SCATTERING PARAMETER MEASUREMENT TECHNIQUES IN MICROSTRIP

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Abstract

Measurements are made on microstrip waveguides with coaxial-to-microstrip wave transitions, by means of a sliding obstacle method, and S-parameters of the transitions and the microstrip are derived for a range of frequencies from 1 to 11 GHz.

Introduction

With the advent of solid-state devices for power generation in the frequency region between 10 and 100 GHz, it becomes necessary to have available design information regarding passive components and their behaviour at these frequencies. Microstrip and other similar distributed structures will probably be the media used for forming and interconnecting components of microwave integrated circuits, while connections to the circuits will be through coaxial connectors and cables. Characterization of microstrip and various types of discontinuity caused by changes in dimension, connection to active devices, and transitions from and to coaxial line, is necessary before characterization of interconnected components is possible [1,2].

The theoretical approach to such characterization has so far remained intractable. Experimental methods have been widely used, but they generally tend either to ignore factors which are increasingly important at higher frequencies, or to concentrate on a particular parameter such as characteristic impedance, parasitic reactance, or attenuation [1,2,3]. It is felt that a technique must be developed which allows measurement of as many parameters as possible, over a wide range of frequencies, and which is applicable to a variety of guiding structures.

The Scattering-Parameter Approach

To consider microstrip as a general wave-guiding structure supporting dispersive hybrid propagating modes, as well as possible radiation, is a more realistic approach than that of the experimental methods referred to above, which treat microstrip as two-conductor transmission line. The phrase "quasi TEM behaviour" cannot obscure the fact that such descriptions of microstrip are only asymptotic at low frequencies. This view is certainly supported by theory [4] are experiment [1] for uniform microstrip. The concept of characteristic impedance becomes less relevant to design than are their equivalent voltages and currents, although the concept of their normalized parasitic impedance is still useful.

Experimentally, the ease of making swept-frequency S-parameters measurements, and the capability of on- or off-line computer correction of instrumentation errors, makes the scattering-parameter measurement approach a logical one. There is a fundamental complication, though, in that such measurements must be made through one or two coaxial-to-microstrip transitions, whose scattering effects have been confirmed by ourselves and others [2] to be significant at X-band and even below. The problem, then, is first to characterize these transitions, or launchers, by their scattering matrices as functions of frequency, and then to make measurements, through these transitions, of other discontinuities of interest.

The majority of structures which must be measured can be considered as a cascade of 2-port microwave networks. They are linear and passive and therefore, with the usual normalization, reciprocity implies that $S_{12} = S_{21}$ for each 2-port. These considerations apply to many other wave-guiding structures besides microstrip, in fact in any case where there are imperfect transitions between measuring equipment and single-mode transmission media, such as the yagi wave-launchers on dielectric image line investigated by McRitchie and Beal [5], or the coaxial-to-symmetrical trough waveguide transition measured by Wen [6]. In such situations it is impossible to construct adequate sliding short circuits or sliding matched loads useful in the graphical analysis of 2-ports as described by Storer et al. [7].

The simplicity of the network representation of Fig. 1 is deceptive, as is evident when S-parameters of the overall network are considered. When two networks, say [Lij] and [Mij], are connected in cascade, the scattering parameters of the overall two-ports thus formed are:

$$S_{11}=\ell_{11}+\frac{\ell_{12}^2 m_{11}}{1-\ell_{22}m_{11}}\ , \quad S_{22}=m_{22}+\frac{m_{12}^2\ell_{22}}{1-\ell_{22}m_{11}}\ ,$$

$$S_{21}=S_{12}=\frac{\ell_{12}m_{12}}{1-\ell_{22}m_{11}}\ .$$

S_{11}, for example, is the familiar bilinear transformation of m_{11} into the input plane of [Lij]. In most cases of measurement, the overall 2-port will consist of three in cascade. The expressions for the overall scattering parameters in terms of the individual two-ports are quite complicated, but an important simple case is that of figure 1, with two general, nonidentical transitions [A] and [B] connected by a known length of single-mode equivalent transmission line. It should be possible by varying ℓ to use this arrangement to measure the parameters of the launchers as well as the propagation coefficient of the microstrip. But this would require several microstrip boards, and owing to imperfections in fabrication of the launcher-to-strip contact, it has been found impossible to assume that launchers are identical from board to board. Thus measurements must be confined to a single circuit of fixed length. Little can be determined from measurements of its scattering parameters at a single frequency.

