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Microstrip - Slotline Transitions: Simulation Versus Experiment

Matthew M. Radmanesh
Bradford W. Arnold
Electrical and Computer Engineering Department
California State University, Northridge

I. Introduction

The slot line introduced in 1969 is an alternate transmission line for application in microwave and millimeter wave circuits [1]-[4]. Slot line consists of a narrow slot or gap in a thin conductive layer on one side of a dielectric substrate. This configuration offers a planar geometry and a TE dominant mode, similar to a rectangular waveguide. Unlike waveguides, slot line has no cutoff frequency and propagation along the slot occurs at all frequencies down to D.C. The basic electrical parameters of slot lines are the characteristic impedance (Z_o) and phase velocity (V_p). Due to the non-TEM nature of slot line waves, these parameters are not constant but vary with frequency. This feature is in contrast with quasi - TEM wave propagation in microstrip lines, where Z_o and V_p are independent of frequency for the first order approximation [5]-[7].

A slot line on one side can be combined with microstrip lines on the other side of a dielectric substrate. When close to each other, coupling between the two types of lines will exist, and when sufficiently apart, they will be independent. Henceforth, slot line can be incorporated in microstrip circuits by etching slot line into the microstrip ground plane. This type of hybrid combination saves substrate area, enhances design flexibility, and lends itself to some novel circuits with improved performance.

In this paper, simulation as well as experimental verification of microstrip - slot line transitions, as shown in Figure 1, is investigated. A brief theoretical analysis and supporting formulation is discussed in Section II. Simulation results are obtained via EEsof's powerful microwave software "Touchstone/Libra" for microwave circuit design. Simulation results and experimental verification for several configurations have been carried out, and are presented in Section III. These experimental verifications are in good agreement with the simulation results and substantiate our theoretical analysis as presented in Section II. A summary and conclusions follow in Section IV.

II. Theoretical Analysis

When a microstrip line and a slot line of equal or near-equal characteristic impedances cross each other at right angles (and ideally extend a quarter wavelength beyond the crossing point), coupling between the two lines will be strong and a transition covering approximately 30% bandwidth can be achieved as reported in literature [8]-[10]. Our experimental findings (in the frequency range of 0.130 - 8.5 GHz) not only verified these results but actually achieved bandwidths better than 50%.

In the presence of uniform microstrip and slot lines and neglecting reactances due to discontinuities, the equivalent circuit of a single transition as shown in Figure 1 can be represented by the equivalent transmission line circuit of Figure 2. This equivalent circuit implies that perfect coupling between the microstrip and slot line currents takes place. Each transition is modeled by a) a series stub of length (lm), characteristic impedance (Zm), terminated in a load (Zlm), and b) a parallel stub of length (ls), characteristic impedance (Zs), and terminated in a load (Zls). The series and parallel stubs represent the microstrip and slot lines extending beyond the crossing point, respectively.

For the configuration of Figure 2, transmission coefficient (S_{21}) is of significant importance to our work, which can be obtained easily under simplified conditions. With the introduction of normalized impedance factors for the series and parallel stubs:

$$V = \frac{Zs}{50\Omega} \tag{1}$$

$$W = \frac{50\Omega}{Zm} \tag{2}$$

and assuming Zm = Zs = 50Ω, ßsls = ßmlm = ßl, Zlm = ∞, and Zls = 0, the magnitude of the transmission coefficient ($|S_{21}|$) becomes:

$$| S_{21} | = [1 + (\frac{1}{V} - \frac{1}{W})^2 \cdot \frac{\cot^2 \beta l}{4} + (\frac{\cot^2 \beta l}{2VW})^2]^{-\frac{1}{2}} \tag{3}$$

