National Taiwan University

薄膜型揚聲器的聲場和電聲固多物理耦合模擬分析 by COMSOL Multiphysics

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Industrial Technology Research Institute

NTU Nano-BioMEMS Group

大綱

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2.駐極體揚聲器之結構建模與驗證

3.駐極體揚聲器之指向性建模與驗證

4. 結論

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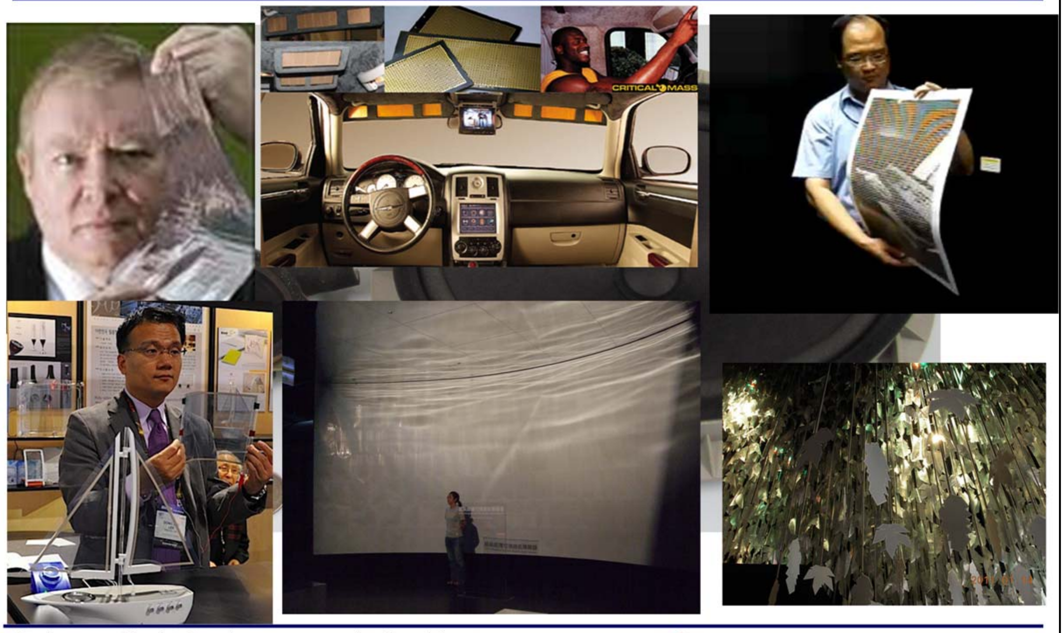
1. 簡介

Flexible Thin-film Loudspeaker



http://www.warwickaudiotech.com/
http://www.itri.org.tw
http:// www.fils.co.kr
http://www.audiojunkies.com/blog/268/the-most-expensive-car-audio-system-in-the-world-25

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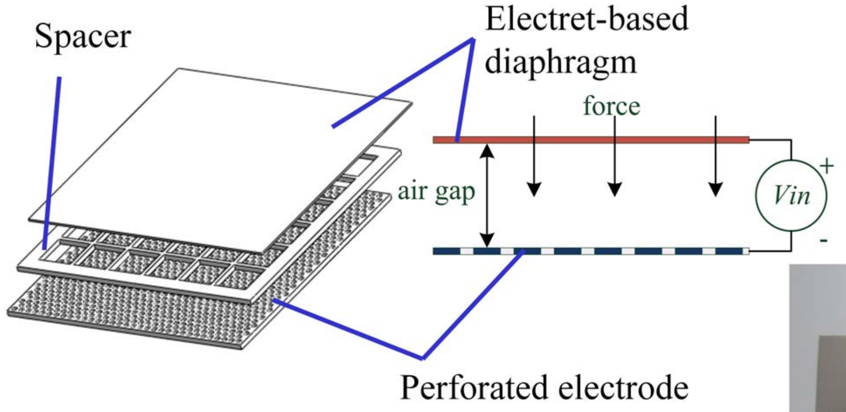
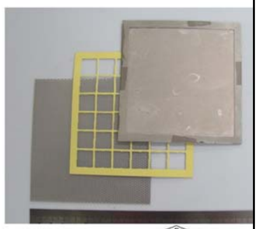
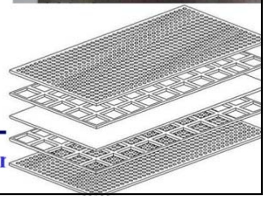
ELECTRET LOUDSPEAKER DESIGN AND FABRICATION





