Coplanar Stripline Propagation Characteristics and Bandpass Filter

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***Abstract*—In this paper, a coplanar stripline bandpass filter is developed. The propagation characteristics of the coplanar stripline used for the construction of the filter are presented in the form of phase constant and attenuation constant. The filter is characterized experimentally as well as theoretically by use of the finite-difference time-domain (FDTD) technique. The agreement between the measured and modeled filter characteristics is very good.**

I. Introduction

Coplanar stripline (CPS) [1] as a transmission medium with the capability to provide uniplanar designs was introduced in the mid 1970's. It is well known that CPS lines make efficient use of the wafer area, have the capability to sustain back metallization without exciting parasitic modes within the range of the operating frequency and to simplify heat sinking and packaging in high-power applications (CPS power amplifiers). Extensive work on CPS lines in the recent past [2]–[4] has shown that CPS has the capability to provide excellent propagation characteristics and small discontinuity parasitics when appropriately designed. Recent studies of several CPS discontinuities have shown that CPS lines can find applicability to wireless communications through low-cost uniplanar microwave circuits such as filters, mixers, and antennas [2], [4]. Based on these results, CPS bandstop filters have been designed and characterized and these filters have demonstrated many advantages.

CPS filters have several unique features and advantages. Their uniplanar construction allows ease of fabrication. Also, these filters use series resonating elements which are fabricated within the 50-Ω strip conductors and, hence, are extremely compact when compared to microstrip filters. In addition, they do not require bond wires and air bridges to suppress higher order modes at discontinuities, resulting in simpler design when compared to conventional coplanar waveguide (CPW) filters.

This work presents a study of the dispersion characteristics of the CPS line along with its attenuation as a function of frequency. In addition, a CPS bandpass filter has been designed and fabricated, and its performance has been characterized both experimentally as well as numerically by FDTD simulation for performance verification.

Manuscript received February 17, 1997. This work was supported by the office of Naval Research.

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Publisher Item Identifier S 1051-8207(97)05424-X.

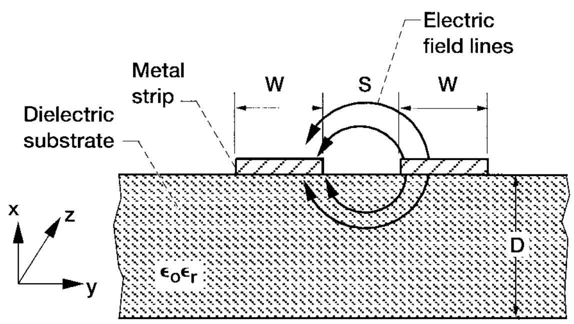

Fig. 1. Cross section of CPS.

II. Theoretical and Experimental Characterization

The coplanar stripline is supported by a dielectric substrate of relative permittivity ϵ_r and thickness D, as shown in Fig. 1. In a CPS [1], the electric lines extend from the edges of the strip conductors of width W across the slot of width S and remain strongly bound to the aperture between the two adjacent strips. As a result, the lines exhibit characteristics which are rather insensitive to the substrate thickness and presence of metallization on the other side of the substrate. Below, theoretical and experimental results for wave propagation characteristics in CPS lines and a CPS BP filter are presented and discussed extensively.

A. Measurement/De-Embedding Technique

All the measurements have been performed with the 8510 network analyzer using a set of CPS TRL on-wafer standards. The calibration standards consist of a CPS Thru, a CPS short circuit, and a CPS delay line and is performed using National Institute of Standards and Technology (NIST), a de-embedding software program [5]. This program solves a 12-term error model from the thru-line two-port measurements, the delay line two-port measurements, and the two one-port reflection measurements. The program then establishes electrical reference planes to which all de-embedded S-parameters are referred. In addition, it provides, the attenuation constant α. In order to suppress spurious modes, the CPS substrate is stacked on top with a 0.031-in-thick ($\epsilon_r = 2.2$) RT/Duroid 5880 and a 0.25-in-thick microwave absorber.

