3P3-15

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 505-506
18-20 November, 2009

# Optimal design of the ultrasonic 2D array transducer

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## 1. Introduction

Ultrasonic planar 2D array transducers are used to do volumetric imaging by operating each piezoelectric element with a time delay. For high resolution of the image, a lot of elements are required, but the cross-coupling between the elements is also increased in proportion to the number of elements. The crosstalk can change the beam pattern and sensitivity of the transducer, so it is necessary to find a way to reduce the cross talk between the elements. The main components of the transducer which can affect the cross talk are known to be kerfs [1-3]. In case of a 1D array, the kerfs are separated in the transducer but the kerfs are connected with each other in the 2D array. So the crosstalk mechanism in the 2D array is more complex than that of the 1D array. The sensitivity and beam pattern are affected by the crosstalk level.

In this paper, the characteristic of the transducer was analyzed according to the structural variables of the transducer using the commercial finite element analysis (FEA) code PZFlex. Based on the analysis result, variation of such transducer performance factors was investigated as the crosstalk, sensitivity, and -3dB acceptance angle. Further the optimal design of the ultrasonic 2D array transducer was accomplished to increase the sensitivity while decreasing the crosstalk level.

## 2. Finite Element Analysis

The transducer considered in this paper is operating at 3.5MHz and is composed of 17 by 17 piezoelectric elements, a backing layer, two front impedance matching layers, and an acoustic lens, where all of which are separated by major and minor kerfs. **Fig. 1** is the finite element model. The model is a quarter of the whole transducer with symmetric boundaries on *xy* and *yz* plane. An absorption boundary condition was applied to the bottom of the backing layer so that the effect of a backward wave from the piezoelectric element could be ignored.

The piezoelectric element is PZT-5H and its thickness coincides with a half wavelength $\lambda$ at the 3.5 MHz and its aspect ratio is 0.5. The pitch between the elements is also a half wavelength. Material properties of the components of the transducer are shown in **Table 1**.

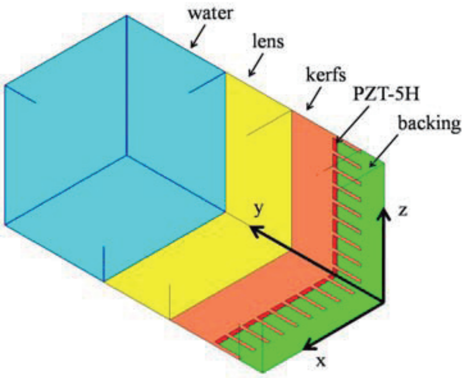

Fig. 1 Finite element model of the planar 2D array transducer

Table 1 Material properties

| Material | Density [kg/m$^3$] | Velocity [m/s] | | Damping constant [dB/mm @ 3.5MHz] | |
|---|---|---|---|---|---|
| | | Longi-tudinal | Shear | Longi-tudinal | Shear |
| Backing | 2000 | 2500 | 1250 | 12.40 | 49.60 |
| 1$^{st}$ M/L | 3596 | 2500 | 1250 | 1.01 | 4.04 |
| 2$^{nd}$ M/L | 904 | 2600 | 1300 | 3.29 | 13.16 |
| Lens | 1000 | 1500 | 375 | 2.00 | 16.00 |
| Kerfs | 1500 | 1500 | 750 | 13.60 | 54.40 |

Table 2 Variation ranges of the structural variables

| Structural variables | -1.0 | -0.5 | 0.0 (basic) | 0.5 | 1.0 |
|---|---|---|---|---|---|
| 1$^{st}$ M/L thickness | $\lambda_{1st\ M/L}$ / 4.50 | $\lambda_{1st\ M/L}$ / 4.25 | $\lambda_{1st\ M/L}$ / 4.00 | $\lambda_{1st\ M/L}$ / 3.75 | $\lambda_{1st\ M/L}$ / 3.50 |
| 2$^{nd}$ M/L thickness | $\lambda_{2nd\ M/L}$ / 4.50 | $\lambda_{2nd\ M/L}$ / 4.25 | $\lambda_{2nd\ M/L}$ / 4.00 | $\lambda_{2nd\ M/L}$ / 3.75 | $\lambda_{2nd\ M/L}$ / 3.50 |
| Width of major kerf | $\lambda_{water} \times$ 0.2250 | $\lambda_{water} \times$ 0.2375 | $\lambda_{water} \times$ 0.2500 | $\lambda_{water} \times$ 0.2625 | $\lambda_{water} \times$ 0.2750 |
| Depth of major kerf | $\lambda_{water} \times$ 2.100 | $\lambda_{water} \times$ 2.215 | $\lambda_{water} \times$ 2.330 | $\lambda_{water} \times$ 2.445 | $\lambda_{water} \times$ 2.560 |
| Width of minor kerf | $\lambda_{water} \times$ 0.2250 | $\lambda_{water} \times$ 0.2375 | $\lambda_{water} \times$ 0.2500 | $\lambda_{water} \times$ 0.2625 | $\lambda_{water} \times$ 0.2750 |
| Depth of minor kerf | $\lambda_{water} \times$ 1.44 | $\lambda_{water} \times$ 1.45 | $\lambda_{water} \times$ 1.46 | $\lambda_{water} \times$ 1.47 | $\lambda_{water} \times$ 1.48 |