An obstacle which may be accurately positioned along the microstrip but whose scattering effects are independent of position (as long as it is not close to the launchers), introduces a variable assymmetry in the network properties of the test structure. If the obstacle is thin, it may be represented as a lossy shunt admittance across the equivalent transmission line of the microstrip (see fig. 2) The loss associated with the admittance Y includes radiation from the microstrip induced by the discontinuity. The scattering matrix for a shunt admittance is shown in Fig. 2. The effect of the movable obstacle on the scattering matrix of the transmission line section between the launchers may be seen in the lower matrix of Fig. 2. These and the coefficients of the overall matrix including the effects of the two transitions to co-axial line may be written by successive use of the cascading formulas given above, or by signal-flow-graph reduction. The expressions for the scattering parameters become:

$$S_{11}=a_{11}+\frac{a_{12}^2[b_{11}(\frac{2-y}{2+y})e^{-2\gamma\ell}-(\frac{y}{2+y})e^{-2\gamma(\ell-x)}]}{1+b_{11}(\frac{y}{2+y})e^{-2\gamma x}-a_{22}[b_{11}(\frac{2-y}{2+y})e^{-2\gamma\ell}-(\frac{y}{2+y})e^{-2\gamma(\ell-x)}]}$$

$$S_{22}=b_{22}+\frac{b_{12}^2[a_{22}(\frac{2-y}{2+y})e^{-2\gamma\ell}-(\frac{y}{2+y})e^{-2\gamma x}]}{\text{Denominator as above}}$$

$$S_{21}=\frac{a_{12}b_{12}e^{-\gamma\ell}(\frac{2}{2+y})}{\text{Denominator as above}}\ .$$

These expressions are so complicated that it seems worthwhile making some simplifying assumptions. The phase constant may be determined easily, if attenuation is low, by noting the distance over which the obstacle is moved, to bring the reflection coefficient once around a closed trajectory in the ρ-plane. The geometry of these trajectories may be analyzed by making the further assumption that the scattering shunt admittance is small, typically $|y|\leq 0.1$. Then, the factors $\frac{2-y}{2+y}$ and $\frac{2}{2-y}$ are nearly unity, and since the denominator contains products of small quantities, it too is nearly unity. The expressions for the S-parameters have become:

$$S_{11}=[a_{11}+a_{12}^2b_{11}e^{-2j\beta\ell}]-[a_{12}^2(\frac{y}{2+y})]e^{-2j\beta(\ell-x)}$$

$$S_{22}=[b_{22}+b_{12}^2a_{22}e^{-2j\beta\ell}]-[b_{12}^2(\frac{y}{2+y})]e^{-2j\beta x}$$

$$S_{21}=a_{12}b_{12}e^{-j\beta\ell}.$$

For the reflection coefficients, the first bracketed term locates the centre, and the second determines the radius of a small circle in the ρ-plane. From the centres and radii of measured circles, one can get immediately estimates of a_{12}, b_{12} and y. These along with measured β, may be substituted into the general expressions in an iterative scheme to solve for the remaining unknown parameters a_{11}, a_{22}, b_{11} and b_{22}.

Measurements have been made on microstrip sections, about four wavelengths long at 10 GHz, with nominal 50Ω characteristic impedance. The transitions include OSM strip to miniature coaxial adapters, and OSM tapered adapters to type N connectors. As shown in Fig. 3, the obstacle is simply a copper wire stretched close above the strip and arranged to be moved along the strip with constant spacing from it. Preliminary measurements indicated that the two transitions may be assumed identical, and that with offline computer error correction, the accuracy of measurement of S-parameters of the assembly is within two percent.

Swept-frequency measurements of the input reflection coefficient showed the VSWR rising above 2.0 at some frequencies, which emphasizes the need for design data on the transitions.

At a fixed frequency, as the obstacle was moved through several half-wavelengths, the small circular reflection-coefficient trajectories described earlier, were observed. As well, the transmission coefficient was nearly stationary. This justifies the approximations of low-loss microstrip and low-admittance obstacle.

Results will be presented showing the parameters of the transitions as functions of frequency. These are expected to reveal increasing scattering effects with increasing frequency in the range from 1 to 11 GHz. Dispersion and loss characteristics of the microstrip will also be presented. Further experiments would use this knowledge of the launchers and the microstrip to characterize other discontinuities in the microstrip such as step changes in line width and coupled line sections.

