# EXPERIMENTAL MODELS OF SERIES AND SHUNT ELEMENTS IN COPLANAR MMICs

**Arvind K. Sharma and Huei Wang**
**TRW / ESG**
**Electronics and Technology Division**
**One Space Park, Redondo Beach, CA 90278**

## ABSTRACT

Experimental models of several grounded coplanar waveguide discontinuity structures, such as series as well as shunt inductors and capacitors, have been developed using experimental measurements and computer optimization. The equivalent circuit models have been derived in terms of structural parameters of the discontinuity structures to facilitate their easy use in the design of coplanar MMICs.

## INTRODUCTION

Microwave and millimeter-wave monolithic integrated circuits utilizing grounded and ungrounded coplanar waveguides (CPW), along with planar transmission lines such as microstrip and slot line, referred to as coplanar MMICs (CMMICs), are now being actively pursued for components requiring a high level of integration. This is attributed mainly due to ease in the integration of shunt as well as series circuit elements. Balanced circuits such as mixers are easy to implement in coplanar waveguide and slot line environment. In addition, the fabrication process eliminates the yield limiting backside processes such as wafer thinning and via etching [1, 2].

The lack of design information of discontinuity structures in coplanar waveguide and other interacting structures formed with planar transmission lines has so far precluded them from being extensively used CMMICs. Consequently, a designer has to design circuits using heuristic procedures which neither inspire confidence nor achieve first pass-success.

The early paper by Houdart [3] presented some basic series and shunt elements in coplanar waveguide and their equivalent circuits. As long as the stub lengths are less than the quarter wavelength in the coplanar waveguide, their equivalent circuit models are fairly simple. At millimeter-wave frequencies, quarter-wave stubs cause resonances which require somewhat complex equivalent circuits. Models of some coplanar waveguide junction discontinuities have been attempted in the past. Simon and Ponchak [4] presented models of open end, series gap, and a symmetric step for coplanar waveguide. They also presented models of open end and a right angle bend for a channelized coplanar waveguide [5]. The experimental results have been presented for a low dielectric constant material ($\varepsilon_r=2.2$). Dib et al [6] recently presented closed form equations for series inductor and capacitor for a coplanar waveguide on a composite dielectric substrate with $\varepsilon_{r1}=9.9$ and $\varepsilon_{r2}=2.2$. The theoretical results were obtained from solution of surface integral equation in the space domain and verified with experiments. To this date, accurate models of grounded coplanar waveguide discontinuity structures are not available in the literature which can be effectively used in microwave and millimeter-wave monolithic integrated circuits.

The objective of this paper is, therefore, to present experimental models of grounded coplanar waveguide (GCPW) structures suitable for CMMICs.

As shown in Fig. 1, a reticle containing more than 350 structures was fabricated on a 100 µm thick GaAs substrate. The test patterns were designed in a systematic manner to arrive at practical models for a range of structural parameters frequently used in CMMIC designs.

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On wafer RF transmission measurements were performed on an HP8510 from 1 to 26.5 GHz to obtain frequency dependent S-parameters. The equivalent circuit models were then obtained using computer optimization of transmission measurement data.

## SERIES CAPACITOR

A series capacitor, as shown in Fig. 2(a) in GCPW, is formed using interdigital structure with an open circuited stub of length L. The gap in the center conductor formed by the finger width W1 and spacing G1 essentially provides the series capacitance at microwave frequencies. Fig. 2(b) illustrates the series capacitance as a function of W1 and G1. The value of series capacitance increases almost linearly with the length of the interdigital structure. But it decreases as the width W1 increases.

## SERIES INDUCTOR

The series inductor, as shown in Fig. 3(a) in GCPW, is also formed using an interdigital structure with a shorted stub of length L. The inductance is mainly contributed by the narrow center conductor. The series inductor is modeled as a series R and L network. The series inductance increases with the length of the interdigital section and decreases with an increase in width W1. The behavior of the series resistance is similar to that of the inductance, as shown in Fig. 3(b).

## SHUNT CAPACITOR

A shunt capacitor is GCPW (Fig. 4(a)) is formed by open circuited stubs of length L, width W1 and gap G1. The shunt capacitor is modeled as a lumped pi - network consisting of a series inductance (L) and two shunt capacitances (C). As shown in Fig. 4(b) an increase in open circuited stub length increases both the shunt capacitance as well as series inductance. However, an increase in width causes an increase in shunt capacitance value and a slight decrease in series inductance.

