MUTUAL INTERFERENCES REDUCTION BETWEEN SONARS OR BARRIER MODULES OPERATING IN THE SAME AREA

ANDRZEJ ELMINOWICZ, LEONARD ZAJĄCZKOWSKI

R&D Marine Technology Centre
Dickmana 62 Str., 81-109 Gdynia, Poland
andrzeje@ctm.gdynia.pl

This paper describes key features of a Mutual Interference Reduction (MIR) in sea area, especially in shallow water, where some acoustic devices may operate simultaneously. MIR is an essential problem in mono– and multistatic systems. Receivers of sonars or barrier modules, operating in these systems, can receive signals from other acoustic devices by direct track, as echoes from the targets or as reverberations. The mutual sonars interference level depends on many parameters, like: the transmitting signal parameters (modulation, SL, B, T) and bands aliasing, mutual sectors coverage, the distance and mutual localization of transmitting transducers and receiving arrays, as well as type of matched filtration. The degradation of mutual interferences by matched filtration has been determined. Influence of modulation type, B and T parameters on MIR at the matched filtration output have been presented also.

INTRODUCTION

Some of important sonars disturbances are signals emitted by the other sonars operates in the same sea area. The signals can be received by direct way, as echoes from targets situated in the area or as surface/bottom reverberations. The level of the disturbances depends on signals parameters (modulation type, signal level, frequency, bandwidth and signal length), mutual localization of the sonars/barrier modules, mutual localization of the sector, as well as environmental and propagation condition. The problem of MIR is especially important for acoustic protection systems operating in shallow water. The presence of some acoustic devices in limited region of shallow water (sea depth not greater than 20 m) and the high bottom and surface reverberations level creates a serious challenge for designers of acoustic devices integrated in one system – usually multistatic system (MS). Utilizing a few type of signals commonly used in hydroacoustic devices, the four methods of MIR in sonar systems have been tested by computer simulation.

1. USED SIGNALS

The basic sonar's signals are rectangular envelope pulses with linear or hyperbolic modulation. The signals may be expressed as:

LFM: $$s(t) = A_c rect(\frac{t}{T}) \exp(i2\pi(f_0 t \pm \frac{Bt}{2} \mp \frac{Bt^2}{2T})) \quad \text{UP/DOWN} \tag{1}$$

HFM $$s(t) = A_c rect(\frac{t}{T}) \exp(i2k_0 \pi \ln\left(1 \mp \frac{t}{t_0}\right)) \quad \text{UP/DOWN} \tag{2}$$

where: $t_0 = T(f_0/B \pm 0.5)$, $k_0 = \mp t_0(f_0 \mp B/2)$

or HFM $$s(t) = A_c rect(\frac{t}{T}) \exp(i2\pi k \ln(m - t)) \quad \text{UP} \tag{3}$$

$$s(t) = A_c rect(\frac{t}{T}) \exp(-i2\pi k \ln(m - t) + 2 f_0 t) \quad \text{DOWN} \tag{3a}$$

where: $B_h = B/2$; $k = -0.5 (f_0 - B_h)*(f_0 + B_h)T/B_h$ and $m = 0.5(f_0 + B_h)T/B_h$.

Three above mentioned modulations and following signal parameters: frequency 60 kHz, bandwidth 20 kHz and 20 ms pulse length has been used in computer simulation. For comparison CW pulse has been analyzed also.

2. MUTUAL INTERFERENCES REDUCTION

2.1. TRANSMISSION CONTROL

The mutual interferences between sonars can be reduced by selection of transmission control. Three modes of transmission control for mutual interference reduction can be defined: independent, sequential or coordinated.

For sequential transmission once a ping is transmitted at full band and any type of modulation can be used. Next ping is transmitted after time indispensable for attenuation signals from previous sonar. The every sonar operating in the system has limited operation time and reduced effectiveness.

Coordinated transmission occur according to an established few types of sequences (one, two or three pings are transmitted parallel) for which mutual interference reduction can be carried out by matched filtration, or by frequency separation.

Independent transmission requires full separation of all devices but not only by frequency separation. Separation can be support by changing additional parameter of transmitted pulses and matched filter.

The performance of each transmission mode may be evaluated by information capacity (IC) which can be extracted from system consist of "*n*" sonars.

For sequential transmission:

$$IC = [(B_1T_1N_1 + B_2T_2N_2 + \dots + B_nT_nN_n)\, 2\log_e(1 + SNR)]/n \tag{4}$$

Full band and any type of modulation and pulse duration can be used for sequential transmission.

