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SIMPLIFIED COMPUTER-AIDED DESIGN OF MICROSTRIP-SLOTLINE CIRCUITS

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ABSTRACT

A simplified design procedure for microstrip-slotline circuits is introduced. Based on a comparison between slotline characteristics obtained by a highly accurate numerical procedure and those calculated from functional approximations, an easy-to-handle transmission line model is used to analyse the different structures involved. Theoretical results of the microstrip-slotline transition as the integral element are found to be in reasonable agreement with measured data. The overall design is demonstrated at the example of a variable PIN diode microstrip-slotline attenuator.

I. INTRODUCTION

Microwave integrated circuits (MIC's) in microstrip-slotline technology have found widespread applications in miniturized mixers and phase shift keying (PSK) modulator circuits [1,2]. The structures combine the advantages of good coaxial interconnections via the microstrip line and the possible integration of semiconductor devices across the gap of the slotline. Since microstrip and slotline circuits usually are etched from opposite sides of a metallized substrate, a special coupling section (microstrip-slotline transition) can be used instead of manufacturing-intensive plated-through hole fabrication.

While sufficiently accurate models for microstrip computer-aided design are available [3,4], Cohn's slotline analysis method [5] suffers from relatively high CPU-time requirements. Functional approximations of Cohn's results [6,7], however, cover a wide range of practically required slotline characteristics and are found to be well suited for a simplified design procedure as is demonstrated in this paper at the example of a slotline quarter-wavelength transformer.

The microstrip-slotline transition forms the integral element in double-sided MIC design. Based on comparisons between a transmission line model and an accurate analysis method as presented in [8], simplified expressions have been used in [9,10] neglecting the influence of the substrate thickness and possible field distortions at the discontinuities involved.

Based on these results, this paper focuses on a simplified design of double-sided MIC components. The procedure is demonstrated at the example of a variable PIN diode attenuator (c.f. Fig. 1) utilizing measurements and equivalent circuit models given in [11,12] for the PIN diode. The theoretical design achieves broadband operation and continuously variable attenuation levels up to 80 dB.

