Microstrip Computer-Aided Design in Europe

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Abstract —The purpose of this survey is to provide a general idea on present research activities in microstrip in Europe, emphasizing computer-aided design. Attention is drawn to the particularities of microstrip, which make its design particularly difficult. The survey covers the description of microstrip lines, discontinuities, patch antennas, and computer programs for circuit analysis, synthesis, and layout, followed by a brief description of relevant areas in MMIC and nonlinear CAD.

I. Introduction

FIRST OF ALL, CAD is only feasible when a suitable mathematical description is available—not too complex, but accurate enough [1]. At microwave frequencies, particular challenges are presented by dimensions and device environment. Microstrip systems exhibit several peculiarities—outlined in the next three sections—which make their design particularly demanding in terms of accuracy.

II. Inherent Stiffness of Microstrip Design

Most "classical" microwave designs, based on waveguide technology, include some provisions for final adjustments. These may take the form of tuning screws, and it is always possible to introduce in the waveguide some inductive post or dielectric insert to correct a mismatch. As a rule, frequency-sensitive waveguide components, for instance filters, require a "final tuning" step to reach the specified requirements. Quite elaborate procedures have actually been worked out specifically for this purpose. How should one transpose them to microstrip, which has little or no capability for adjustments?

In microstrip circuit fabrication, one first has to prepare a layout, analyze its theoretical response, optimize it to get as close as possible to the desired performance, draw the circuit's outline, cut the mask, reduce it photographically, expose, etch, and dry it, and then mount the finished circuit and measure its actual performance. What happens then if the circuit does not meet the desired requirements? Practically, this means return to square one, or next to it, with the hope that things will work out better next time!

Microstrip design should be just right the first time! An accurate description of the circuit's components is therefore required, and only a very thorough theoretical analysis can provide it. There should be as little difference as possible between the predicted performance and the measured data. (After all, since Maxwell, electromagnetics is supposed to be an exact science!)

A final waveguide design may consist of an assembly of components bolted together. In microstrip technology, on the other hand, it is much better to build all components right on the same piece of dielectric, in order to avoid reflections at transitions. One cannot start by testing the components separately, and assemble them afterwards. In microstrip, this procedure requires at least two steps, both of which involve circuit fabrication.

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III. Threefold Inhomogeneity

In terms of the electromagnetic field distribution, the microstrip structure is quite complex. It actually presents three kinds of inhomogeneities (Fig. 1).

1) The propagation region, over which the fields are spread out, is composed partly of dielectric (the substrate) and partly of air. This implies that the waves which propagate along the structure are not transverse electromagnetic, and thus exhibit dispersion (fortunately, this effect may be neglected in many practical situations) [2].

2) The metal layer on top of the dielectric (upper conductor) only covers it partially. This is the second inhomogeneity: the boundary conditions which are to be met by the fields are not the same at all points on the air–dielectric interface.

3) The dielectric substrate and the ground plane have finite dimensions. They may be enclosed in a box (circuits) or left open (antennas). Radiated waves or surface waves on the air–dielectric substrate bounce back and forth, scattered by the edges, producing spurious coupling between elements.

Due to the presence of these three kinds of inhomogeneities, the accurate study of microstrip structures is almost prohibitively difficult. It requires sophisticated mathematical techniques and high-performance computers for their resolution. In the past, a number of simplifying assumptions have been made, yielding approximations which were, rather often, not accurate enough. Nowadays, it has become possible to solve in an "almost rigorous" manner the problem with inhomogeneities 1) and 2) [3], and attempts are also being made to take into account the finite size of the substrate [4].

The practicing engineer requires simple-to-use formulas or computer packages to help him solve actual design problems. Complex approaches may present little interest

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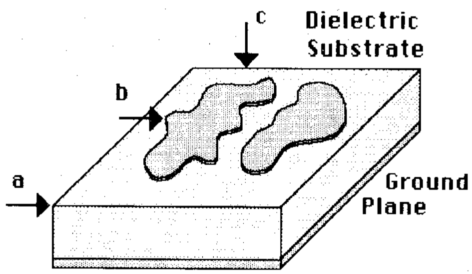

Fig. 1. General microstrip structure showing the locations of the three inhomogeneities.

for him if they require complicated procedures and expensive equipment. *Therefore*, the researcher must "translate" his results and present them in a form—simple but accurate—which the practitioner can use.

IV. Measurement Problems

Experimental fact plays a fundamental role in technical development, as a necessary complement to theoretical derivations. Only by carefully checking a theory against measured data can one determine whether the basic assumptions made are really valid.