For coordinated transmission performance with two pings transmitted parallel:

$$IC = (B_1T_1N_1 + B_2T_2N_2)\ 2\log_e(1+SNR) \quad (5)$$

For every pair of sonars B, T and modulation type should be carefully selected for reducing mutual interferences and reach proper processing gain (range of detection) for every sonar. For independent transmission IC is maximal and equal:

$$IC = (B_1T_1N_1 + B_2T_2N_2 + \ \dots + B_nT_nN_n)\ 2\log_e(1 + SNR) \quad (6)$$

Where for equations (4), (5) and (6): B_n – sonar bandwidth, T_n – pulse length, N_n – number of transducer elements and SNR – signal-to-noise (reverberation) ratio.

2.2. MIR BY MF FOR VARIOUS TYPE OF MODULATION

Influence of various bandwidth, pulse length and type of modulation on mutual interferences reduction of DDS or barriers integrated in one system, have been tested by computer simulation. Results of this simulation will be verified experimentally in the next stage of the research and development project No R 00 025 02. Computer simulations have been performed in MATLAB, covers of influence examination:

- modulation type on the MIR,
- pulse parameters(bandwidth and pulse length) on the MIR,
- SNR on the MIR.

Fig. 1, 2, 3 and 4 shows selected results of the simulations.

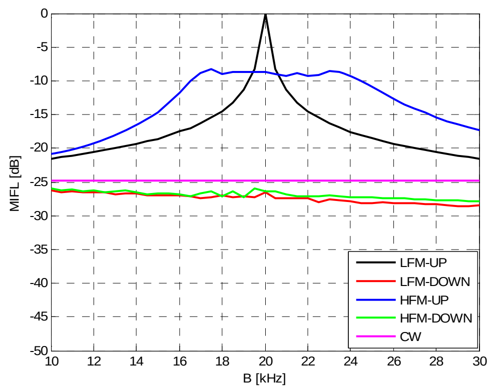

Fig.1 MIFL versus bandwidth
Filtrated signals: f_0 = 60,0 kHz, T = 20 ms, B = {10 kHz ÷ 30 kHz}

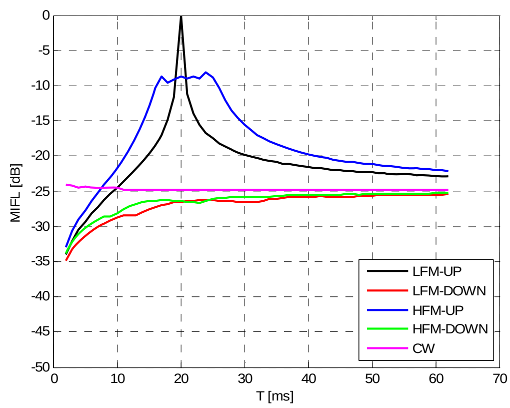

Fig.2 MIFL versus pulse length
Filtrated signals: f_0 = 60,0 kHz, B = 20 kHz, T = {2 ms ÷ 62 ms}

In Figs 1 i 2 matched signals are LFM-UP, in Figs 3 and 4 matched signals are HFM-UP. Parameters of the signals are the same: f_0 = 60 kHz, B = 20 kHz, T = 20 ms.

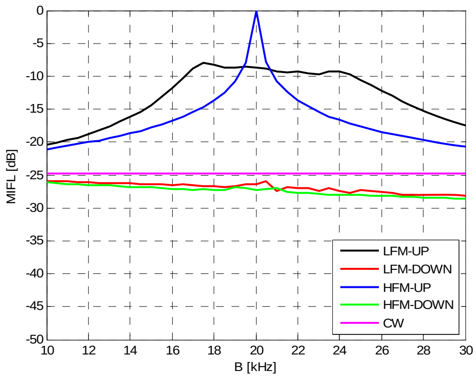

Fig.3 MIFL versus bandwidth
Filtrated signals: f_0 = 60,0 kHz, T = 20 ms, B = {10 kHz ÷ 30 kHz}

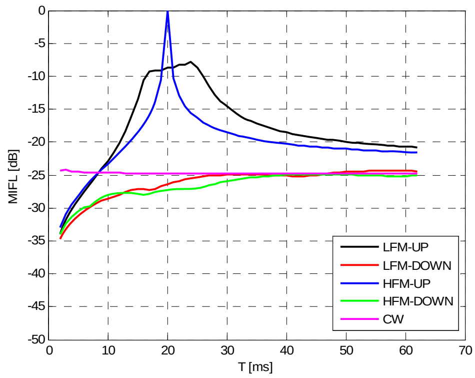

Fig.4 MIFL versus pulse length
Filtrated signals: f_0 = 60,0 kHz, B = 20 kHz, T = {2 ms ÷ 62 ms}

Based on these results, we can state that change of modulation type (UP → DOWN), independently from the modulation is LFM or HFM, decreases of mutual interference filtration level (MIFL) about 27 dB, the reduction is independent from bandwidth and pulse length for pulse longer than pulse length of matched signal.

