W-BAND FINITE GROUND COPLANAR (FGC) LINE CIRCUIT ELEMENTS

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1.0 Abstract

This paper describes the modeling and experimental evaluation of Finite Ground Coplanar (FGC) lines, stubs, and filters between 2 and 110 GHz. These lines provide a very low loss alternative to microstrip or coplanar waveguide for millimeter- and submillimeter-wave applications without the use of vias. Their mode free operation allows excellent agreement between measured data and LIBRA modeling to 110 GHz. The lines have very low loss at W-band and filters have a loss comparable with the best membrane filters reported recently. The paper includes details of analytic and FDTD investigations of the lines, a description of the fabrication and measurement calibration and measured data on lines, tuning stubs, and a variety of low-pass filters.

2.0 Introduction

Passive component design and fabrication are important parts of microwave engineering at millimeter-wave frequencies. Microstrip and coplanar waveguide are two planar waveguiding structures which have been used extensively in high-frequency applications because of their monolithic configuration and their compatibility with solid-state devices.[1-3] However, their use in millimeter-wave frequencies has not been problem-free for a variety of reasons which are particular to the geometry of the waveguiding structure. Specifically, microstrip performance strongly depends on wafer thickness and requires increasingly thinner substrates as frequency increases to avoid overmoding, unacceptable radiation, and ohmic loss. On the other hand, coplanar waveguide propagation characteristics are less dependent on wafer thickness but performance dramatically deteriorates in the presence of backside metallization due to the excitation of parasitic parallel plate waveguide modes. These problems lead to complex and costly solutions such as wafer thinning and backside processing. Specifically, in the case of coplanar waveguide, the elimination of parallel plate modes requires an excessive number of vias which, if added carelessly, can introduce additional parasitic effects requiring even more complex solutions. The presence of a parasitic mechanism not only complicates fabrication but design in general, since conventional design tools such as LIBRA become increasingly inaccurate. Coplanar lines with finite ground plane configurations, an alternative guiding medium described in this paper, overcome many of the parasitic and modeing problems observed in microstrip and coplanar waveguide structures. This paper describes the development of circuit components using finite-ground coplanar lines for operation between 2 GHz and 110 GHz. The study presented herein presents theoretical as well as experimental results and provides extensive comparisons for validation.

3.0 Development of FGC Components

Finite Ground Coplanar (FGC) lines have a geometry similar to conventional CPW except the ground planes are narrow, thus simulating a three-strip structure (see figure 1). This structure has many of the advantages of CPW including balanced propagation, coplanar configuration, and ease of fabrication. In addition, FGC provides the capability to control the cut-off frequencies of the higher order modes and thus allows for higher operating frequencies. The result of this ability is the elimination of the parasitic parallel plate mode and the reduction of parasitic loss. Further advantages of this line are provided by the finite size of the grounds and the capability to change their size in order to control line performance. Specifically, the width of the ground planes is chosen so that the lateral size of the structure is much less than half of the lowest wavelength of interest. This increases the cut-off frequency of the higher order mode and eliminates the need for via holes when back-size metallization is present. Furthermore, in this structure wafer thickness is not critical to performance and wafer thinning is not required.

Several finite ground coplanar circuits have been fabricated on 500 μm thick GaAs substrates. The lateral size L of the FGC line has been chosen equal to 460 μm thus pushing the cut-off frequency of the first higher order mode to 180 GHz. The back side of the wafer side is not metallized but is in contact with the metal chuck during measurements. Air bridges are used to keep the two coplanar grounds at the same potential but vias are not incorporated in the circuit as the potential of the two ground strips is intentionally floating. During the presented study, a variety of circuits were designed and measured. The results of this study for a few of these circuits will be presented herein.

A variety of similar structures of varying length were designed for each type of passive component desired. In most case there were four or five of such structures. The passive component was then placed at the calibration reference point on an equivalent thru line as the calibration standard. Air bridge structures were added where necessary to keep the grounds at the same potential. The LIBRA model utilized all the structures to find the effective dielectric constant, line shortening, attenuation, and impedance of the structure. With these parameters, design can be done with ideal lossy transmission line theory in LIBRA. As will be shown, the models describe the characteristics of the FGC line passive components very well.