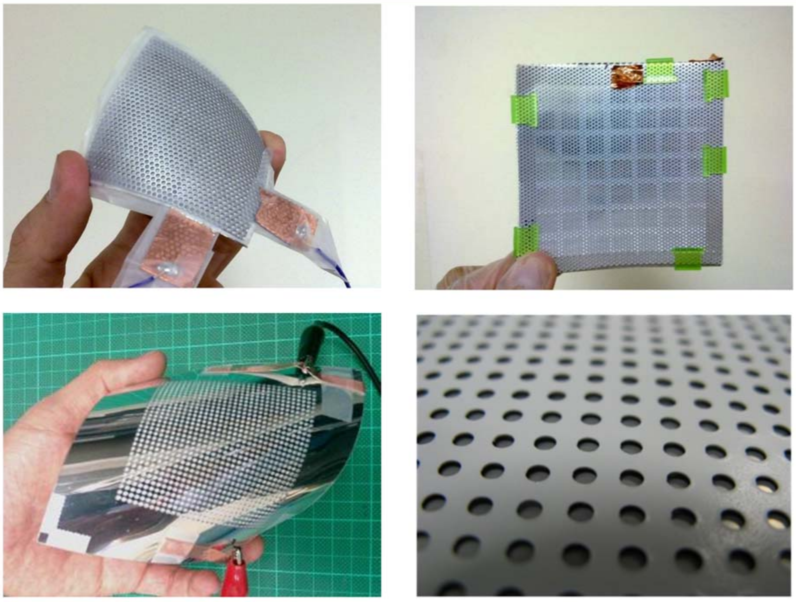
$$F = \frac{\varepsilon_{r1} S_c}{8\varepsilon_0}\left(\frac{2\varepsilon_0\varepsilon_r e_{in} + h\sigma_m}{\varepsilon_r(d+\delta)+\varepsilon_{r1}h}\right)^2$$

$$= \frac{\varepsilon_{r1} S_c}{2(\varepsilon_r(d+\delta)+\varepsilon_{r1}h)^2}\left(\frac{h^2{\sigma_m}^2}{4\varepsilon_0} + \varepsilon_r h\sigma_m e_{in} + \varepsilon_0\varepsilon_r^2 e_{in}^2\right)$$



T. Mellow and L. Kärkkäinen, "On the forces in single-ended and push-pull electret transducers," *Acoustical Society of America,* vol. 124, pp. 1497–1504, September 2008.

Fabricate the flexible electret loudspeaker



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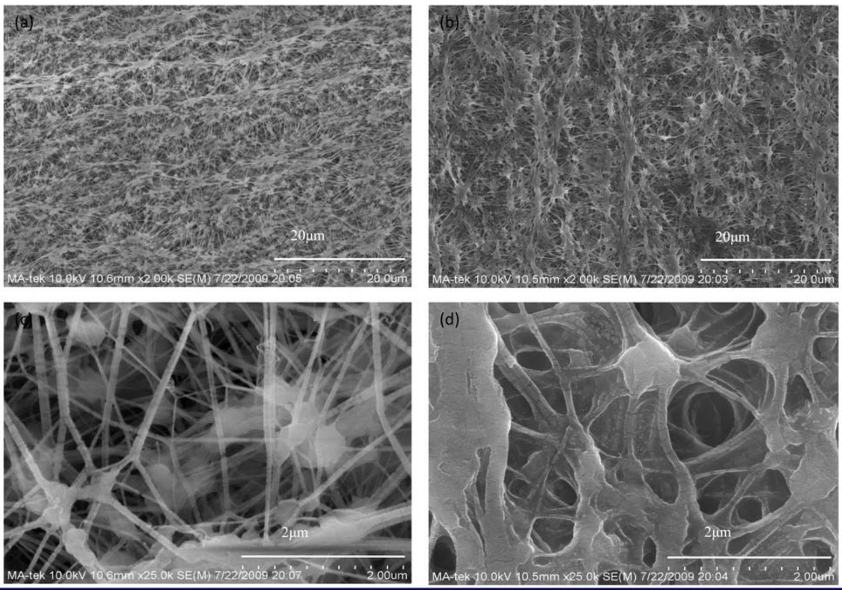
SEM of PTFE/COC



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2. 駐極體揚聲器之結構建模與驗證

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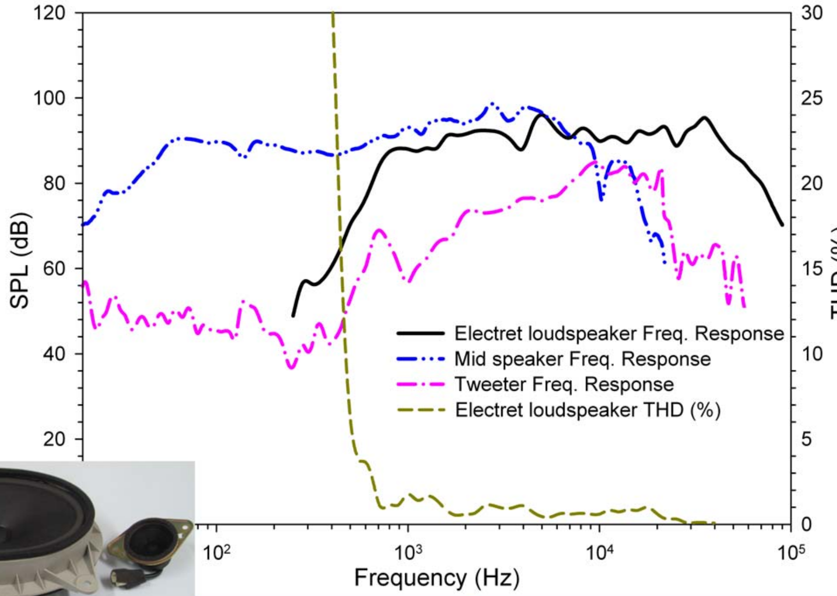
Frequency response and THD of various speakers