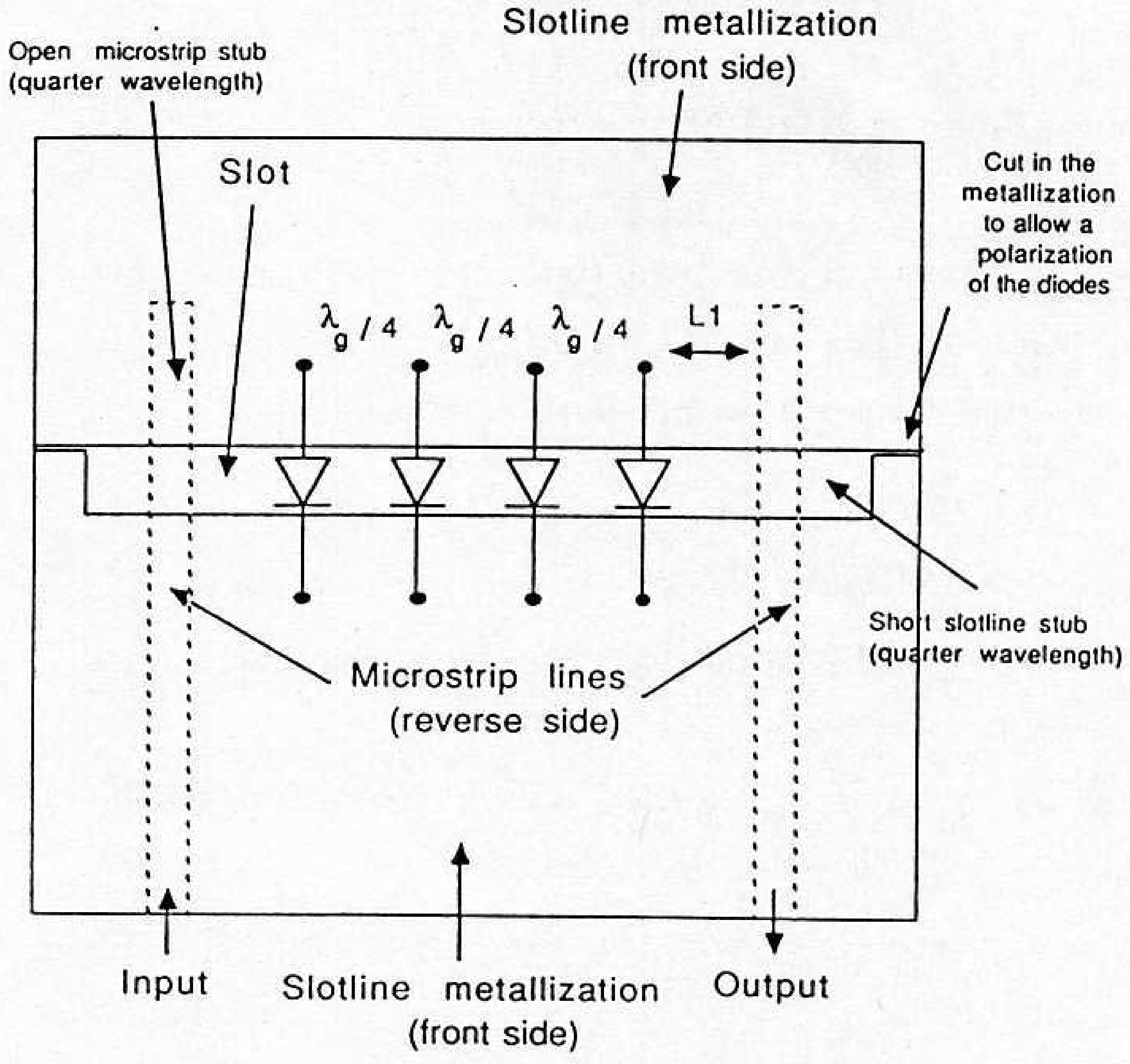

Fig. 1 Microwave PIN diode attenuator in microstrip-slotline technology.

II. THEORY

The simplified design presented here is based on transmission line theory involving the propagation constant and characteristic impedance for straight line sections. Microstrip parameters are calculated using the model presented in [3]. Although dispersion and open end effects have not been included so far, closed form expressions given in [4] may easily be implemented. Slotline characteristics are computed according to [6] (reprinted in [4]) in general, and according to [7] in the special case of the wide slotline on a low-permittivity substrate. These expressions include frequency-dependent terms since they are derived from functional approximations on data obtained from a finned waveguide model in [5].

The equivalent circuit of the microstrip-slotline transition [9] is shown in Fig. 2. Its ABCD matrix

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1+\frac{Z_1}{Z_2} & Z_1 \\ \frac{1}{Z_2} & 1 \end{pmatrix} \qquad (1)$$

is given in terms of the input impedances of the stubs

$$Z_1 = \frac{Z_m}{j\ tan(\beta_m \ell_m)} \qquad (2)$$

$$Z_2 = j\ Z_s tan(\beta_s \ell_s) \qquad (3)$$

where indices m,s correspond to the microstrip and slotline, respectively. The lengths l_m and l_s are usually designed for a quarter wavelength at midband frequency.

The PIN diodes in the microstrip-slotline attenuator are characterized by its high frequency equivalent circuit (Fig. 3). Since the ABCD matrix contains three zeros, only matrix element C need to be calculated.

$$C = \frac{1}{R_S}\ \frac{1 - w^2T_1T_2 + jw[T_1+T_2]}{1 - w^2T_3[T_1+T_2] + jw[T_1+T_3-w^2T_1T_4^2]} \qquad (4)$$

$$\text{with } T_1 = R_jC_j\ ,\ T_2 = R_sC_p \qquad (5)$$

$$\text{and } T_3 = L_p/R_s\ ,\ T_4 = \sqrt{L_pC_p} \qquad (6)$$

The overall ABCD matrix is obtained by multiplying the individual matrices involved and converting it to the scattering matrix using input and output port impedances for normalization. In case of the microstrip-slotline attenuator example, the distance L1 (c.f. Fig. 1) remains the only parameter which needs to be optimized, e.g., for constant attenuation over a desired frequency band.