When analyzing microstrip structures, an additional difficulty arises because measurements are never taken on the microstrip itself. Measurement test gear is practically always in coaxial line or waveguide, and the microstrip is actually "seen" through some transitions and connectors (as through a glass, darkly?). Additional reflections, and transmission losses, are thus introduced, making it difficult to determine the actual properties of the structure one wishes to measure. Several means for "de-embedding" the circuit have been proposed. One may compare it with straight sections of microstrip line (connections must be assumed to be identical). Also, the circuit may be inserted within a resonant ring, and its properties determined from the changes observed in the resonance parameters. The most significant new development in the field is undoubtedly the HP8510 Network Analyzer, in which the "gating" function actually can be used to separate connector and circuit measurements [5]. Still, if a transition is really lossy or badly mismatched, no reliable data can be obtained across it.

V. Activities in Europe

Over the years, many activities have taken place in the microwave field, as evidenced by the number of contributions presented at the yearly European Microwave Conference. Many small research groups are involved in this field, in many locations spread out all over Europe. Space won't permit listing all of them here. Only topics directly related to CAD will be reviewed.

Microwave computer-aided design and measurement were emphasized in Liège, Belgium, in 1984 at the 14th European Microwave Conference [6]. In addition to the contributed papers, the program included four invited papers, a tutorial session [1], and a specialized exhibition devoted to these topics. Last but not least, a CAD workshop organized by Professor G. R. Hoffman, of the University of Ghent, followed the conference.

Since then, a specialized workshop was held in November 1985 in London under the auspices of the Professional Group E12 (Microwave Devices and Techniques) of the IEE [7]. A special issue of the *IEE Part H Proceedings* will shortly be devoted to microwave CAD, with R. S. Pengelly as Guest Editor.

VI. Transmission Lines

Many new models and approaches were developed during the 1970's to describe the single microstrip transmission line; this topic has now matured and become rather quiet. The conformal mapping approach developed by Schneider [8] and subsequently refined by Hammerstad [9] has provided accurate relationships nowadays used by most designers. Research proceeds over the lossy and inhomogeneous substrates encountered in MMIC's [10].

Coupled lines come next: here too, a number of approaches were added to the technical literature. Emerging from the lot are the equations of Kirschning and Jansen [11], which combine high accuracy with ease of operation for CAD purposes. Lines laid over semiconducting substrates are being evaluated at the University of Lille [12], [13]. Various geometries suitable for coupler design have been reported [14], and the use of coupled lines for decoupling in circuits has been proposed [15]. The analysis has also been extended to lines having more than two upper conductors [16], [17].

A related area which is drawing a lot of attention, in conjunction with MIC design, involves coplanar lines, both conductor-backed and non-conductor-backed. These were considered in Torino [18], [19] and Lille [20], [21]. Also, particular geometries encountered in transitions from microstrip to coplanar line have been investigated [22].

Microstrip computer programs for a variety of single, coupled, multiconductor microstrip geometries have been commercialized in Germany [23].

VII. Bends, Junctions, and Discontinuities

The study of discontinuities of all kinds has proceeded in an extremely active fashion in Germany, under the guidance of Professor Ingo Wolff and his group. A recent bibliographical survey lists no less than 135 papers [24]. The spectral domain approach for MIC was recently described by Jansen [25], who also revised the description for step discontinuities [26]. Effects of radiation and surface waves can now also be taken into account by means of an approach devised for patch antennas [27]. New techniques for modeling and measurements have been presented [28].

Hoffman has published the most comprehensive book on microstrip circuits available to date, listing altogether 1256 references [29]. Computer programs have also become available to characterize a variety of steps, bends, junctions, hybrids, and filters [23].

VIII. Patch Antennas

Much of the R & D work on microstrip antennas in Europe has been coordinated, under the expert guidance of Professor Folke Bolinder, of Sweden, within the frame of the COST-204 project [30]—presently followed by project COST-213—of the European Communities. The two projects deal with phased array antennas. Patch antennas and arrays have been designed in England [31], [32], Belgium [33], [34], France [35], and Sweden [30]. Reviews of the main research topics were presented at a specialized symposium set up by the European Space Agency [36].

The rigorous treatment of radiation from microstrip structures of arbitrary shapes has been considered, making use of an integral formulation in terms of Green's functions, followed by the numerical evaluation of Sommerfeld integrals [27], [37]. A project looked at the scattering produced by the edges of the dielectric substrate [4]. The time-domain response of microstrip antennas has been analyzed [38], [39]. Microstrip patches can also be used as feed elements for reflector antennas [40].

IX. Analysis and Synthesis

In France, the high-level program ACLINE has for some time been the generally accepted standard for microwave designers. It offers impressive optimization facilities to its users, and a number of microstrip elements are available in an interactive way [41]. The computer package ACCAD was developed specifically for the analysis, synthesis, and broad-banding of microwave amplifiers [42]. A rather intriguing approach for the CAD of microwave amplifiers has been proposed, in which new components are added randomly [43]. The application of symbolic analysis to microwave CAD is presently under development in Bagneux, France, using flow-graph representation and upward hierarchical decomposition [44]. Symbolic analysis provides results in an analytical form, in which the parameters selected by the user appear. Once the symbolic analysis has been made, the postprocessing phase is carried on very efficiently, making the technique particularly well suited for optimization processes.

