Variations in the relationship between sound pressure, velocity of radiating surface and electrical driving caused by air bubbles.

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1. Introduction.

In a transducer array consisting of equal elements, the elements can have different resonance frequency and Q-value caused by inhomogenities in the radiation medium.

This paper presents results from an investigation on single stationary air bubbles in front of an element. The investigation was carried out to get indications of the fluctuations in radiation impedance and relationship between acoustic pressure, velocity of radiating surface and electrical driving which occur when air bubbles come in front of a transducer. Such fluctuations can generate variations in the beam pattern. The fluctuations can be compared with the error that can be accepted in the velocity distribution of the radiating surface when the sidelobe level shall not increase above a certain level with a given probability.

2. Equipment and methods.

The measurements were done in a tank with dimension 3mx2mx2m (LxWxH). The mechanical setup is shown in fig. 1. The element was hanging in the electrical terminals in such a way that the radiating surface was 2 mm below the water surface.

Two different elements were used in the investigation and the series (f_s) and parallel (f_p) resonance frequencies in air were: Element A: f_p = 38,3, f_s = 36,5, Element B: f_p = 42,6, f_s = 40,5 (kHz)

To keep the air bubbles in a spesified posision the air bubbles were put under a thin sheet of plastic which could be moved up and down. The air bubbles were placed in the prolongation of the axis through the element. Measurements without air bubbles under the plastic sheet showed that the sheet as it was moved up and down had very little influence.

The diameter of the air bubbles was varied between 4 and 14 mm which corresponds to resonance frequencies between 1670 and 230 Hz. At 40 kHz the diameters correspond approximately to .1 and .35 of the wavelength in water.

The acoustic pressure was measured with a hydrophone mounted at the axis through the element and air bubble. The pressure was measured at a distance of 7,3 cm or 15 cm from the radiating surface. Both distances are in the farfield of the transducer.

With an air bubble placed under the sheet the electrical impedance versus frequency was measured for different distances of the air bubble. For the same positions of the air bubble the amplitude and phase of the acoustic pressure were measured relative to voltage and current at the electrical terminals.

From the measured electrical impedances the variations in radiation impedance and velocity of the radiating surface were calculated. Each part of the elements were described as a transmission line and equivalented with the T-equivalent of the line.

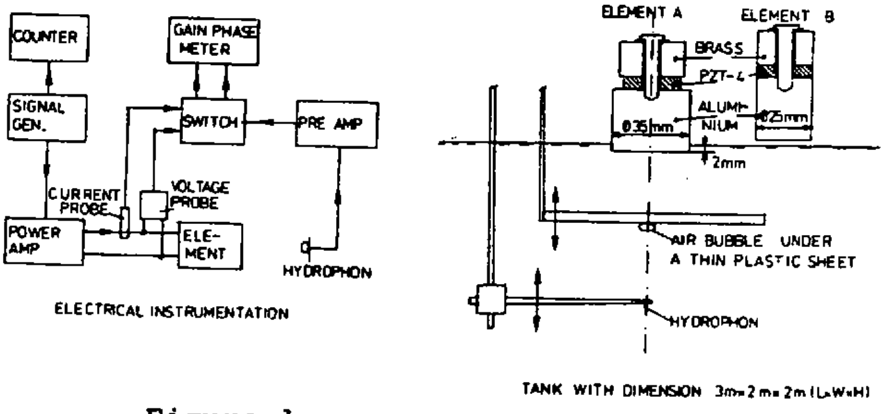


Figure 1

3. Results and discussion.

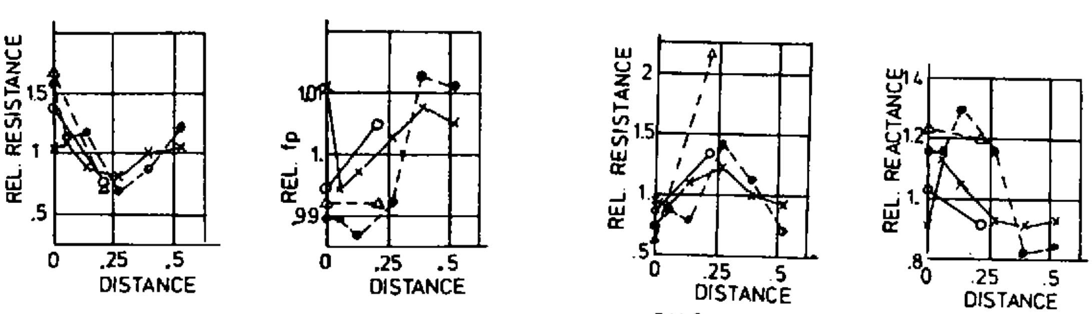
Figure 2 shows measured relative variations in f_p and electrical resistance at f_p and calculated relative variations in the radiation impedance at f_p when air bubbles are placed at different distances.

