PRACTICAL SUPERGAIN HEAD SIZED ARRAYS

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ABSTRACT

This paper carried out a new design of head sized sensor arrays with a simple delay-and-sum beamforming which provides useful amounts of directivity index with sufficient robustness to errors. A frequency-independant sidelobe reduction is proposed to achieve optimal frequency characteristics. In order to obtain this control, a principle of combining multiple level of array structures is established. Results are presented for spherically isotropic noise. It is found that good performance can be obtained for a head sized array by combining multiple level structures with simple delay and sum beamformer.

1. INTRODUCTION

The aim of this paper is to present a performant head sized array structure using sum and delay beamforming to benefit from low power consumption of such processing. Early work involved designing of linear endfire arrays with simple delay and sum beamforming [1], [2] by shading to reduce sidelobes and modest oversteering to reduce mainlobe. A limitation of such beamforming when applied to head sized arrays is that they are not optimum for low frequencies. [3], [4] investigated delay and sum beamforming head sized arrays. He developed cardioid directional microphone arrays in both broadside and endfire configurations to be placed on an eye glass frame. [5] proposed in a more general approach fixed arrays using different types of directional microphones. Directivity up to 8 dB was obtained with a weighted white noise sensitivity of 3 dB and a dispersion of directivity index up to 7 dB on the audiometric spectrum [500 − 4000] Hz. In this paper, a frequency optimisation of directivity index is proposed by cancellation of fixed wave directions. Therefore, we establish a principle of combining multiple level structures. After investigation of simple basic array structures, we apply this principle to propose with simple guidelines new and performant structures. Performance metric used here are frequency shape of directivity index, weighted directivity index and weighted noise sensitivity [5] (to take into account different contributions of different frequencies in speech discrimination).

2. GENERAL BASIC STRUCTURES

2.1. Array Cancelling One Fixed Direction - Structure A

2.1.1. Endfire Array

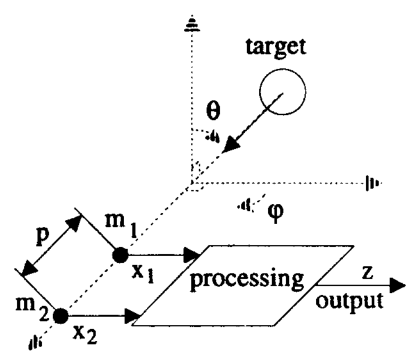

Figure 1: Position of different elements versus θ and φ

To cancel a fixed wave direction (θ_0, φ_0), i.e. $z(\theta = \theta_0, \varphi = \varphi_0) = 0$, we should compensate the existing phase delay in sensor output responses (x_1, x_2) to that wave direction. This delay is given for two sensors m_1 and m_2 of Fig. 1 by :

$$\Delta\varphi = \varphi_2 - \varphi_1 = \frac{p\omega}{c}\sin(\theta_0)\cos(\varphi_0) = \frac{p\omega}{c}a \qquad (1)$$

However, this type of processing can lead to harmonic target cancellation. To avoid this drawback, we limit the phase difference resulting from a signal coming from target direction for all the frequencies of the audiometric spectrum. This leads to a limitation constraint on sensor spacement (small value for p) and therefore increases the white noise sensitivity. So, there is no benefit from applying this structure to many sensors.

2.1.2. Broadside Arrays

The same principle of phase delay compensation between output sensors can be applied to cancel fixed directions in a broadside array. However symmetrical caracteristics of this structure implies that for each rear cancelled wave direction, the symmetrical front wave direction is cancelled. This symmetrical caracteristics of broadside arrays limits severely their performance.

2.2. Arrays Maximising Target Direction Response - Structure B

Cancellation of fixed direction improves directivity index. To make the resultant structure robust against spatially white noise perturbation, signal response should be maximised relative to white noise response.
To maximise signal response, phases should be aligned for the different sensor outputs in response to wave coming from target direction. For endfire structure, this can be done by delaying outputs of the frontal sensors.
For broadside structure, since sensors responses to target wave are in phase, a simple summation provides maximum response to target. Fig. 2 shows weighted directivity index for different spanning of an endfire and a broadside arrays of five sensors. For the same structure, the white noise sensitivity is plotted for different number of microphones in Fig. 3. Both structures

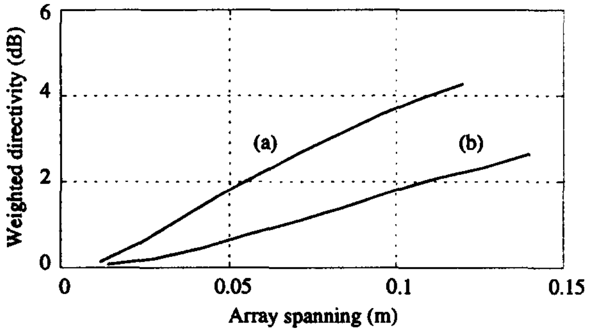

Figure 2: Weighted directivity index as function of array spanning for an endfire (a) and broadside (b) arrays with five sensors

provide low directivity indexes but offer low noise sensitivity. Then they can be used for improvement of robustness against white noise.

