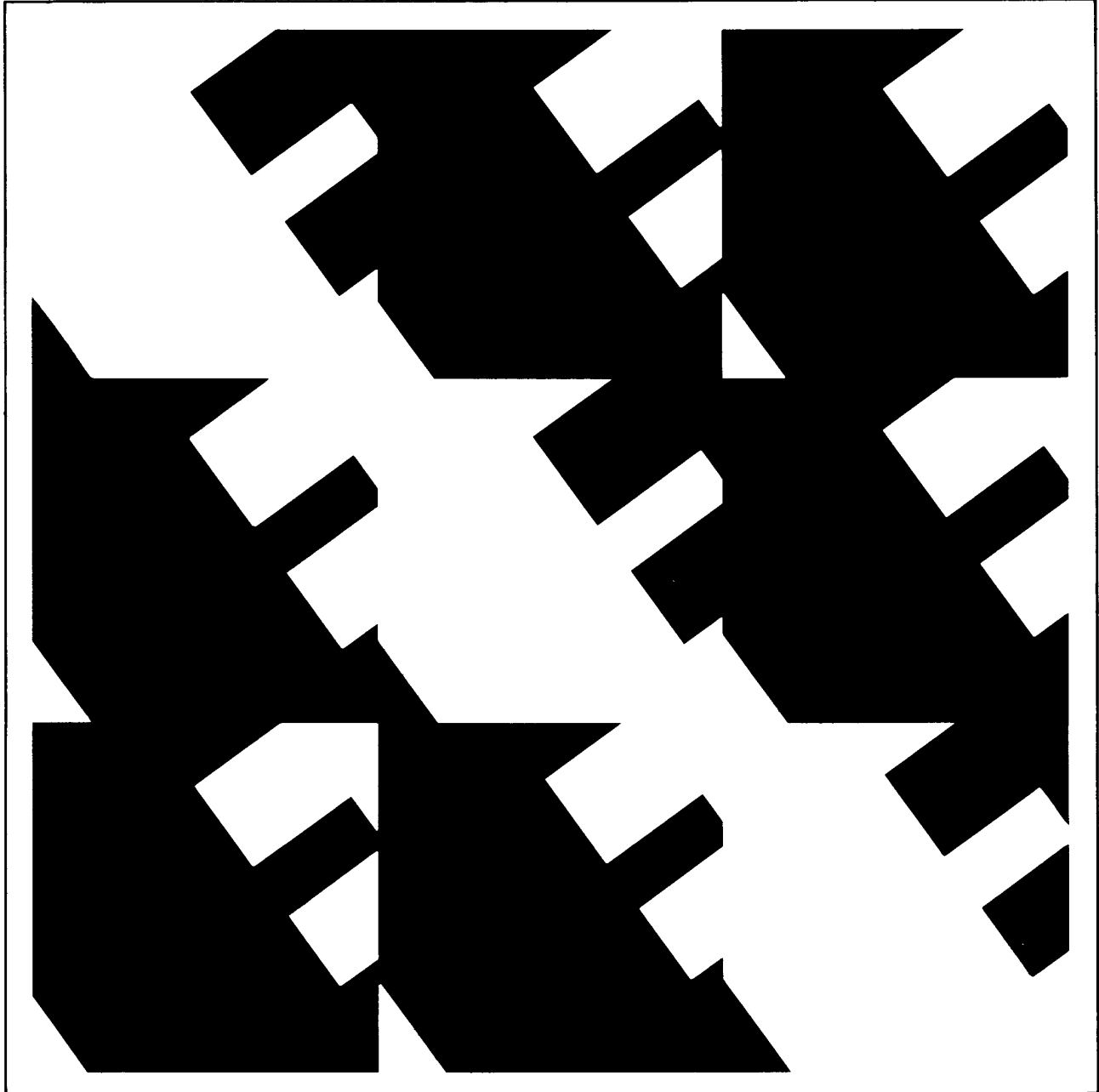


IEEE Standard Definitions of Planar Transmission Lines



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An American National Standard

**IEEE Standard Definitions of
Planar Transmission Lines**

Sponsor

**Standard Coordination Committee on
Planar Transmission Lines of the
IEEE Microwave Theory and Techniques Society**

Approved December 10, 1987

IEEE Standards Board

Approved August 4, 1988

American National Standards Institute

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Foreword

(This Foreword is not a part of ANSI/IEEE Std 1004-1987, IEEE Standard Definitions of Planar Transmission Lines.)

