How to maximize energy harvesting on a piezoelectric stuck for Aircraft application

S. A. Mansoura [1], A. Jean-Marie [1]

[1] Altran, 2 rue Paul Dautier, CS 90599, 78457 Vélizy Villacoublay

• Introduction

Context:

Phononic crystals (PC) present special guiding and filtering properties. The range of applications of PC is widened with the use of active materials, enabling the control of their properties. The electrical impedance of a piezoelectric layer is related to the characteristics of the surrounding layers. This study deals with the electrical impedance tuning and simulation of passive/active periodic structures, including electrically tuned piezoelectric layer.

Objectives:

A thickness mode model is developed to determine the electrical impedance of a piezoelectric layer integrated inside a finite multilayer structure. In this study, the effect of electrical loads connected on the piezoelectric layers within a PC is investigated as a tuning possibility.

• Modeling

Piezoelectricity: Case of thickness mode.

- ♦ The piezoelectric layer is considered homogeneous, and perfectly flat.
- ♦ The lateral dimensions are greater than the thickness.
- ♦ The electrodes are thin compared to the piezoelectric layer.

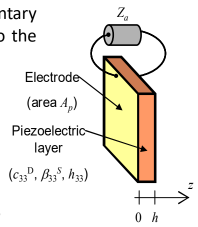
One-dimensional electromechanical equations:

$$\begin{cases} T_3(z) = c_{33}^D S_3(z) - h_{33} D_3(z) \\ E_3(z) = -h_{33} S_3(z) + \beta_{33}^S D_3(z) \end{cases}$$

where (T_3, S_3) are the mechanical stress and strain, respectively, (E_3, D_3) are the electrical field and displacement, respectively. The piezoelectric properties are c_{33}^D the elastic constant at constant electric displacement, β_{33}^S the dielectric permeability constant at constant strain and h_{33} the piezoelectric constant.

The connection of the electric impedance load Z_a imply supplementary electric boundary conditions. The application of this conditions yield to the following expression of D_3

$$D_3(Z_a) = \frac{h_{33}}{\beta_{33}^S h . \left(1 + \frac{Z_a}{Z_0}\right)} \left(u_3(h) - u_3(0)\right)$$



where $u_3(z)$ is the mechanical displacement along the z direction, $Z_0 = 1/(j\omega C_0)$ is the electrical impedance corresponding to the capacitive effect $C_0 = A_p/(\beta_{33}^S h)$, and Z_a corresponds to the outer electrical impedance, which causes a new dependency.

Mechanical displacement:

$$u_3^{(n)}(z) = A^{(n)}.e^{+jk^{(n)}z} + B^{(n)}.e^{-jk^{(n)}z}$$

Acoustic boundary conditions and continuity equations for $N = n_p.n_s$ layers:

$$\begin{cases} T_3^{(1)}(0) = 0 \\ T_3^{(N)}(h_N) = 0 \end{cases} \quad \text{and} \quad \begin{cases} T_3^{(n)}(h_n) = T_3^{(n+1)}(0) \\ u_3^{(n)}(h_n) = u_3^{(n+1)}(0) \end{cases} \quad \text{for} \quad n \in [1, N-1]$$

A global matrix $[M]$ is expanded as a function of the $[AB]$ vector made of the $A(n)$ and $B(n)$ coefficients and the $[SM]$ vector:

$$[M].[AB] = D_3^{(m)} h_{33}^{(m)}.[SM] \qquad \text{and} \qquad [SM] = \begin{cases} 0 \text{ for } 1 \le k \le (2m-1) \\ 1 \text{ for } 2m \le k \le (2m+1) \\ 0 \text{ for } (2m+2) \le k \le 2N \end{cases}$$

As a result, the coefficients $c_A^{(m)}$ and $c_B^{(m)}$ are obtained:

$$\begin{cases} c_A^{(m)} = A^{(m)} / D_3^{(m)} \\ c_B^{(m)} = B^{(m)} / D_3^{(m)} \end{cases}$$

The electrical impedance of the layer indexed (m) is written:

$$Z_e^{(m)} = Z_0^{(m)} . \left(1 - \left(k_t^{(m)}\right)^2 \frac{c_{33}^{D,(m)}}{h^{(m)} h_{33}^{(m)}} \left(c_A^{(m)} \left(e^{+jk^{(m)}h^{(m)}} - 1\right) + c_B^{(m)} \left(e^{-jk^{(m)}h^{(m)}} - 1\right)\right)\right)$$

The final expression of the electric impedance takes into account the position of the piezoelectric layer within the PC and the electrical loads connected on each piezoelectric layer.

• Numerical modeling

A multilayer periodic structure composed of (n_p =7) periods is studied. The elementary cell is made of a PMMA passive layer and a PZ27 piezoelectric layer. In the first studied configuration, measurements are performed on the first piezoelectric layer whereas three different electric boundary conditions are considered (open circuit, short circuit capacitance load). A comparison with the band structure of the PC is done.

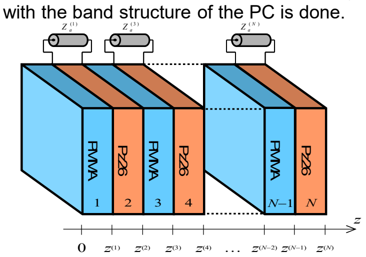
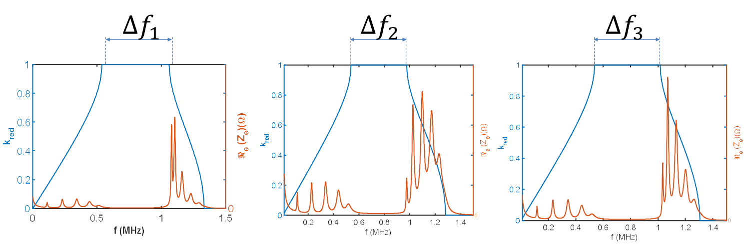


Table 1. Physical properties of the constituting layers.

Material	h (mm)	ρ (kg/m³)	c_L (m/s)	Z (MRa)
PMMA	4.13	1140	2740	3.12
Pz27	1.98	7700	4530	34.9

h: thickness; ρ: density; c_L: longitudinal velocity; Z: acoustical impedance.

• Results



Frequency control

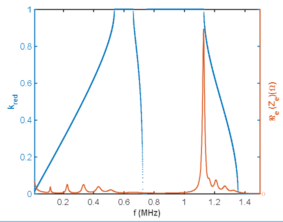
$\Delta f_1 > \Delta f_2 > \Delta f_3$

Δf_1: Open circuit

Δf_2: Capacitance 10 nF

Δf_3: Short circuit

Hybridization mode



• Conclusions and outlooks

- ➢ An analytical model was developed to establish the electrical impedance of an active layer within a piezoelectric phononic crystal.
- ➢ The model takes into account each electrical outer impedance connected in parallel to each piezoelectric layer.
- ➢ The calculated electrical impedance on the first active layer shows some significant changes depending on the considered electrical impedance loads.
- ➢ The shift in the impedance spectrum are in a good agreement with the modifications in the band structure of the PC.
- ➢ This model can be used to develop new resonators or filters devices with tuning frequency properties for which the frequency can be controlled.

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Contact : sidali.mansoura@altran.com

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