IV-5 COMPUTER-AIDED ANALYSIS AS A QUANTITATIVE DESIGN TOOL FOR FERRITE PHASE SHIFTERS AND RESONANCE ISOLATORS

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The use of digital computers as a tool in the analysis of ferrite devices permits a significant change in design philosophy. It is becoming increasingly apparent that no longer is it necessary to restrict the role of the theoretical analysis of ferrite components to that of providing design guidelines. To be sure, providing general guidelines and developing meaningful physical and mathematical models is and will remain an important task of the analyst, especially in the investigation of new devices. In addition to this traditional role, however, through computer-aided analysis, precise design information can now in many cases be provided[1,2,3,4]. Once the analysis programs for a basic configurational type are established, a few minutes of computation time can suffice to examine a variety of trial device configurations having different dimensions and/or material parameters. By taking advantage of this capability, a large portion of the experimental cut-and-try normally required to arrive at a satisfactory design can be replaced by a few runs on the computer.

The ability to predict with precision the loss and phase characteristics of microwave devices depends upon having a) an accurate mathematical representation of the materials utilized in the device, b) a configurational model of the device which is both sufficiently complete to insure adequate quantitative accuracy of final results and sufficiently simple to be amenable to analysis, and c) a technique for solving the equations arising in the analysis. Clearly these requirements cannot currently be met for all ferrite devices. However, many ferrite components can even now be analyzed with precision, and advances in technology will inevitably continually add to the list of mathematically manageable devices.

Typically the analysis of a component proceeds step by step from modeling, to solution of the boundary value problem for the model, to experimental validity checks of sample calculations, to utilization of the program in design. The equations arising in the boundary value problems are usually transcendental equations involving several complex variables. Such equations can best be solved by iterative techniques.

An an illustration of a fertile class of problems which are both amenable to analysis and serve as accurate models for several practical devices, consider a rectangular waveguide filled with full height interleaved slabs of dielectrics and ferrites. Resonance isolators, field displacement isolators, analog phase shifters, single and multiple toroid digital phase shifters, cut-off switches, etc. can all be represented by models of this form. The performance of these devices can be predicted by solving the appropriate boundary value problems. To obtain the precision required for satisfactory design, it is usually necessary to include dielectric and magnetic losses exactly in the boundary value problem. Waveguide copper losses can be determined by standard perturbation techniques.

Sample results of the analysis of several structures of the interleaved slab type are presented below. Dielectric and magnetic losses were included exactly in the boundary value problems. Comparison of calculated with measured response is made for both low loss and high loss devices. The properties of the ferrite for both magnetically saturated and partially magnetized materials are accounted for in a manner that allows device characteristics to be related directly to intrinsic material parameters. This enables the engineer not only to determine device performance for a given set of material parameters but also to discover modifications in material characteristics leading to improved device performance.

Figure 1 is an example of the ability of a "complete" boundary value analysis to predict both isolation and insertion loss as a function of frequency for a resonance isolator. The structure is a single full height ferrite slab with a dielectric loading slab. The ferrite properties are accounted for via the complex Landau-Lifshitz permeability tensor. Agreement between predicted and measured response is good.

Figure 2 shows the predicted and measured differential phase shift and insertion loss for an analog phase shifter. The basic structure and the manner in which ferrite properties are accounted for are the same as for the isolator. Again the agreement between predicted and measured response is excellent.

Another device of current interest is the waveguide digital or latching phase shifter. A simple form of this device is a single ferrite toroid with a dielectric core in rectangular waveguide. A useful model for this digital phase shifter is a dielectric loaded twin ferrite slab structure. The dielectric constant of the dielectric loading slab of the model is the volumetric average of the dielectric constants of the core and toroid. The ferrite properties are accounted for by an "averaged" complex tensor permeability[5,6] which takes into account the average effects of domain structure and permits loss and phase to be related to properties such as intrinsic linewidth and saturation magnetization. Figure 3 shows the variation of loss per 360° of differential phase shift (LP 360) with linewidth and saturation magnetization. Dielectric and copper losses play an increasingly important role in determining LP 360 at low linewidths as the normalized saturation magnetization ($m_s = \gamma 4\pi M_s/\omega$) is decreased. Magnetic losses increase linearly with linewidth.

Figures 4 and 5 present calculated differential phase shift and LP 360 for a digital phase shifter in which dielectric slabs have been added against the waveguide walls and against the toroid respectively. In both cases, differential phase shift decreases and LP 360 increases as loading slab thickness increases. The effect is more abrupt in the case of the slab against the waveguide wall.

As a final example the effect of dielectric constant and dielectric loss tangent on losses in a dielectric loaded guide are presented in Figure 6.

All the structures discussed here are formed from full height dielectric and ferrite slabs in rectangular waveguides. Such structures and a few other configurations in circular cylindrical, coaxial, and rectangular waveguide are readily amenable to straightforward analysis. In general, however, the analysis of ferrite loaded transmission structures cannot be so carried out and indeed it may not even be possible to set up the boundary value problem in a precise fashion. For example, it is very difficult to apply boundary condition to any structure for which the interfaces between the various constituent media do not coincide with constant parameter surfaces of one of the coordinate systems in which the pertinent wave equation is separable. Equally difficult are structures in which different boundary conditions must be applied over a single coordinate surface. Two examples of commonly used structures whose analysis present real challenge are the partial height slabs in rectangular waveguide and partially loaded stripline. One possible approach to such configurations is the point-matching technique[7]. This approximate technique can yield precise design information.