The IEEE has undertaken the development of standards for definitions pertaining to the transmission of microwave energy along guided lines. Several standards have been approved and published covering waveguides and components, active and passive. They are as follows:

ANSI/IEEE Std 146-1980, IEEE Standard Definitions of Fundamental Waveguide Terms
ANSI/IEEE Std 147-1979, IEEE Standard Definitions of Terms for Waveguide Components
IEEE Std 148-1959 (R1971), IEEE Standard for Measurements of Waveguides and Components
ANSI/IEEE Std 457-1982, IEEE Standard Definitions of Terms for Nonlinear, Active, and Nonreciprocal Waveguide Components
IEC Publication 50 (726), International Electrotechnical Vocabulary (ch 726, *Transmission Lines and Waveguides*)

Within the last few years, it was recognized that a similar standard was needed for planar transmission lines, which are an important transmission medium in hybrid and monolithic circuits. In June 1983, the P1004 Committee was convened for the first time to develop this standard of definitions for planar transmission lines.

The purpose of this standard is to provide a uniform basis of understanding, communication, and definition to benefit those engaged in the use and design of planar transmission lines.

The standard provides definitions of the planar transmission line configurations and also their physical and electrical characteristics. It excludes definitions for circuit elements, components, materials, and fabrication techniques. Some of these topics may well be the subject of future standards. This standard also excludes the definitions of general terms, which can be found in ANSI/IEEE Std 100-1984.

Although some of the definitions presented in this standard differ from those in IEC Publication 50 (726), the committee has deemed it fitting to retain them since they are intended to clarify these terms as related specifically to planar transmission lines rather than the broad coverage provided by IEC Publication 50 (726).

At the time this standard was approved the members of the Standards Coordinating Committee were as follows:

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An American National Standard

IEEE Standard Definitions of Planar Transmission Lines

1. Configurations

compound microstrip. A microstrip line in which the substrate consists of two or more layers of different electromagnetic properties.

coplanar strip transmission line. A planar transmission line consisting of two parallel thin conducting strips of finite width, separated by a finite gap and affixed to the same plane surface of an insulating substrate of arbitrary thickness (see Fig 1).

coplanar waveguide. A planar transmission line consisting of a single thin conducting strip of finite width situated between two semi-infinite ground planes and separated from them by finite gaps, which are all affixed to the same plane surface of an insulating substrate of arbitrary thickness (see Fig 2).

E-plane line. A rectangular waveguide containing one or more planar conducting structures, with or without dielectric backings, which are oriented in the plane defined by the electric field and the direction of propagation of the dominant waveguide mode. The guiding structures consist of one or more thin conducting strips, each having one edge extending to the broad wall of the enclosure.