## SHUNT INDUCTOR

A shunt inductor, as shown in Fig 5(a), consists of short-circuited stubs of length L, width W1 and gap G1. Similar to the shunt capacitor, it is modeled as a lumped - pi network consisting of series and shunt inductors. Both the series and shunt inductor values increase with an increase in length of the stub. They also increase with a decrease in the width (W1), as illustrated in the plots of Fig. 5(b).

## CONCLUSIONS

In this paper, we have presented lumped element equivalent circuit models of series and shunt capacitors as well as inductors in grounded coplanar waveguide at microwave frequencies. Due to systematic design of the experiments, we have developed models for a range of structured parameters frequently used in CMMIC designs. These simple models can be integrated with any simulation program to facilitate their easy use.

## REFERENCES

[1] T. H. Chen, et al, "A Q-band monolithic balance resistive mixer using CPW/slot line balun," 1990 IEEE GaAs IC Symposium Digest, pp. 177-180.

[2] T. N. Ton, et al, "A Q-band monolithic AlGaAs/GaAs HEMT CPW downconverter," 1990 IEEE GaAs IC Symposium Digest, pp. 185-188.

[3] M. Houdart, "Coplanar lines: Application to broadband microwave integrated circuits," Proc. of 6th European Microwave Conference, pp. 49-53, 1976.

[4] R. N. Simons and G. E. Ponchak, "Modeling of some coplanar waveguide discontinuities," IEEE Trans. on Microwave Theory Tech., vol. MTT-36, pp. 1796-1803, Dec. 1988.

[5] R. N. Simons et al, "Channelized coplanar waveguide: Discontinuities, junctions, and propagation characteristics," in 1989 IEEE Int. Microwave Symposium Digest, pp. 915-918.

[6] N. I. Dib et al, "Coplanar waveguide discontinuities for PIN diode switches and filter applications," in 1990 IEEE Int. Microwave Symposium, pp. 399-402.

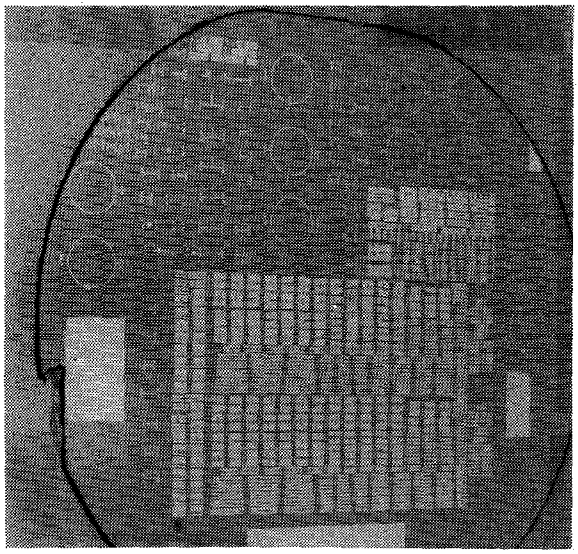
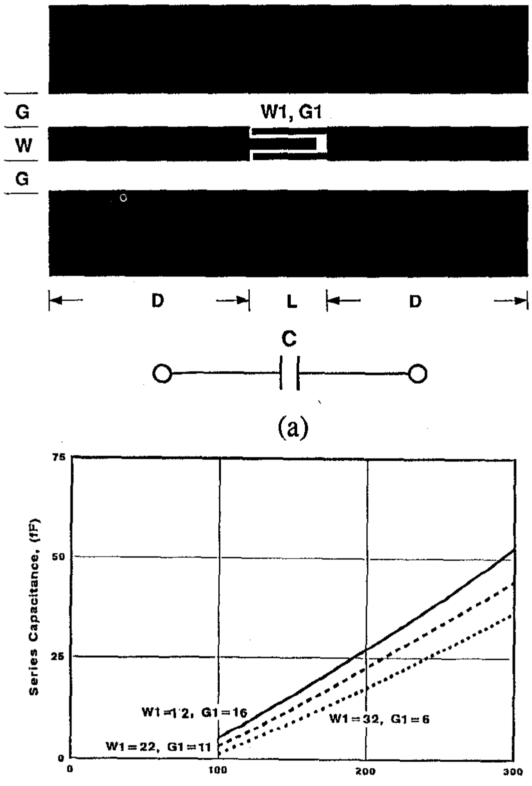