Following design, the circuits are realized. The fabrication of these structures is very simple because it requires two basic steps. First the circuits are metallized, and then the air bridges placed. For this case, a 500 μm thick GaAs wafer and 1 μm of metal was used to produce the circuits. Later air bridges were formed. Backside processing such as wafer thinning, via etching, or even backside metallization is unnecessary.

Following the fabrication, S-parameter measurements are straight forward. The circuits include standards for network analyzer calibration. Using the designed TRL calibration set and the NIST software [5,6], a good calibration was obtained. The various circuits were measured with probes from 2 to 110 GHz (with a gap in the data from 40 to 50 GHz) using several test sets. The resulting S-parameter data was then investigated using LIBRA. The measured data on the lines shows very low loss. The loss was approximately 0.3 dB/wavelenth at 100 GHz. The loss as a function of wavelength shows the inverse square dependence common to conductor loss

4.0 Results

W-band detectors and multipliers are very important circuit components in millimeter-wave communications systems and sensors. The development of these active components require solid-state devices as well as passive elements such as stubs, filters, and diode mounting structures. It is these type of passive components that we investigate in this work.

4.1 Stub

The first example circuit is a balanced open stub. A photograph of the circuit is shown in figure 2. The slot- line-slot dimensions for the thru line are 45-50-45 μm and for the stubs are 20-20-20 μm. The finite grounds are 160 μm wide and the stubs are 1440 μm long. Measured and modeled data from LIBRA are compared in figure 4 and show excellent agreement. This agreement indicates the capability of the FGC lines to operate as ideal transmission lines and to excite an almost pure TEM mode as high as 110 GHz. The equivalent circuit consists of the thru section and a parallel combination of the two balanced stubs. The attenuation model parameter fit to the measured data indicates a line loss of 0.23 dB/mm at 20 GHz.

4.2 Low-Pass Filters

The next example is of the five section Butterworth filter shown in figure 3a. The slot-line-slot dimensions are 120-10-120 μm and 10-230-10 μm for the high impedance and low impedance sections respectively. The filter length is approximately 1 mm. The measured and fitted S_{11} and S_{21} data is shown in figure 5. The straight lines in the data between 40 and 50 GHz correspond to missing data. As can be seen, the measured insertion loss is below 0.5 dB up to 40 GHz.

The third example circuit is the five section Butterworth filter with length 0.6 mm shown in figure 3b. The measured and fitted S parameter data is shown in figure 6. With a cutoff frequency of approximately 80 GHz, the measured insertion loss is less than 0.5 dB to 60GHz. The insertion loss of these filters is comparable to the best available planar filters in W-band. [4]

5.0 Conclusions

The properties of FGC lines, stubs, and filters have been described. This line is a very low loss and easy to fabricate structure at millimeter-wave frequencies. Tuning stubs and low pass filters show both excellent performance and a good match to model performance predictions. These lines will provide a useful starting point for a variety of millimeter- and submillimeter-wave frequency components.

6.0 Acknowledgments

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7.0 References

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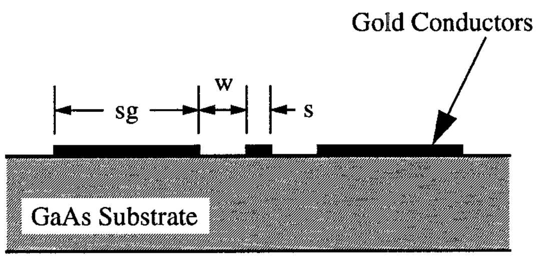

Fig. 1. Cross Section of a Finite Ground Coplanar (FGC) Line circuit.

