A NOVEL APPROACH TO COMPUTER AUTOMATED MICROWAVE CIRCUIT MASK DESIGN

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ABSTRACT

A novel computer program is presented which automates the design of microwave circuit masks using a library of verified elements. Three library elements are fabricated, evaluated using computer-aided time domain techniques, and compared with CAD model predictions.

INTRODUCTION

The next generation of missile, radar, and communication systems will involve increasingly more complex microwave hardware. Moreover, there will be increased emphasis on reducing the microwave engineering costs of these systems. Lower cost can only be accomplished through the use of computer-aided engineering techniques. Maximum engineering cost reductions will be achieved when computer-aided design is fully integrated with computer-aided manufacturing.

A critical step in the establishment of an integrated computer-aided design, manufacture and test system for microstrip and stripline components, about which very little has been presented in the literature[1], is the demonstration of an automated technique for the layout and fabrication of microwave circuit masks. This paper will describe a recently developed, novel technique for computer automated mask design and will show both theoretical and experimental results for three circuit design examples fabricated using this approach.

DESCRIPTION OF AUTOMATED ARTWORK GENERATION PROGRAM

A time sharing program has recently been developed which simplifies the mask design process. The FORTRAN program called BAA (BEDFORD AUTOMATED ARTWORK) runs on a CDC cyber computer and provides a user friendly interface between the design engineer and the Gerber automated drafting machine and photo-plotter which generate the actual circuit mask. Users access BAA via a graphics terminal such as the Tektronix 4012. The BAA commands define a powerful language which allow the user to describe his desired microstrip or stripline circuit in consistent mechanical or electrical terminology. The user selects building blocks from a library of commonly used microwave components. Typical library elements which have been implemented include branch line couplers, ring hybrids with equal or unequal power division, overlay couplers, interdigitated DC blocks, distributed RF chokes, mitred bends, and other components. In order to specify a circuit, each BAA element is described by giving the generic name (component type), parameters, specific name, and position of the component. The position is specified by three numbers representing the X and Y coordinates and the angular orientation (rotation) of the component in the circuit.

For example, a hybrid ring can be specified by a single statement,

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RATEQ w,wr,d  (Name (x,y,a) )
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where w is the line width at the ports, wr is the width of the ring line, d is the ring mean diameter, "Name" is the name of one particular hybrid (perhaps more than one hybrid will be needed, so each is given a unique name), and (x,y,a) are the coordinates and angle of the origin of the hybrid named "Name". BAA also includes a variety of component interconnection commands which automatically connect element ports with prescribed line widths. Depending upon the angular orientation of the components which are to be interconnected, the program will chose an optimum method to minimize mismatch. If two components are inline a straight line will be used, however, an ogee curve will be generated for component ports which are offset. When component connections require that a particular path be followed the designer can specify a set of points which will be traced by the program to form the interconnecting line.

A preview feature allows the engineer to display the circuit layout on a graphics terminal. Once the layout is complete, a magnetic tape of commands is generated. The tape is used to control the Gerber photoplotter to make the actual mask at any desired magnification. Most masks are made at large scale, typically 10X, and then photoreduced. The BAA program automatically selects and changes photoplotter aperatures to obtain an optimum trade-off between writing speed and good circuit definition. An etch factor dimension may also be specified and is scaled appropriately.

Initially, all BAA elements were designed to be specified in mechanical terms such as line width or ring diameter. The program has recently been extended to include elements specified in electrical terms. This allows design "intelligence" to be stored in the element library. The program can now perform the required conversion from electrical specification to mechanical dimensions for several components. The goal is to establish a library of verified designs for microwave components. One example of a BAA element which is described in electrical terms is a ratrace coupler with equal or unequal power division. The ratrace is specified as follows:

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ERATEQ ps, freq,er,z0,h
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where ps is the desired power split, freq is frequency, er is the substrate relative dielectric constant, z0 is the desired input impedance, and h is the substrate ground plane spacing.

SPECIFIC DESIGN EXAMPLES

In order to illustrate the performance of BAA library elements, three sample circuits were fabricated using BAA masks and tested. These were a microstrip capacitor, an inductor, and a rat race coupler. The circuits were fabricated on alumina substrates, with a relative dielectric constant of 9.8, and a substrate height of 0.025 inches. Figure 1 shows the capacitor and inductor circuit patterns as presented by the BAA preview feature while the mask pattern for the hybrid ring is shown in Figure 2.

