

**STUDIES ON MICROSTRIP-LIKE TRANSMISSION LINES
FOR MICROWAVE AND MILLIMETER-WAVE
INTEGRATED CIRCUITS**

By

SHIBAN KISHEN KOUL

CENTRE FOR APPLIED RESEARCH IN ELECTRONICS

Dissertation Submitted

in Fulfilment of the Requirements of the

Degree of

DOCTOR OF PHILOSOPHY

**DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, DELHI**

NEW DELHI — 110 016

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Dedicated to my Parents

CERTIFICATE

This is to certify that the work reported in this thesis entitled 'Studies on Microstrip-like Transmission Lines for Microwave and Millimeter-wave Integrated Circuits' by Mr. Shiban Kishan Koul has been carried out under my guidance and supervision. The results contained in it have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

Bharathi Bhat

Prof. Bharathi Bhat
Centre for Applied Research in Electronics
Department of Electrical Engineering
Indian Institute of Technology
New Delhi 110 016, India

ACKNOWLEDGEMENTS

I acknowledge with great pleasure the guidance and encouragement received from Professor Bharathi Bhat throughout the course of this work.

I extend my sincere thanks to all my friends and colleagues for their help and moral support during the course of this work.

My sincere thanks are also due to Mr. M.C. Krishnaswamy for helping me in carrying out part of the experimental work reported in Chapter VIII.

During the course of this work, I was employed in the project 'Millimeter Wave Techniques' supported under the Research and Training Scheme of the Defence Research Development Organisation (DRDO) of the Ministry of Defence, India. This support is thankfully acknowledged.

Finally, I am thankful to Mr. P.M. Padmanabhan Nambiar for typing the manuscript and to Mr. Arora for preparing the drawings.

Shiban Kishen Koul

ABSTRACT

This thesis presents a comprehensive unified analytical study of a wide variety of microstrip-like transmission line structures having single and coupled strip conductors and with iso/anisotropic dielectric substrates. The basic structures considered are : (a) sandwiched microstrip, (b) inverted microstrip, (c) suspended microstrip, and (d) double layer microstrip. The utility of some of these structures in realising practical devices is experimentally investigated.

A unified analytical procedure for determining the characteristic impedance, effective dielectric constant and phase velocity of an infinitely long strip conductor embedded in multilayer iso/anisotropic dielectric substrates is evolved by combining the variational technique in space domain and also Fourier transformed domain in conjunction with the transverse transmission line technique. This technique is further extended to analyse the lumped capacitance, open-circuit end effects and edge-capacitance of semi-infinitely long strip conductor embedded in multilayer iso/anisotropic dielectric substrates.

The analysis of sandwiched microstrip, inverted microstrip, suspended microstrip and double layer microstrip, in isolated and edge-coupled configurations, is carried out using the unified approach. Numerical data on the characteristic impedance, effective dielectric constant and phase velocities are presented. The conductor and dielectric loss characteristics of these structures

in isolated configuration are computed. The effects of (a) shielding side and top walls, (b) finite thickness of the strip conductor, and (c) dielectric anisotropy are studied. Sensitivity analysis of inverted microstrip and suspended microstrip is carried out to study the effects due to a small change in the airgap height and also the relative permittivity of the dielectric substrate. For the edge-coupled inverted microstrip and edge-coupled suspended microstrip, the effect of dielectric overlay on the bottom ground plane is studied. Various schemes of phase velocity equalisation in edge-coupled microstrip-like structures are described. Nomograms to design high directivity backward-wave directional couplers in these configurations are presented.

Various broadside-coupled structures, namely: (a) broadside-coupled sandwiched microstrip, (b) broadside-coupled inverted microstrip, and (c) broadside-coupled suspended microstrip are analysed using the unified approach. The analysis of broadside, edge-coupled transmission line structures, which include: (a) broadside, edge-coupled homogeneous strip transmission line, (b) broadside, edge-coupled microstrip, (c) broadside, edge-coupled microstrip with inverted dielectric, (d) broadside, edge-coupled inverted microstrip, and (e) broadside, edge-coupled suspended microstrip, using the same unified approach is also presented. Extensive numerical data on the characteristic impedance, effective dielectric constant and phase velocity, for all the possible propagating modes, are computed. The effects of shielding side walls and the dielectric anisotropy are studied. The characteristics of broadside-coupled

inverted microstrip and broadside-coupled suspended microstrip, suspended in the E-plane of WR-28 waveguide are also computed.

The lumped capacitance of conductor patches in sandwiched microstrip, inverted microstrip, suspended microstrip and double layer microstrip are analysed using the unified approach. Numerical data are presented for the capacitance of square and rectangular conductor patches, open-circuit end effects and edge-capacitance of semi-infinitely long lines in these configurations.

The characteristic impedance and effective dielectric constant of inverted microstrip and suspended microstrip are measured and verified with theoretical results. Dispersion characteristics of the inverted microstrip and suspended microstrip are also measured. The loss and Q factors of these transmission lines are experimentally estimated. Various circuit components, which include (a) branch line couplers, (b) parallel coupled directional couplers, (c) high directivity directional couplers, (d) balanced mixer, (e) band pass filters, and (f) SPST switch and attenuator, in inverted microstrip and/or suspended microstrip are fabricated at frequencies up to X-band. Besides, transitions from waveguide to inverted microstrip and waveguide to suspended microstrip are also fabricated at X-band.

The unified analytical approach presented in this thesis enables determination of the propagation parameters of a class of single and coupled microstrip-like transmission lines, irrespective of the number of dielectric layers whether isotropic or anisotropic. Coupled structures include two conductor as well as

four conductor configurations possessing a plane or planes of symmetry for even- and odd-mode excitations. This method, besides being general, is the simplest compared to other analytical procedures reported in the literature. In order to compute the parameters, namely, characteristic impedance, effective dielectric constant and phase velocity and also to study the effect of thickness of the strip conductor of various structures, it is only required to change a single parameter, namely, the admittance at the charge plane of the specific structure. This parameter can be determined using the standard expression for the characteristic impedance of a section of transmission line. The same technique also enables the determination of lumped capacitance and open-circuit end effects of resonators in microstrip-like configurations.

The results presented in this thesis should find extensive application in the design of MIC components/subsystems at microwave and millimeter-wave frequencies.

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