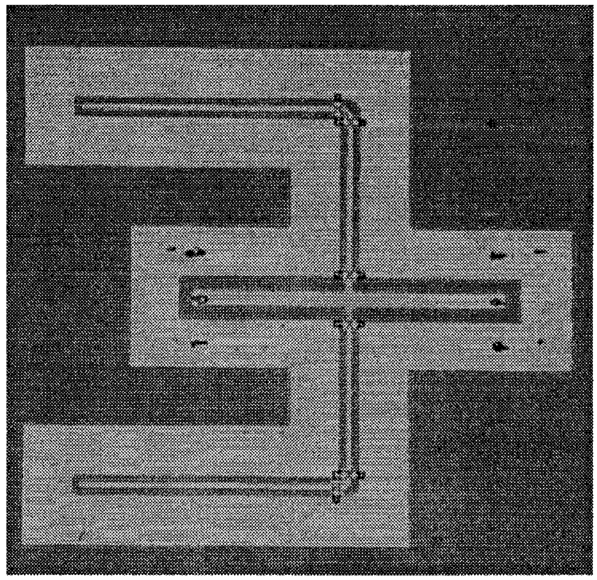

Fig. 2. Photograph of 1440 μm long balanced open stubs on a 1000 μm long FGC thru line.

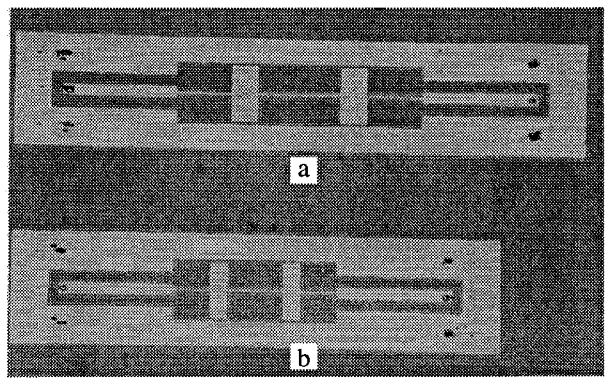

Fig. 3. Photograph of two 5-section Butterworth filters realized in Finite Ground Coplanar (FGC) lines: a) 1mm long, b) 0.6 mm long.

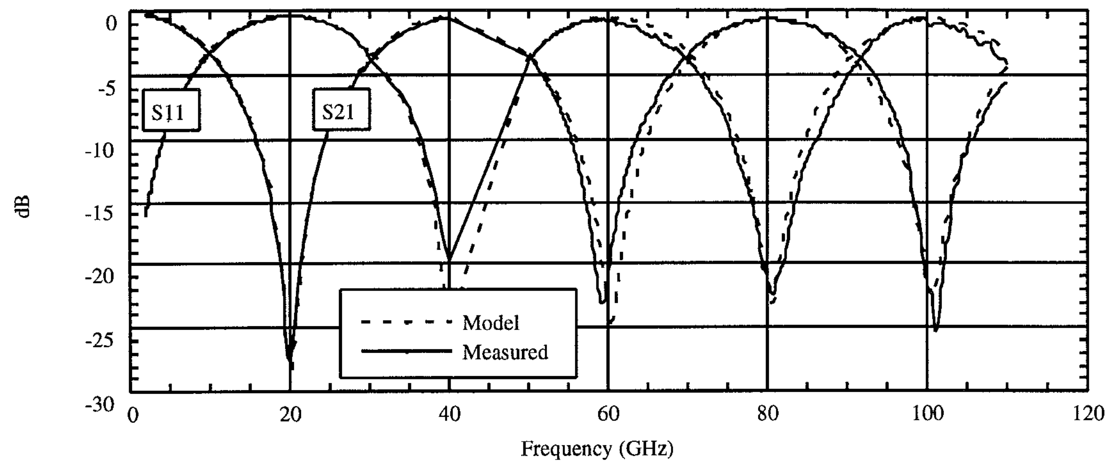

Fig. 4. Measured and Modeled S-parameter data for 1440 μm long balanced open stubs.