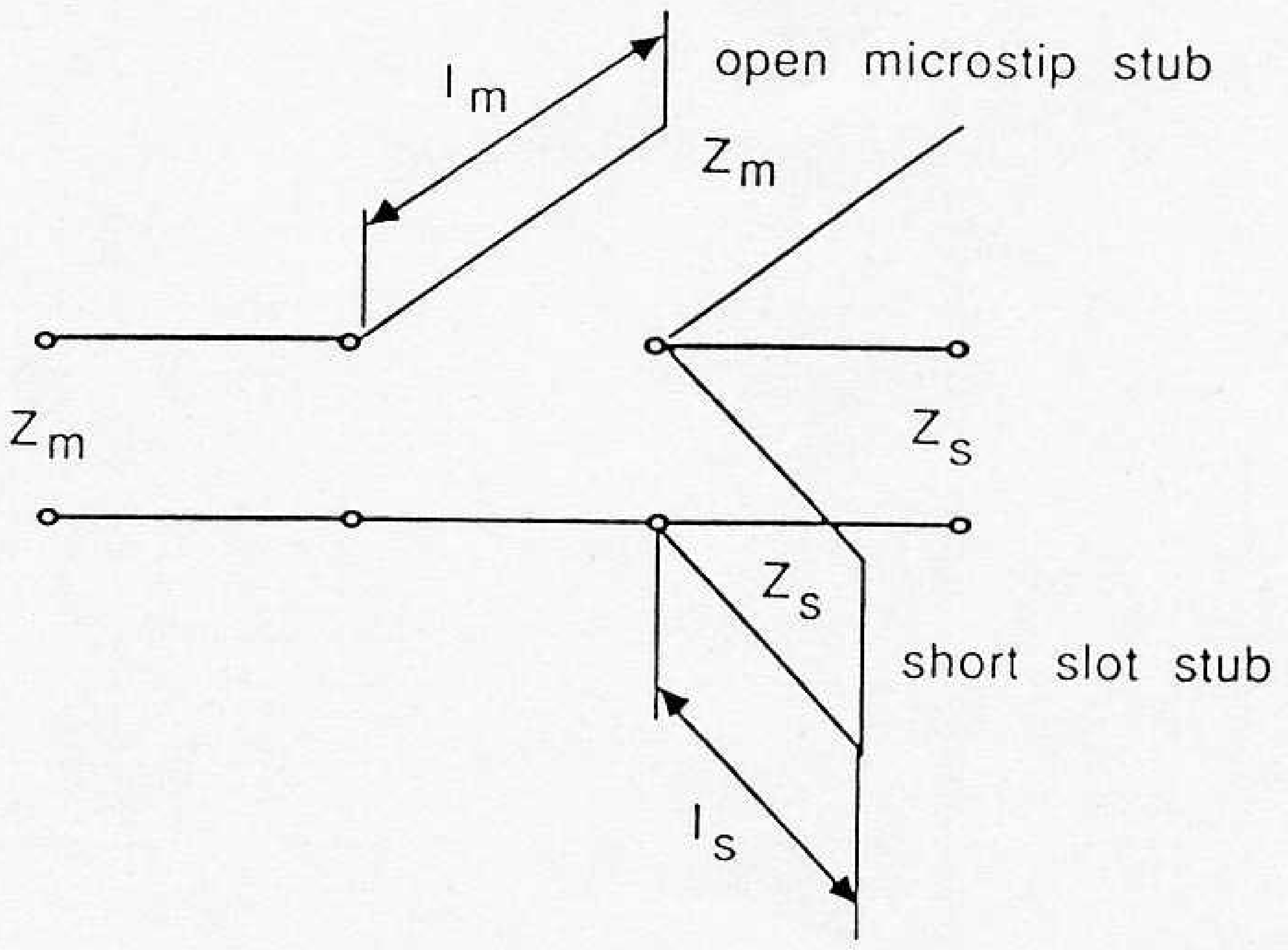

Fig. 2 Equivalent circuit of microstrip-slotline transition.