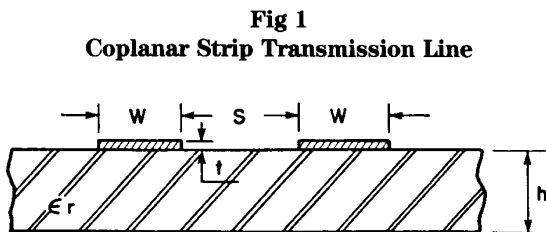


Fig 1
Coplanar Strip Transmission Line

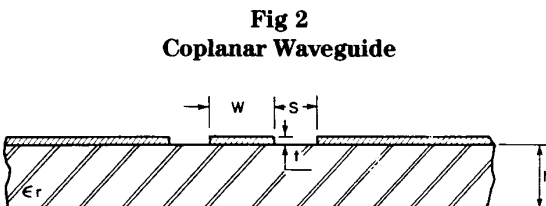


Fig 2
Coplanar Waveguide

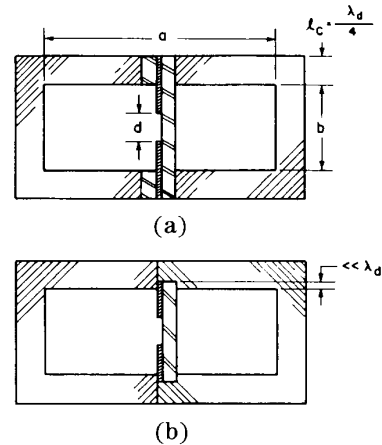


Fig 3
Finline
(a) Insulated (b) Grounded

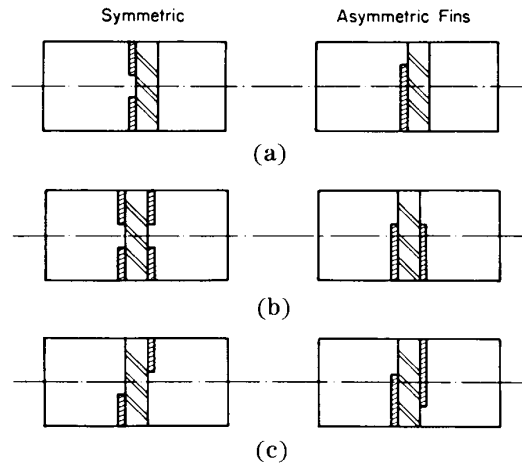


Fig 4
Fin Configurations
(a) Unilateral (b) Bilateral (c) Antipodal

finline. An E-plane line in which the planar conducting structure is affixed to a dielectric substrate. The thin conducting strips (fins) may be insulated or grounded (see Fig 3). They can be arranged in various configurations as shown in Fig 4.

image guide. A planar dielectric waveguide composed of one or more dielectric strips of finite width affixed to one side of a single extended conducting ground plane.

image line. A planar dielectric waveguide composed of one or more dielectric strips of finite width affixed to one side of a single extended conducting ground plane.

insulated image guide. A planar dielectric waveguide composed of one or more dielectric strips of finite width affixed to an extended dielectric layer of lower dielectric constant and finite thickness, attached in turn to an extended conducting ground plane (see Fig 5).

inverted microstrip. A compound planar transmission line consisting of one or more thin conducting strips of finite width affixed to an insulating substrate of finite thickness and suspended above a single extended conducting ground plane with the strips facing the ground plane and separated from it by free space. The semi-infinite space above the strips is also free space (see Fig 6).

inverted strip dielectric waveguide. A planar dielectric waveguide consisting of one or more dielectric strips of finite width affixed to an extended conducting ground plane on one side and to an extended dielectric layer of finite thick-

ness and higher dielectric constant on the other side (see Fig 7).

metallic E-plane line. An E-plane line in which there is no insulating substrate.

microstrip. A class of planar transmission lines consisting of one or more thin conducting strips of finite width parallel to a single extended conducting ground plane. In its common form, the strips are affixed to an insulating substrate attached to the ground plane. The semi-infinite space above the strips is filled with a medium of relative permittivity and permeability equal or less than the substrate (see Fig 8).

planar dielectric waveguide. A planar transmission line consisting of one or more dielectric layers or dielectric strips of finite width, or both, located above a single or between a pair of extended conducting ground planes.

planar transmission line. A transmission line composed of one or more parallel plates, slabs, or sheets of conducting or insulating materials, including free space, and in which one or more layers are composed of materials of differing electromagnetic properties, arranged in strips of finite cross section and aligned with the axis of propagation to form the guiding structures. The line may be enclosed laterally by conducting walls aligned parallel to the axis of propagation.

