An Experimental and Theoretical Comparison of the Electric Fields Above a Coupled Line Bandpass Filter

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Abstract

We present an experimental and theoretical comparison of the tangential electric fields within 100 μm above a three stage coupled line bandpass filter (8.0 GHz-10.5 GHz). Using the experimental technique of modulated scattering, complete electric field intensity images of the tangential electric field components are displayed and compared with the calculated electric fields obtained through the finite difference time domain (FDTD) method in both the passband (10 GHz) and the rejection band of the filter (12 GHz).

Introduction

Knowledge of the electric field intensity and phase over a microwave circuit is extremely useful in directly identifying microwave circuit problems such as the existence of substrate modes, circuit radiation, device to device coupling as well as giving important information about the propagation constants of transmission lines used. With tighter control over line lengths and losses that may be derived from electric field intensity and phase maps, it may be possible to reduce the number of iterations during the design of microwave monolithic integrated circuits (MMIC) and multi-chip modules (MCM). Also, with a map of the electric field intensity above the substrate it would be possible to define low electric field regions around a device that could be used for placement of more circuitry, thus saving valuable chip real-estate.

A convenient technique for measuring the near electric fields around horn antennas, called modulated scattering, was developed by several groups in 1955 (Richmond [1], Cullen and Parr [2], and Justice and Rumsey [3]). In this technique, a small dipole with a diode mounted at the center of the dipole arms is placed in the near field of an antenna or circuit of interest. By modulating the bias of the diode at a frequency much lower than the radio frequency (RF), a modulated scattered RF signal would return to the transmitter [1]. The strength and phase of this modulated signal are directly proportional to the electric field intercepted at the position of the dipole probe [1] and can be detected by the transmitter through the use of a directional coupler and a quadrature mixer.

Recently, Zürcher expanded this technique to map the tangential near fields over microstrip circuits (patch antennas and hybrid couplers) at frequencies centered around 1.8 GHz [4, 5]. By passing an electrically small dipole or monopole probe over a device under test (DUT), a small scattered signal will return to the input port. This signal is directly proportional to the strength of the electric field intercepted by the probe in both polarization and phase. An improved electric field imaging system has been developed at The University of Michigan by Budka and Rebeiz [7]. The system currently operates from 0.5 GHz to 18 GHz. This system is extremely useful for MMIC diagnostics because it can be used to simultaneously detect normal and tangential electric fields and the net electrical phase delay within a microwave circuit.

Experiment

Figure 1 displays the geometry of a three stage coupled line filter fabricated on Rogers Corporation RT/Duroid® (ε_r=10.8, h=635 μm). The edges of the microstrip lines were moved from their optimal positions so that they would be aligned with a grid that would facilitate computer simulations of the filter.

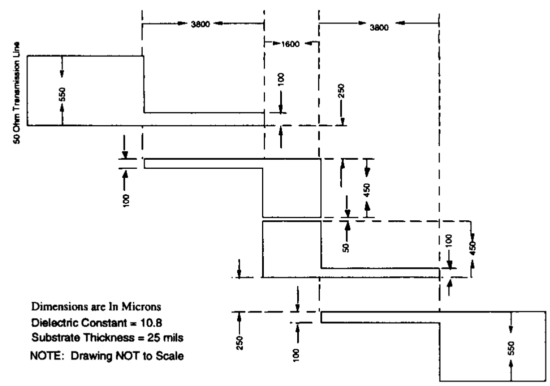

Figure 1. The geometry of the three stage coupled line bandpass filter used in this study.

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The bandpass filter has a measured insertion loss of 2.0 dB in the passband from 8.0 GHz to 10.5 GHz and provides better than -25 dB rejection at 12 GHz. Figure 2 displays the measured and FDTD calculated S-parameters of this filter. The plot shows that good agreement is achieved between measurements and FDTD calculations. The calculated and measured transmission coefficient match very well down to -40 dB, but the reflection coefficients deviate from each other in the passband. This deviation is most likely due to imperfect SMA to microstrip transitions at the input and output of the filter beyond 10 GHz.

