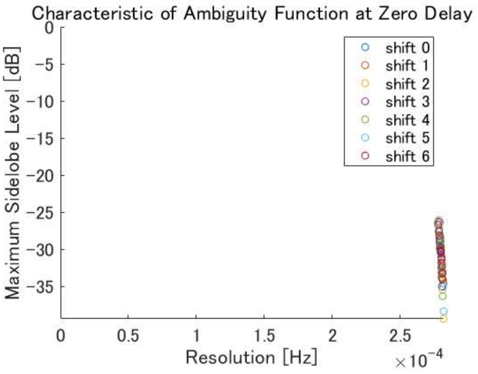

Fig. 5 Characteristics of Ambiguity Function at $\tau = 0$