

A Hands-On Microwave Laboratory Course Using Microstrip Circuits

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Abstract—An increasing number of universities are including microwave circuit and device courses into their undergraduate and graduate curriculum. The microwave region of the electromagnetic spectrum provides an excellent vehicle for introducing electromagnetic concepts. Unfortunately, the relatively high cost of microwave experiments make it difficult to reinforce lecture material with laboratory exercise. In this paper we discuss how a CAD program and a nonconventional fabrication procedure have been used in a two semester microwave course at Cornell University to design and build a variety of low-cost microstrip circuits.

I. INTRODUCTION

COURSES in microwaves provide an alternative perspective with which to view difficult electromagnetic concepts. One particular form of microwave circuit—the microstrip circuit—also provides a unique vehicle for students to gain valuable experience in design and testing. Microstrip is a printed circuit transmission line that has become widely used in the microwave industry. Microstrip circuits can be used to introduce transmission lines, antennas, filters, and amplifiers. Students can do real world designs, fabricate them in microstrip, and measure their performance.

II. DESIGN

There are a number of commercially-available IBM personal computer programs for designing microstrip circuits. However, there are problems associated with using these packages in a university. These programs are expensive, often require specialized hardware like extended memory, and usually come with copy-protection devices. This makes it difficult to distribute them on a large number of machines. The algorithms and modeling are usually proprietary, and this often forces the documentation to be incomplete and difficult to scrutinize. To help students design their own circuits, a microwave computer aided design package called *Puff*, was co-developed by Richard Compton and David Rutledge [1]. *Puff* runs on an IBM PC, PS/2 or compatible, and features a single interactive-graphics screen which displays all aspects of the design (Fig. 1). Circuit elements, such as transmission lines,

coupled lines, and lumped elements, are selected from a parts list and drawn on the screen using cursor keys. The circuit analysis can then be performed directly from the screen drawing.

Puff is easy to use, is distributed free of charge, and has been used in microwave courses in universities throughout the US and the rest of the world. Since its official release in June 1987, *Puff* has been distributed to nearly 5000 users. The models used by *Puff* and the analysis methods are thoroughly documented, and students are invited to contribute to the program's development. Feedback from users has been enthusiastic and has led to several refinements in the program. These enhancements have included more accurate modelling of dispersion, improved mask-making capabilities, better hard copy facilities, and a network analyzer interface. Using a standard dot-matrix printer, *Puff* generates a medium resolution artwork mask in as little as 30 s. A companion program called *Picasso* [1] has been developed to complement the output mask-generating capacity of *Puff*. *Picasso* is a stand alone program that can generate masks on a HP compatible plotter. Masks can also be generated on a postscript laser printer.

III. FABRICATION

Precise fabrication of microstrip circuits requires etching tolerances of a few thousands of an inch. Until recently this has involved a costly combination of photo-reduction and photolithography. Over the past year, progress has been made at Cornell University on a simple low cost circuit fabrication process. Masks are generated directly by *Picasso* on a laser printer. A special film [2] similar to overhead transparency film is used which produces a mask that is heated and transferred directly onto a copper circuit board. Last minute touch-up or modification of the circuit can be performed using a felt resist pen. The circuit board is then etched in a ferric chloride solution (Fig. 2). The total cost per circuit for the process is less than \$1.00. The entire procedure takes just a few minutes and so far has a 100 percent success rate. Some examples of microstrip circuits are shown in Fig. 3. Other circuits that can be built include microstrip resonators for measuring dielectric constants and losses, FET switches, and patch antennas.

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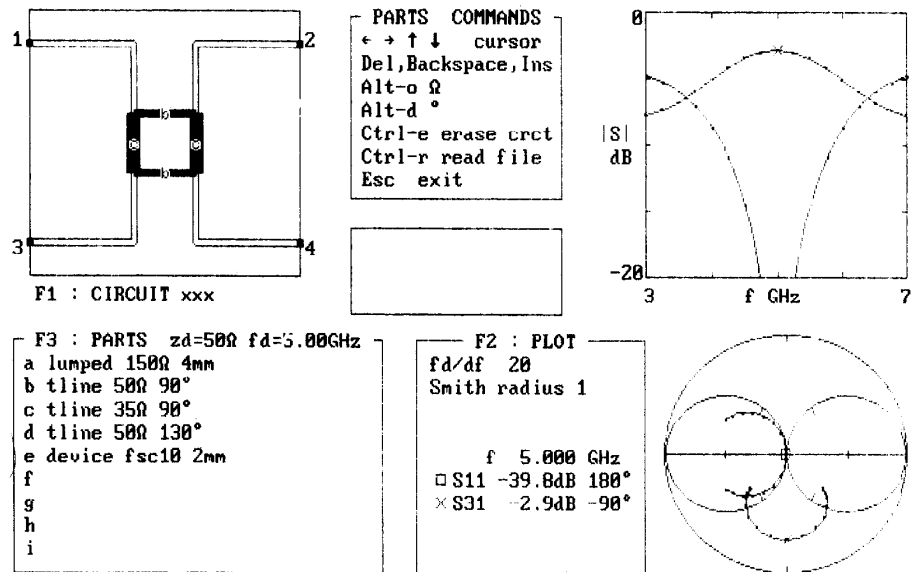


Fig. 1. Screen display of *Puff* on an IBM personal computer. The screen is divided into three main windows. Components selected from the parts window in the bottom left are laid out on the circuit board in the top left corner. Results of the analysis are plotted on the right hand side of the screen in the plot window.