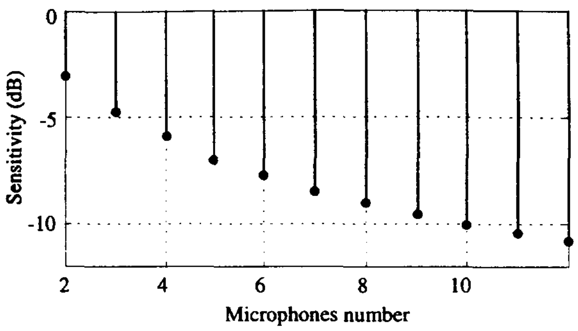

Figure 3: Noise sensitivity versus number of sensors for structure B

3. MULTIPLE LEVEL ARRAY STRUCTURES

3.1. Principle of Combining Multiple Level Structures

Let us look at the array in Fig. 4, where x_{ij} is the output of sensor m_{ij} denoting the j^{th} sensor of the i^{th} second level structure array. Both level structures are linear arrays.

Sensor outputs of the i^{th} second level array can be

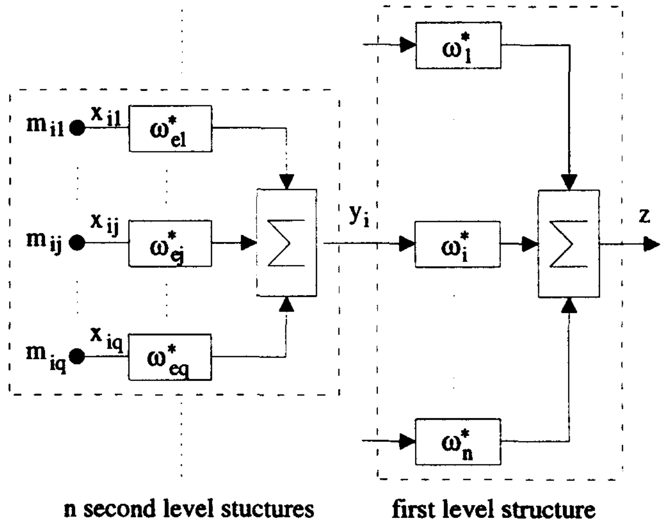

Figure 4: A two level array structure

rearranged into a column vector e_i, so the output could be written as :

$$y_i = \omega_e^* \, e_i \quad ; \quad i = 1, \ldots, n \tag{2}$$

where ω_e^* is the row vector of weights $[\omega_{e1}^* \ldots \omega_{eq}^*]$. The response e_i, to a plane wave could be written as :

$$e_i = x_{i1} \, d_e \tag{3}$$

where d_e is a column vector of phase delays to align the ouputs of the second level sensors given by :

$$d_e = [1 \dots e^{j \overrightarrow{k} \cdot \overrightarrow{m_{i1} m_{iq}}}]^T \qquad (4)$$

Then, we define the transfer function F_2 between y_i and x_{i1} as :

$$F_2 = \omega_e^* \, d_e \qquad (5)$$

The shape of $F_2(\theta, \varphi)$ characterizes the beam pattern of the second level structure. In the same way, we define the transfer function F_1 between z and y_1 by :

$$F_1 = \omega^* \, d \qquad (6)$$

where ω^* is the row vector of weights $[\omega_1^*, \dots, \omega_n^*]$ and d is a column vector of phase delays to align inputs of the first level structure.

$$d = [1 \dots e^{j \overrightarrow{k} \cdot \overrightarrow{m_{11} m_{n1}}}]^T \qquad (7)$$

We therefore get :

$$z = F_1 \, F_2 \, x_{11} \qquad (8)$$

The transfer function of the whole array is therefore the product of the first level and second level transfer functions. this principle of multiplication allows us to build complex array structures with simple guidelines. In fact, it allows us to control array caracteristics by more than one transfer function. Besides, we can use this priciple to combine structures with complementary characteristics so that the whole array acquires better performance. Moreover, it allows us to achieve head sized arrays by the possibility of overlapping different arrays.