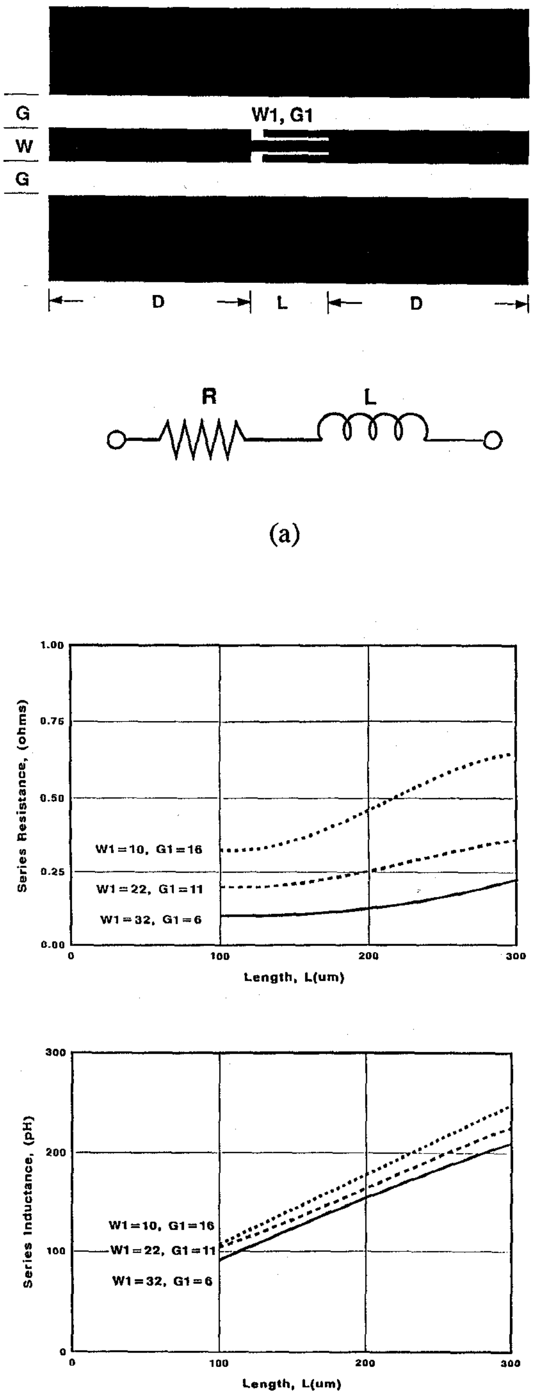
Fig. 1 Microstrip and coplanar passive structures



(a)

(b)

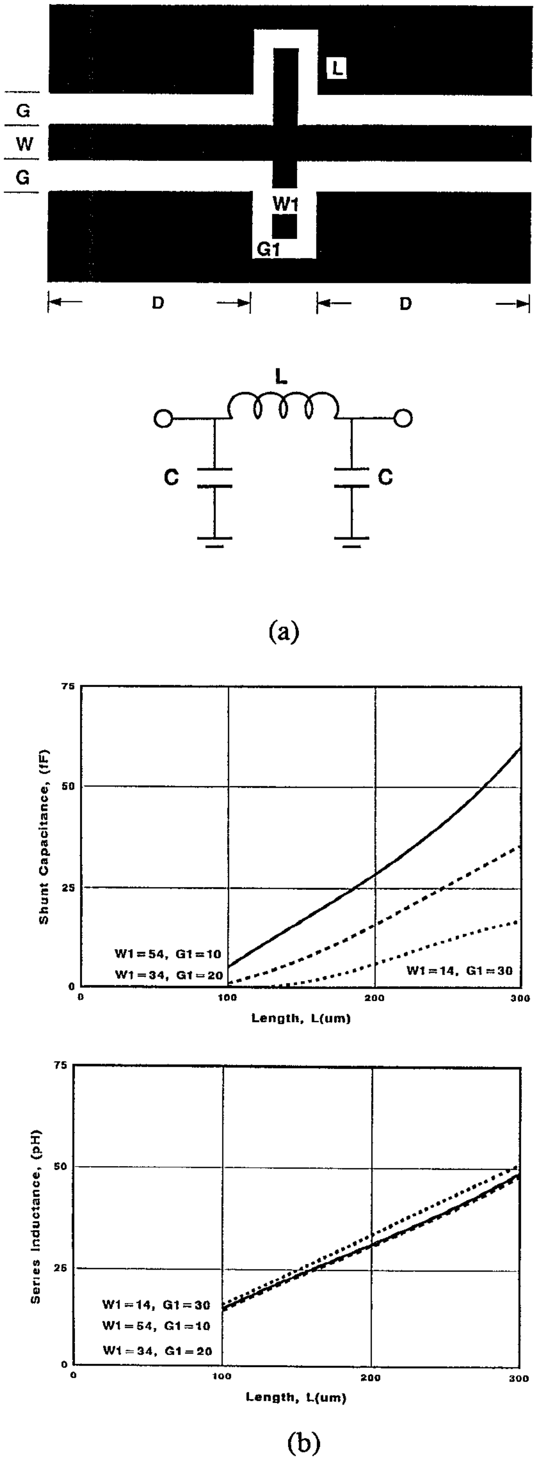
Fig. 2 (a) Series capacitors in grounded coplanar waveguide. (b) Series capacitance as a function of W1 and G1. W=66 μm, G=40 μm , D=500 μm, $\varepsilon_r$=12.8 and substrate thickness=100 μm.