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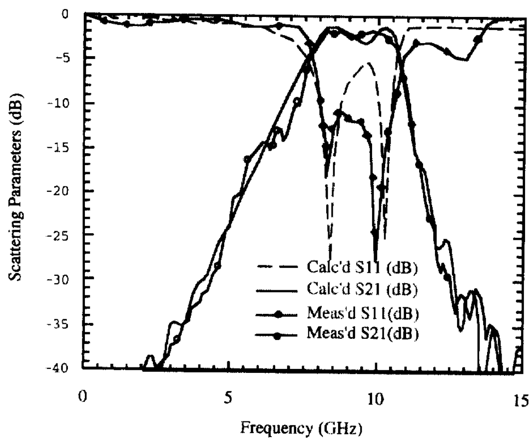

Figure 2. The measured and calculated (FDTD) scattering parameters for the three stage coupled line bandpass filter. The passband is from 8.0 GHz to 10.5 GHz with an insertion loss of 2.0 dB.

Application of the FDTD Method

For a theoretical analysis of the coupled line filter, the FDTD method [8] is employed. The first step is to define a problem space of reasonable dimensions for computation. For this case, the space increments of the Yee's mesh are chosen to be 52.9 µm for the vertical direction, 100 µm for the propagation direction and 25 µm for the direction normal to propagation. The time step is chosen to be 73 fsec to satisfy the Courant stability criterion. These choices result in a structure with 140x234x448 cells. The first-order Mur's absorbing boundary condition [9] is applied to the boundaries of the problem space with superabsorbers [10] at the input and output planes.

For wideband S-parameter extraction, a Gaussian pulse of 100 psec is used as the source microstrip excitation. Two simulations of pulse propagation along the microstrip line are made: one simulation for the filter and a second simulation for a 50 Ω microstrip through-line. For the filter simulation, the sum of the incident and reflected waveforms is calculated and for the through-line, the incident waveform is calculated. The reflected waveform at the input port is found by subtracting the incident waveform of the throughline from the total waveform of the filter. The reflection coefficient, S_{11}, is given by the ratio of the Fourier transforms of the reflected and the incident waveforms. The transmission coefficient, S_{21}, is given by the ratio of the Fourier transforms of the transmitted and the incident waveforms. The waveforms are probed at distances far enough from the filter discontinuities to eliminate the effects of evanescent waves.

For the electric field calculation to compare with the experimental results, sinusoidal waves of 10 GHz for the passband and 12 GHz for the rejection band calculations are used as microstrip excitations. The excitations are vertical and are matched to the feedline (total impedance of the source region equal to the characteristic impedance of the feedline - 50 Ω). The source is applied 5 meshes inside the feedline in the propagation direction and the values of the electric fields are calculated during the 6th period of the sinusoidal waveform, to avoid the transition-period effect.

Measurements

Figure 3 displays tangential electric field images obtained from modulated scattering measurements (fig. 3a.) and calculations (fig. 3b). A 100 µm long dipole probe was scanned across an area of 12750 µm by 3750 µm over the filter with the dipole oriented in the direction of propagation. Over the large scan area, the height of the probe above the filter varied from 50 µm to 100 µm due to bowing of the substrate and alignment errors. From studies of the decay of the electric field intensity with height, the error introduced by a height misalignment of 100 µm can be at most 4 dB. Tighter alignment is possible with planar semiconductor substrates and with tests over smaller areas.

The calculated electric field images presented were smoothed over a 400 µm by 200 µm region centered around the dipole where the smaller dimension is in the direction of the dipole arms. It was empirically determined that the 100 µm long dipole coupled to this region by comparing results from different smoothing operations over larger and smaller areas. This spatial averaging is the expected response for a dipole of finite length and finite height above the filter. More work will be performed in support of this calculation and results will be presented at the conference.

In figures 3a and 3b the input and output levels of the electric field intensity around the microstrip feeds are both -20 dB of the peak tangential electric field intensity within the filter. Both figures also predict a tangential electric field null halfway along each stage of the coupled line filter and display null regions of the tangential electric field within the substrate. The calculated electric field image predicts some small side peaks at the input and output and at the center which were not seen in the modulated scattering measurements. One possibility for this discrepancy may be due to the effects of metal loss which were not taken into account in the theoretical model. This would tend to reduce the peaks in areas where there is weak coupling between adjacent microstrip lines such as at the input and output microstrip lines on the side away from the first and last stage of the filter.

