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# HYBRID SEMI-ANALYTICAL METHOD FOR ANALYZING THE EFFECTIVENESS OF ENCLOSURE SHIELDING, COMBINING EQUIVALENT CIRCUITS AND MODIFIED NODAL ANALYSIS

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**Introduction.** Protecting sensitive electronics equipment from electromagnetic interference is becoming increasingly difficult. Today's components operate at high frequencies and are densely packed into extremely tight spaces. To address this, engineers typically house them inside metallic enclosures. The challenge, however, is accurately evaluating their actual shielding effectiveness. Standard numerical methods provide high accuracy, but they require significant computational resources and time. Consequently, engineers cannot efficiently rely on them during the early stages of product design. Classic analytical approaches, like the equivalent circuit model, offer high computational efficiency. However, the application of these classic models is generally restricted to simple, single cavity enclosures [1]. A review of recent global research highlights a critical need for rapid and computationally efficient calculation methods [2].

Engineers need a fast yet adaptable tool capable of handling complex enclosures comprising multiple sections and various internal materials. To address this challenge, this paper introduces a hybrid method that merges standard equivalent circuit principles with Modified Nodal Analysis. Instead of treating the enclosure as a single 3D object, the proposed approach decomposes its physical domains, including external power sources, slotted walls, internal waveguides, and dielectric materials, into an equivalent circuit. Consequently, this approach automatically formulates a system of linear algebraic equations based on the circuit’s nodal connections. This eliminates the need for engineers to perform manual algebraic derivations for every structural modification. To validate the proposed methodology, we developed a custom desktop application implementing this mathematical model, significantly accelerating the iterative phase of enclosure design.

**Main Part.** At its core, the proposed hybrid approach integrates the traditional spatial breakdown of the equivalent circuit method directly with Modified Nodal Analysis. In this model, the physical components of the shield such as the outside signal source, the front wall with specific openings, the internal cavities, and any dielectric materials inside, are treated as components of an equivalent electrical network. The most significant advantage of this integration is scalability. With conventional equivalent circuit techniques, researchers were required to perform complex analytical transformations to determine nodal voltages. Scaling this manual process for an enclosure divided into multiple sections quickly becomes computationally impractical [1].

Modified Nodal Analysis entirely resolves this limitation. By adopting it, the new method instantly generates a system of linear equations based strictly on how the components connect and conduct. This mathematical system scales effortlessly to handle multiple sections linked by narrow apertures, spaces packed with dielectric materials, and even removable covers that act as quarter-wave resonators [2]. Ultimately, the proposed computational algorithm that automates the formulation and solution of these nodal equations was implemented into a custom software application, providing engineers with a straightforward way to evaluate highly complex shielding configurations.

**Conclusion.** In practice, this hybrid method gives researchers and engineers a tool that is both incredibly highly efficient and flexible. Deriving complex mathematical formulas from scratch for every design iteration is highly inefficient [1]. We validated our new models against reference numerical data, and the results demonstrated excellent agreement, across a wide sweep of frequencies, the accuracy remained tightly aligned with the references. The theoretical model remained robust whether the enclosure comprised one, two, or three sections and the matrix formulation ensures it can easily scale up to handle many more.

Furthermore, the algorithm accurately evaluated configurations containing dielectric materials and apertures with removable covers. Future work aims to integrate this custom software directly into standard industrial testing workflows. Additionally, we plan to expand its capabilities to simulate various aperture geometries and active electronic components operating within the enclosure.

## Literature


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