The curves show that when the air bubbles are close to the radiating surface the electrical resistance increases due to reduction in the radiation resistance. As the distance between the air bubble and the radiating surface increases the electrical resistance has a minimum at a distance of $\lambda/4$ and a new maximum at $\lambda/2$. The curves also show that the resonance frequency has a maximum when the bubbles are close to the surface and at a distance of $3/8\ \lambda$ and that it has a minimum when the bubbles are at a distance of $\lambda/8$. These variations with distance are explicable when the air bubbles are assumed to reflect some of the acoustic energy with a phaseshift of 180^o.

At a distance of $\lambda/8$ the reflected wave is -90^o out of phase with the transmitted wave and looks like a negative mass. At $\lambda/4$ the reflected wave is in phase with the transmitted wave and looks like an increase in resistance. At $3\lambda/8$ the reflected wave is $+90^o$ out of phase with the transmitted and looks like a positiv mass. At $\lambda/2$ the reflected wave is 180^o out of phase with the transmitted and looks like a decrease in resistance.

The curves show that the variations in radiation and electrical resistance exceed 3 dB and that the resonance frequency is changed more than ±1%.

The accuracy of the measured electrical impedances is ±.5 dB in amplitude and $\pm 2{,}5^o$ in phase.



MEASURED VARIATIONS IN f_p AND ELECTRICAL RESISTANCE VS. DISTANCE OF AIR BUBBLE

CALCULATED VARIATIONS IN RADIATION IMEDANCE VS. DISTANCE OF AIR BUBBLE

Figure 2

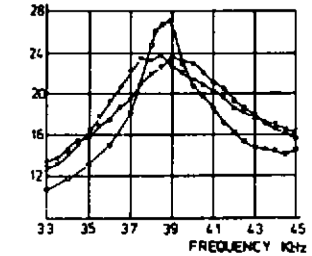
Figure 3a shows the measured electrical conductance of element B for three positions of an air bubble (Ø 7 mm). The curves show that the series resonance frequency changes from 38.1 kHz to 39.3 kHz which corresponds to a variation of 3%. Variations in the conductance at f_s are 3.8 dB.

Figure 3b shows the corresponding variations in pressure amplitude relative to voltage measured at a distance of 7.3 cm. The maximum in amplitude is displaced in accordance with the displacement of f_s. The amplitude shows some more fluctuations than the measured electrical admittance but the main variations with frequency are the same. At 38 and 39 kHz the variations in amplitude are 3.5 and 5.5 dB, respectively.

Figure 3c shows the corresponding variations in pressure calculated from the measured admittance. A comparison with the measured pressures shows that there are good conformity in the region near f_s. At low and high frequencies the calculated pressures are higher than the measured. At low and high frequencies great variations in radiation impedance give small variations in the electrical admittance. Therefore, the accuracy of the measured admittance and sensitivity of the mathematical model may be the limiting factor. Both measured and calculated pressures show variations of 4 to 6 dB.

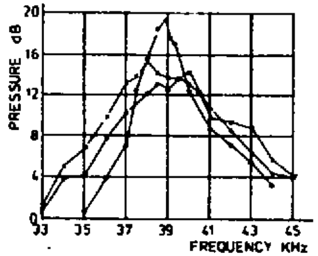
Figure 3d shows the corresponding variations in amplitude of the velocity of the radiating surface relative to voltage calculated from the measured admittance. The curves show that the amplitudes and the displacements of the maximum in amplitude are in agreement with the measured pressures and variations in conductance. Therefore these curves give variations in velocity of radiating surface which may be expected if an air bubble comes in front of an element. Table 1 summarize variations in velocity amplitude at different frequencies for the cases shown in figure 3d. At 38 and 39 kHz the air bubble introduce variations of 7.3 and 6.3 dB respectively.

Figure 3e shows measured phases between acoustic pressure at the distance of 7.3 cm and voltage. In these values the phaseshifts caused by transmission from radiating surface to hydrophone are subtracted assuming no change in sound velocity in the three cases. The main characteristics of the curves are that they are almost parallel and equal spaced at low and high frequencies and the variations in phase versus frequency are in the region near the resonance frequency. The value of the parallel displacement is as great as 40-50°.