Figures 4a and 4b display the electric field intensity over the same region but in the rejection band of the filter at 12 GHz. The images have similar features but differ for mainly two reasons. Because the FDTD calculations do not include the effects of finite conductivity of the copper, we expect larger peaks in the calculated electric field image than with the measured image. Also, because the modulated scattered signal must travel from the point of interest back to the input port, there is an additional loss of the RF signal for points nearer the output port when compared with points closer to the input port. Therefore, areas of the circuit furthest away from the input port with the modulated scattering experiment will appear much less intense than areas closest to the input port.

Conclusions

In this paper a comparison of the operation of a three stage coupled line bandpass filter has been presented. First, the use of the

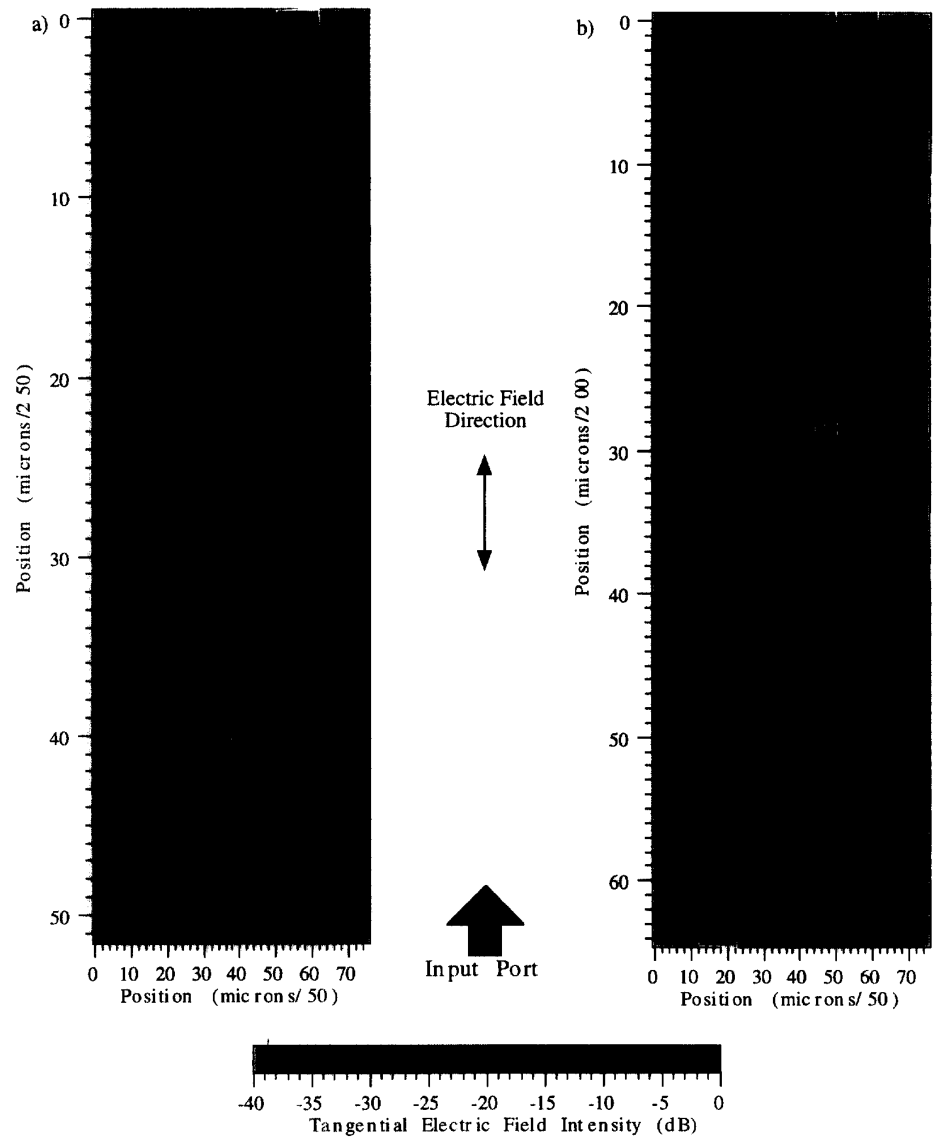

Figure 3. Tangential electric field intensity images above a three stage coupled line filter in the passband at 10 GHz. a) Experimentally measured with the modulated scattering technique. b) theoretically calculated with the FDTD technique.