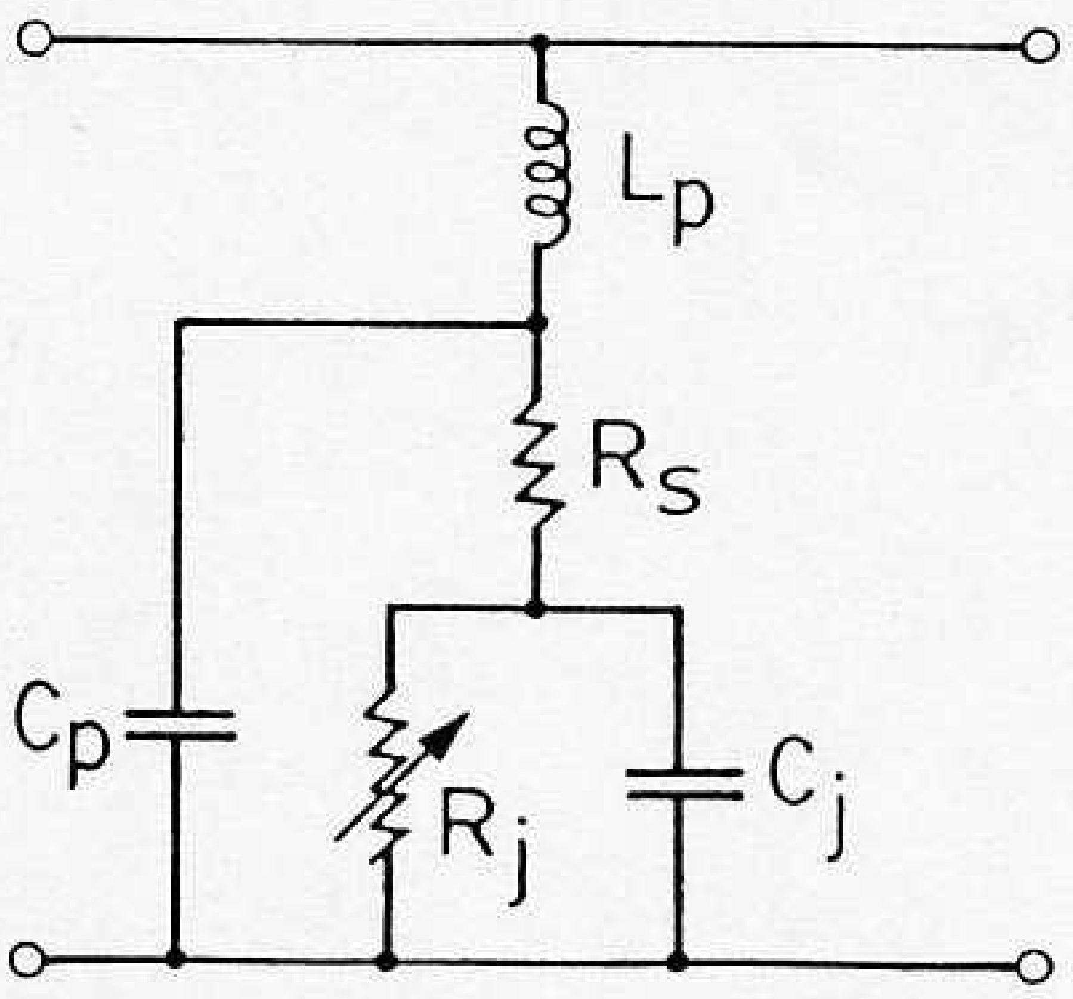

Fig. 3 Equivalent circuit of beam-lead PIN diode.

III. RESULTS

Fig. 4 compares computed slotline characteristics in a circuit environment. A five-step impedance transformer design is analyzed using three different methods: the accurate method [5] for propagation constants and impedances, the accurate method [5] for the propagation constants only, and approximate methods [6,7] for both the propagation constants and the impedances. Since the basic shape is almost identical and deviations occur below a reflection coefficient value of -25 dB, the approximate procedures (solid lines in Fig. 4) provide sufficient accuracy for the design of slotline circuits.