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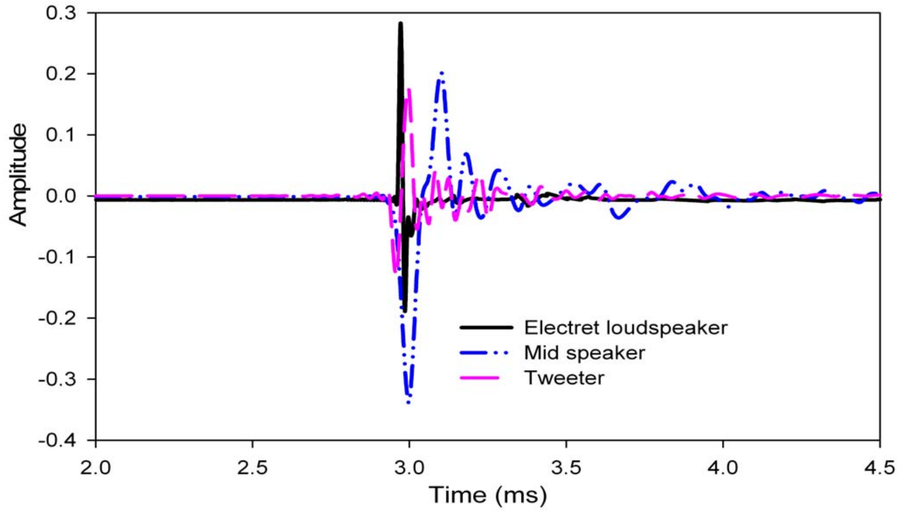
Impulse response of various speakers



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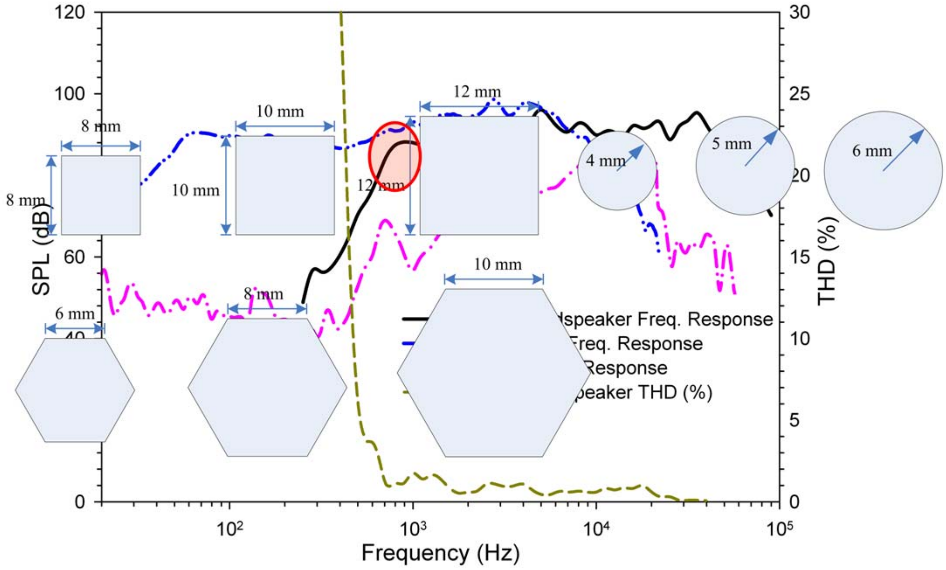
Different shapes and sizes of audio radiation area



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Material properties of the electret cell actuator

Parameters	Electret-based diaphragm
Geometry	Square (Length) : 8mm, 10mm, 12mm Circle (Radius) : 4mm, 5mm, 6mm Hexagon (Edge) : 6mm, 8mm, 10mm
Thickness (mm)	20×10^{-3}
Young's modulus (Pa)	553×10^{6}
Poisson's ratio	0.33
Density (kg/m^3)	460
Initial normal stress (Pa)	$\sigma_{xi}=47\times10^{3}$, $\sigma_{yi}=47\times10^{3}$,