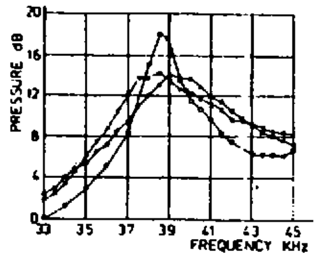
MEASURED ELECTRICAL CONDUCTANCE
VS. FREQUENCY

Figure 3a



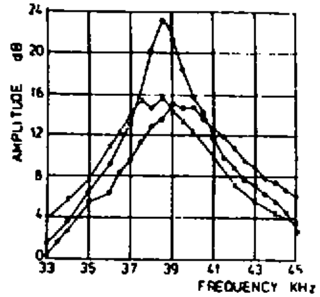
MEASURED PRESSURE AMPLITUDE
VS FREQUENCY

Figure 3b



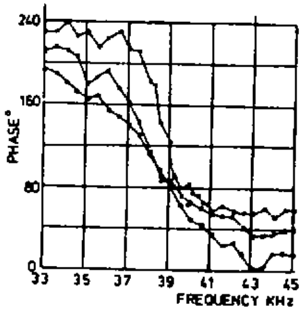
CALCULATED VARIATIONS IN
PRESSURE VS FREQUENCY

Figure 3c



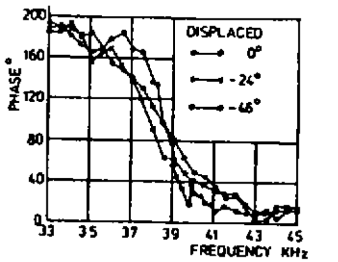
CALCULATED AMPLITUDE OF VELOCITY
OF RADIATING SURFACE VS FREQUENCY

Figure 3d



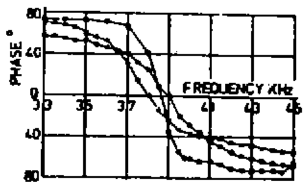
MEASURED PHASE OF PRESSURE REL.
VOLTAGE VS. FREQUENCY

Figure 3e



MEASURED PHASE BETWEEN PRESSURE
AND VOLTAGE VS FREQUENCY

Figure 3f



CALCULATED PHASE OF VELOCITY OF
RADIATING SURFACE VS FREQUENCY

Figure 3g

Variations in electrical conductance and amplitude and phase of velocity of radiating surface and acoustic pressure in a distance of 7.3 cm rel. voltage caused by an air bubble. Element B

If nothing more happened with the phase during transmission from radiating surface to hydrophone position than the subtracted phase shift, these curves should give the variations in phase between the velocity of the radiating surface and the voltage. When phase is calculated from different and known radiation impedances such displacements at low and high frequencies are not observed. Therefore these parallel displacements must come up during transmission from radiating surface to measuring position. One explanation is that the air bubble introduces a momentary phase shift with a value of the displacement. Another explanation is that the air bubble causes change in the sound velocity which gives different phase shift during transmission.

Figure 3f shows the phase curves when they are displaced to be equal at high and low frequencies. These curves should give the variations in phase between velocity of radiating surface and voltage versus frequency. The changes in Q-value and f_s are now clearly shown. Compared with the measured admittance and pressure they show good accordance.

Figure 3g shows the calculated variations in phase between velocity of radiating surface and voltage. Compared with figure 3f the curves show good agreement for frequencies near f_s. At low and high frequencies there are some discrepancy which may have the same reasons as the discrepancy in amplitude.

Table 1 shows the calculated variations in phase at different frequencies. At 38 kHz and 39 kHz the variations are 38° and 31°, respectively.

FREQ KHz		38	38,5	39	39,5	40	fs (KHz)
AMPL. dB	●	12,8	13,5	15,1	14,7	14,8	39,3
	X	14,7	15,7	14,3	13,3	12,3	38,1
	o	20,1	23,1	21,3	18,5	15,7	38,6
PHASE ∠°	●	+25	+9	+1	-20	-29	39,3
	X	+2	-13	-25	-33	-37	38,1
	o	+40	+9	-30	-55	-61	38,6

CALCULATED VARIATIONS IN VELOCITY REL.
VOLTAGE. Ø7mm AIR BUBBLE IN
DISTANCE: 20mm (●), 11mm (X), 5mm (O)
ELEMENT B.