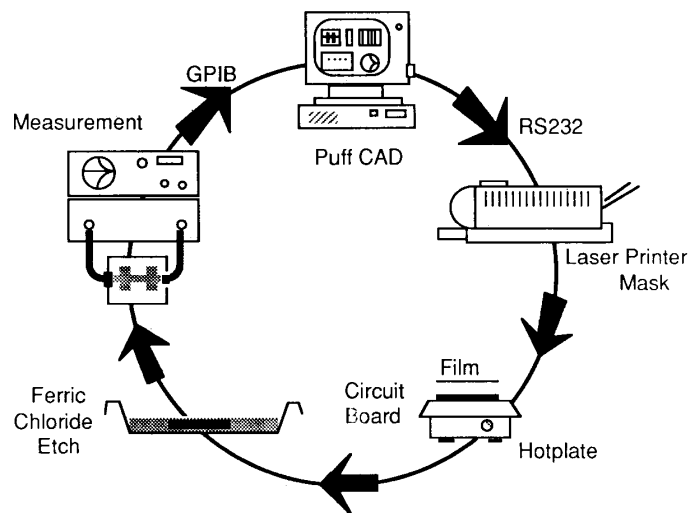


Fig. 2. Microstrip fabrication procedure. Circuits designed with *Puff* are printed on a special plastic film [2]. The resulting mask is heat transferred to a copper-clad circuit board and then etched. Measurements made on a network analyzer are down-loaded to PC for comparison with theory.

IV. MEASUREMENT

By measuring their own circuits, students get to see that the theories, equations, and proofs that they've seen in class really work. A comparison between measurements

and *Puff's* predictions for a coupler are shown in Fig. 4. Students find it rewarding when their designs work, and enjoy competing to produce the sharpest filter or the best amplifier. If their circuit doesn't perform exactly as pre-

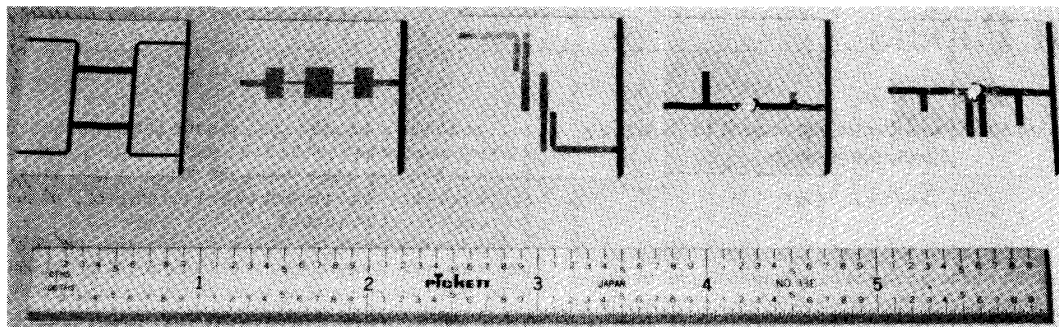


Fig. 3. A collection of microwave circuits designed by *Puff* and fabricated on either 0.635 mm (25 mil) or 1.27 mm (50 mil) 1 oz *Duroid* (6010.2). Pictured from left to right are a branch-line coupler, low-pass filter, bandpass filter, FET amplifier and oscillator. These circuits were designed to operate at frequencies ranging from 2 to 7 GHz.

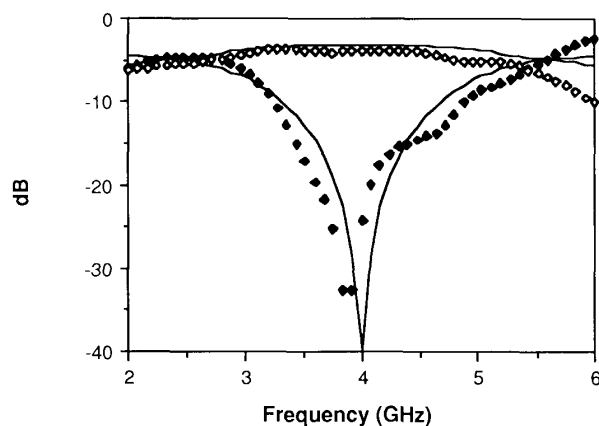


Fig. 4. Reflection and transmission properties for a ring branchline coupler. The solid lines represent predictions made by *Puff* and the triangles represent network analyzer measurements.

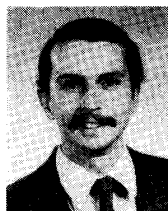
dicted they can investigate the reasons. At Cornell, most measurements are performed at with an HP 8510A vector network analyzer that measures the phase and magnitude of *s*-parameters in the range 0.5 to 18 GHz.

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REFERENCES

- [1] R. C. Compton and D. B. Rutledge, *Puff: Microwave Computer Aided Design, Manual and Software*. Yee Publishing, June 1987. Copies of *Picasso* and *Puff* along with a manual may be obtained for free by writing to the authors.
- [2] TEC-200 Film. Meadowlake Corporation, P.O. Box 497, Northport, NY 11768.



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