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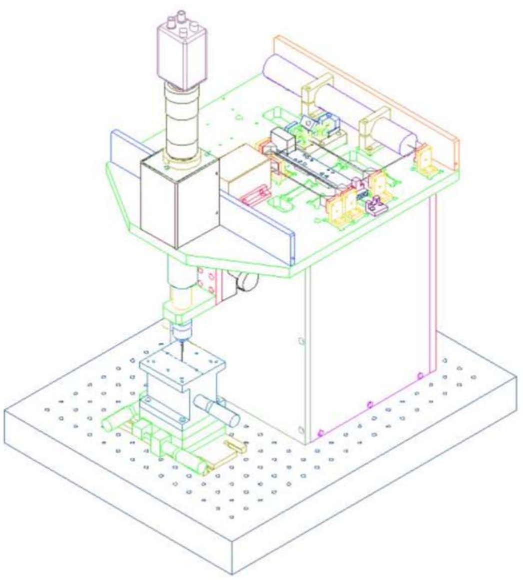
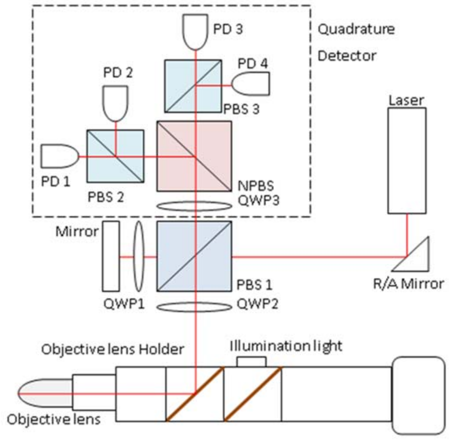
Advanced vibrometer/interferometer device measurement system





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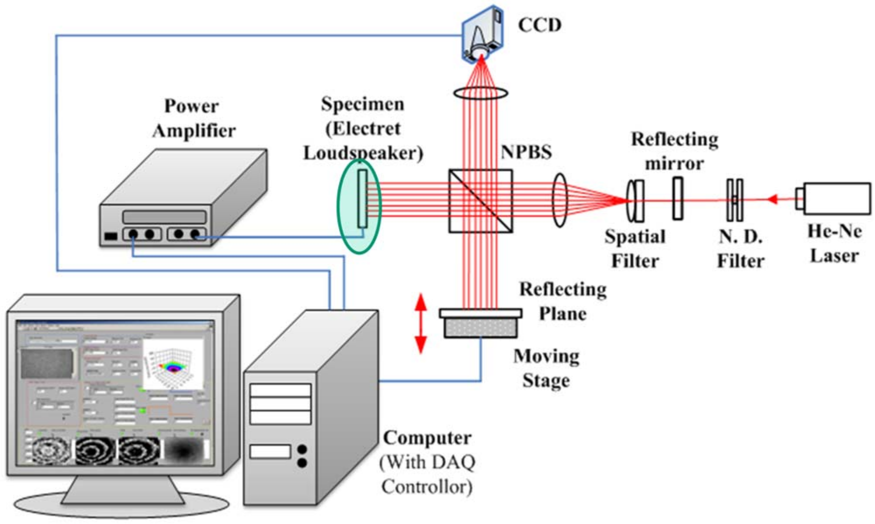
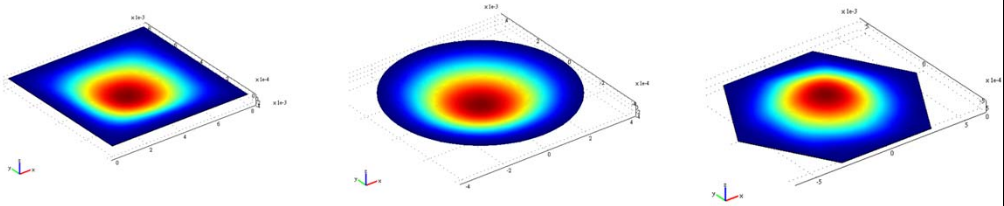
The schematics of the ESPI system

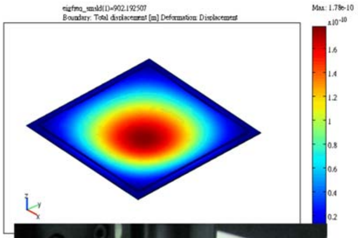


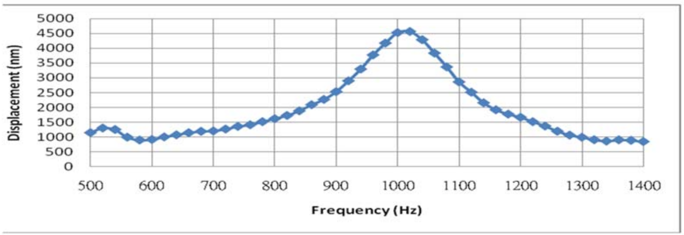
First resonance frequency of electret cell actuator

