27
9-20-76
n 5 sep 8 11 15
BDX-613-1477

THE NECESSITY OF CHARACTERIZING
HYBRID MICROCIRCUIT ELEMENTS
AT MICROWAVE FREQUENCIES

PDO 6984889, Topical Report

J. L. Taylor, Project Leader

Project Team:

L. W. Williams

✓ G. D. O'Dell

R. M. Tellez

Published August 1976

MASTER

Prepared for the United States Energy
Research and Development Administration
Under Contract Number E(29-1)-613 USERDA

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche \$2.25
Paper Copy \$3.50

BDX-613-1477
Distribution Category UC-38

THE NECESSITY OF CHARACTERIZING
HYBRID MICROCIRCUIT ELEMENTS
AT MICROWAVE FREQUENCIES

Published August 1976

Project Leader:
J. L. Taylor,
Department 842

Project Team:
L. W. Williams
✓ G. D. O'Dell
R. M. Tellez

PDO 6984889
Topical Report

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

Technical Communications

**Kansas City
Division**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THE NECESSITY OF CHARACTERIZING HYBRID MICROCIRCUIT ELEMENTS AT MICROWAVE FREQUENCIES

BDX-613-1477, UNCLASSIFIED Topical Report, Published August 1976

Prepared by G. D. O'Dell, D/842, under PDO 6984889.

As a result of efforts to develop packaging techniques for large radio frequency HMCs, the need for characterization of hybrid microcircuits became apparent. Characterization of hybrids and their manufacturing processes for radio frequency applications is required for economic production. Many of the present rf HMC circuits require extensive circuit adjustments to obtain desired function. The problems involved are partially the result of the lack of accurate rf characterization of the components and manufacturing processes as they relate to rf HMC applications.

WPC-dvh

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THE BENDIX CORPORATION
KANSAS CITY DIVISION
P.O. BOX 1159
KANSAS CITY, MISSOURI 64141

A prime contractor for the United States Energy Research and Development Administration
Contract Number E(29-1)-613 USERDA

CONTENTS

Section	Page
SUMMARY.	4
DISCUSSION	5
SCOPE AND PURPOSE.	5
PRIOR WORK	5
ACTIVITY	5
<u>RF Characterization.</u>	5
<u>The HMC Characterization Problem</u>	7
<u>Application of RF HMC Characterizations.</u>	10
FUTURE WORK.	11
BIBLIOGRAPHY	12
DISTRIBUTION	13

ILLUSTRATIONS

Figure	Page
1 Basic Lumped Element Models.	7
2 Via Test Fixture	10

SUMMARY

In any electrical circuit it is necessary to characterize or describe electrically the components of that circuit. This report outlines the need for the development of suitable characterizations for radio frequency (rf) hybrid elements and hybrid microcircuit manufacturing processes in terms of their effects on circuit function at microwave frequencies.

None of the various elements found on rf hybrid microcircuits have been completely characterized. These elements may be active or passive and include deposited thin film conductors and resistors, chip capacitors, printed inductors, vias, transformers, toroids and solenoids, as well as rf diodes and transistors.

Many of the present developmental rf hybrid circuits require extensive circuit adjustments consisting of component matching and selection to obtain desired functions. Admittedly some degree of tuning in the form of component selection and placement may be inevitable, but it should be possible to significantly reduce this requirement and have both a more manufacturable and a more reliable product.

The tuning problems associated with these circuits are partially the result of the unavailability of accurate rf characterizations of components and manufacturing processes as they relate to hybrid applications at microwave frequencies. Without characterizations of these elements, problem solving is restricted to "cut and try" analysis. As a consequence, the ability to identify critical or sensitive hybrid components or fabrication processes prior to or during production is drastically limited.