2.3. MIR BY MF AND FREQUENCY SEPARATION WITH ADJACENT OR PARTIALLY COVERED BANDS

To examine MIR by MF and frequency separation, two configurations of the bands has been investigated. First configuration have been carried out with such selection of frequency and bandwidths that the bands are adjacent (Fig. 5a), and second configuration have been carried out for the bands partially covered (Fig. 6a). Both configurations were analyzed versus bandwidth and pulse length. Some results are shown in Figs 5 and 6.

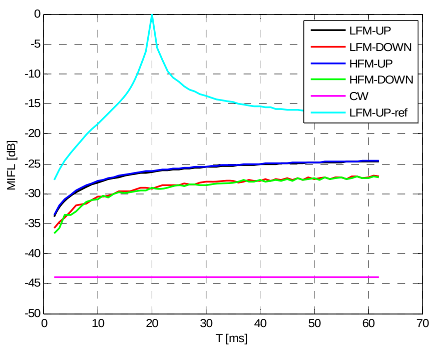

Fig.5 MIFIL versus pulse length
Matched signal: LFM-UP, : f_0 = 57,5 kHz, B = 5 kHz, T = 20 ms
Filtrated signals: f_0 = 62,5 kHz, B = 5 kHz, T = {2 ms ÷ 62 ms}

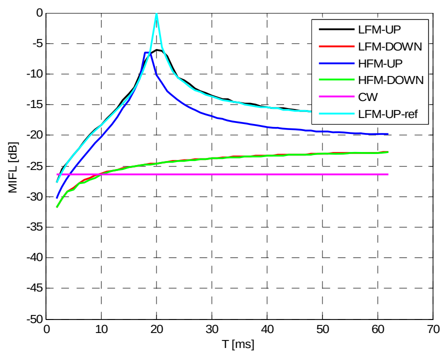

Fig.6 MIFIL versus pulse length
Matched signal: LFM-UP, : f_0 = 60,0 kHz, B = 10 kHz, T = 20 ms
Filtrated signals: f_0 = 55,0 kHz, B = 10 kHz, T = {2 ms ÷ 62 ms}

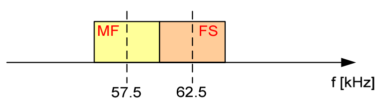

Fig.5a Diagram of compared signals: MS – matched signal, FS – filtrated signals: LFM UP and DOWN, HFM UP and DOWN, CW

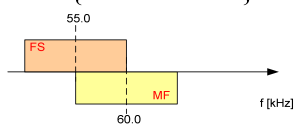

Fig.6a Diagram of compared signals: MS – matched signal, FS – filtrated signals: LFM UP and DOWN, HFM UP and DOWN, CW

Results of performed analysis shows that a change of bandwidth and/or mutual localization of the bands (changes of frequency) is an effective method of interference reduction and 27 dB reduction for pulses with the same modulation may be obtained.

2.4. MIR BY MF AND SIGNAL PARAMETERS (B AND T)

The possibility of separation of signals with the same bandwidth and central frequency as well as same modulation type has been analyzed. Analysis was performed for signal LFM–UP with 60 kHz central frequency including processing gain of the MF. The analysis was found that separation level depends on pulses parameters; – see Figs 7 and 8.

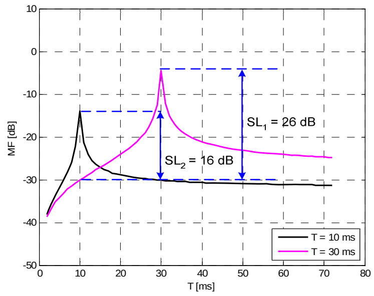

Fig.7 Separation level when pulse length is the separation parameter (B = 20 kHz)

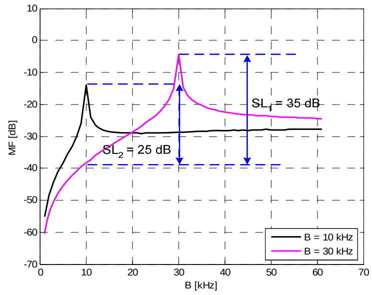

Fig.8 Separation level when bandwidth is the separation parameter (T = 20 ms)

2.5. INFLUENCE OF NOISE ON MIR

Due to all signals coming to receiver contain a noise, the examination of the white noise influence on mutual interference reduction has been carried out. The analysis performed for the same signals as applied in 2.2 and 2.3. One detailed example of the computer simulations is shown in Fig. 9 and all collected results in Fig. 10.