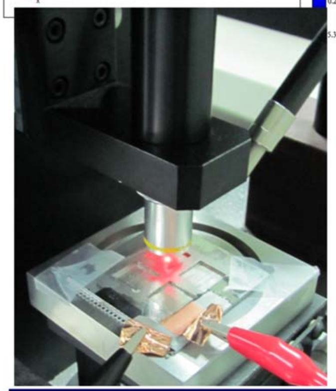
Shape	Square			Circle			Hexagon		
Size(mm)	Edge 8mm	Edge 10mm	Edge 12mm	Radius 4mm	Radius 5mm	Radius 6mm	Edge 6mm	Edge 8mm	Edge 10mm
Simulation(Hz)	1216.8	932	747	1274.88	961	776	1010.74	726	60.58
Experiment(Hz)	1120	966.67	706.67	1283.33	980	733.33	996.67	700	553.33

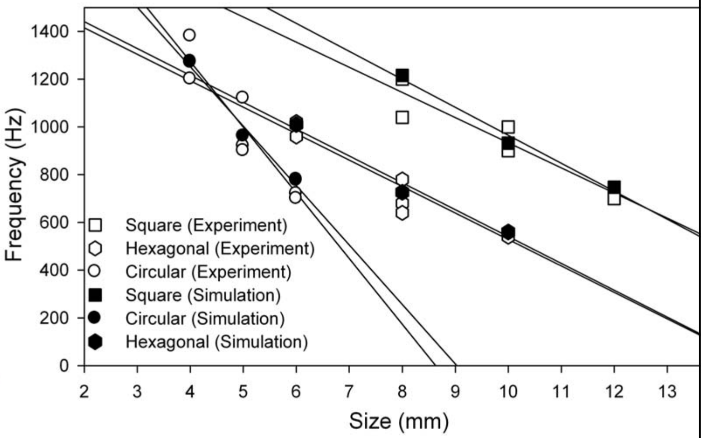


First resonance frequency of the square shape by AVID

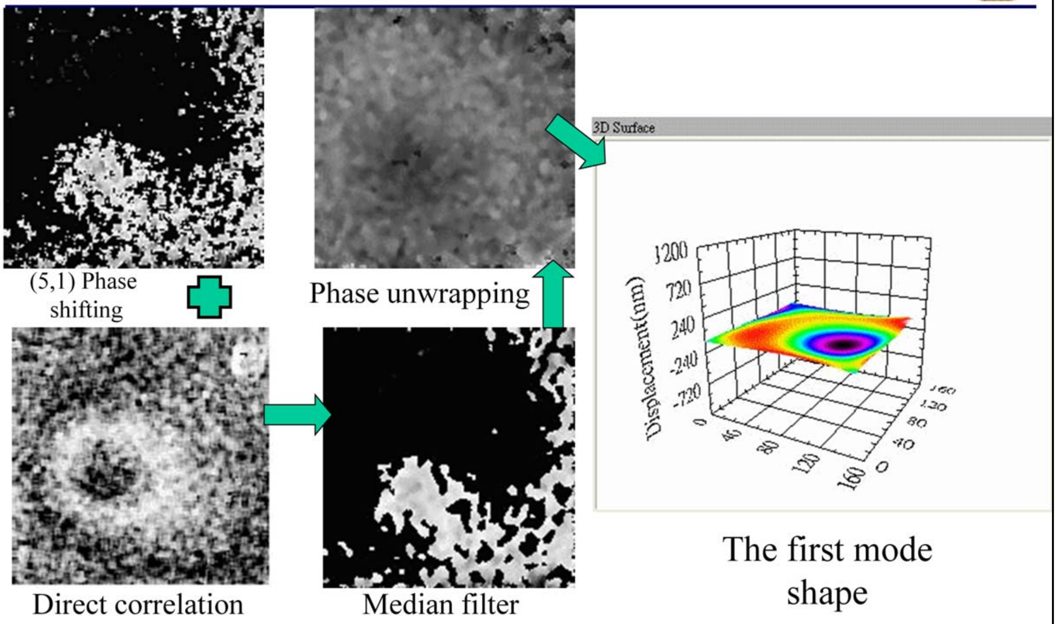








The first mode shape by ESPI



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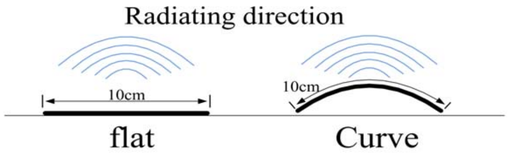
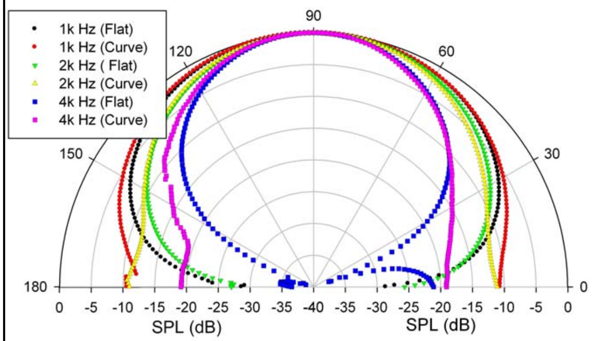
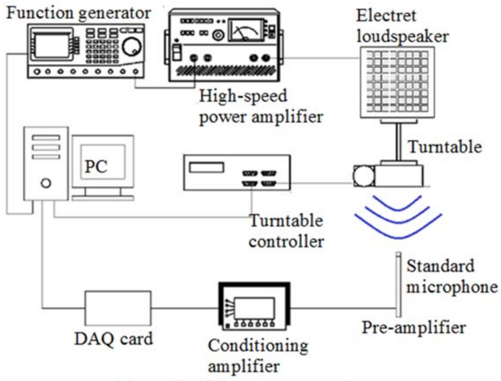
3. 駐極體揚聲器之指向性建模與驗證

Beam patterns of the two shapes at 1k, 2k, and 4k Hz







Schematic of the measurement system set-up

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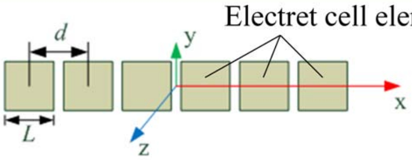