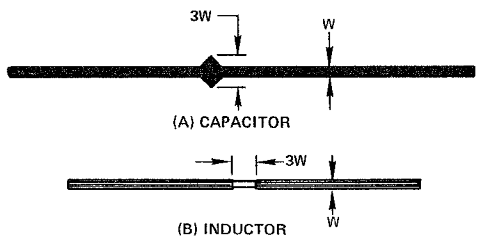

Figure 1 - BAA Mask Pattern of Capacitor and Inductor

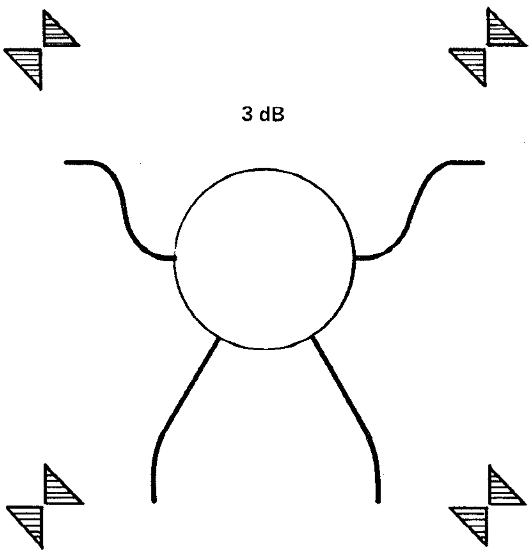

Figure 2 - BAA Mask Pattern of Rat Race Coupler

The circuits were measured over the frequency range of 2.0 to 18.0 GHz using a Hewlett Packard 8409B network analyzer with a Raytheon developed custom software package (RAYCAT). RAYCAT has extensive analysis capability, including the ability to deembed a test circuit so as to eliminate fixture error. The de-embedding is accomplished by calculating an equivalent time-domain, or "tdr" plot from the broadband S11 frequency domain data. This automated time-domain technique is an extension of original work reported by Stinehelfer[2]. It can delete the portions of the time-domain plot which correspond to test lines, connectors, or other parts of the measurement setup external to the circuit element under evaluation. When the time domain plot is de-convoluted to the frequency domain the errors introduced by the fixture are no longer present in the de-embedded data. The resulting data is the impedance that the component under test actually presents to the rest of the circuit when it is fully integrated. The time domain method, therefore provides an accurate way of predicting how a circuit element will perform within an integrated microwave circuit containing may other components.

Figure 3 shows the time plot of the double triangle capacitance of Figure 1a where the fixture reflections are clearly revealed. Measured and de-convoluted (de-embedded) data is shown in Figure 4 where it is compared with the predicted VSWR based upon a theoretical model. The theoretical performance was calculated by modeling the triangle shape as a cascade of a large number of small impedance changes. The de-embedded data shows excellent correlation with this theoretical model over a broadband frequency range. The small series inductors in Figure 1b was fabricated as two parallel high impedance lines. The even-mode for the coupled lines was used to obtain the theoretical model and the theory and de-embedded data is shown in Figure 5. This circuit element may be approximated as a lumped inductor of 0.352 nH up to 10 GHz.

Figure 6 shows the measured, de-embedded and theoretical VSWR for the ratrace. Exact time-domain comparison of these measurements reveal the junction reactances which are causing the differences between measurement and theory.