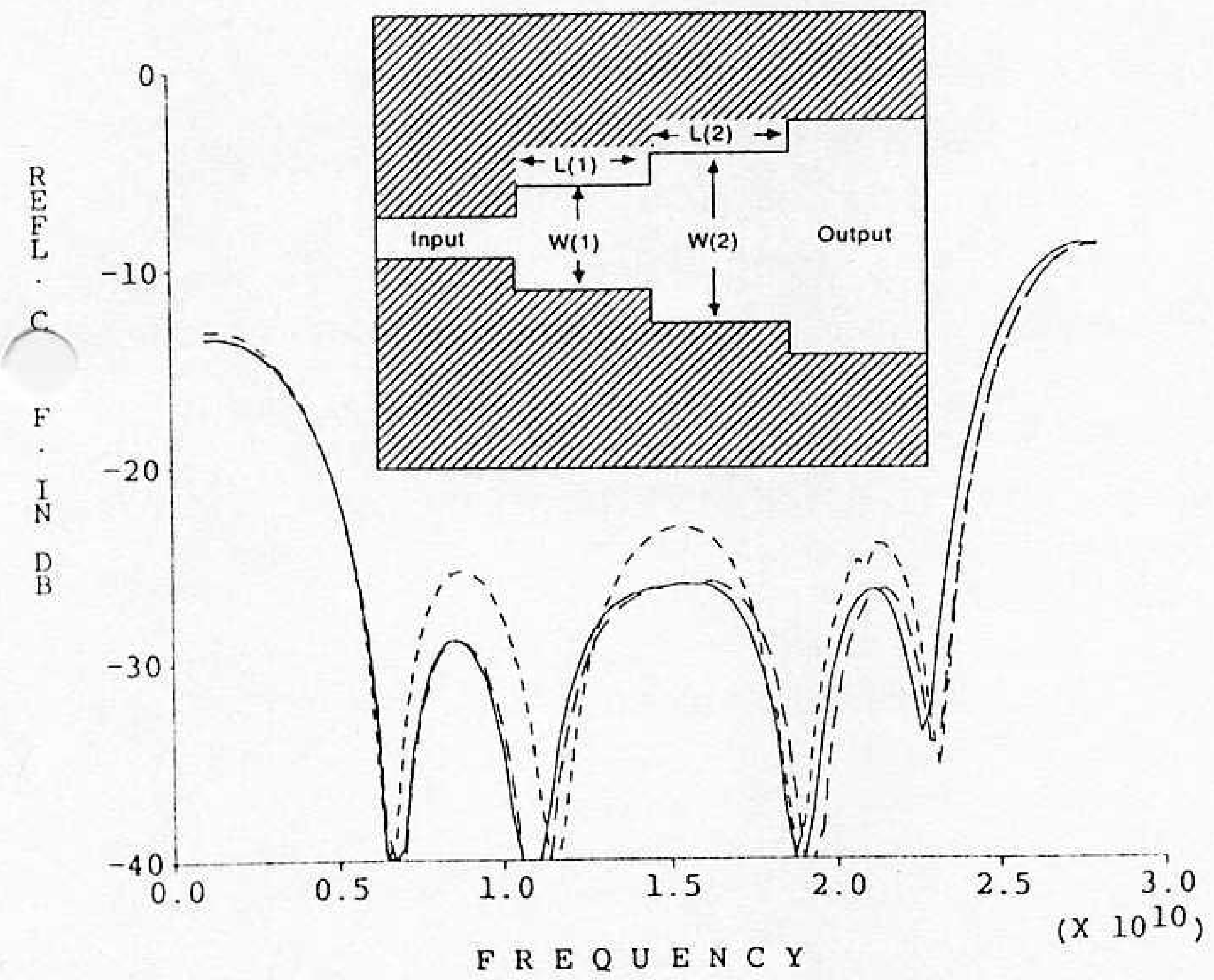

Fig. 4 Calculated input reflection coefficient of a five-step slotline impedance transformer. Slotline characteristics (β, Z_L) according to [5] (short-dashed), β[5] and Z_L[6,7] (long-dashed), both β and Z_L according to [6,7] (solid).