The beam pattern of the array



The beam pattern of the array
$\mathrm{b}(\theta) \equiv v^2(\theta)$

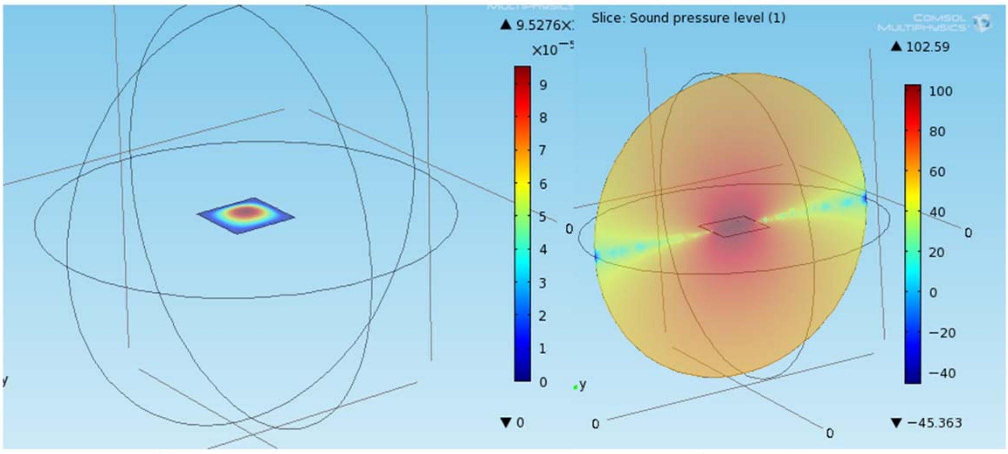
$$= \left\{ \frac{1}{N} \frac{\sin(N \cdot \frac{\pi d}{\lambda} \sin\theta)}{\sin(\frac{\pi d}{\lambda} \sin\theta)} \right\}^2$$

where d is distance span of two electret cell elements, λ is wave length. Assume there are N elements of the array.

- Area of electret loudspeaker ↑
- N↑
- SPL↑
- Directivity ↑

J. W. Caruthers : *Fundamentals of Marine Acoustics* (Elsevier Oceanography Series, 1977)

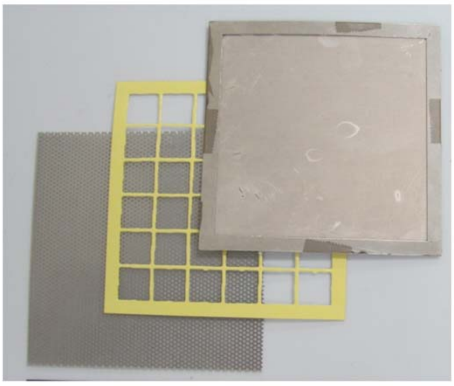
Simulation of
Electret cell at 1st resonance

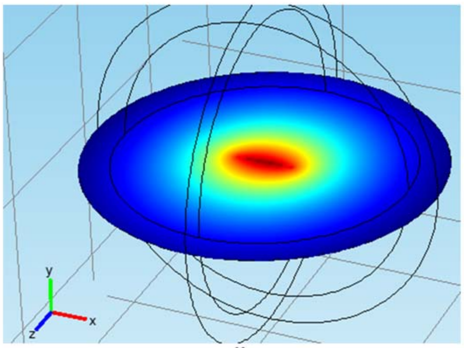


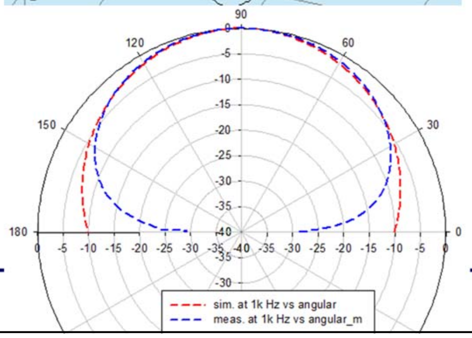
Structure Acoustic

Directivity of the electret loudspeaker (10cm x 10cm)