Fig 5
Insulated Image Guide

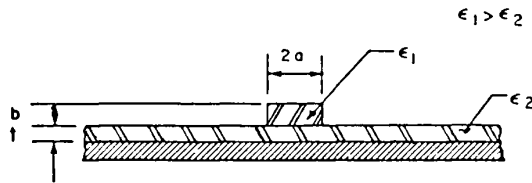


Fig 6
Inverted Microstrip

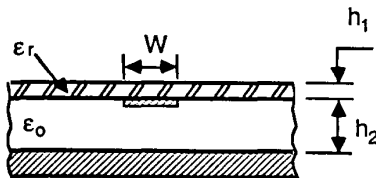


Fig 7
Inverted Strip Dielectric Waveguide

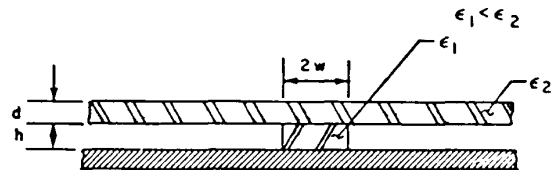
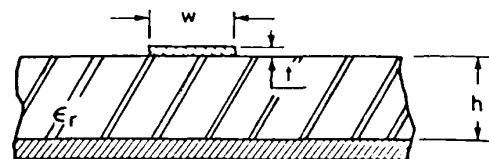


Fig 8
Microstrip



slot line. A planar transmission line consisting of two semi-infinite coplanar conductors affixed to the same side of an insulating substrate of arbitrary thickness and separated by a finite gap (see Fig 9).

stripline. A class of planar transmission line characterized by one or more thin conducting strips of finite width parallel to and approximately midway between two extended conducting ground planes. The space between the strips and the ground planes is filled by a homogeneous insulating medium (see Fig 10).

suspended stripline. A type of stripline in which the major dielectric is empty space. The strip

Fig 9
Slot Line

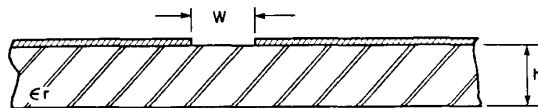


Fig 10
Stripline

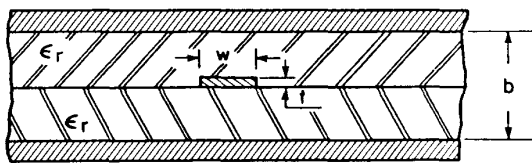
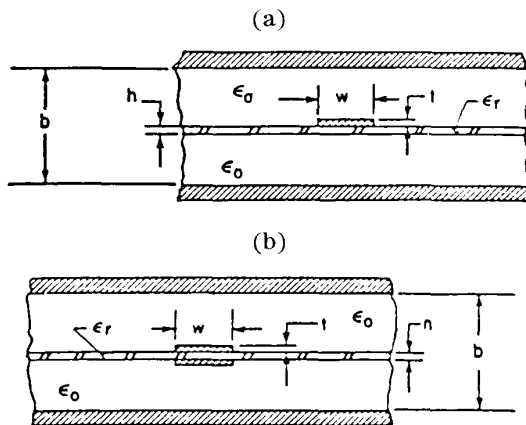


Fig 11
Suspended Substrate Stripline
(a) Single Strip (b) Double Registration Strips



conductor is located on a thin dielectric substrate supported between two ground planes. The conductor can be either a single strip or two strips in double registration acting electrically as a single conductor.

suspended substrate microstrip. A compound planar transmission line consisting of one or more thin conducting strips of finite width affixed to an insulating substrate of finite thickness and suspended above a single extended conducting ground plane with the strips facing the ground plane and separated from it by free space. The semi-infinite space above the substrate is also free space (see Fig 12).

transmission line. A structure designed to guide the propagation of electromagnetic energy in a well-defined direction. For purposes of definition and description relating to wave propagation, planar transmission lines are usually assumed to be of invariant cross section along the direction of propagation.

trapped inverted microstrip. A type of inverted microstrip where the ground plane below the substrate completely encloses the strip conductor (see Fig 13).