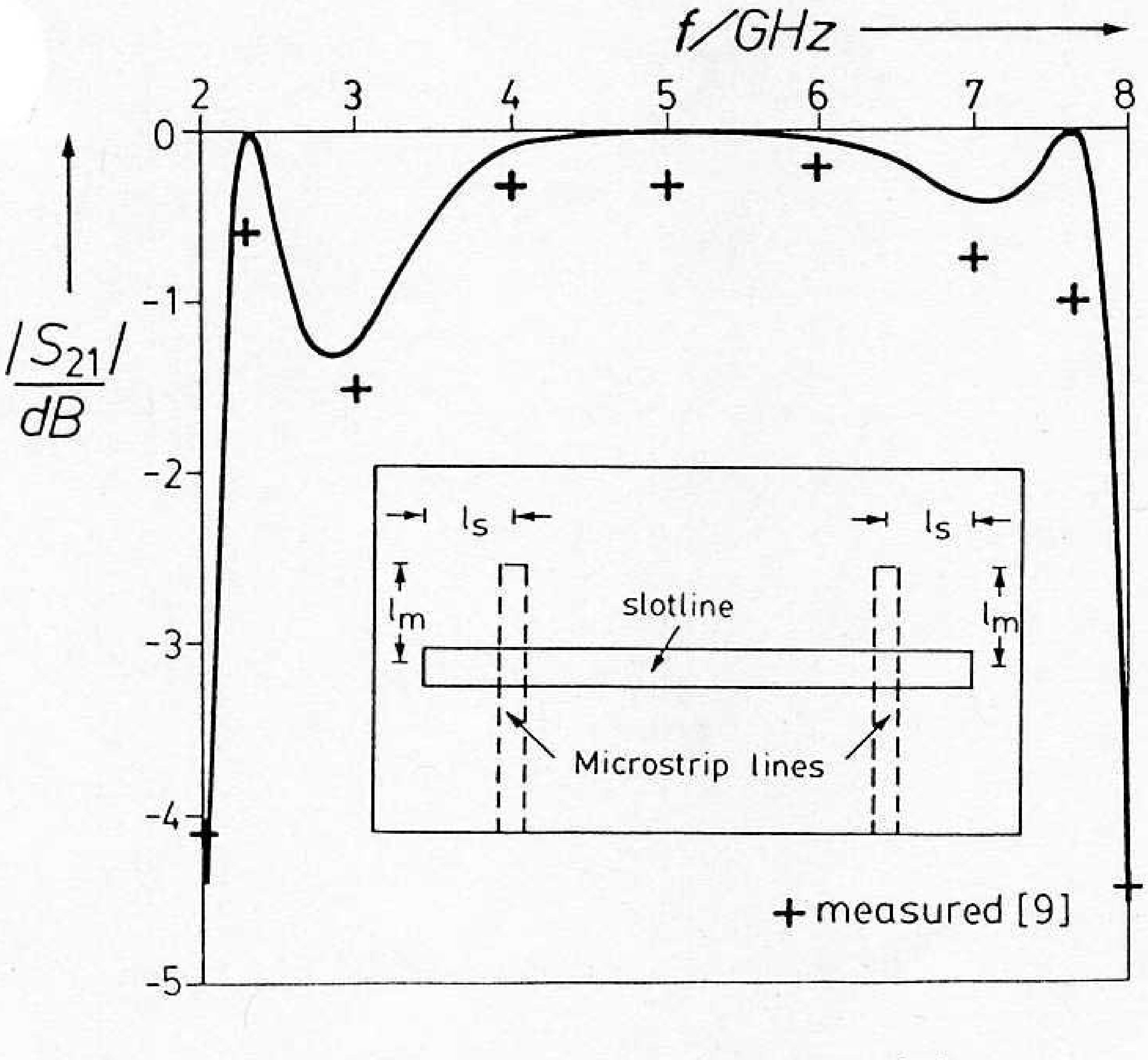

Fig. 5 Transmission coefficient of two cascaded microstrip-slotline transitions (— this theory, + measured [9]).

Fig. 5 shows the comparison between calculated results using this theory and measured data presented in [9]. Except for a 1 dB difference at 7.6 GHz, deviations are less than 0.5 dB. This is a reasonable value considering the fact that precise circuit dimensions and etching tolerances are not specified in [9].

The transmission behavior of the microstrip-slotline attenuator design using 6 Alpha DSG 6474E diodes is presented in Fig. 6. Since measured data in [11] have been used to determine the element values of the diode's equivalent circuit, the attenuation versus frequency characteristic is given with the junction resistance as parameter instead of the d.c. current of the diode. It should be noted that using Cohn's method [5] for the calculation of the slotline parameters (dashed lines in Fig. 6) leads to discrepancies between 0.1dB for low attenuation and 1.5 dB at the 80dB level. However, a CPU time ratio of usually 1:10 in favour of the approximate design clearly demonstrates the advantage of the simplified procedure presented here.