X. Layout

Even when a particular design has been carefully analyzed and optimized, taking into account the most accurate models available, a critical step remains to be taken: its physical realization. Of course, very accurate masks can be cut on coordinatographs or drawn on photoplotters, but these machines are quite expensive and are well beyond the financial reach of many small research laboratories or academic institutions.

The layout and cutting of masks can now be done quite accurately at a much lower cost. An original approach developed in Switzerland makes use of desktop computers to cut the masks on standard plotters with a specially designed cutting tool. The program is "user-friendly" and is completely self-contained (it does not require extensive reading of manuals before its use). The operator specifies the circuit dimensions, operating frequency, substrate permittivity and width, and characteristic line impedance. A number of elements are available to design his circuit: couplers, hybrids, dividers, step transformers, and bandpass and low-pass filters. He can position and interconnect them at will, with bends and sections of line, right on his computer screen to prepare his layout. If he wishes, he may also define his own elements, for instance patch antennas. The mask is then cut on a Rubylith sheet, all in a matter of minutes with computer accuracy. To give an idea of what can be achieved, Fig. 2 shows the performance of a bandpass filter realized using this technique. The arrows 2 and 3 show the edges of the specified passband, the arrows 4 and 5 those of the specified 25-dB points [45].

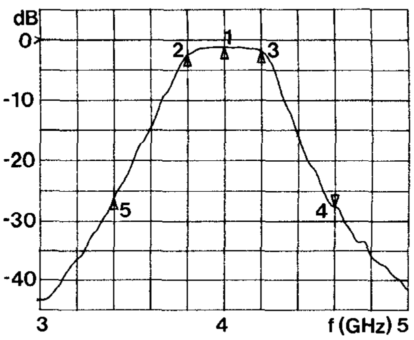

Fig. 2. Response of a bandpass filter realized using the program MICROS as measured on the HP8510 Network Analyzer.

The design of such frequency-sensitive components as filters requires a precise knowledge of the substrate's permittivity. It was found that manufacturer's specifications for high-permittivity substrates are often too loose for design purposes. A program has therefore been written for the computer-aided measurement of permittivity—under the actual conditions and in a structure similar to the circuit to be realized [46].

A general program for the layout of planar circuits has recently been developed at British Telecom combining theoretical models with experimental data, including a wide range of flexible facilities to improve designer productivity [47].

XI. Monolithic Microwave Integrated Circuits

The field of MMIC's is closely related to that of microstrip. In fact, it contains a mixture of distributed elements (which must be considered in terms of microstrip line theory) and of lumped and concentrated elements (which are small with respect to a wavelength and can be treated by network theory). The considerations made for microstrip in previous sections remain valid for MMIC's and become even more stringent. As devices tend to be crammed close to one another to save real estate, coupling effects become significant. Semiconductor layers are in general stratified and lossy, so that the characterization of lines and components becomes even more difficult [48]. Still, the challenge has been picked up and many realizations have been reported. In England, the Allen Clark Research Centre develops computer aids running on desktop computers involving device modeling from both theoretical prediction and experiment.

From Germany comes the CAD package LINMIC, which represents one of the most significant new approaches to layout-oriented design of single- or multilayered MIC's/MMIC's [49]. The program combines (apparently for the first time) a rigorous field analysis—based on an enhanced spectral-domain technique—followed by sensitivity analysis, with an interactive optimization procedure making use of a conjugate direction algorithm. The LINMIC package even has the potential to describe complex structures for which no analytical models are available: interdigital capacitors, multiturn square inductors, and coupled meander lines. Very high accuracy, a wide validity range, and a high computation speed drastically expand the range of applications.

A quasi-monolithic approach for GaAs has been developed in Italy [50]. Models for MIC passive components can be obtained with a random search process devised by Baden Fuller [51].

XII. Nonlinear Analysis

Finally, since many devices implanted or introduced within microstrip systems exhibit nonlinearities—wanted or unwanted—a definite need exists for nonlinear analysis. Professor Rizzoli, from Bologna, has considered the technique available to solve this difficult problem on a computer [52]. Computation times become quite significant, but fortunately can be reduced considerably by using a vectorial processor or supercomputer [53]. The fundamental frequency harmonic balance approach has been used to model GaAs power FET's [54]. A new approach to the optimization of nonlinear circuits comes from Limoges [55]. Nonlinear CAD has been applied to mixer optimization [56], [57].

XIII. Conclusions

It is hoped that this brief survey will provide an accurate first impression about institutions carrying out microstrip CAD in Europe. The information presented is like the tip of an iceberg, it is certainly far from exhaustive. The aim is to provide a fairly even coverage, drawing attention mostly to significant new results not achieved elsewhere.

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