FRONTLINE

Phys. Educ. 52 (2017) 043007 (4pp) iopscience.org/ped

The skin effect: a fresh look

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Abstract

Based on network analysis, a simple method has been suggested to explain the skin effect to undergraduate students. The mathematics required is an elementary idea of calculus giving a surprising insight into how nature behaves.

1. Introduction

Ohms law is an important concept which is introduced to students in schools at an early stage (13–14-years-old). The concept of resistance at this stage is introduced from an experimental point of view (which is also the historical route). This is followed by theoretically explaining resistance due to electron scattering by the lattice (Drude model) [1]. Ohms law is then derived by introducing the simple concepts of free electrons, and relaxation time. The connection between the experimental Ohms law ($V = IR$) and Drude's expression for current density ($\mathbf{J} = \sigma\mathbf{E}$, where $\sigma = ne^2\tau/m^*$) is also introduced.

However, young students are usually surprised when told that the alternating current (AC) 'resistance' or 'impedance' of a wire is very different from its direct current (DC) value. The initial explanation given is that a wire is a lumped circuit i.e. a resistance and inductor bundled together which cannot be isolated makes sense to the young mind. However, when the idea is introduced that the electrons of the metal wires have a tendency to move along the surface of the conductor (figure 1) in the case of AC, implying that the cross-section through which current flows decreases as the AC signal's frequency is increased leads to the question of *'why?'*, which is usually rarely cleared up at high school or college entry level. Later, in the final year, the skin effect is introduced as a spin off of electromagnetic wave propagation. The base line is that the skin effect and its relevance is still a confusing topic for a young mind.

The remedy to rectify this confusion is that AC impedance needs to be taught from a more fundamental approach. The theme in this paper is to introduce AC impedance, and indeed the skin effect, using network theorems which students do study in high school and in introductory levels at colleges without invoking electromagnetic considerations.

2. The skin effect, from first principles

The skin effect has been eloquently explained without mathematics by Griffth [2]. He explains that when an AC signal is applied to a wire, the changing current through the bulk of the conductor brings forth changes in magnetic flux, which in turn introduce induced currents in accordance with Faradays law of induction and the Lenz's law. The induced eddy currents 'behave' in such a way that it opposes the change in magnetic flux itself. The form and orientation of eddy currents can be represented as tiny circulating currents in the plane of the its axis, surrounding the magnetic line of fields, which are perpendicular to the axis of the conducting cylinder. The induced current

