CLASSIFICATION UNCLASSIFIED	**SYSTEM NUMBER** 510023

TITLE

AN ADAPTIVE PROCESSING STRUCTURE FOR INTEGRATED ACTIVE-PASSIVE SONARS DEPLOYING CYLINDRICAL ARRAYS

DCIEM-98-P-10

An Adaptive Processing Structure for Integrated Active-Passive SONARs Deploying Cylindrical Arrays

(Invited Paper)

Amar C. Dhanantwari * and Stergios Stergiopoulos †

* Department of Electrical and Computer Engineering, University of Western Ontario, London, Ontario, N6A 5B9
† Defense and Civil Institute of Environmental Medicine, P.O Box 2000, Toronto, Ontario, M3M 3P9, CANADA

Abstract: The paper details the development and implementation of an adaptive processing structure for integrated active-passive SONARs deploying cylindrical arrays. The main concept includes decomposition of the computationally intensive multidimensional beamformer into two simple modules, which are line and circular array beamformers. Thus, the multidimensional beamforming process can now be divided into coherent sub-processes which lead to efficient implementation in real-time sonar systems. This new approach makes the implementation of adaptive schemes in multidimensional sensor arrays practically achievable. The proposed adaptive processing concept has been implemented in an integrated active-passive real-time sonar deploying a cylindrical array. Real data results demonstrate the superior performance of the adaptive beamformers over the conventional beamformer in suppressing the reverberation and cluttering effects in active sonar applications. Moreover, for passive sonar applications, the adaptive processing provides substantially improved angular resolution. These performance improvements for cylindrical array SONARs are of particular importance in mine hunting operations.

CYLINDRICAL ARRAY BEAMFORMER

Consider the cylindrical array shown in Fig. 1 with $\aleph$ sensors, where $\aleph = NM$, N is the number of circular rings and M is the number of sensors on each ring. The angular response of this cylindrical array to a steered direction at (θ_s, ϕ_p) can be expressed by Eq. 1 below.

$$B(f,\theta_s,\phi_p) = \sum_{r=0}^{N-1}\sum_{m=0}^{M-1} X_{(r,m)}(f)\, D_{(r,m)}(f,\theta_s,\phi_p) \tag{1}$$

where $X_{(r,m)}(f)$ is the fourier transform of the received signal by the m^{th} sensor on the r^{th} ring [1, 2], $D_{(r,m)}(f,\theta_s,\phi_p) = \exp(jhf(rd_z \cos\phi_p + R\sin\phi_p \cos(\theta_s - \theta_m))$, R is the radius of the cylinder, d_z is the distance between adjacent rings along z-axis and $\theta_m = 2\pi m / M$, $m = 0,1,..,M-1$. Eq. 1 may be rewritten as

$$B(f,\theta_s,\phi_p) = \sum_{r=0}^{N-1} D_r(f,\theta_s,\phi_p)\left[\sum_{m=0}^{M-1} X_{(r,m)}(f) D_m(f,\theta_s,\phi_p)\right] \tag{2}$$

where, $D_r(f,\theta_s,\phi_p) = \exp(jhfrd_z \cos\phi_p)$ and $D_m(f,\theta_s,\phi_p) = \exp(jhfR\sin\phi_p \cos(\theta_s - \theta_m))$. It is clear that in Eq. 2, $D_r(f,\theta_s,\phi_p)$ is the kernel of line array beamformer and $D_m(f,\theta_s,\phi_p)$ is the kernel of circular array beamformer. This suggests the decomposition of the cylindrical array beamformer into two steps, circular array beamforming of each of the N rings and line array beamforming of these outputs, or line array beamforming of the staves followed by circular-array beamforming. This new efficient implementation based on the decomposition of the cylindrical beamformer into simple line-array and

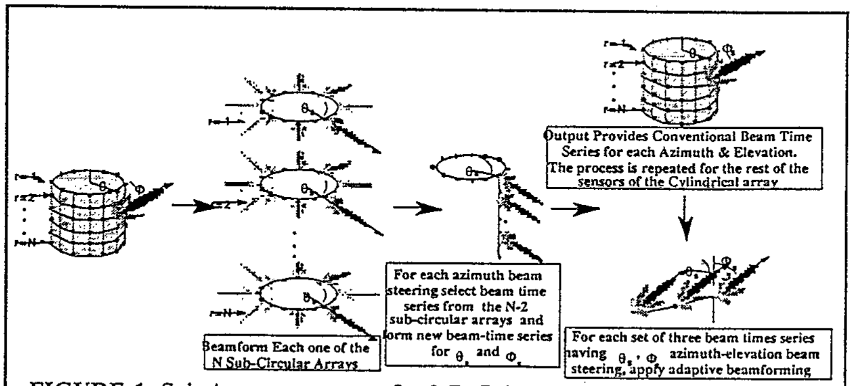

FIGURE 1. Sub-Aperture concept for 3-D Cylndrical Adaptive Beamformer.

