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Dear Editors,

We are pleased to submit the attached article entitled “Enhanced tunability in ferroelectric metamaterials through local field enhancement and the effect of disorder” for consideration for publication in *Journal of Applied Physics*. The main point of this manuscript is to investigate the effective permittivity of ferroelectric-dielectric mixtures under a static electric field by using a refined model to take into account the coupling between the electrostatic problem and the electric field dependent permittivity of the ferroelectric material.

Ferroelectric materials play a crucial role in tunable microwave devices, with typical applications including antenna beam steering, phase shifters, tunable power splitters, filters, voltage controlled oscillators and matching networks [Tagantsev AK et al (2018) Ferroelectric Materials for Microwave Tunable Applications. J. Electroceram. 11(1-2):5–66]. Both bulk ceramics and thin films have been employed to design frequency agile components [Vendik O et al, (1999) Ferroelectric tuning of planar and bulk microwave devices. Journal of Superconductivity 12(2):325–338.] and metamaterials. The key requirements for antenna and microwave applications are large tunability and low losses. Ceramic materials exhibiting ferroelectricity have usually high permittivity values, often leading to slow response time and impedance mismatch, which can be an issue in some practical applications. Thus it has been considered to mix ferroelectric ceramics to low-index and low-loss non-tunable dielectrics in order to reduce both permittivity value and losses. It has been found that the permittivity can be greatly reduced while losses and tunability are much less sensitive to the dielectric phase addition [Sherman VO et al, (2006) Ferroelectric-dielectric tunable composites. Journal of Applied Physics 99(7):074104].

Our study investigates the effective permittivity of dielectric/ferroelectric composites by using a two-scale convergence method[Allaire G (1992) Homogenization and two-scale convergence. SIAM Journal on Mathematical Analysis 23(6):1482–1518.]. The originality lies in the fact that a fully coupling model is employed to calculate the electrostatic field distribution when a uniform biasing field is applied on the structures, which will result in a local modification of the permittivity in the ferroelectric phase due to the microstructure. As compared to a simple uncoupled model where the ferroelectric phase is only modified through the biasing field, the resulting effective permittivity, dielectric losses, tunability and anisotropy significantly differ. Compared to the case where the coupling is neglected, numerical results show a lower tunability because of a redistribution of the local electric field due to the dielectric inclusions.

We believe this work may serve for designing improved materials for microwave devices such as antennas or sensors where one can control the electromagnetic properties of such composites. Those are affected by multiple factors: geometry and the spatially dependent electric field that will induce locally a tunable, anisotropic response in the ferroelectric phase depending on its amplitude and direction. This suggest that the performances of the composites may be enhanced by distributing the two phases in an optimal way to get high tunability and low losses.

Thank you for receiving our manuscript and considering it for review. We appreciate your time and look forward to your response.

Sincerely,

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