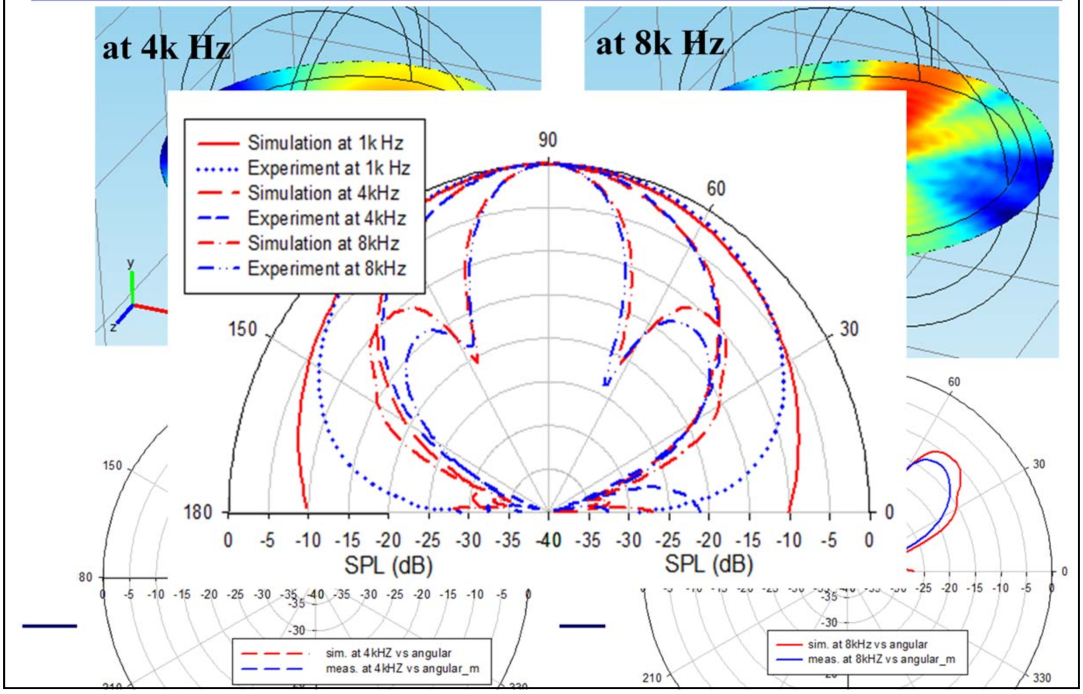
at 1k Hz



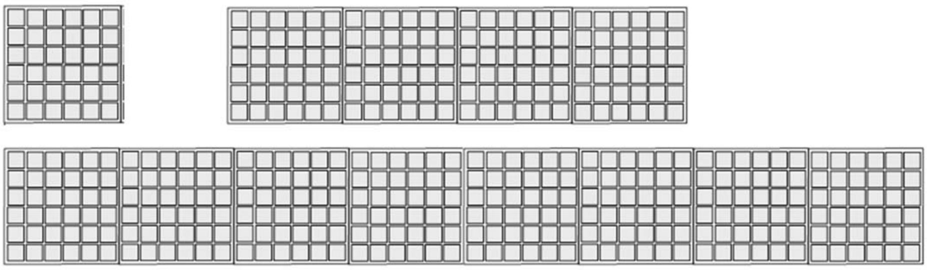


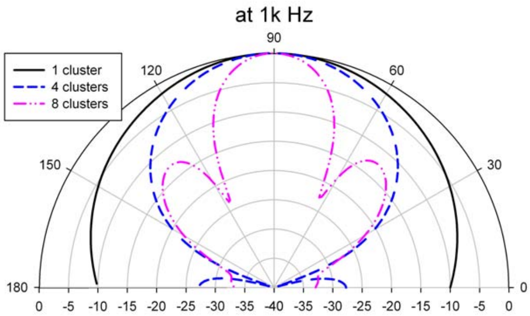


Directivity of a electret loudspeaker (10cm x 10cm)