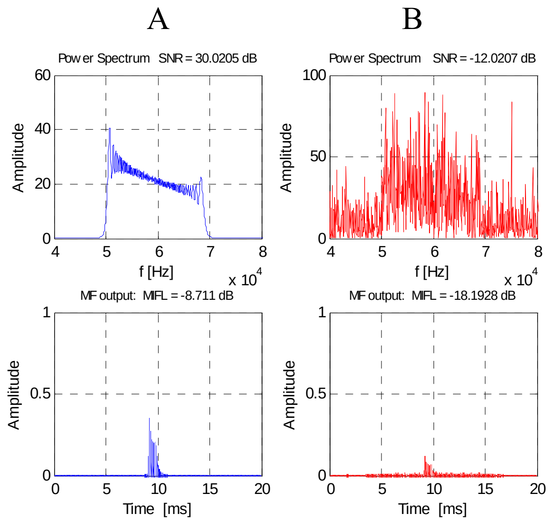

Fig.9 The signals (HFM–UP), in frequency domain, on the MF input and the signals, in time domain, on the MF output (matched signal LFM–UP). Parameters all signals are the same (f_c = 60 kHz, B = 20 kHz, T = 20 ms). SNR = 30 dB – fig. A and -12 dB – fig.B.

MIFL are -8.7 dB and -18.2 dB respectively.

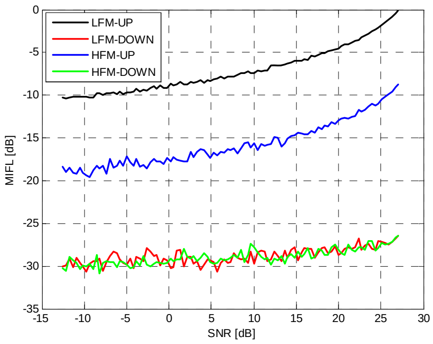

Fig.10 MIFL versus SNR.

The matched signal is LFM–UP. Signals parameters are such as in Fig. 9.

These analyses demonstrate that influence of the noise on the MF output is especially clear for modulation with the same characteristic inclination (MIFIL decrease approx. 10 dB), in the rest cases the influence of noise may be practically omitted.

3. CONCLUSION

For the multimonostatic and bi– or multistatic systems, especially when operating in shallow water, the separation of the signals is indispensable. MIR between acoustic devices can be enabled by: sequential transmission (separation in time), frequency/bandwidth separation, matched filtration by changes signal parameters: modulation type, bandwidth, frequency and pulse length. The limitations of the MIR methods are: significantly decrease of information arriving from system's devices in sequential transmission, frequency separation can be used in multimonostatic system only, matched filtration needs a few types of filters for extraction of required echoes.

The signals arriving to receiver from same sources (different transmitters, different targets and different echoes of the targets) can be separated by:

application of different signal modulation, both type and inclination, changes of signal parameters.

The influence of the noise on the MIR by MF may be practically omitted. It should be noted that relative level of echoes decreases with the noise increases (approx. 10 dB echo decrease at 40 dB noise increase).

ACKNOWLEDGMENT

This work is financed by found dedicated for research and development projects realized during 2006 ÷ 2009 years. Research and development project has a No. R 00 025 02.

REFERENCES

[1] M A. Ainslie, Bistatic Sonar Performance Assessment. UDT Europe, London, 2000.

[2] A. Elminowicz, L. Zajączkowski, Multistatic Systems, XXII Symposium on Hydroacoustic, Krynica Morska 2006.

[3] A. Elminowicz, The Harbour and Anchorage Protection by Underwater Acoustic Barriers, UDT Europe, Hamburg 2006.

[4] A. Elminowicz, L. Zajączkowski, Bistatic Systems, Archives of Acoustics, Vol. 31, No 4, Warszawa 2006.

[5] A. Jedel, R. Salamon, J. Marszal, J. Kaczmarek, Z. Ostrowski, Mutual Interference Reduction in Pulse Sonars with Frequency Modulation, OSA 27, Polanica 2001.