Abstract

Conductive structures composed of multiple layers are found in a number of problem and applications. These multi-layer conductors normally present themselves in the form of flat conductive layers stacked on top of one another or cylindrical conductive layers centred on the same axis. Even though significant details vary between problems, the majority of their solutions are dependent on the determination of the current density, electric field and magnetic field distribution within these layers. Two groups of multi-layer conductors are identified which comprise the majority of multi-layer problems. The first group, predominantly concerned with eddy current testing and magnetic shielding, is shown to have received significant analytical investigation over the last fifty years. The second group, even though under consideration for the same amount of time, lacks any significant analytical development, with existing analysis limited to numerical simulations and experimental measurements.

This thesis addresses this second group's shortcomings, by focussing on the development of analytical solutions to the current density, electric field and magnetic field, along with their subsequent impedance. These focus points are selected as they form the fundamental building blocks of these multi-layer conductors, and will be invaluable in the development of current and future multi-layer applications.

This investigation starts by performing an in depth study of single layer equations, their existing solutions and factors governing them. A number of important findings are highlighted. It is firstly shown that the flat conductor approximations, which are required to allow for the single-layer flat conductor solution, produce negligible error under a given thickness-to-width ratio. Secondly, it is found that the well-known solution of Dowell has inherent limitations, while lastly, a previously proposed wave analyses method is shown to be identical to the existing single layer solution.

These findings are subsequently used in the development of a multi-layer methodology, where the methodology is based on the continuity of the tangential components of the electric field and magnetic field intensity. It enables the derivation of a solution to the current density, electric field and magnetic field intensity of a multi-layer conductor, with no limitation placed on the number of layers. The current density, electric field and magnetic field intensity solutions to the two- and three-layer flat and cylindrical conductors were subsequently derived, and verified through FEM. The advantages of these analytical solutions, over that of FEM, are clearly shown. The two most predominant being, near instantaneous results and insight into the factors governing the distributions through visual inspection. It is, however, found that a direct relation exists between the solution complexity and the number of layers, resulting in visual inspection becoming difficult for three-layers or more.

With the use of the distribution equations, impedance equations are derived. They are subsequently applied to three-layer differential conductor configurations and verified through experimental measurement. Measurement was achieved through the use of a precision LCR meter. The experimental verification serves two main purposes. Firstly, as FEM simulations are just an approximation and can suffer from convergence issues, it was used to verify the derived impedance equations. Secondly, the verification of the impedance equations is used to infer the correctness of the distribution solutions, on which the impedance equations are based, which in turn infers the validity of the multi-layer methodology.

This thesis therefore provides a significant advancement in the understanding of multi-layer conductors, with one of the most important contributions being the development of the multi-layer methodology. This methodology serves as an enabling tool, allowing for the derivation of multi-layer conductor distributions equations, along with their subsequent impedance equations. With the use of these equations, freedom from numerical simulations methods (such as FEM) is achieved, while providing a means to understand the factors governing these conductors from more than just a qualitative perspective.