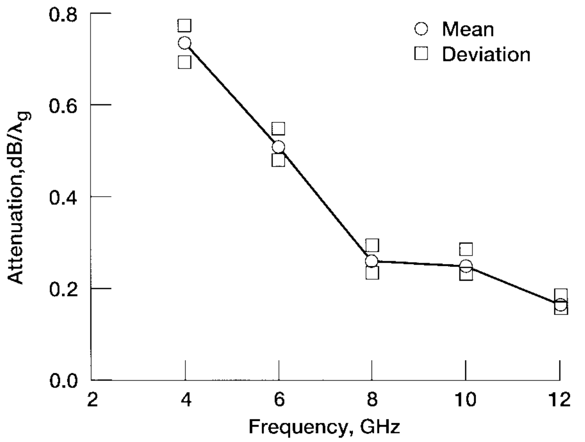

Fig. 2. CPS measured attenuation.

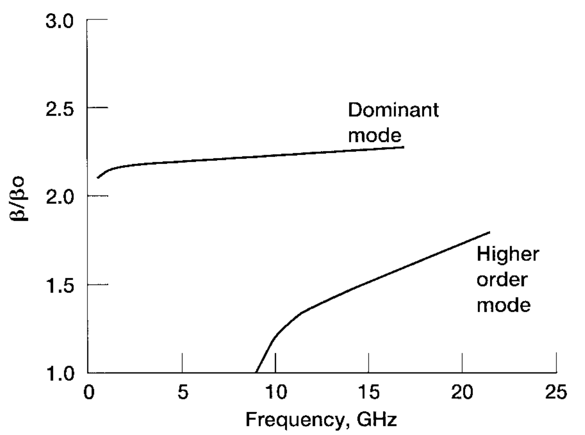

Fig. 3. CPS computed dispersion and higher order mode.

B. Theoretical Modeling

As mentioned above, the modeling was performed using the FDTD method, which is based on expressing Maxwell's curl equations in discretized space and time domains. In order to characterize a planar discontinuity, propagation of a specific time-dependent function is simulated using FDTD technique. In characterizing the filter mentioned above, a Gaussian pulse is used. The space steps Δx, Δy, and Δz are carefully chosen such that integral numbers of them can approximate the dimensions of the structure. In order to minimize the truncation and grid dispersion errors, the maximum step size is chosen to be less than 1/20 of the smallest wavelength in the computational domain. The Courant stability criterion is used to select the time step to ensure numerical stability. The values for Δx, Δy, Δz, and the time step Δt used for modeling the bandpass filter here are 127.0, 101.6, and 203.2 μm and 0.23 ps, respectively. The front and back planes of the FDTD mesh are terminated using super-absorbing first-order Mur boundary condition [6]. All the other walls are terminated using the first-order Mur boundary condition [7]. The circuit dimensions indicated in the following sections are the actual dimensions after fabrication. However, while performing the FDTD analysis, the exact fabricated dimensions could not be incorporated due to limitations in the uniform discretization adopted in the modeling.

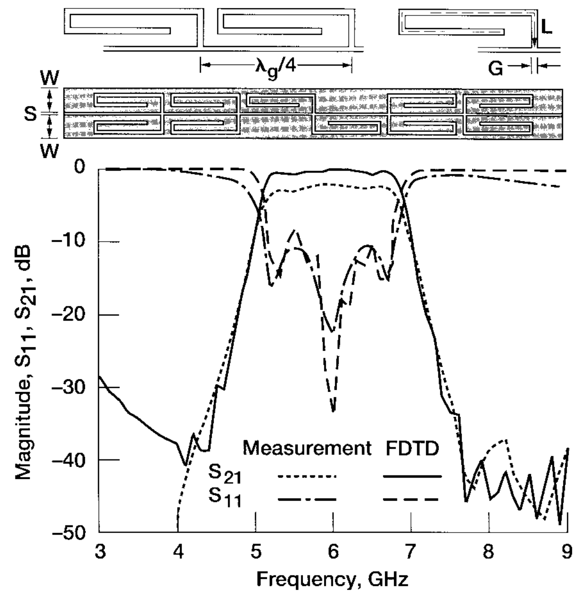

Fig. 4. CPS bandpass filter—geometry and measured/modeled characteristics.