Device characterizations are readily available for ideal circuit elements which do not alter circuit performance by slight variations in component location, do not interact with adjacent circuitry, and have measured characteristics which are independent of both test fixtures and testers. Unfortunately some of the components found on rf hybrids are widely divergent from ideal elements, do radically alter circuit performance with even minute variations in component location, do interact freely with adjacent circuitry, and are dependent upon both test fixtures and testers.

Future effort should include the characterization of each hybrid element. Where practical these characterizations would then be related to the function of each individual rf hybrid by computer aided analysis. The end result of this approach would be the ability to realistically evaluate hybrid components and manufacturing processes in terms of circuit function.

DISCUSSION

SCOPE AND PURPOSE

During development work on packaging techniques for large rf hybrid microcircuits (HMC), existing fabrication processes and component inspection techniques used with rf HMCs were found to be inadequate to economically produce them--largely because of an incomplete understanding of the rf characteristics of components, component attachments, and test fixtures. This report sketches briefly the nature of the problem uncovered. Completion of necessary work in this area goes well beyond the scope of the present effort on large rf HMCs but the problem is being outlined here because of its importance to economic production.

PRIOR WORK

As a result of earlier work on this project, small 1-inch (25.4 mm) square rf hybrid microcircuits were combined into larger (approximately 1- by 2-inch [25 by 50 mm]) hybrids having the combined function of two original hybrids. This combination resulted in the elimination of highly tuned multiple impedance transformation and associated circuitry for each combination. During this effort the rf HMC characterization problem became apparent.

Although work on accurate rf hybrid component models has not been attempted, some preliminary S-parameter data was taken for a few devices. Lumped element models of both capacitors and inductors had been developed with limited success as a result of effort on another project.

ACTIVITY

Work on the description and characterization of rf HMC elements has not been formally initiated. What follows is a survey of the difficulties and complexities involved in the characterization of HMC circuit elements at microwave frequencies.

RF Characterization

Definition

Characterization may be defined as the accurate, complete, and total description of the electrical function of a given device. In this report, discussion will be restricted to the electrical components found on hybrid microcircuits used at microwave frequencies. Such elements may be either active or passive, and include deposited thin film conductors and resistors, chip capacitors, printed inductors, vias, transformers, toroids, and solenoids, as well as rf diodes and transistors.

Possible Characterizations

Characterization of electrical devices may be based on either lumped or distributed parameters. A given circuit element may be considered lumped provided its physical dimensions do not represent a significant fraction of a wavelength at the frequency of operation. An electrical circuit element can no longer be considered lumped when it exhibits appreciable phase shift because of electrical length. When this occurs and the effects of the device cannot be localized to a single discrete point in the circuit, the element is said to be distributed. Without exception, rf HMC components have been found to exhibit some distributed characteristics at microwave frequencies.

Lumped Models

One method of describing circuit element parameters is with a model composed of a number of lumped elements. For example, capacitors and inductors may be modeled as shown in Figure 1.

Such models have been used with some effect in a previous endeavor. In principle these models might be used to represent various hybrid components with additional lumped elements accounting for the parasitic effects resulting from connection in the circuit. The major drawback of this approach lies in the complexity of the actual distributed parameters being modeled. As more and more of these effects are included in the model, the number of lumped elements required increases, as illustrated by the inductor in Figure 1. Besides being more difficult to solve, such models are still not complete and do not account for all the resonances and circuit parameters of the actual device. Because of these drawbacks, other models based more directly on the combined effects of lumped, distributed, and parasitic parameters are, in general, preferable.

Distributed Models

Given that a device is to be modeled in terms of the combined effects of lumped, distributed, and parasitic characteristics, one of two circuit descriptions is generally adopted. If possible, a theoretical model of the device is used. This is generally suitable for only those devices which can be described by a simple field solution. The calculation of values for a single hybrid element such as a chip capacitor would be a fairly difficult field problem requiring multiple manyears of effort. Even this effort would have to be based on at least a partial computer solution as any purely analytic solution would be virtually impossible. However, for some rf elements such as thin film conductors and resistors, characterization as distributed transmission lines is most appropriate. The remaining task for these elements is to develop either theoretical or empirical values for attenuation.

