Modeling of Lossy Piezoelectric Polymers in SPICE

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Background: "Smart materials" like piezoelectric polymers are of interest in ultrasonic, MEMS, medical and other applications. They have lossy and dispersive dielectric properties and exhibit higher viscoelastic losses. Due to their lossy behavior, the lossy models developed for piezoceramics [1], are insufficient for evaluating polymers. In this work we present a novel SPICE implementation of piezoelectric polymers model which includes the mechanical, electromechanical and dielectric losses. The implementation of piezoelectric polymer model in SPICE is advantageous as it enables the study of polymer and the conditioning electronics together. This approach is helpful as, instead of optimizing the transducer and electronics separately, it enables the overall sensor system optimization.

Method: For a polymer in thickness mode, rearranging the mathematical relations and comparing them with the standard telegraphist's equations yields the analogy between acoustic transmission and electrical transmission line. The mechanical loss due to the viscoelestic property of the polymers is represented by a lossy electrical transmission line. A complex elastic constant is used for getting the parameters of the electrical transmission line. Due to analogy, frequency dependent *G* term represents the mechanical loss, instead of *R* term. The conversion from mechanical domain to electrical, i.e the from the transmission line to the electrical side, is done by an equivalent transformer which has been implemented by using controlled voltage source in SPICE. The transformation ratio of this transformer and hence the gain of the controlled sources depends on the piezoelectric constant. The electromechanical loss is taken in account by using a complex value of piezoelectric constant. On the electrical side, the polymer is represented by its static capacitance. To incorporate the dielectric losses, the static polymer capacitance is made lossy and is implemented in SPICE with a controlled source whose gain depends on the complex value of dielectric constant.

Results: The equations of IEEE standard on piezoelectricity can not be used to find constants of polymers like PVDF as they have figure of merit of 2-2.5 [2]. Thus, the complex elastic, piezoelectric and dielectric constants were derived from the impedance measurements of a PVDF-TrFE sample by using piezoelectric resonance analysis program [3]. The simulated impedance and phase obtained from the SPICE simulation are compared with the impedance measurements and they are found to be in good agreement. Study of losses independently shows the major component of the losses comes from the transmission line or in other words, from the viscoelastic property of polymer.

[1] A. Püttmer et al., *IEEE Trans. Ultrason, Ferroelect., Freq. Contr.*, 44, 60-66, 1997.
[2] L. F. Brown, *IEEE Trans. Ultrason., Ferroelect, Freq. Contr.*, 47, 1377-96, 2000.
[3] TASI Technical Software Inc., Ontario, Canada.

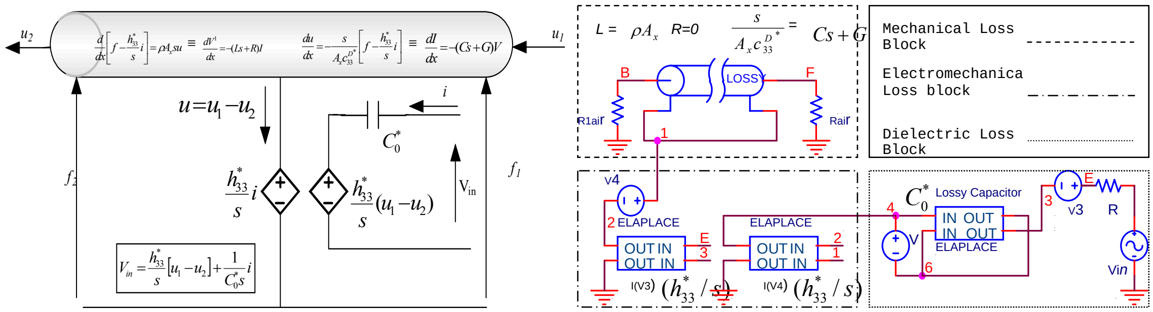

Fig 1: Piezoelectric polymer model and its implementation in PSpice. Here, h_{33}^* is the piezoelectric constant, u is the particle velocity, f is the force and s is Laplace operator, $c_{33}^{D*} = c_{33}^{D}(1 + i \tan \delta_m)$ is the elastic constant, $\varepsilon_{33}^{S*} = \varepsilon_{33}^{S}(1 - i \tan \delta_e)$ is dielectric constant and $k_t^* = k_t\,(1 + i \tan \delta_k)$ is electromechanical coupling constant.

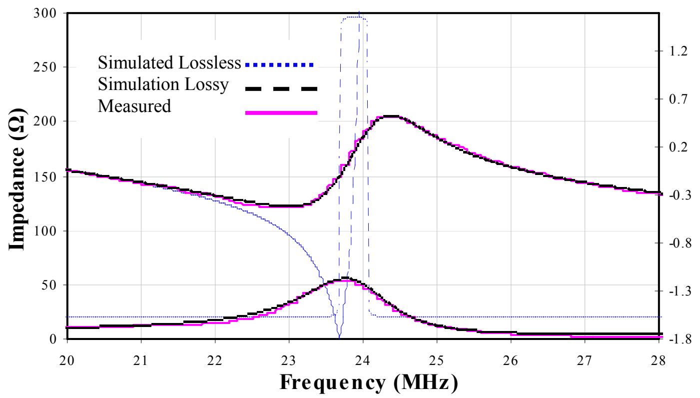

Fig 2: Comparison of Impedance and phase of a PVDF-TrFE sample (t = 50µm, A_x = 7mm x 7mm, ρ = 1880 Kg/m^3) around fundamental resonance. The simulated plots under lossless and lossy conditions have been compared with measured data. The impedance and phase were measured by HP4285A LCR meter.