Fig 12
Suspended Substrate Microstrip

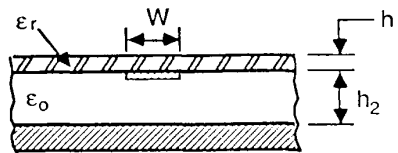
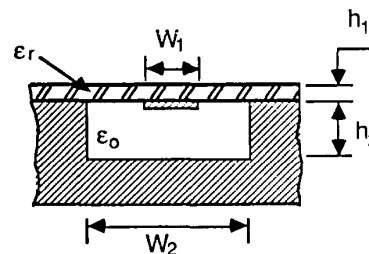


Fig 13
Trapped Inverted Microstrip



2. Physical and Electrical Characteristics

anisotropic substrate. A substrate whose electric or magnetic properties, or both, are directionally dependent.

attenuation constant. The real part of the propagation constant, describing the exponential decay of the field amplitude of a mode in the direction of propagation. It is expressed in nepers (or decibels) per unit length.

characteristic impedance (Z_o). A parameter having the dimensions of impedance (volt per ampere=ohm) that characterizes a mode of propagation. For a transverse electromagnetic (TEM) mode propagating in a single direction on a two-conductor transmission line,

Z_o = the ratio of voltage to current at any cross section or

$$Z_o = \sqrt{Z/Y}$$

where

Z = series inductance per unit length

Y = shunt admittance per unit length of the transmission line

$$\begin{aligned} Z_o &= V^2/2P \\ &= 2P/I^2 \end{aligned}$$

where

P = time-average power transmitted through any cross section

V = amplitude of the voltage

I = amplitude of the current

For modes other than TEM, different definitions will not in general provide the same numerical value; in those cases, the definition of the characteristic impedance is dictated by custom and by its usefulness in the specific application in question. For most planar transmission lines, the fundamental propagation mode is not purely TEM and a characteristic impedance cannot be defined unambiguously. Techniques for defining and calculating impedances in these cases can be found in the literature.

characteristic impedance of a symmetrical pair of coupled lines. The geometric mean of the even and odd mode characteristic impedances.

conductor loss. That contribution to the attenuation constant of a propagating mode on a planar transmission line that represents losses

attributed to the finite conductivity of the conductors involved.

coupled line. A transmission line with multiple guiding members whose propagating waves interact with each other.

coupling coefficient. A number used as a measure of the degree of interaction between the members of a coupled line. One commonly used definition of the coupling coefficient of a symmetrical coupled pair of transmission lines is K , a voltage or field ratio:

$$K = \frac{\frac{Z_{0e}}{Z_{0o}} - 1}{\frac{Z_{0e}}{Z_{0o}} + 1}$$

where

Z_{0e} and Z_{0o} = even- and odd-mode characteristic impedances

covered line. An idealized planar transmission line with two conducting ground planes, parallel to the strip conductor. One of the ground planes has only a minor effect on the propagation properties of the line.

cutoff frequency. For a given mode in a planar transmission line, the frequency below which the mode is not guided by the line. For a shielded transmission line (with a finite cross section), the mode phase constant is very small compared to the attenuation constant below cutoff, and is zero if the line is nondissipative. For an open transmission line (infinite cross section), the mode is guided above cutoff and radiating below cutoff.

dielectric loss. That contribution to the attenuation constant of a propagating mode on a planar transmission line that represents losses associated with the dielectric properties of the substrates (and overlays) materials involved, which may also include conduction mechanisms.

discontinuity. An abrupt change in the cross section of the planar transmission line. Abrupt refers usually to a change in dimensions or material over a length short compared to a wavelength.

dispersion. The property of a planar transmission line whereby the phase velocity of the mode of propagation is frequency dependent, or equiva-

lently, the phase constant is not proportional to frequency.