The examplesgiven illustrate the type of data one can obtain from computer-aided analysis of ferrite devices. The outstanding advantage of the computer-aided analysis approach to device design is its flexibility. Not only can one basic program often serve for the analysis of several different devices but investigations of frequency response, effects of dimensional and/or material changes, etc. for a given device can be carried out with ease, free from many of the frustrations that plague such studies in the laboratory.

ACKNOWLEDGEMENT
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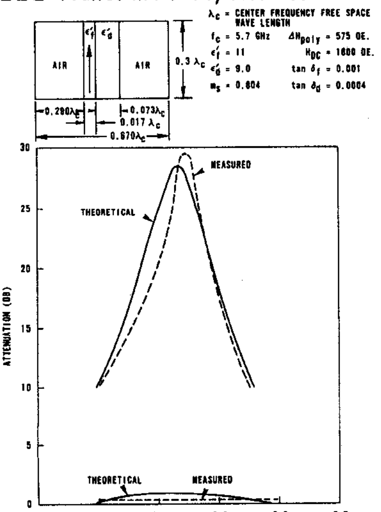

FIG. 1 - Isolation and Insertion Loss for a Resonance Isolator

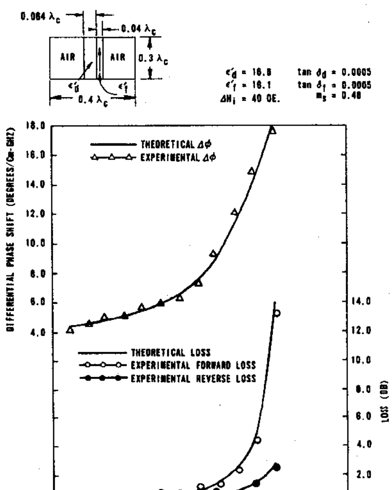

FIG. 2 - Phase Shift and Insertion Loss for an Analog Phase Shifter

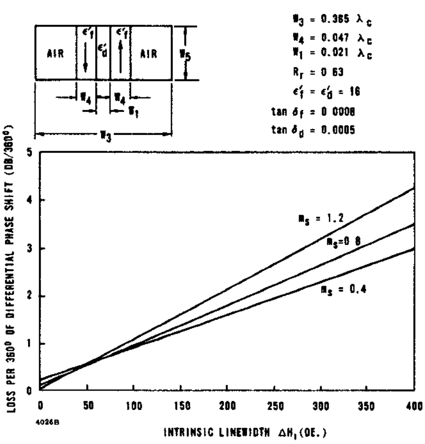

FIG. 3 - LP360 vs Intrinsic Linewidth for a Digital Phase Shifter

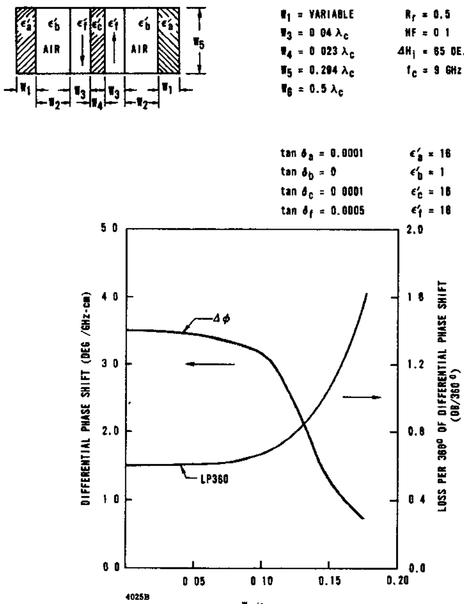

FIG. 4 - Effect of Loading Slabs Against Side Walls

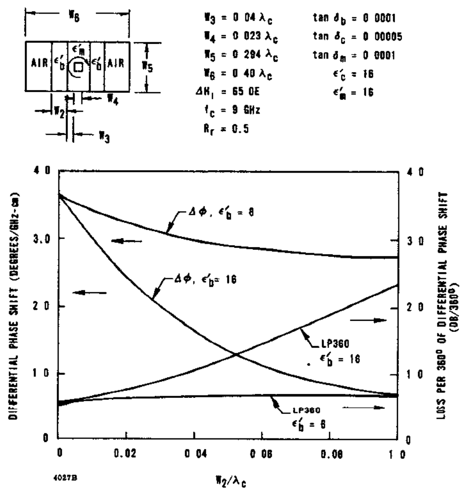

FIG. 5 - Effect of Loading Slabs Against Toroid

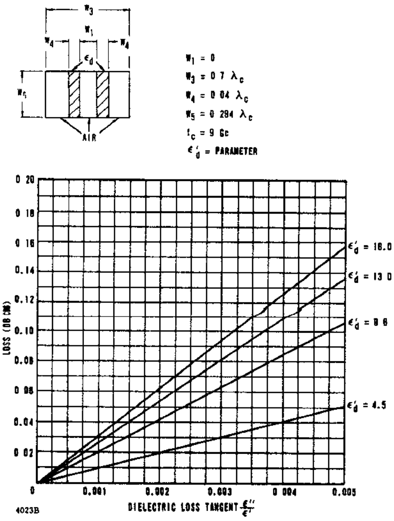

FIG. 6 - Losses in a Dielectric Loaded Waveguide