# Measurement Issues in the Characterization of Ferrite Magnetic Material


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*Abstract* - **Ferrites have been examined in great detail since they were first introduced in the middle of the century, and standardized material data sheets are widely available. While these test data are particularly useful in a common applications, there are still areas where the available material information is lacking. In particular, in order to evaluate the dimensional effects encountered in some larger cores it is important to have information not only on the permeability and loss density of the core but also on the electrical conductivity and dielectric constant—or permittivity—of the material. This paper reviews measurement techniques for determining ferrite material characteristics and illustrates the impact of winding location and sample size on the measured material characteristics.**


## I. Introduction

As power conversion circuits continue to evolve, there is an increased need for reliable data on the magnetic materials used to construct the transformers and inductors used in high-frequency, high-power circuits. Such circuits require magnetic components with large magnetic core structures. However, since the material data available in core manufacturer's catalogs is the result of testing performed on small toroidal cores, it is not always clear that these data are adequate for use in designing devices that use larger cores. These larger cores can suffer from dimensional effects such as large eddy-current losses and dimensional resonance. These dimensional effects can be modeled analytically and numerically as detailed in [14]; such modeling efforts, however, rest on the availability of reliable data for the ferrite material electrical and magnetic characteristics. In this paper, the magnetic material characterization efforts reported in [14] are explored in greater depth with a focus on the specific laboratory testing methods used to derive the material data for MnZn ferrites.

### A. *Background on Core Geometry Effects*

The combination of high frequency excitation and physically large magnetic cores can result in losses and field distributions that are not encountered in lower power and lower frequency devices. This is particularly true for the ferrite core devices that are often used for such applications. These losses related to the physical dimension of the core were explored in the early history of ferrites [2] in connection with the use of large MnZn cores for accelerator magnet applications. In recent years the issues encountered in large ferrite cores have been of particular concern in high-power inductive coupling applications [13]. Such high-power applications require devices that can couple large amounts of power in a reasonable size, and this emphasis on size reduction necessitates a relatively high operating frequency. At such frequencies, ferrite materials—and MnZn ferrites in particular—are generally superior to other options such as strip or powder cores due to ferrite's inherently low losses.

While the ferrite materials themselves have relatively low losses at frequencies in the hundreds of kilohertz, specific ferrite core structures may have significantly higher losses than expected for several reasons. Flux may crowd in corners or be unevenly distributed due to uneven core cross-sectional area. This flux crowding causes higher loss hot-spots in some regions of the core, but is only rarely a significant concern. Eddy currents induced in the core can be a significant loss component for very large cores. If the induced currents are large, they shield the flux from the inner sections of the core cross-section resulting in a flux skin effect analogous to the skin effect in the conductors of windings. Finally, dimensional resonance due to the propagation of electromagnetic waves within the structure can significantly change the overall flux distribution and lead to additional losses.

### B. *Standard Measurement Techniques*

The material characteristics reported in this paper are derived from a set of specially constructed toroidal cores and ferrite slabs meant to minimize geometrical effects. In contrast, standard magnetic measurements reported by manufacturers are based on tests of standard toroids—typically using a one–inch outer diameter core—tested using a relatively standard test apparatus such as the Clark Hess core characterization tester [1, 9]. Such measurements methods are convenient, provide a way to track variation in the manufacturing process, and establish a measure of relative performance between various materials.