Acknowledgement

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References

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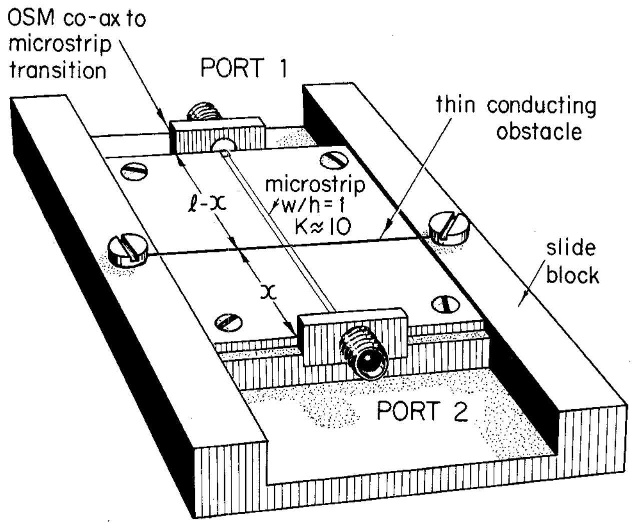
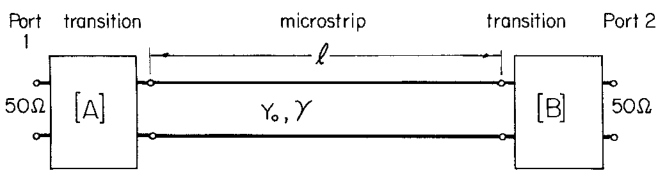


FIG. 2 SCATTERING PARAMETERS WITH MOVING OBSTACLE



Scattering matrices:

Transitions:

$$[A]=\begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix},\quad [B]=\begin{bmatrix}b_{11} & b_{12}\\ b_{21} & b_{22}\end{bmatrix}$$

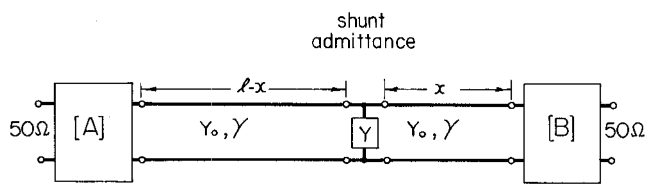
$a_{12} = a_{21}$
$b_{12} = b_{21}$
$a_{12} \neq b_{12}$
$a_{11} \neq b_{22}$
$a_{22} \neq b_{11}$

Microstrip of length ℓ: $\begin{bmatrix}0 & e^{-\gamma\ell}\\ e^{-\gamma\ell} & 0\end{bmatrix}$, $\gamma = \alpha + j\beta$

Cascaded unit:

$$\begin{bmatrix} a_{11} + \dfrac{b_{11}a_{12}^2 e^{-2\gamma\ell}}{1-b_{11}a_{22}e^{-2\gamma\ell}} & \dfrac{a_{12}b_{12}e^{-\gamma\ell}}{1-b_{11}a_{22}e^{-2\gamma\ell}} \\ \dfrac{a_{21}b_{21}e^{-\gamma\ell}}{1-b_{11}a_{22}e^{-2\gamma\ell}} & b_{22} + \dfrac{a_{22}b_{12}^2 e^{-2\gamma\ell}}{1-b_{11}a_{22}e^{-2\gamma\ell}} \end{bmatrix}$$

FIG. 1 SCATTERING PARAMETERS FOR TEST UNIT



Scattering matrices:

Obstacle:

$$\begin{bmatrix} \dfrac{-y}{2+y} & \dfrac{2}{2+y} \\ \dfrac{2}{2+y} & \dfrac{-y}{2+y} \end{bmatrix}$$

$y = \dfrac{Y}{Y_o}$

Microstrip of length ℓ with obstacle at x:

$$\begin{bmatrix} \dfrac{-y}{2+y}e^{-2\gamma(\ell-x)} & \dfrac{2}{2+y}e^{-\gamma\ell} \\ \dfrac{2}{2+y}e^{-\gamma\ell} & \dfrac{-y}{2+y}e^{-2\gamma x} \end{bmatrix}$$

FIG. 3 MICROSTRIP TEST UNIT