# A General Formula for the Effective Pyroelectric Coefficient of Composites

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## ABSTRACT

**We have derived a general formula for the prediction of the effective pyroelectric coefficient of composites. In this relation, the pyroelectric coefficient of the composite is written as a function of the pyroelectric coefficients and dielectric constants of the constituents and the effective dielectric constant of the composite material. In contrast to other formulas in the field, shape and spatial arrangement of the components and the volume ratio are not directly involved in our relation. The influence of these is completely included in the effective dielectric constant of the composite. Therefore, the new relation gives a correct description for all kinds of connectivities and provides an easy tool for the optimization of pyroelectric composites.**

Index Terms — **Pyroelectricity, nonhomogeneous media, ferroelectric materials, composites, effective permittivity.**

## 1 INTRODUCTION

**COMBINING** ferroelectric ceramic particles and a polymer matrix to form composites can give advantages of mechanical flexibility and low acoustic impedance while retaining useful pyroelectric and piezoelectric properties. Such materials have a considerable potential in sensor and transducer applications, especially due to the possibility of tailoring properties to specifications by a judicious selection of constituent components and of their volume ratio. An additional degree of freedom is made available by employing a polymer matrix that is also ferroelectric, in which case the state of its polarization may be manipulated by poling techniques.

The effective physical properties of composites are generally depending on the properties of the constituents, the volume ratio, and the shape and spatial arrangement of the components (e.g. the connectivity) in a quite complex way. This is the reason why problems like the dielectric constant of composites have kept scientists busy over more than a century.

Most dielectric theories assume simple or simplified topologies. Rayleigh had discussed a simple-cubic arrangement of dielectric spheres in a dielectric medium [1]. The probably best known formula for the effective permittivity for a binary mixture is associated with Maxwell and Wagner. Maxwell had discussed the effective conductivity of a system of spheres of one conductivity uniformly distributed in a matrix of a different conductivity [2], while Wagner adapted Maxwell's expression to the dielectric case [3]. Wiener gave limits between which the effective dielectric permittivity must lie for given volume fractions of the constituents [4]. An implicit formula which is better suited also for higher volume fractions of the inclusions and which is therefore widely used for 0-3 composites was derived by Bruggeman [5]. A theory which covers different topologies, but which is not easy to handle had been given by Bergman [6]. A simple explicit formula which predicts results for 0-3 composites which are close to the Bruggeman theory was recently derived by Poon and Shin [7]. Furthermore, there exists a large number of semi-empirical formulas for the

*Manuscript received on 10 May 2006, in final form 13 June 2006.*