14-4

AN IMPROVED MODEL FOR SHORT- AND OPEN-CIRCUITED SERIES STUBS IN FIN LINES

Miles BURTON and Wolfgang J.R. HOEFER

Department of Electrical Engineering
University of Ottawa
Ottawa, Ontario, Canada K1N 6N5

ABSTRACT

This paper presents empirical closed-form expressions for the scattering parameters of series stubs in single-ridge, unilateral fin line with narrow gap width. These expressions show the effect of fin gap width, stub length, and frequency and are suitable for computer-aided design.

INTRODUCTION

The series stub has been a popular circuit element in the design of oscillators and narrow-band filters in fin line [1], [2]. However, the available information is neither accurate nor versatile enough for most practical design problems. We therefore saw the need for an improved model which incorporated the effects of the frequency, substrate thickness, fin line gap width and stub length.

Hence, this paper significantly increases the available design information for short- and open-circuited series stubs in fin line.

The stubs are modeled by an equivalent circuit which takes into account the field disturbances at the branching points and at the far end. Expressions for the circuit elements have been derived from measurements. They are valid over one waveguide band and are suitable for unilateral fin lines on low permittivity substrates (ε_r=2.22) with narrow gap widths (d/b << 1).

THE STUB MODEL

A fin line stub can be described either by its S-parameters or by an equivalent circuit with lumped elements. The latter has two advantages. Firstly, it directly depicts the circuit behaviour of the discontinuity. Secondly, it separately describes the various field disturbances at the branching points and at the far end of the stub.

These effects were incorporated into the equivalent transmission line circuits shown in Fig.1(a) and (b). Then, measurements were made with an automatic network analyzer to determine the dependence of the equivalent circuit parameters on frequency, stub length, and fin line gap width.

Each measured stub was centered between two identical waveguide to fin line tapers which were etched on 0.76 mm thick Rt/duroid (ε_r=2.22), and mounted in WR-90 waveguide. (See Fig.2). All stubs had a standard width of 1 mm.

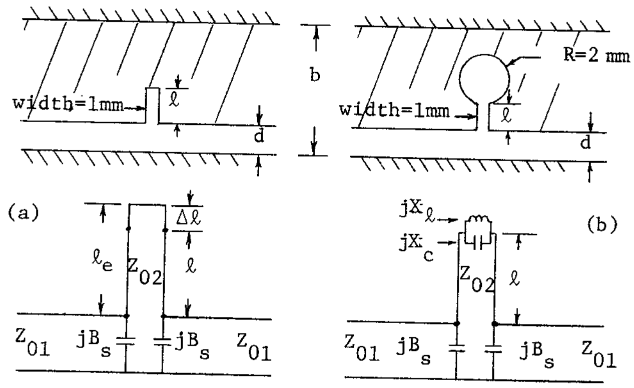

Fig. 1 - Equivalent transmission line circuits for the short-(a) and open-(b) circuited series stubs in unilateral single-ridge fin line.

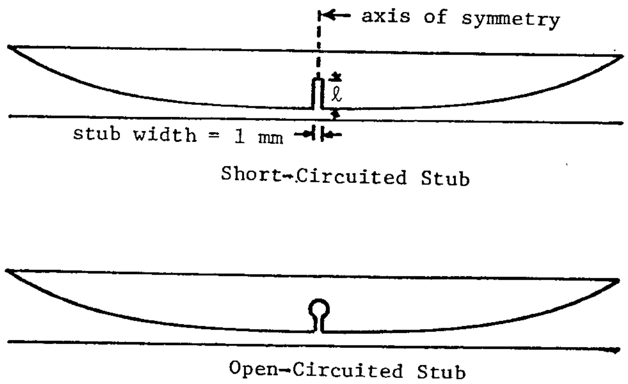

Fig. 2 - Metalization patterns used to measure the scattering parameters of the stub discontinuities in unilateral fin line (WR-90) (ε_r=2.22, substrate thickness s=0.762 mm.)

DE-EMBEDDING THE STUBS

To de-embed the stubs, the scattering parameters of the tapers were found by a method used to characterize connections to a transmission medium in which no standard loads are available [3], [4]. In this method transmission and reflection measurements are made on two similar two-ports. Each is composed of two identical connectors (waveguide to fin line tapers in our case) separated by a length of transmission medium of known electrical length.

The intervening transmission medium of one two-port is approximately one quarter wavelength shorter than that of the other two-port. The method yields scattering information for the taper in the form of S_{11}, S_{22} and the product $S_{21} \cdot S_{12}$.

In [3, 4], a quasi-closed form expression for each of S_{11}, S_{22}, and $S_{21} \cdot S_{12}$ are derived. Higher order terms in S_{11} and S_{22} also appear in these expressions but their effects are ignored by assuming $|S_{11}|$, $|S_{22}| \simeq 0$. This assumption restricts the application of the method to cases involving nearly reflectionless connectors.