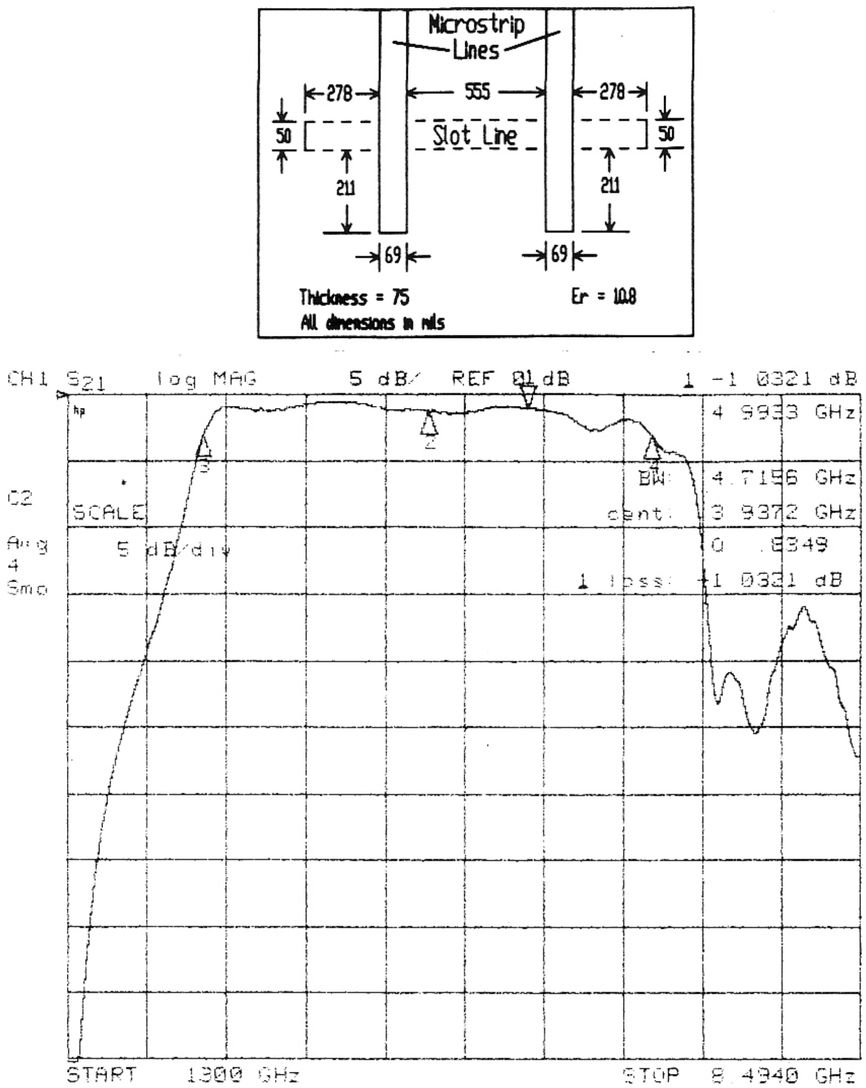
In order to obtain a useful configuration and one that can lend itself to frequency response measurements, a cascade of two generalized transitions separated by a slotline was considered (see Fig. 3). The equivalent circuit representation of this generalized double microstrip-slotline configuration is shown in Figure 4.

Simulation results and experimental work has been performed for this configuration and is presented in the next section. Good agreement between simulation results and experimental findings is observed which demonstrates the accuracy of our theoretical analysis.

III. Experimental Results

Simulation as well as experimental results were obtained for three different sets of parameters for the double microstrip-slotline configuration as shown in Figures 3 and 4. Circuit prototypes were designed and measured in the frequency range of 0.130 to 8.5 Ghz on dielectric substrates (6010 RT/Duroid, ϵr = 10.5 and h = 125 mils, ϵr = 10.8 and h = 75 mils). The microstrip dimensions were computed using EEsof's "LineCalc" software, while the slot line dimensions were computed from approximations found in the literature [11-12]. Simulation of the transitions was performed on a SUN Sparc II workstation using EEsof's "Touchstone/Libra" software. The

Figure 7b. Experimental Transmission Results - Configuration III



measurement setup consisted of a vector automatic network analyzer (HP8720 Series) working in the frequency range from 130 MHz to 8.5 GHz.

EEsof simulation results for the three circuit configurations are shown in Figures 5a, 6a, and 7a, while the experimental test results are shown in Figures 5b, 6b, and 7b, respectively. The physical dimensions of the circuits and substrate permittivities are provided as inset in each of the graphs for convenience. From these figures, it can be seen that these circuits function like a passband filter with the center frequency adjustable with the proper choice of different length parameters. Very good agreement is observed in the passband portion of the frequency response, and the difference between experimental and simulated results is found to be less than 1.0 dB overall. At frequencies outside the passband, the simulation results and experimental findings diverge and this difference increases with frequency.