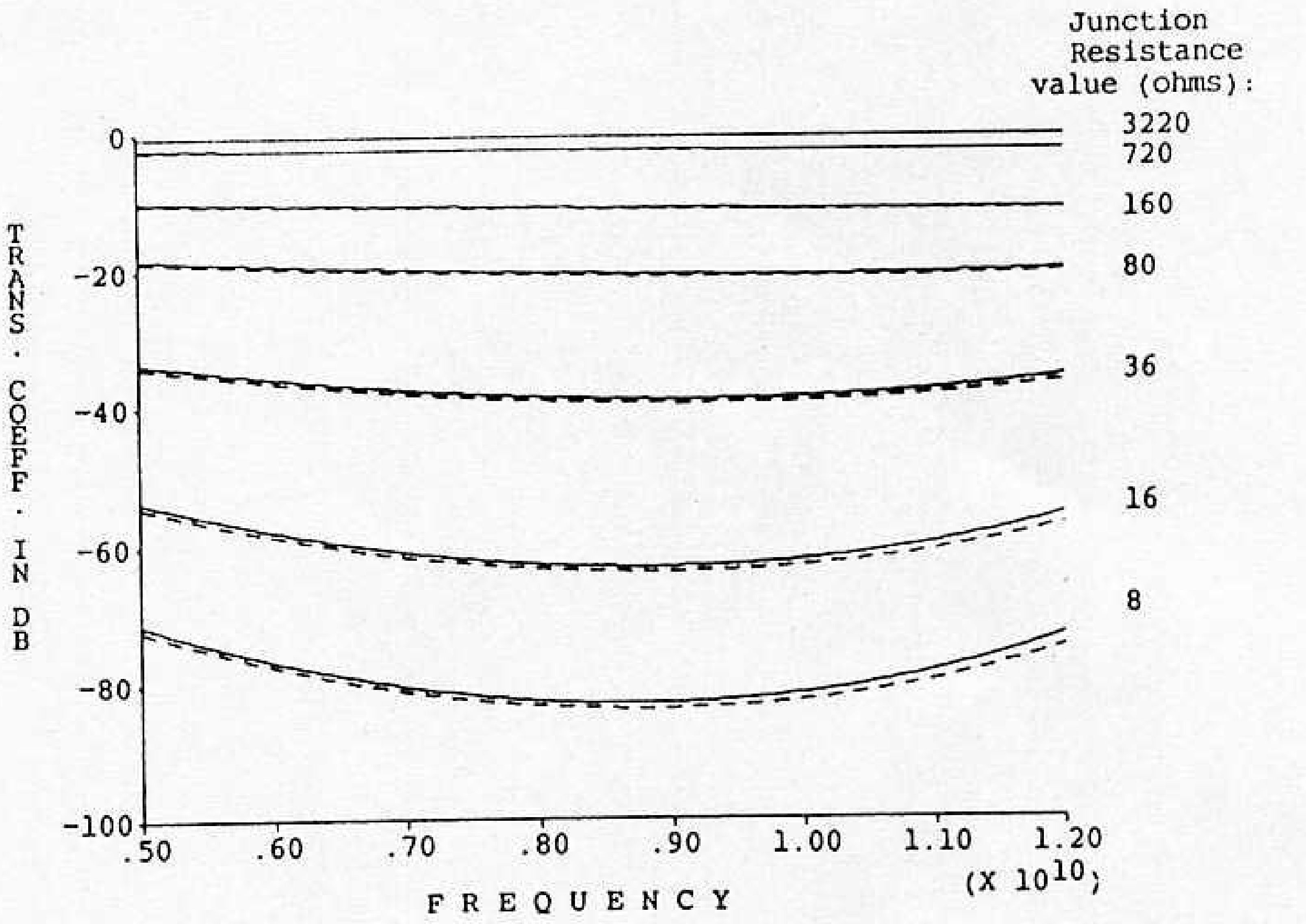

Fig. 6 Calculated transmission behaviour of microstrip-slotline attenuator as a function of PIN diode junction resistance (design with six diodes).

IV. CONCLUSIONS

It is demonstrated that sufficient accuracy in the design of slotline circuits is obtained when CPU-time intensive numerical procedures are replaced by functional approximations for slotline characteristics. Theoretical results, which are based on a simple transmission line model of a microstrip-to-slotline transition, are found to be in reasonable agreement with measured data. Therefore, microstrip-slotline circuits can be designed using a simplified procedure as is demonstrated at the example of a variable PIN diode attenuator in double-sided MIC technology.

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