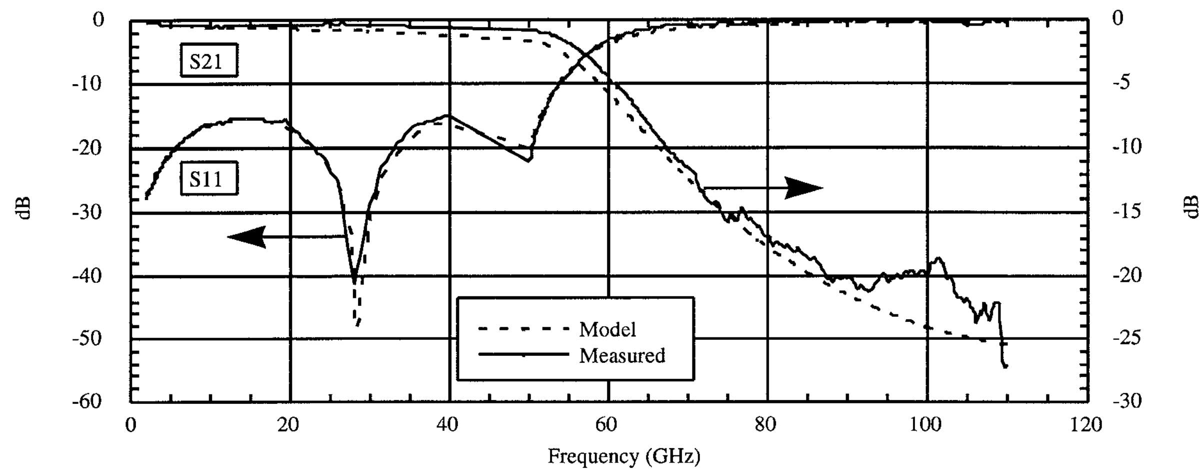

Fig. 5. Measured and Modeled S-parameter data for a 1 mm, 5 section Butterworth filter.

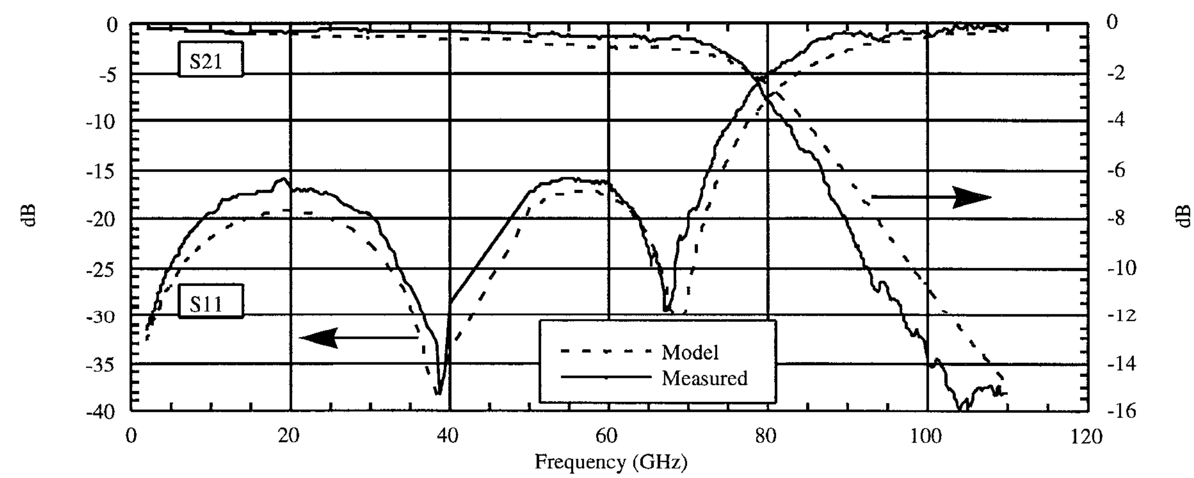

Fig. 6. Measured and Modeled S-parameter data for a 0.6 mm, 5 section Butterworth filter.