Practical Guidelines for PWB Circuits Using Reactive Field Theory

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Guidelines for arranging striplines and vias on high-frequency printed wiring boards (PWBs) based on reactive field theory will be presented. These guidelines, generated from HFSS simulations, provide the foundation for preventing unwanted stripline and via coupling in PWBs. A novel method of preventing undesired transmission line coupling without using numerous ground vias will also be presented.

As versatile wireless technology advances, the demand for smaller PWBs that operate at increasingly higher frequencies rises. The principle means by which signals are transmitted on single layers of a PWB is the stripline. To carry signals between layers of a PWB, vias are used. PWBs operating at high frequencies suffer from a phenomenon known as "reactive fields." Reactive fields are undesired electromagnetic fields that arise from high-frequency signals propagating through uncontained striplines and vias. Higher-order modes are excited as a result, causing energy loss and unwanted coupling between the striplines ("crosstalk"). Due to the presence of these reactive fields, striplines and vias cannot be placed within close proximity of each other, making the reduction of circuit footprints challenging.

Some preliminary work has been published analyzing the higher-order modes that exist in striplines and vias (M. H. Burchett et al., "Rigorous analysis…" *IEE Proc. – Microwaves, Antennas and Propagation*, vol. 141, no. 3, 1994). Additional research has been performed with regards to the impact of stripline bends and vias at high frequencies (W. Y. Chang et al., "Impact of Bends and Ground Return Vias…" in *Asia-Pacific Symp. on Electromagnetic Compatibility…*, Singapore, 2008, pp. 502-505). These papers acknowledge the importance of stripline placement to mitigate unwanted coupling. However, little has been presented to give definitive high-frequency PWB design guidelines based on reactive fields. The current method of suppressing reactive fields in PWBs is to place ground vias where the reactive fields occur. While this method works, it makes the PWB more complex and more expensive to manufacture. Additionally, the ground vias take up real estate that could otherwise be occupied by crucial components.

To address the PWB design concerns, models of striplines and vias were created in HFSS to study the reactive fields. Striplines were embedded in multiple layers of a dielectric and connected by signal-carrying vias. Analyses of the electric fields in the surrounding dielectric show that, without reactive field containment, the field strength outside of the striplines and vias is comparable to the intended transmitted signal. Stripline and via models utilizing the conventional ground via method show little to no fields outside of the transmission line area. However, the number of vias required to fully suppress the reactive fields is significant, indicating that the cost and complexity to manufacture a single transmission line is likewise considerable. As an alternative to the numerous ground vias, perfect electric conductor (PEC) blocks are placed on both sides of the stripline ports. These PEC blocks prevent higher-order modes from existing in the model, thus reducing reactive fields without the need for a large number of ground vias. PEC blocks are also easier to manufacture than vias, making this approach appealing from an additive manufacturing perspective. Furthermore, HFSS models were built to study the coupling between two adjacent multi-layer transmission lines. For various separations between the transmission lines, the coupling magnitude was measured and the electric field pattern graphed. These results provide further insight into the limitations for how closely together transmission lines can be placed.

The guidelines developed from this research will help designers of high-frequency PWBs to lay out transmission lines in a fashion that minimizes cost, complexity, and size.