Structural variables of the transducer are thicknesseses of the two front impedance matching layers, and width and depth of the major and minor kerfs. The variation ranges of the structural variables are shown in **Table 2**. The cross talk level was estimated by the ratio of the peak to peak voltage $V_{pp}$ of an element adjacent to the excited

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element to the excitation voltage $V_0$ as expressed in **Eq. 1**.

$$\text{crosstalk voltage level (dB)} = 20\log_{10}\left(\frac{V_{pp}}{V_0}\right) \qquad (1)$$

According to the analysis result, the most effective variable on the crosstalk and sensitivity turned out to be the width of the minor kerfs as shown in **Fig. 2**. The sensitivity and the cross talk level are inversely proportional to the variation of the width of the minor kerfs. When the width of the minor kerfs is increased to reduce the crosstalk level, the effective area of the element is also decreased and thus the sensitivity is reduced in turn. On the other hand, the width of the major kerfs turned out to be most influential on the -3dB acceptance angle as shown in **Fig. 3**. Fig. 3 also depicts the relationship between the crosstalk level and the acceptance angle in terms of the width of the major kerfs.

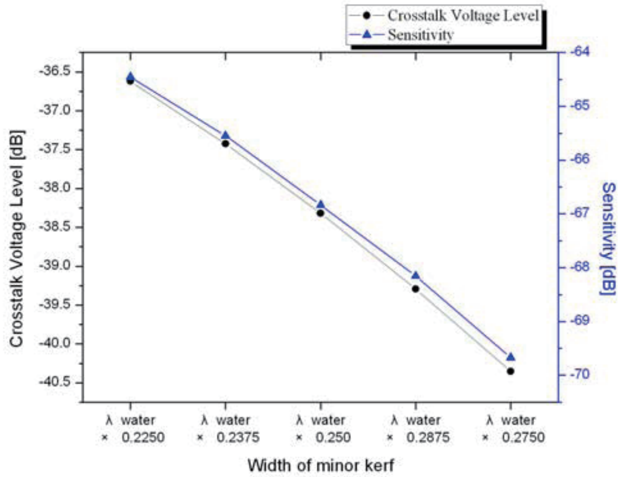

Fig. 2 Crossstalk voltage level and sensitivity according to the width of the minor kerfs

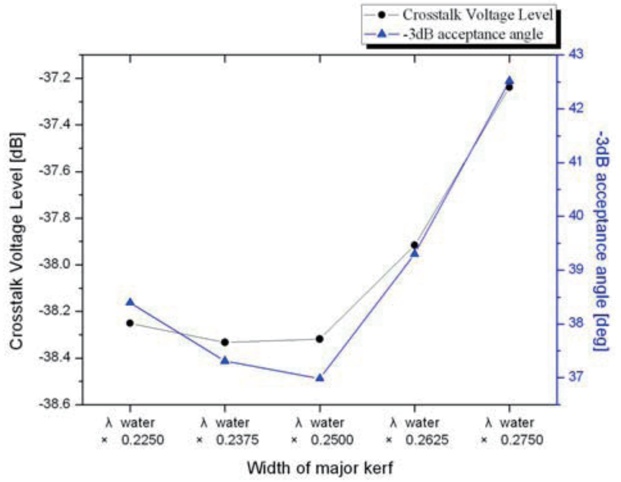

Fig. 3 Crosstalk and -3dB acceptance angle according to the width of the major kerfs

Normally, as the effective radiation area of the excited element decreases, the acceptance angle is likely to become wider. However, because of the crosstalk from adjacent elements, the -3dB acceptance angle varied in the opposite way in Fig. 3, which manifested the significance of the crosstalk effects on the performance of the 2D array transducer.

Through a statistical multiple regression analysis of the FEA results, the functional forms of the crosstalk level, the sensitivity and the -3dB acceptance angle were derived in terms of the structural variables. The coefficient of the determination was 0.9936, 0.9989 and 0.7885 for the crosstalk, the sensitivity and the acceptance angle, respectively. Using the derived functions, the structural variables were optimized to meet the target function in **Eq. 2** under the constraints that the acceptance angle and frequency bandwidth should be larger than those of the basic model. The optimization was accomplished by means of genetic algorithm. The optimized results are in **Table 3**.

$$f = \text{Minimize}\left\{\left|\frac{\text{Sensitivity Level}}{\text{Crosstalk Level}}\right|\right\} \qquad (2)$$

Table 3 Optimization result

| | Basic | Optimized |
|---|---|---|
| Crosstalk voltage level | -38.31[dB] | -39.08[dB] |
| Sensitivity | -66.83[dB] | -66.73[dB] |
| -3dB acceptance angle | 36.98[deg] | 38.70[deg] |
| -6dB center frequency | 3.49[MHz] | 3.48[MHz] |
| -6dB bandwidth | 2.01[MHz] | 1.93[MHz] |

## 3. Conclusions

The characteristics of the ultrasonic 2D array transducer were analyzed using the finite element method according to the structural variables. The most effective structural variable on the crosstalk level and sensitivity was the width of the minor kerfs. On the -3dB acceptance angle, the width of the minor kerfs was most influential instead. Based on the analysis result, the structure of the 2D array transducer was optimized and the optimized structure showed a lower crosstalk level and a higher sensitivity as well as a wider acceptance angle and a frequency bandwidth.

## References

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