IV. Conclusions

This experimental work has demonstrated that microstrip - slot line transitions can be successfully simulated with good accuracy using linear modeling techniques. The error between experimental and simulated results was found to be less than 1.0 dB near the design frequency. This 1.0 dB difference is attributable to the insertion loss of the dielectric in the passband, which is assumed to be nonexistent in the simulation process.

This approximate transmission line representation can be simulated on

"Touchstone/Libra" to obtain a "first-order-solution" with good accuracy. These results agree well with experimental results, making "Touchstone" simulations practically invaluable for microstrip-slotline design and analysis. Use of the EEsof's full set of software, in particular "Touchstone/Libra" and "LineCalc" proved to be of significant interest and provided a relatively accurate first order of approximation to a non-linear problem which is at best very difficult to solve rigorously.

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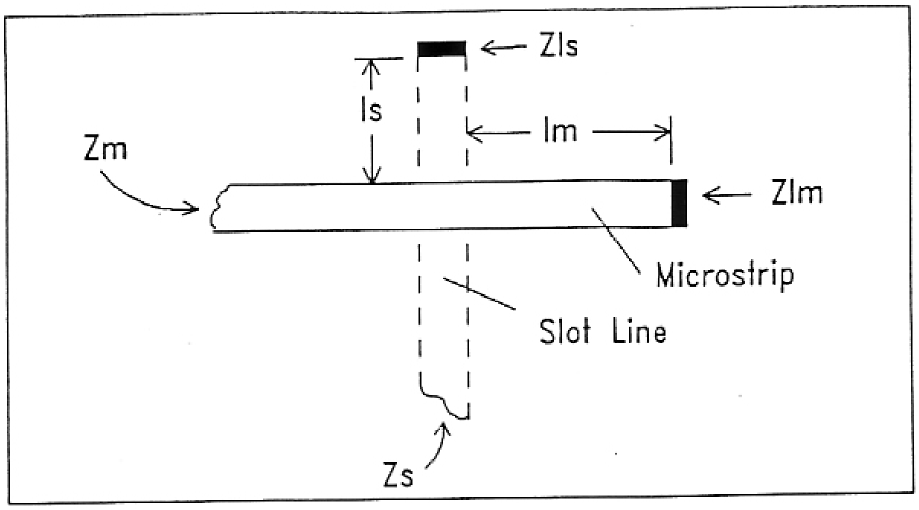

Figure 1. Physical Layout of a Single Generalized Microstrip–Slotline Transition

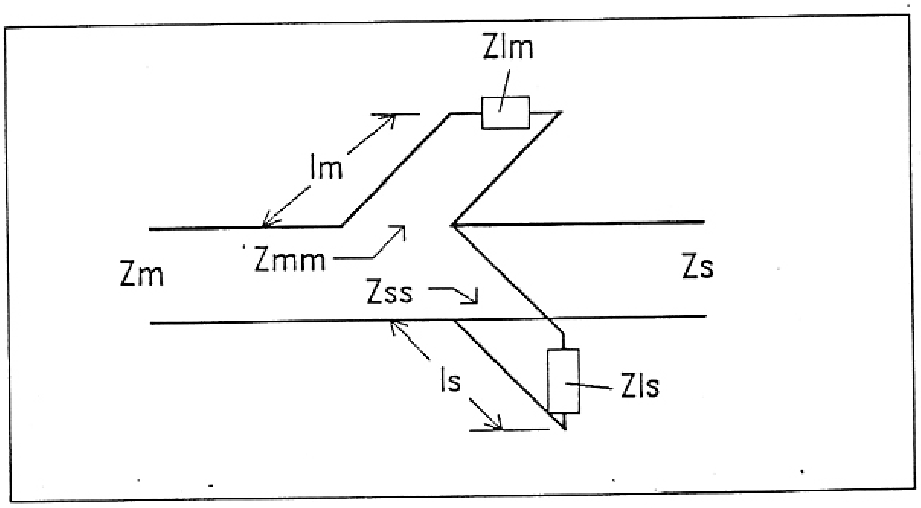

Figure 2. Equivalent Circuit of a Single Generalized Transition.