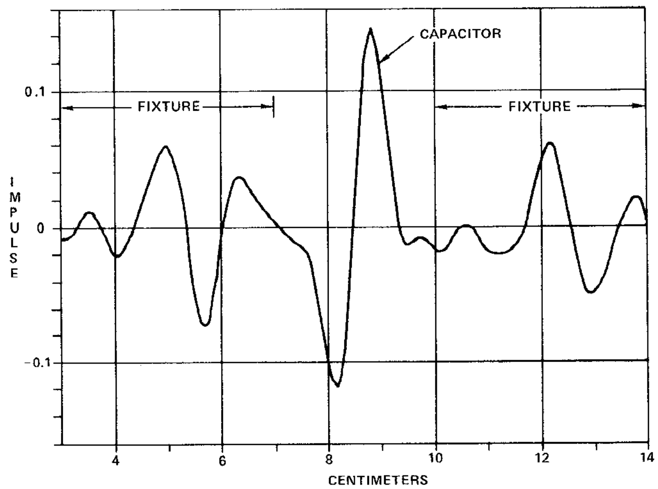

Figure 3 - Impulse Time-Plot of Capacitor and Fixture

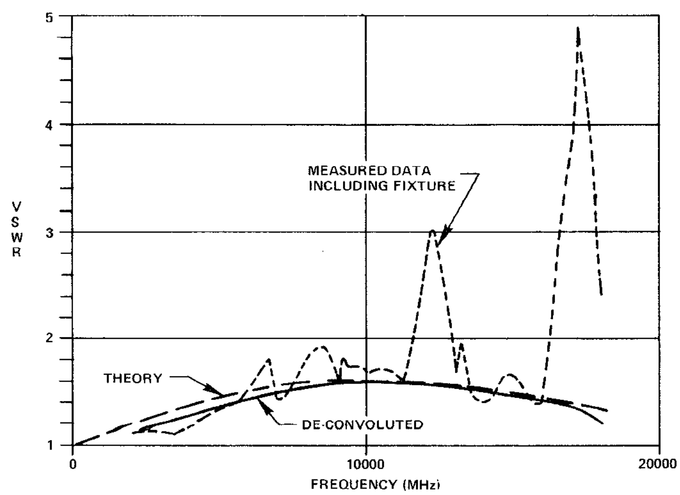

Figure 4 - Overlay of Measured, Theory and Deconvoluted VSWR for Microstrip Capacitor

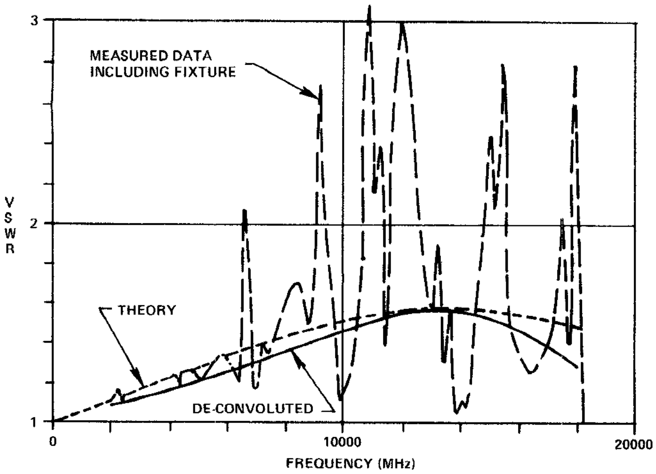

Figure 5 - Overlay of Measured, Theory and Deconvoluted VSWR for Microstrip Inductor

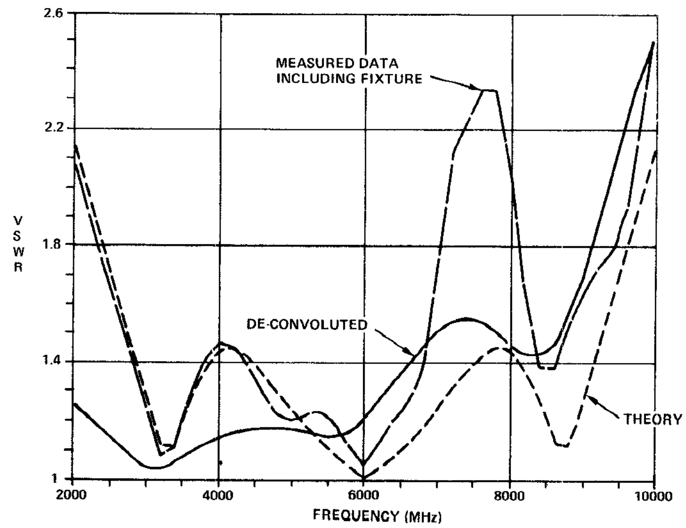

Figure 6 - Overlay of Measured, Theory and Deconvoluted VSWR for Microstrip Hybrid

CONCLUSION

A novel automated technique for the layout and generation of microwave circuit masks for use in microstrip and stripline circuits has been described. Several library elements have been fabricated using BAA mask designs and agreement of test results with CAD models has been demonstrated. While presently used to drive a Gerber automated drafting machine and photoplotter, the BAA program could be modified to drive other types of pattern generators such as the Mann, and Electron Beam Machine. In the future it can be extended to monolithic circuit applications requiring multiple mask levels with excellent registration. The BAA technique is being used to generate hundreds of masks each year and design cycle times have been reduced significantly, resulting in a large increase in engineering productivity. Design quality has also been improved through the implementation of verified library elements. It is evident that with further advancements in microwave computer-aided engineering, shorter development cycles and increased productivity will reduce the cost of developing and producing microwave hardware.

REFERENCES

1. S. Horvitz, "Microwave Printed Circuit Design Procedure", Meeting of Automated Radio Frequency Group, Princeton, N.J. 1981.
2. H.E. Stinehelfer, Sr., "Time-Domain Analysis Stops Design Guesswork", Microwaves, September 1981, pp. 79-83.