Table 1

Figure 4a shows the measured electrical conductance of element A for three positions of an air bubble. The maximum in conductance change 2 dB and f_s changes from 34.7 to 35.9 which corresponds to 3.4%.

Figure 4b shows the corresponding variations in pressure amplitude relative to voltage measured at a distance of 15 cm. Compared with the curves for element B these curves show more fluctuations. At a specified frequency variations of 4 dB in amplitude are easily seen.

Figure 4c shows the acoustic pressure calculated from the measured admittance. These curves are smoother than the measured values but the main characteristics are the same.

Figure 4d shows the amplitude of the velocity of radiating surface relative to voltage calculated from the measured admittance. They show variations of 6 to 7 dB.

Figure 4e shows measured phases between acoustic pressure at the distance of 15 cm and voltage. The values are the measured values corrected for phase shift caused by transmission a distance of 15 cm in water. They have the same characteristics as the curves shown for element B, - great parallel displacements at low and high frequencies. The parallel displacements are about the same as for element B.

Figure 4f shows the phase curves when they are displaced to be equal at low and high frequencies. The change in phase caused by the change in Q-value and resonance frequency are now clearly shown.

Figure 4g shows calculated variations in phase between velocity of radiating surface and voltage. Compared with measured variations they show good conformity inside the bandwidth of the transducer.

Table 2 shows the calculated variations in amplitude and phase of velocity relative to voltage at different frequencies.

When the curves are drawn relative to current into the elements the same variations are observed near f_p.

FREQ. KHz		34,5	35	35,5	36	36,5	fs [kHz]
	o	11,5	13,3	14,1	13,5	12,7	35,9
AMPL.	●	12,9	13,5	10,7	8,1	7,2	34,7
dB	X	13,3	16,3	16,7	14,1	12,1	35,4
	o	+49	+35	+5	-5	-30	35,9
PHASE	●	+7	-15	-35	-45	-55	34,7
∠°	X	+50	+21	-12	-37	-51	35,4

CALCULATED VARIATIONS IN VELOCITY REL.
VOLTAGE AT DIFFERENT FREQUENCY. ELEMENT A.

Table 2

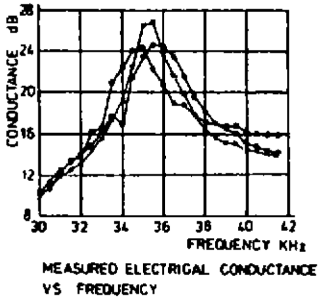


Figure 4a

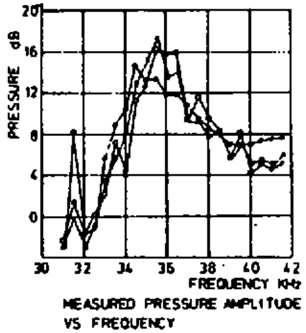


Figure 4b

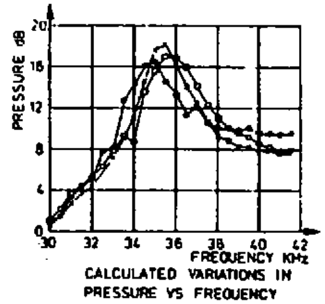


Figure 4c

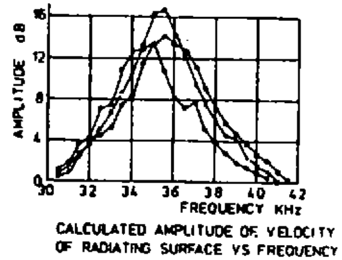


Figure 4d

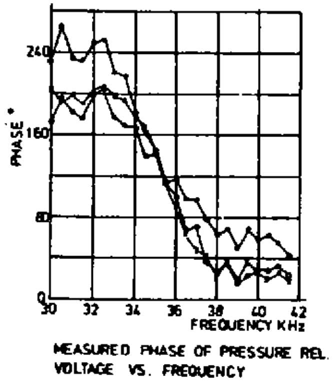


Figure 4e

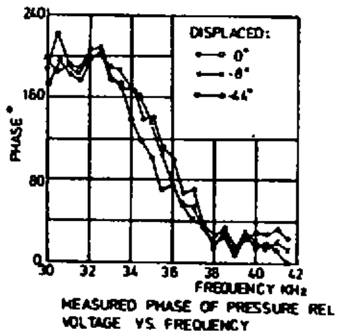


Figure 4f

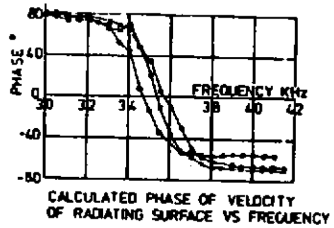


Figure 4g

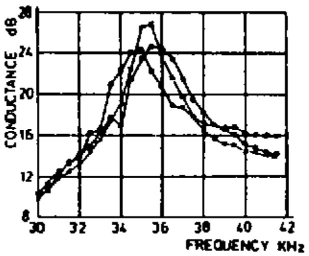
Variations in electrical conductance and amplitude and phase of velocity of radiating surface and acoustic pressure in a distance of 15 cm rel. voltage caused by an air bubble. Element A