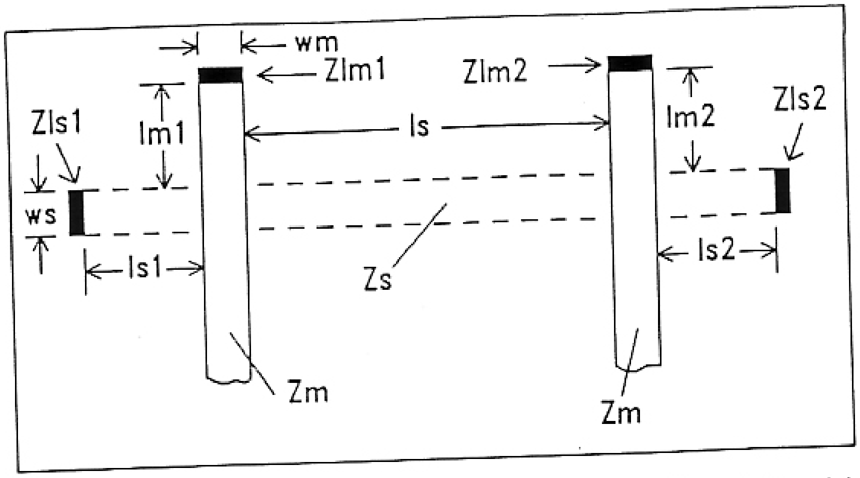

Figure 3. Physical Layout of a Generalized Double Microstrip–Slotline Transition

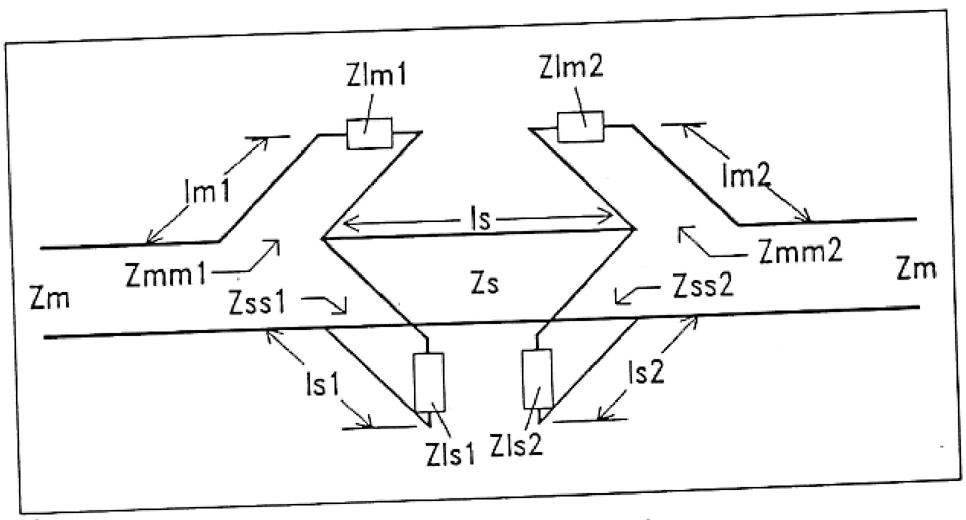

Figure 4. Equivalent Circuit of a Generalized Double Microstrip–Slotline Transition