beamformers is also shown in Figure 1. A non-uniform spatial shading window may be applied in the conventional circular beamformers and a uniform shading window may be applied to the conventional line array beamformer to improve the angular response in both the azimuth and elevation angles. This new approach also makes the incorporation of the adaptive schemes for cylindrical arrays feasible. In this case the sub-aperture concept for line arrays [1] and circular arrays [2] forms the basis of our sub-aperture concept for cylindrical arrays [2], as shown in Figure 1. In a sense, the sub-aperture approach minimizes the degrees of freedom for the adaptation process. This processing step is essential to achieve near instantaneous convergence for integrated active-passive applications [1].

ADAPTIVE BEAMFORMING SCHEMES

The goal of an adaptive beamformer scheme is to optimize the beamformer response so that the output contains minimal contributions due to noise and signal arriving from directions other than the desired signal direction. The two adaptive beamformer schemes are considered here are the Generalized Sidelobe Canceller (GSC) and the Steered Minimum Variance (STMV) beamformer [1,2]. The GSC formulation produces a much less computationally intensive implementation and in combination with the Normalized Least Mean square (NLMS) adaptive algorithm produces near instantaneous convergence. The Steered Minimum Variance (STMV) algorithm differs from the basic MVDR algorithm in that the STMV algorithm uses a Steered Covariance Matrix (STCM) that is derived from a band of frequencies and the MVDR algorithm uses a Covariance Spectral Density Matrix (CSDM) that is derived from a single frequency bin. The number of statistical degrees of freedom available to estimate the STCM in increased by this fact. Therefore, the STMV method achieves significantly shorter convergence times than adaptive algorithms based on CSDM without sacrificing spatial resolution.

EXPERIMENTAL RESULTS AND CONCLUSION

The conventional and adaptive beamformers were tested with real and synthetic hyperbolic FM pulses, and synthetic narrowband signals. Figure 2 shows the matched filter output for adaptive active applications. Inputs to the replica correlator are beam time series of conventional and adaptive beamformers. The replica correlator output provides a measure of temporal coherence properties (or optimum processing) achieved by the conventional beamformer, the sub-aperture GSC and the STMV algorithms for the case of cylindrical array. The results suggest that the sub-aperture STMV adaptive beamformer has achieved near instantaneous convergence since its replica correlation output is equivalent to that of the conventional beamformer, which is the optimum case [1]. Figure 3 shows the results of the beamformers in the passive configuration with narrowband signals.

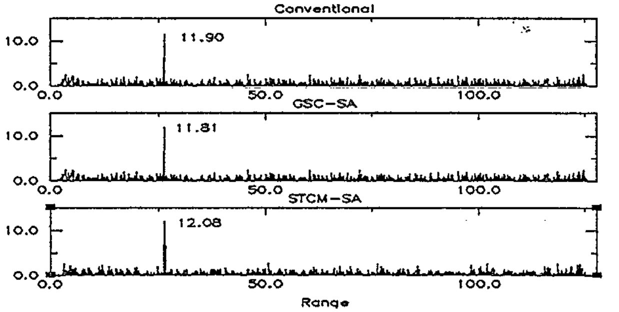

FIGURE 2. Matched Filter output for adaptive and conventional beam time series of cylindrical array beamformer.

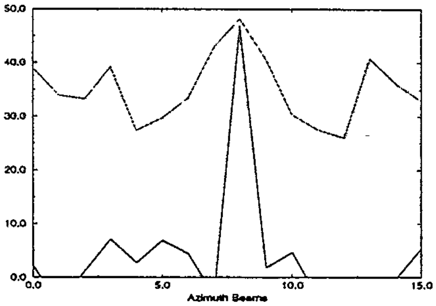

FIGURE 3. Passive conventional with spatial window (upper curve) and adaptive (lower curve) beamforming (azimuth) results for cylindrical array.

In conclusion, the results of this study indicate that the sub-aperture adaptive concept addresses practical concerns of near-instantaneous convergence, shown in Figure 2, for integrated active-passive sonar and radar applications. The performance improvements of the adaptive beamformers compared with that of the conventional beamformer are significant improvements in array gain (or bearing estimates, Figure 3), for both active and passive applications.

REFERENCES

[1] S. Stergiopoulos, *Proceedings of the IEEE*, 86(2), 201-239, February 1998.

[2] Tawfik A., Dhanantwari A.C. and Stergiopoulos S., A "Generic Adaptive Beamforming Structure for 2-D & 3-D Arrays of Sensors", *Conference Proceedings OCEANS '97 MTS/IEEE*, 369-373, Halifax, N.S., Oct.-1997.

510023