3.2. Combined Arrays Cancelling Fixed Rear Directions - Structure C

Improvement of structure A can be obtained by using it as a first and a second level structure with different fixed cancelled directions, then higher directivity indexes are obtained without excessive increase of noise sensitivity. Besides the corresponding directivity will vary slowly with frequency because of the fixed cancellation. Sensor spacement of the first level array, p_1 and that of the second level array, p_2 are chosen so that cancelled target frequencies are situated out of our spectrum of interest. Fig. 5 shows variation of directivity index over audiometric spectrum for different cancelled directions. Results are obtained by fixing the cancelled direction of the first level array and varying that of the second level. Maximum directivity index variations of 1.5 dB are obtained. Variation of the cancelled direction is nothing more than variation of time delay involved in this structure. This invariance of directivity

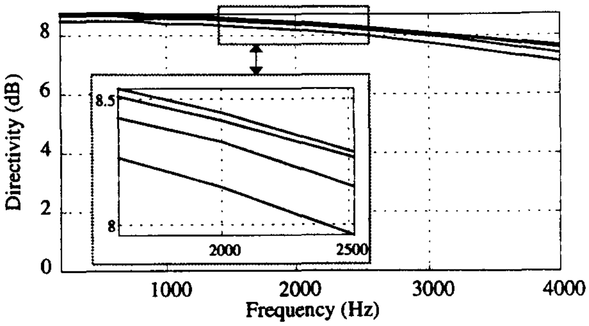

Figure 5: Shape of directivity index for different rear cancelled directions of the second level array ($p_1 = 0.02, p_2 = 0.025, a_1 = 0.2 \dots 0.8, a_2 = 0.2$

index against time delay provides the structure good immunity over practical realisation.

3.3. Use of Multiple level Structures to Decrease Noise Sensitivity

3.3.1. Endfire Arrays

One alternative to improve white noise sensitivity of structure C is to combine it with an other level structure that maximises response to target. Besides this combination may carry out an extra increase in directivity index. Therefore we use here structure C as a second level array with a simple delay and sum beamformer as a first level array. Design parameters here are parameters of both structures, number n of second level arrays and spacement between them. Cases of $n = 2$ and $n = 3$ were simulated. Fig. 6 shows directivity index for different delays in the second level arrays versus frequency. Sensor spacements of the different arrays are

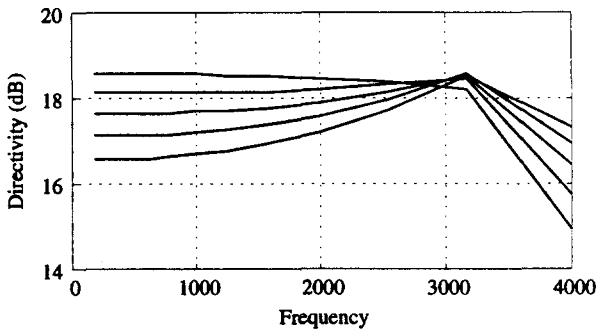

Figure 6: Shape of directivity index for different delays t_d in the second level arrays: $t_d = 48.5\mu s \dots 78.3\mu s$

chosen so that there is no overlap. Parameters of the obtained array structure are adjusted to increase white noise gain.

By using two second level arrays of type C ($n = 2$), it was found that for an array spanning 11.1 cm ($p_1 = 0.033$, $p_2 = 0.028$, $a_1 = 0.9$, $a_2 = 1$ and spacement between arrays C is $x = 0.05$) the achieved weighted noise sensitivity is 0.68 dB and the weighted directivity index is 18.2 dB. By using three second level arrays ($n = 3$), it costs about 1.3 cm increase in array spanning. However higher white noise gain and directivity index are achieved. As an example, for an array spanning 12.4 cm, a weighted noise sensitivity of −0.71 dB is obtained ($p_1 = 0.033$, $p_2 = 0.026$, $a_1 = 0.9$,$a_2 = 1$ and spacement between arrays C is $x = 0.03$). Directivity index against white noise sensitivity for this structure is shown in Fig. 7.

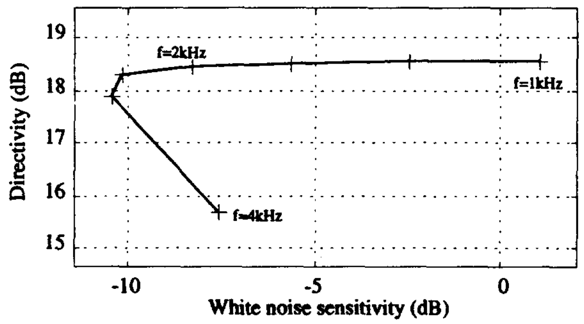

Figure 7: Directivity index vs white noise sensitivity for diffrent frequencies (1000 − 4000) Hz for the case $n = 3$, the weighted noise directivity is 19.1 dB

3.3.2. Mixed Broadside and Endfire Arrays

Here, we use simple summing broadside beamformer to decrease noise sensitivity of structure C. In order to prevent rear extention of endfire arrays in the broadside structure which is objectionable, the number of first level sensors is limited to two. For a spanning endfire arrays of 5.9 cm, a weighted white noise sensitivity of 0.68 dB with a weighted directivity index of 7.78 dB are obtained. This array takes less space than previous multiple endfire arrays. It can therefore be used when poor directivity indexes are needed.

4. CONCLUSION

Using multilevel structure, it is possible to achieve a significiant improve in directivity index and weigthed noise sensitivity for head sized arrays. An essential practical future of the developed head sized arrays is that they provide uniform directivity for a large range of the used delays.

5. REFERENCES

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