Conclusion

Standard deviations of 1 dB in amplitude and 10° in phase are not unreasonable when specifying the phase and amplitude of the velocity of the radiating surfaces of the elements in an array. The values depend on the number of elements and the probability with which the greatest increase in sidelobe level relative to mainlobe will exceed a given level (refr. 1). Therefore the measured variations in amplitude and phase of velocity of radiating surface relative to voltage and current indicate that air bubbles in front of an array of resonant elements can increase the sidelobe level relative to mainlobe.

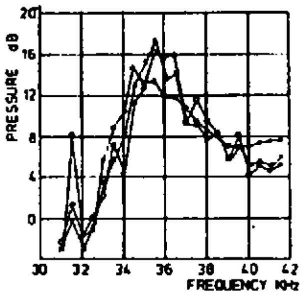
Refr.:

1. Steinberg, B.D.: Principles of apertur and array system design.
John Wiley & Sons, Inc., New York 1976 (p308)



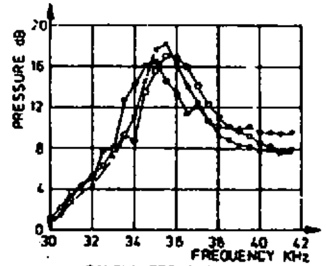
MEASURED ELECTRICAL CONDUCTANCE VS FREQUENCY

Figure 4a



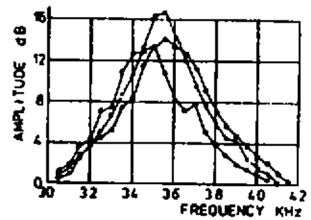
MEASURED PRESSURE AMPLITUDE VS FREQUENCY

Figure 4b



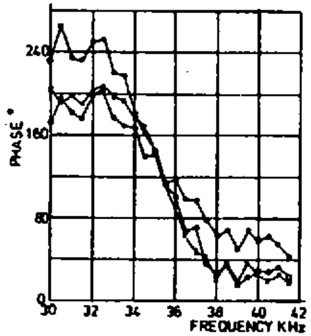
CALCULATED VARIATIONS IN PRESSURE VS FREQUENCY

Figure 4c



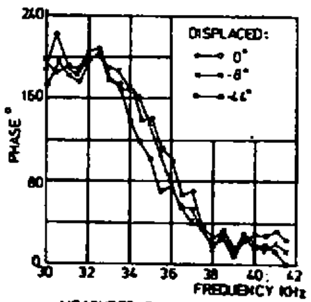
CALCULATED AMPLITUDE OF VELOCITY OF RADIATING SURFACE VS FREQUENCY

Figure 4d



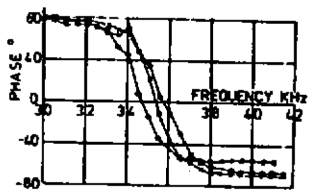
MEASURED PHASE OF PRESSURE REL. VOLTAGE VS FREQUENCY

Figure 4e



MEASURED PHASE OF PRESSURE REL VOLTAGE VS FREQUENCY

Figure 4f



CALCULATED PHASE OF VELOCITY OF RADIATING SURFACE VS FREQUENCY

Figure 4g

Variations in electrical conductance and amplitude and phase of velocity of radiating surface and acoustic pressure in a distance of 15 cm rel. voltage caused by an air bubble. Element A

Conclusion

Standard deviations of 1 dB in amplitude and 10^{o} in phase are not unreasonable when specifying the phase and amplitude of the velocity of the radiating surfaces of the elements in an array. The values depend on the number of elements and the probability with which the greatest increase in sidelobe level relative to mainlobe will exceed a given level (refr. 1). Therefore the measured variations in amplitude and phase of velocity of radiating surface relative to voltage and current indicate that air bubbles in front of an array of resonant elements can increase the sidelobe level relative to mainlobe.

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