Figure 1. Basic Lumped Element Models

When theoretical solutions are not available in a reasonable time frame, the most attractive alternative is characterization by S-parameters. If the S-parameters of a given rf component can be reliably obtained over the desired frequency range, they provide an empirical description which accounts for the effects of distributed parameters. S-parameter measurements may readily be obtained by use of an automatic network analyzer--provided calibration can be accomplished at the device interface.

The HMC Characterization Problem

Device characterizations are readily available for ideal circuit elements which do not alter circuit performance by slight variations in component location, do not interact with adjacent circuitry, and have measured characteristics which are independent of both test fixtures and testers. Unfortunately some of the components found on rf hybrids are widely divergent from ideal elements, do radically alter circuit performance with even minute variations in component location, do interact freely with adjacent circuitry, and are dependent upon both test fixtures and testers.

The non-ideal nature of these devices may be described both in terms of the complexities of the microstrip environment and of the devices themselves. The combination of non-ideal rf hybrid components and the difficulty in removing measurement errors introduced by test fixtures and testers constitute the characterization problem.

The Problem With Microstrip

The ideal device would be either a simple lumped element or a distributed element having a known or readily derived theoretical model. For physical reasons there are no ideal devices. Each rf hybrid component type is for one reason or another non-ideal. Chip capacitors, for example, undergo multiple resonances with frequency and present a complex reactance which at times may even be inductive. None of the rf hybrid elements may be represented simply as a lumped element.

In microstrip, conductors and rf elements are located on one side of a substrate consisting of ceramic or another dielectric material, with a layer of metallization creating a ground plane on the reverse side of the substrate.

The ceramic substrate (Al_2O_3) presently used on rf hybrids has a relatively high dielectric constant (9.8) which tends to concentrate most of the rf energy in the substrate. A portion of the fields are in the air, however, and this presents problems similar to those encountered with dispersive wave guide. Such structures are capable of supporting more than one mode, which results in unequal velocities of propagation for the various modes. As a result of this dispersion, the mode of propagation can only be said to be transverse electromagnetic (TEM) in the quasi-static limit to frequencies in the low GHz range.

The non-TEM nature of microstrip increases the difficulty of obtaining theoretical characterizations based on distributed parameters, as well as increasing the influence of parasitic effects. The parasitics present additional restraints on both hybrid layout and fabrication.

Multiple Component Variables

In addition to the component interaction caused by the increased field content in the air above microstrip there is additional interaction because of the interdependent relationships of hybrid component fabrication variables. An example of the complexity involved may be illustrated by listing the variables influencing the electrical properties of a thin film (gold) conductor or transmission line:

- Substrate dielectric constant,
- Substrate thickness,
- Substrate surface finish,
- Composition of thin film,

- Thin film uniformity,
- Thin film conductivity,
- Thin film thickness,
- Path width, and
- Proximity of adjacent elements.

A change in one of these variables alters the circuit performance of the conductor or transmission line and also can influence to a greater or lesser degree the performance of any number of other hybrid circuit elements. For example, the substrate dielectric constant affects the characteristics of every hybrid element either directly as in the transmission line or indirectly by changing the parasitics involved in the attachment of applique components. There is a further level of complexity encountered should the effects of manufacturing processes be considered. Continuing to use the previous transmission line example, each variable affecting conductor performance is in turn a function of a number of manufacturing processes.

Tester and Test Fixture Errors

Empirical S-parameter characterizations are entirely suitable if S-parameters are known. Perhaps the most significant feature of the automatic network analyzer is that systematic measurement system errors are removed from S-parameter data and random errors reduced by averaging. The remaining restraint on S-parameter accuracy is primarily the effect of test fixture errors on the measured parameters.

