# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Recently, ferroelectric materials have been used in many useful applications e.g. transformer and memory. The design of ferroelectric applications with high efficiency requires specific understanding of hysteresis behavior. For examples, memory application should have remnant polarization large enough for the reader-head to sense and has coercive field large enough for the recorded data to become stable against small noises. On the other hand, transformer application should have small hysteresis area to minimize energy dissipation. As can be seen, the study of hysteresis properties under the affects of electric field has got an intense interest. However, most previous investigations, either from theoretical [1-6] or experimental viewpoints [7-12], focused mainly on the use of simple power law scaling (non-linear fit) to relate the hysteresis properties to the electric field parameter e.g. the area scaling in a form

$$A \propto f^{\alpha} E_0^{\beta}, \qquad (1.1)$$

where $\alpha$ and $\beta$ are exponents to the scaling. As there are many unknown parameters in this non-linear fit, a large number of input-output data is required. For a limited number of input-output data, one generally encounters convergence problems. To avoid, one may extract each exponent separately i.e. to assign a constant to one exponent and feed back into the power law fitting to find another, and repeat this procedure until exponents do not significantly change. Nevertheless, in some complex ferroelectric materials, the scaling parameters in Eq. (1.1) are not truly constants e.g. $\alpha$ may be a function of $E_0$ or $\beta$ may be a function of $f$. Additionally, the hysteresis behavior, in previous studies [1-12], had to be modeled by separating the hysteresis characteristic depending on the range of the field amplitude and frequency. This implies that the hysteresis of ferroelectric materials is somewhat complicated for the simple power law scaling, and another alternative and sophisticated technique is required.

In this research, it is aiming to propose an alternative approach that can be used to model the dynamic ferroelectric hysteresis behavior. Since the hysteresis is periodic signal in time, the discrete Fourier transformation will be considered to analyze the hysteresis in frequency domain. Nevertheless, from literatures, the Fourier capabilities were not fully considered [13-17] so the detailed harmonic analysis of ferroelectric hysteresis has yet to be established. In this work, an extensive harmonic investigation on hysteresis data in modeling hysteresis properties will be proposed using Ising and $BaTiO_3$ hysteresis as applications.

## 1.2 Purpose of the research

The main objective of this research is to establish the relationship between hysteresis properties (i.e. hysteresis area $A$, remnant polarization $P_r$ and coercive field $E_c$) and external perturbation parameters (i.e. temperature $T$, field amplitude $E_0$ and field frequency $f$) of Ising and $BaTiO_3$ ferroelectric by using the discrete Fourier transformation. The appropriate modeling of ferroelectric hysteresis behavior in response to electric field (sine waveform) via the discrete Fourier transformation will be obtained. Therefore, the relationship between hysteresis properties and electric field could be specified. In this research, all possible information which can be extracted from the Fourier analysis will be considered. The amplitude of all Fourier harmonics that relates to hysteresis properties will be investigated. According to the investigation of all important Fourier harmonics, it is possible that the hysteresis properties can be modeled to cover to all conditions of external perturbations (i.e. low, intermediate or high amplitude and frequency of electric field). This is as the conditions of external perturbation results in different shapes of hysteresis loops, and from these shapes, the Fourier can provide informative hysteresis behavior via Fourier coefficient associated with the loops' characteristics.