(a)

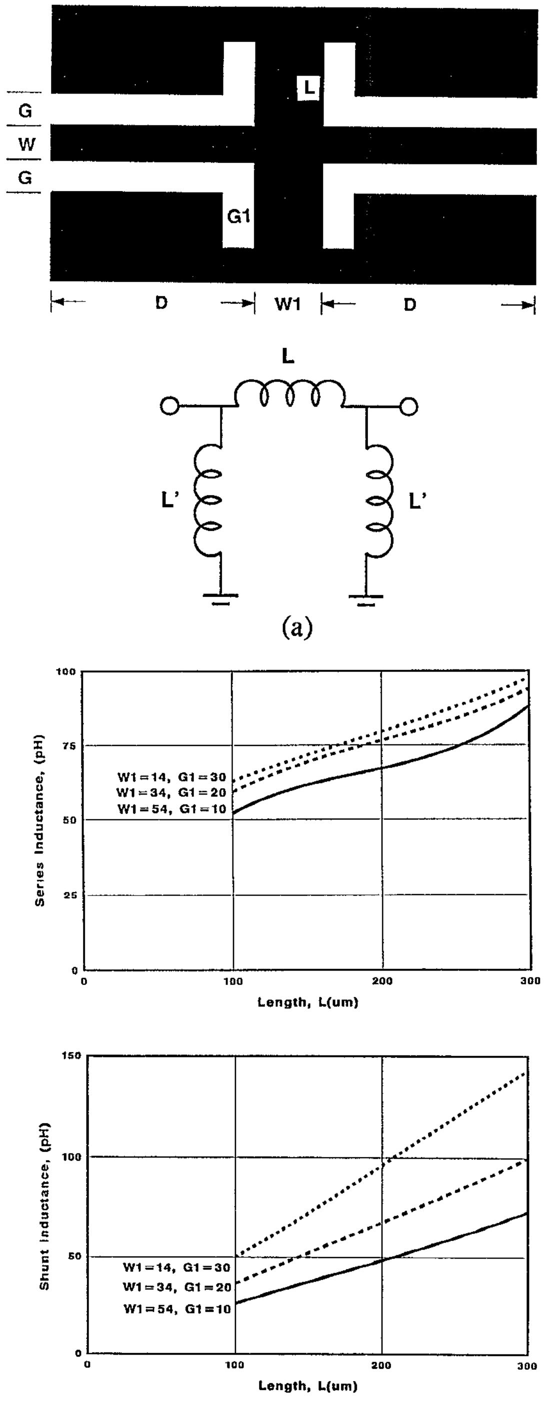
(b)

Fig. 3 (a) Series inductors in grounded coplanar waveguide. (b) series resistance and inductance as a function of W1 and G1. W=66 μm, G=40 μm , D=500 μm, $\varepsilon_r$=12.8 and substrate thickness=100 μm.



(b)

Fig. 4 (a) Shunt capacitors in grounded coplanar waveguide. (b) series inductance and shunt capacitance as a function of W1 and G1. W=66 μm, G=40 μm , D=500 μm, $\varepsilon_r$=12.8 and substrate thickness=100 μm.



(b)

Fig. 5 (a) Shunt inductors in grounded coplanar waveguide. (b) series and shunt inductance as a function of W1 and G1. W=66 μm, G=40 μm , D=500 μm, $\varepsilon_r$=12.8 and substrate thickness=100 μm.