FDTD method was verified by observing good agreement between the calculated S-parameters and the measured S-parameters of the filter. Next, the tangential electric fields obtained from the two methods at 10 GHz and at 12 GHz were compared. Peak electric field locations, relative intensity values and evanescent fields can be detected with both methods, thus making the modulated scattering and FDTD techniques valuable tools for the study of the operation of microwave circuits.

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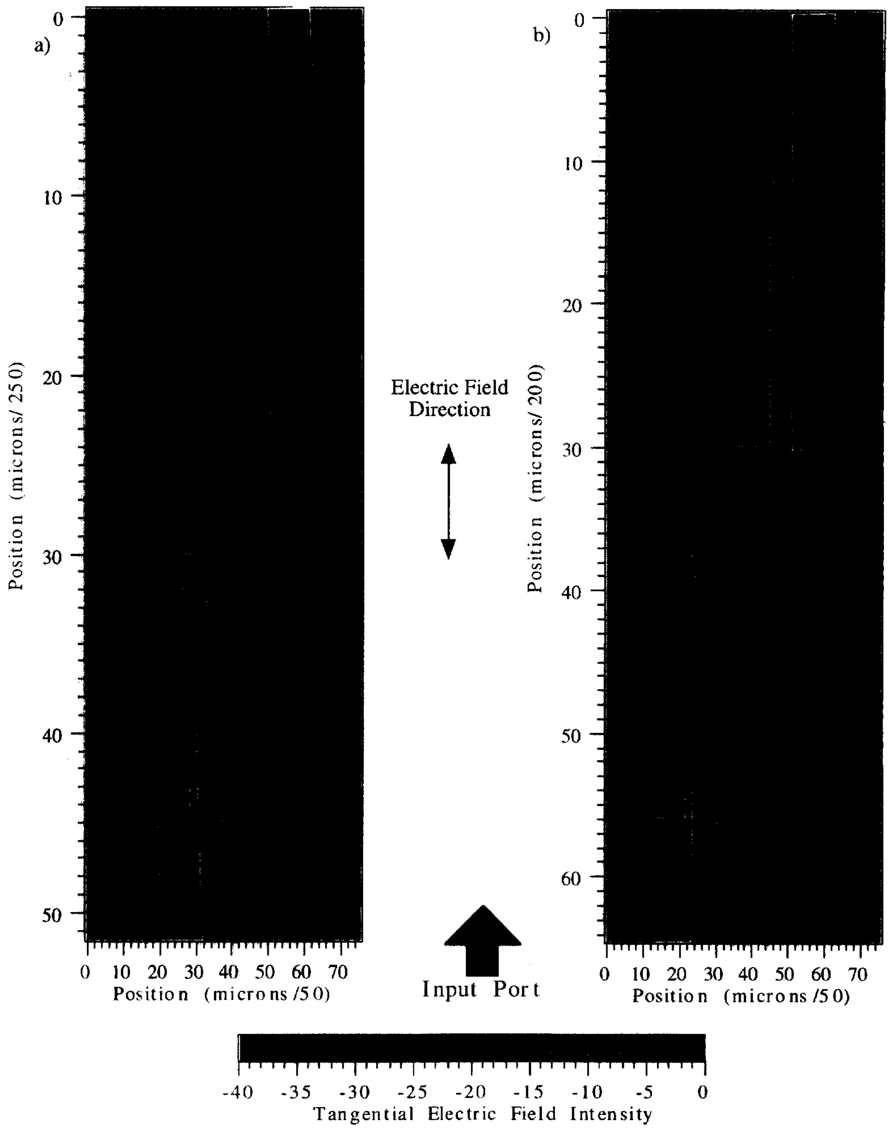

Figure 4. Tangential electric field intensity images above a three stage coupled line filter in the rejection band at 12 GHz (-25 dB transmission). a) Experimentally measured with the modulated scattering technique. b) theoretically calculated with the FDTD technique.

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