Figure 5a. Simulated Transmission Results - Configuration I

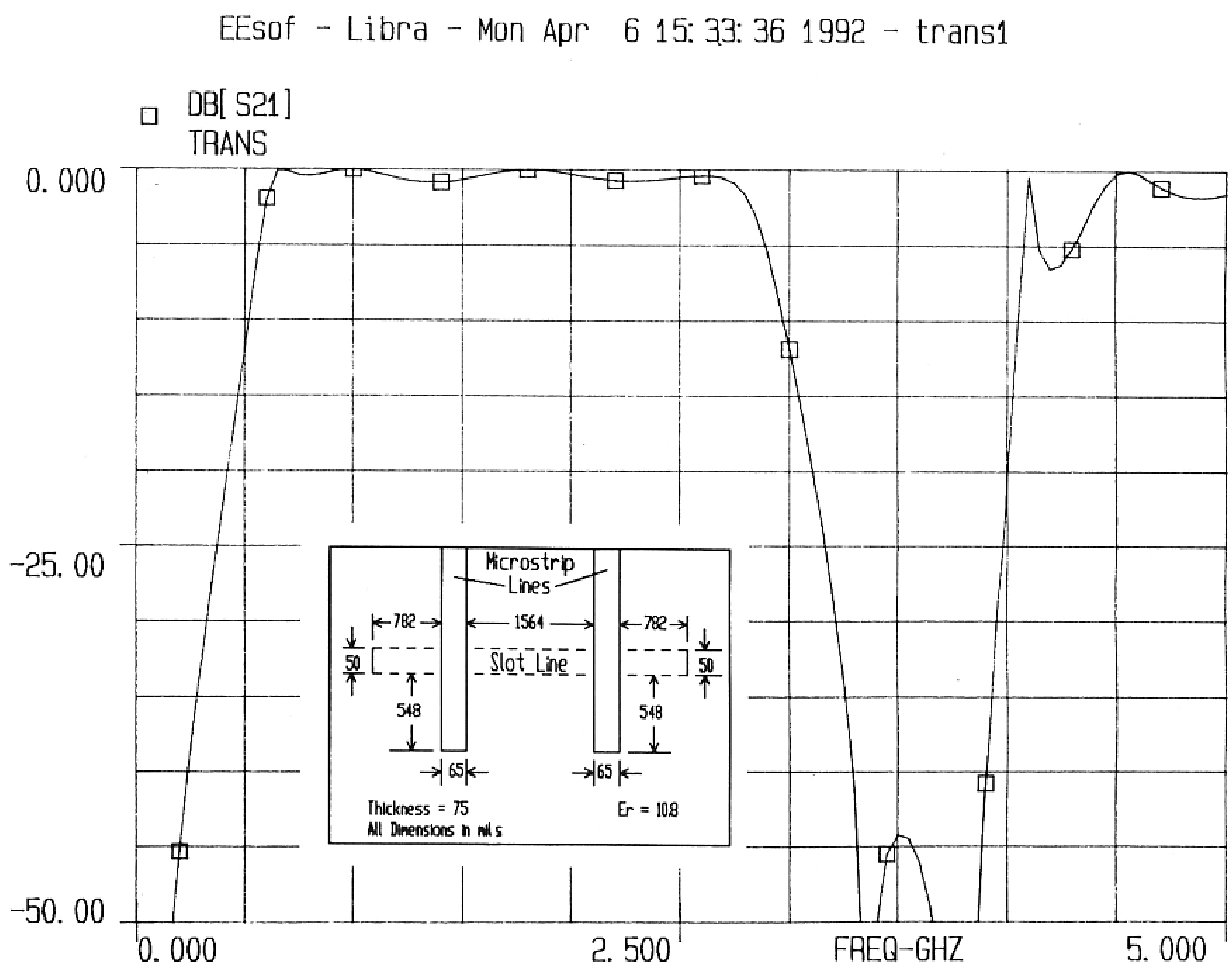

Figure 5b. Experimental Transmission Results - Configuration I