III. Results and Discussion

In the following sections, measured results are shown for the attenuation constant of a CPS line as a function of frequency along with theoretically predicted dispersion and higher order mode characteristics. Also, the measured/FDTD-modeled characterization of a CPS bandpass filter is presented and compared.

A. Measured (De-Embedded) Attenuation

The attenuation α is de-embedded for CPS lines fabricated on RT/Duroid 6010 substrate of thickness $D = 0.03$ in and $\epsilon_r = 10.2$ with 1/2-oz. copper. Measurements are performed on CPS lines with a fixed strip width W $(= 0.065$ in) and slot width S varying from 0.0025 to 0.005 in in steps of 0.0005 in. This includes a 50-Ω CPS line with $W = 0.065$ in and $S = 0.004$ in. Fig. 2 shows the measured attenuation as a function of frequency for the above mentioned set of CPS lines. From the figure, we see that α varies from 0.735 dB/λ_g at 4 GHz to about 0.164 dB/λ_g at 12 GHz. The repeatability of the measurements are within 0.015 dB/λ_g at 4 GHz and 0.093 dB/λ_g at 12 GHz.

B. FDTD-Modeled Dispersion and Higher Order Modes

Fig. 3 shows a plot of the normalized propagation constant β/β_o as a function of frequency obtained using two-dimensional (2-D) FDTD technique for a CPS line with $D = 0.03$ in, $W = 0.065$ in, $S = 0.004$ in, and $\epsilon_r = 10.2$. It is noticed that the dispersion is almost linear up to 9.0 GHz with no higher modes. Onset of higher order modes begins at around 9.0-GHz frequency. This has been confirmed by measuring the S parameters. Measurements on a through line with $W = 0.025$ in, $S = 0.004$ in, $D = 0.01$ in, and $\epsilon_r = 10.5$ have shown that there is no onset of higher order modes up to 40 GHz. Smaller line dimensions and thinner substrates can push the cutoff frequency to higher frequencies thus extending the operating range.

C. CPS Bandpass Filter

The schematic of a CPS bandpass (BP) filter is shown in Fig. 4. The filter consists of five sets of series stubs spaced $0.25\lambda_g$ apart where λ_g is the guide wavelength in the CPS at the center frequency f_o of the bandpass filter. The BP filter was fabricated on an RT/Duroid 6010 substrate of thickness 0.03 in and $\epsilon_r = 10.2$. The design guidelines for the circuit elements of the bandpass filter are summarized as follows: $L = 0.5\lambda_g$, $W = 0.070$ in, $S = 0.0035$ in, $G = 0.008$ in.

The measured and FDTD-modeled insertion loss (S_{21}) and return loss (S_{11}) of the BP filter are shown in Fig. 4. The filter exhibits excellent characteristics. Discrepancies between the measured and FDTD-modeled results for the filter is attributed to the zero-loss assumption incorporated in the FDTD models, in addition to coarse FDTD gridding. It has been observed that the bandpass characteristics repeat at center frequencies where the stub length becomes even multiples of quarter guide wavelength $0.25\lambda_g$ as expected. Also, at frequencies where the stub length becomes odd multiples of quarter guide wavelength $0.25\lambda_g$, low-pass characteristics are observed.

IV. Conclusion

The coplanar stripline as a transmission medium holds a great deal of potential in the emerging wireless communications industry and in the design of low-cost uniplanar microwave circuits such as filters, mixers, and antennas. In view of these advantages, a CPS Bandpass filter has been modeled and its performance has been characterized both experimentally and theoretically. In addition, CPS characteristics such as attenuation, dispersion, and higher order modes have been studied. It has been found that CPS has excellent propagation characteristics with linear dispersion. Onset of higher order modes is at the higher end of the frequency range of interest, thereby making CPS an ideal choice for the type of applications described herein.

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