For each test fixture used, the distance to the measured device from the calibration or reference plane must be known accurately and the reflections and discontinuities encountered in the transition from the reference plane to the device must be removed from the measurement. At present it is not feasible to remove all of the test fixture errors from the S-parameter data, although work toward this goal has been nearly completed.

The transition from a precision calibration interface to a thin film transmission line and attached via on a ceramic substrate is shown in Figure 2. Accurate calibration of an automatic network analyzer is possible at the precision connector interface by measurement of known reference standards. The characteristics of the transition from the connector interface to the via represent an unknown error source by presently available measurement techniques.

Figure 2. Via Test Fixture

Without unduly complicating the problem, a fair degree of accuracy is required to describe this basic element. Even the gap in the transmission line which is without metallization would have to be accounted for. Enough is known about the via characteristics that although they are a great deal like short circuits they differ from ideal shorts by a measurable amount. Determination of this difference certainly requires characterization.

Application of RF HMC Characterizations

Once characterizations are known for rf hybrid elements, the principal remaining task is to relate the characterization to circuit function. It is essential to do so to identify both manufacturing processes and component characteristics which are critical to overall product function. Only when these relationships between components and processes are known can the manufacturability of a specific circuit design and the associated processes required to produce that design be determined.

Because of component interactions and differences in circuit types, each hybrid must be analyzed on an individual basis. The complexity of component interactions and the large number of interrelated variables involved makes computer analysis the only practical means of relating component characterizations and manufacturing processes to circuit performance. Several microwave circuit analysis programs are available and most of these include the capability of inputting S-parameter models which would be obtained for the majority of characterizations.

FUTURE WORK

Future work should include the characterization of each rf hybrid element.

The planned technical approach would involve these steps:

- Develop methods for the characterization of HMC manufacturing processes as they relate to rf applications,
- Characterize the manufacturing processes in terms of their effects upon rf function,
- Characterize the various HMC circuit elements in terms of HMC packaging and the combined effects on rf function, and
- Develop inspection criteria which will control the rf characteristics of the various HMC processes and circuit elements necessary to HMC next assembly function.

BIBLIOGRAPHY

- Gunston, M. A. R. *Microwave Transmission Line Impedance Data*. New York: Van Nostrand Reinhold, 1972.
- Jesch, Ramon L., and C. A. Hoer. *Characterization of a High Frequency Probe Assembly for Integrated Circuit Measurements*. Washington: NBS Technical Note 663, April 1975.
- Ramo, Simon, and others. *Fields and Waves in Communication Electronics*. New York: John Wiley and Sons, 1965.
- Rogers, George J., and others. *Measurement of Transistor Scattering Parameters*. Washington: NBS Special Publication 400-5, January 1975.
- Taylor, J. L. *An Automatic Rf-Network Analyzer as a Support Tool for Engineering and Manufacturing (Final Report)*. UNCLASSIFIED. Bendix Kansas City: BDX-613-1297, June 1975.
- Weiss, Jerald A. *Microwave Propagation on Coupled Pairs of Microstrip Transmission Lines*. New York: Academic Press, 1974.

DISTRIBUTION

	Copy
R. Bulcock, ERDA-KCAO	1
C. R. Alls, SLA	2
R. L. O'Nan, SLA	3
J. D. Corey, D/554, BD50	4-5
L. Stratton, D/554, 2C44	6-8
R. P. Frohmberg, D/800, 2A39	9
A. O. Bendure, D/842, MC39	10
J. S. Bosnak, D/842, MC39	11
L. W. McWilliams, D/842, MC39	12
G. D. O'Dell, D/842, MC39	13-17
J. A. Peters, D/842, MC39	18
D. D. Peterson, D/842, MC39	19
L. S. Robb, D/842, MC39	20
J. L. Taylor, D/842, MC39	21
R. M. Tellez, D/842, MC39	22
T. A. Wiley, D/842, MC39	23
R. E. Kessler, D/865, 2C40	24