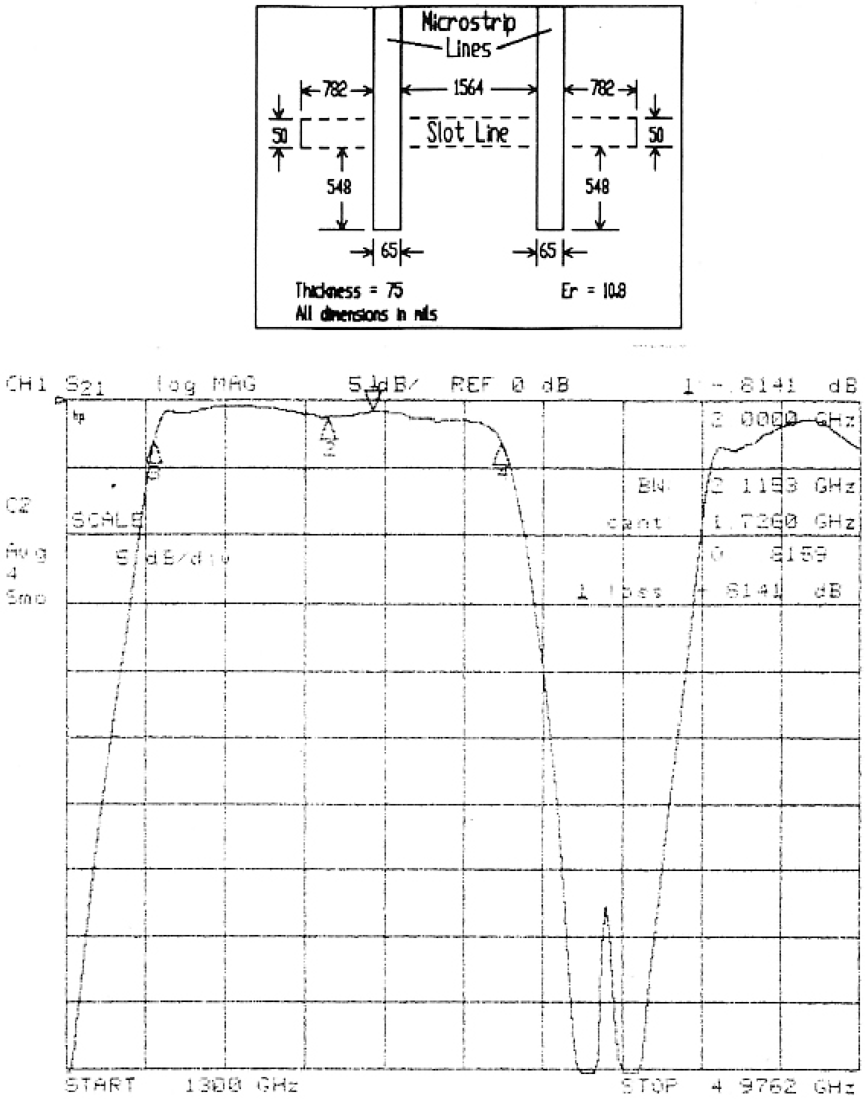

Figure 6a. Simulated Transmission Results - Configuration II

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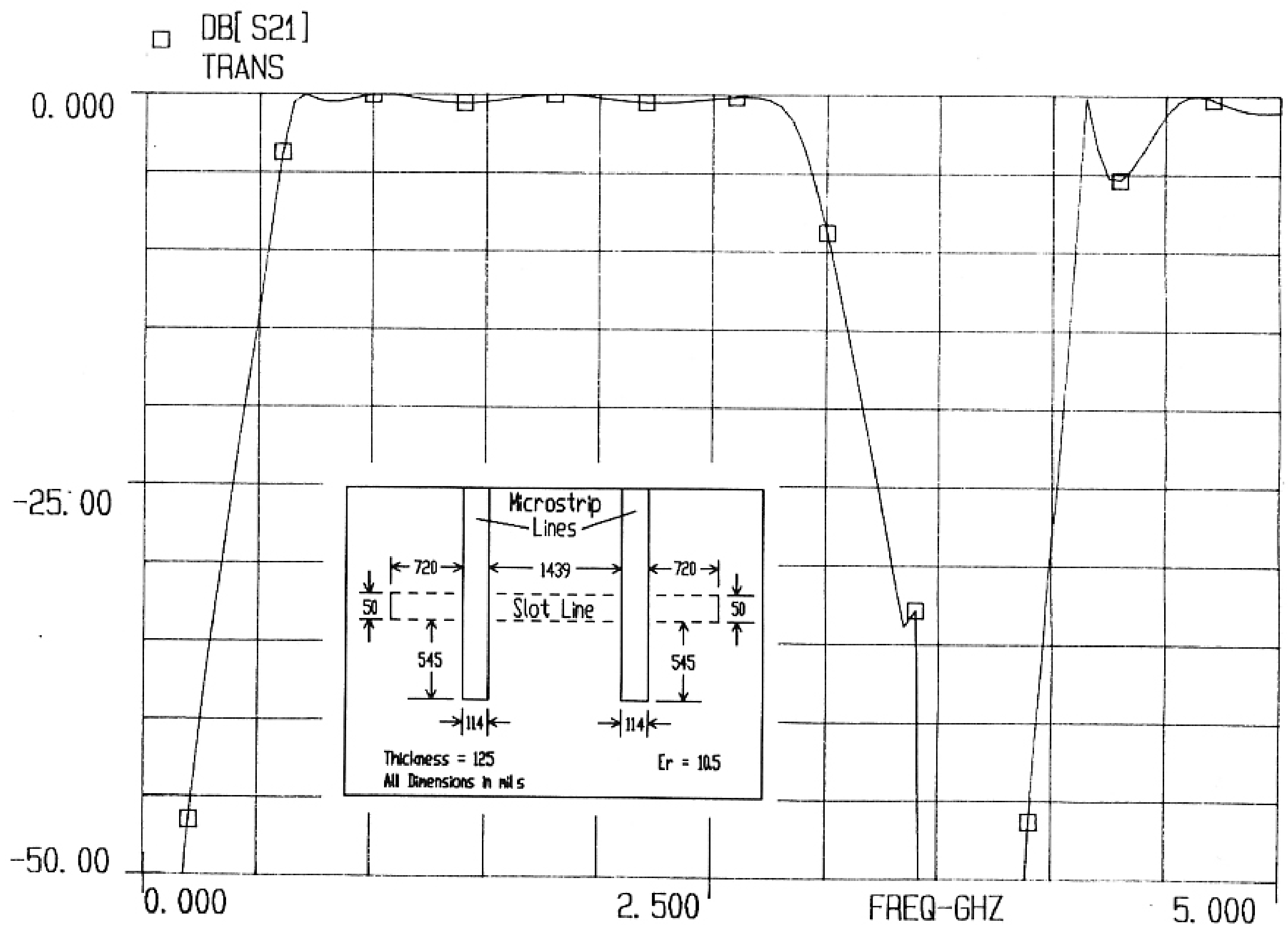