dominant mode of propagation. The mode of propagation with the lowest cutoff frequency. For a planar transmission line containing at least two disjoint conductors, the cutoff frequency can be zero. In this limit, the dominant mode reduces to a static electromagnetic field pattern and is also called the fundamental mode. For a planar transmission line with more than two conductors, there is more than one fundamental mode.

effective dielectric constant. A parameter frequently used to characterize the phase velocity of modes propagating on planar transmission lines with inhomogeneous or anisotropic media. It is the square of the ratio of actual to free space propagation constant of a mode. It is the dielectric constant of an equivalent line filled by a nonmagnetic, homogeneous, isotropic medium in which a TEM wave propagates with the same phase velocity.

effective relative permeability. A parameter frequently used to characterize the phase velocity of modes propagating on planar transmission lines containing a magnetic material as compared to a transmission line of the same configuration and equal dielectric constant, but with free space magnetic properties. It is the square of the ratio of the propagation constants of these two transmission lines.

effective strip width. The strip width of an idealized planar transmission line introduced to model an actual physical structure having equivalent electrical characteristics of interest. Two examples are

(1) *Effective Width of Microstrip* (conductor thickness correction).

The width of a zero thickness microstrip introduced to represent the additional fringing capacitance associated with the finite thickness of the strip conductor.

(2) *Effective Width of Microstrip* (parallel plate waveguide model).

The width of a parallel plate waveguide having magnetic wall boundaries and a height equal to the substrate thickness and having the same phase constant and characteristic impedance as the microstrip mode considered.

even and odd modes. The modes of propagation on a symmetrical planar transmission-line struc-

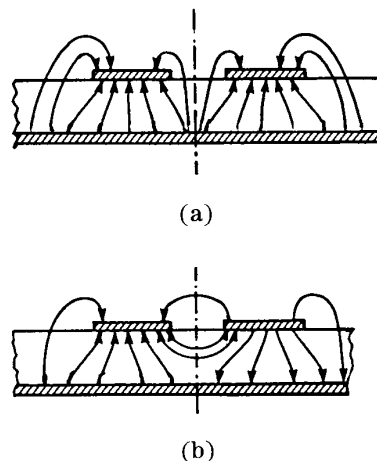


Fig 14
Modes in a Coupled Pair of
Transmission Lines
(a) Even Mode (b) Odd Mode

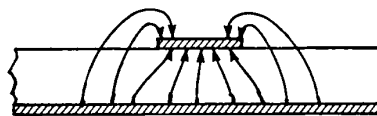


Fig 15
Fundamental Mode in Microstrip (Even)

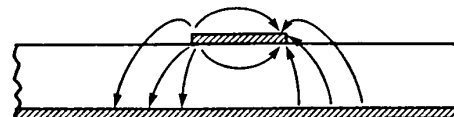


Fig 16
Higher Order Mode in Microstrip (Odd)

ture whose electric field distribution in the transverse cross section in even or odd with respect to reflections in the plane of symmetry of the structure.

A symmetrical coupled pair of transmission lines can support two fundamental modes—an even mode and an odd mode (see Fig 14).

A single planar transmission line can support only one fundamental mode, which may be even or odd, depending on the structure of the transmission line. For example, the fundamental mode on a single microstrip line is an even mode (see Fig 15). The first higher order mode is odd (see Fig 16). On a single slot line, the fundamental mode is an odd mode (see Fig 17).

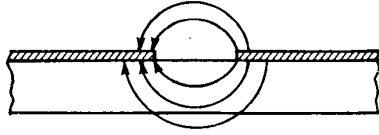


Fig 17
Fundamental Mode in Slot Line (Odd)

even and odd mode characteristic impedances. The characteristic impedances associated with the even and odd modes of a propagation of a symmetrical pair of coupled transmission lines with respect to ground. These impedances are a function of the degree of coupling between the lines.

filling factor, filling fraction. A factor that describes the fraction of energy flow confined in the substrate of a planar transmission line of inhomogeneous cross section.