Directivity influenced by size of array



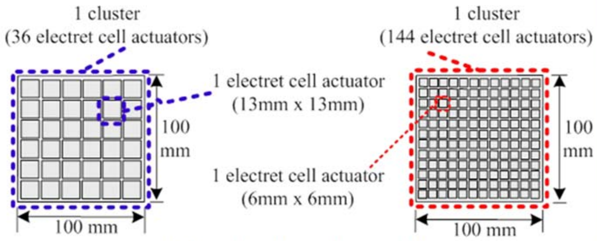


Directivity influenced by weighting function

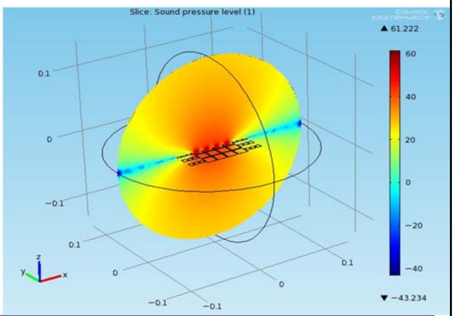
$$b(\theta) \equiv \left\{\frac{\sum_{m=0}^{N-1} C_m \cdot \alpha_m e^{i(k\cdot m\cdot d\cdot \sin\theta+\delta_m)}}{\sum_{m=0}^{N-1} C_m \cdot \alpha_m e^{i\delta_m}}\right\}^2 = \left\{\frac{\sum_{m=0}^{N-1} C_m \cdot e^{ik\cdot m\cdot d\cdot \sin\theta}}{\sum_{m=0}^{N-1} C_m}\right\}^2$$

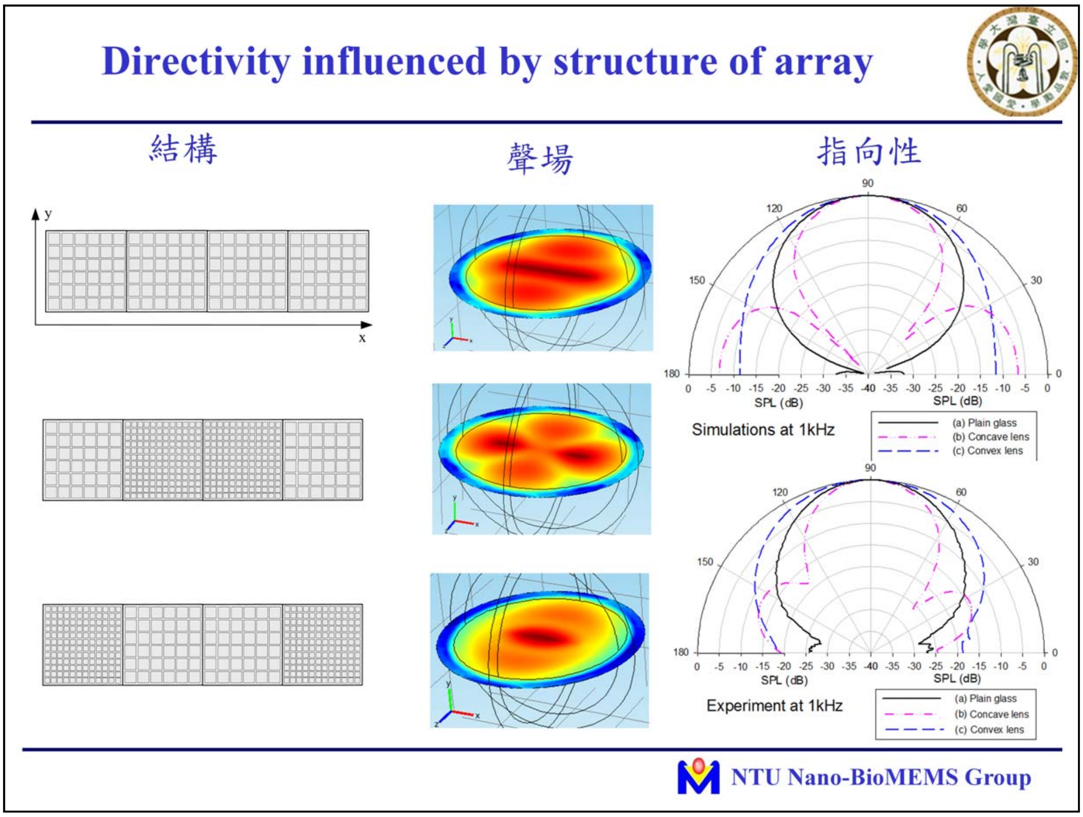
Ex. binomial shading

$$C_m = \frac{1}{10}\{1,5,10,10,5,1\}$$



Schematic of two clusters of structures




Directivity influenced by structure of array
結構
聲場
指向性
Simulations at 1kHz
(a) Plain glass
(b) Concave lens
(c) Convex lens
SPL (dB)
Experiment at 1kHz
(a) Plain glass
(b) Concave lens
(c) Convex lens
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4. 結論

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4. CONCLUSIONS

- Built the FEA model of the electret Cell Actuator by COMSOL.
- Validated the FEA model by using AVID and ESPI measurement system
- Built the FEA model of the electret loudspeaker by COMSOL.
- Validated the FEA model by using acoustic measurement system

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Thank you for your attention