Figure 6b. Experimental Transmission Results - Configuration II

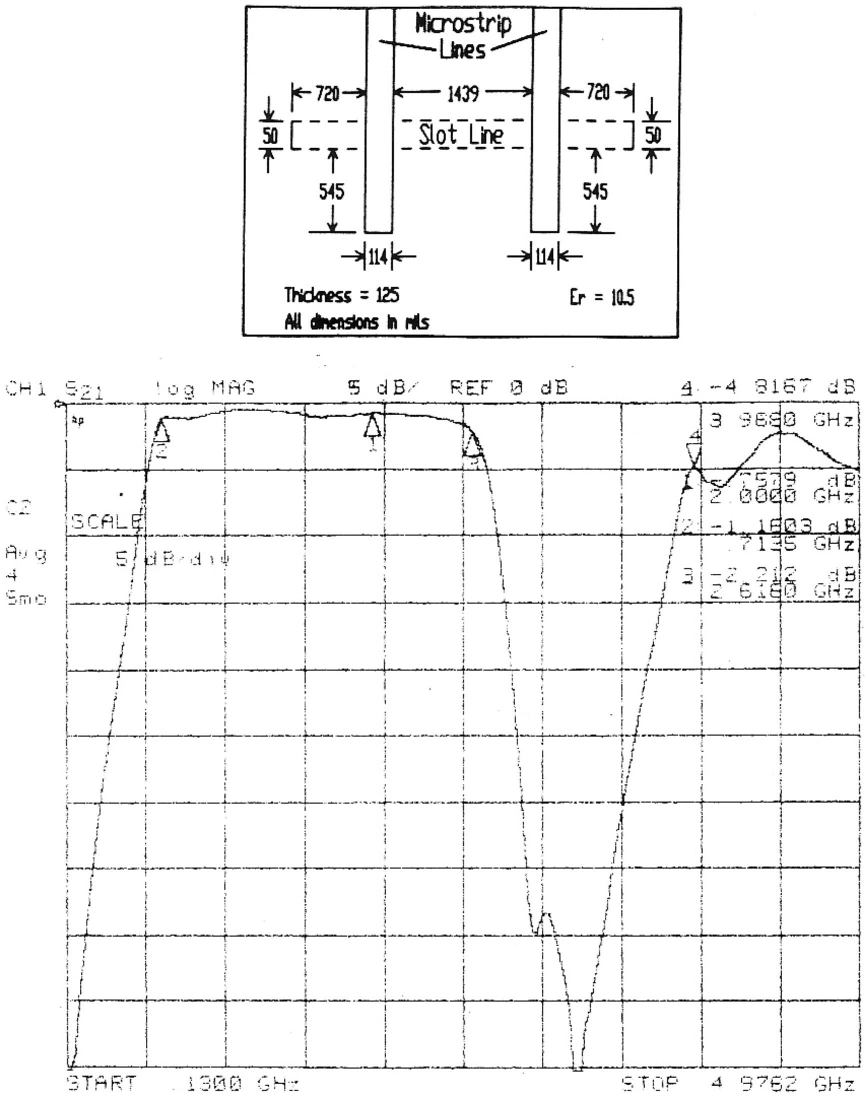

Figure 7a. **Simulated Transmission Results - Configuration III**