(1) **Dielectric Filling Factor (Single Layer Microstrip).** The ratio of

$$\frac{\epsilon_r \text{ eff} - 1}{\epsilon_r - 1}$$

where

ϵ_r = relative dielectric constant of the substrate of a microstrip line

$\epsilon_r \text{ eff}$ = effective dielectric constant

(2) **Dielectric Loss Filling Factor.** The ratio of

$$\frac{\tan \delta_{\text{eff}}}{\tan \delta}$$

where

$\tan \delta$ = dielectric loss tangent of the substrate of a microstrip line

$\tan \delta_{\text{eff}}$ = effective dielectric loss tangent of the line

(3) **Magnetic Filling Factor.** The ratio of

$$\frac{\frac{1}{\mu_{\text{eff}}} - 1}{\frac{1}{\mu} - 1}$$

where

μ = relative permeability of the substrate of a microstrip line

μ_{eff} = effective relative permeability

(4) **Magnetic Loss Filling Factor.** The ratio of

$$\frac{\tan \delta_{m, \text{eff}}}{\tan \delta_m}$$

where

$\tan \delta_m$ = magnetic loss tangent of the substrate of a microstrip line

$\tan \delta_{m, \text{eff}}$ = effective magnetic loss tangent of the line

ground plane. A conducting surface or plate used as a common reference point for circuit returns and electric or signal potentials.

guide wavelength. For a travelling wave in a uniform transmission line at a given frequency and for a given mode, the distance along the axis of propagation between corresponding points at which a field component (or the voltage or current) differs in phase by 2π rad.

higher order mode of propagation. Any mode of propagation characterized by a field configuration other than that of the dominant or first order mode with the lowest cutoff frequency.

magnetic loss. That contribution to the attenuation constant of a propagating mode on a planar transmission line that represents losses associated with the magnetic properties of the substrates (and overlays) materials involved, which may also include conduction mechanisms.

mode of propagation. A form of electromagnetic wave than can advance and can transport energy along the axis of a transmission line without change in the form of the electromagnetic field pattern in successive transverse sections (except for a monotonic decrease in amplitude along the direction of propagation, due to energy dissipation, which is present to some degree in every transmission line).

multiple transmission line. A planar transmission-line configuration employing more than one parallel guiding structure, each of which could form a single planar transmission line.

overlay. A layer of dielectric material placed upon a single or coupled planar transmission line. It is often used to make the two modes of coupled transmission lines have phase velocities nearly the same.

phase constant. The imaginary component of the propagation constant. This is the spatial rate of decrease of phase of a field component in the direction of propagation in radians per unit length.

propagation constant. A complex parameter having the dimension of inverse length, which characterizes the variation of the field magnitude and phase of a mode in the direction of propagation. The real part is denoted as the attenuation constant and the imaginary part as the phase constant.

radiation loss. The loss associated with planar transmission lines having ideal conductors and lossless media, caused by energy leakage from the transmission line.

shielded line. A planar transmission line whose cross section is completely enclosed within conducting boundaries.

single-mode bandwidth. The range of frequencies between the cutoff of the dominant mode of propagation and that of the lowest higher order guided mode.

substrate. The supporting material upon or within which a planar transmission line is fabricated or to which it is attached. A substrate can be composed of one or more nonconducting layers.

surface wave. A mode of propagation where the energy is concentrated near the interface of two media having different electric or magnetic properties, or both, and whose field amplitude decays in a direction normal to the interface.

TEM mode (Transverse Electromagnetic). A mode of propagation characterized by frequency-independent electric and magnetic-field patterns that are purely transverse with respect to the axis of the transmission line; that is, patterns that possess no field component in the direction of propagation. A transmission line cannot possess TEM modes unless there are at least two disjoint conductors in its cross section, and unless the medium filling the cross section is homogeneous and normally isotropic.

waveguide modes. Those spurious modes of a planar transmission line that are guided by the enclosure or shielding of this line rather than the transmission line itself.