We extend the method to cases involving reflective connections by using an iterative computation. Here, the assumption above is the starting point in an algorithm that merely repeatedly computes the same expressions mentioned above. Each iteration after the first invokes the higher order terms by using the previous results for S_{11} and S_{22}. The iterations are stopped when a test for convergence is satisfied.

The stubs were de-embedded by using the explicit formulas of Kruppe and Sodomsky [5] originally intended to correct for the errors in imperfect network analyser test-sets. The test-set error terms in these formulae were replaced by the scattering parameters of the two identical fin line to waveguide transitions.

DERIVING THE EMPIRICAL EXPRESSIONS

The scattering parameters of an ideal series stub in a transmission-line (i.e., one with no losses and zero width and hence no branching point and end effects) are

$$S_{11s} = \frac{z_{in}}{2 + z_{in}} \tag{1}$$

$$S_{21s} = \frac{2}{2 + z_{in}} \tag{2}$$

where z_{in} is the impedance seen looking into the stub normalized to the characteristic impedance of the main transmission line.

$$z_{in} = z \left(\frac{z_t + \tanh \gamma \ell_e}{1 + z_t \tanh \gamma \ell_e}\right) \tag{3}$$

where z is the characteristic impedance of the stub divided by the characteristic impedance of the main transmission line.

$\gamma = \alpha + j\beta$ is the propagation constant in the stub.

ℓ_e = length of the stub in the equivalent circuit.

z_t is the terminating impedance of the stub divided by the characteristic impedance of the stub.

When a shunt admittance jB_s is added as shown in Figs. 1(a) and 1(b) the overall scattering parameters can be found from Mason's non-touching loop rule [6]

$$S_{11} = S_{11b} + \frac{S_{21b}^2 (S_{11s} - \Delta S_s S_{11b})}{1 - 2S_{11s}S_{11b} + \Delta S_s S_{11b}^2} \tag{4}$$

$$S_{21} = \frac{S_{21b}^2 S_{21}}{1 - 2S_{11s}S_{11b} + \Delta S_s S_{11b}^2} \tag{5}$$

where $S_{11b} = \frac{-jb_s}{2+jb_s}$ is the reflection coefficient of a shunt admittance $jb_s = jB_s Z_{01}$ (normalized to the characteristic admittance of the main transmission line), and $S_{21b} = 1 + S_{11b}$ is the transmission coefficient of this shunt admittance, and $\Delta S_s = S_{11s}^2 - S_{21s}^2$. The following formulae were obtained by optimizing the fit of equations (4) and (5) to the experimental data for series stubs. For convenience of scaling, all variables were normalized to the substrate thickness s.

$$b_s = 7.56 \ (s/\lambda) \exp(-0.3117 \ d/s) \tag{6}$$

$$z = 2.0 \ (1.524 \ d/s)^{-0.594} \tag{7}$$

$$\alpha = (0.08 \ s/\lambda) \ \text{Nepers/mm} \tag{8}$$

Short-circuited stubs are terminated by an excess length of line $\Delta\ell$

$$\Delta\ell/s = 0.1082 \ (d/s)^2 \ [1 - \exp(-0.762 \ \ell/s)] \tag{9}$$

Open circuited stubs are terminated by a parallel combination of an inductive and a capacitive reactance, x_ℓ and x_c (See Fig. 1(b)). These reactances are normalized to the characteristic impedance of the stub and given by (10) and (11).

$$x_\ell = (s/\lambda) \ (84.12 - 2.474 \ \ell/s) \tag{10}$$

$$1/x_c = (s/\lambda)(30.93-7.422 \ \ell/s)(0.026-0.17 \ d/s) \tag{11}$$

(10) and (11) can be used to find the normalized terminating impedance

$$z_t = \frac{x_\ell \, x_c}{x_\ell + x_c} \tag{12}$$

Expressions (6) to (11) are valid in the following ranges:

$$1.6 < \ell/s < 5.3 \tag{13}$$

$$0.6 < d/s < 2.7 \tag{14}$$

$$32 < \lambda/s < 49 \tag{15}$$

When the error is computed as the magnitude of the difference between the fitted and measured scattering parameters, the standard deviation for short circuit fit is 0.03 and that for the open circuit fit is 0.045. The reference planes of the scattering parameters are coincident with the stub edges.

The restriction to constant stub width allows simple expressions and should have little effect on the flexibility of practical designs. Also, expressions (6) to (11) do not depend on the waveguide dimensions because small gap ratios (d/b<<1) and narrow substrates (s/a<<1) are assumed.

The expressions operate on normalized dimensions to allow convenient scaling to frequencies higher than x-band. Losses are expected to increase linearly with frequency as indicated by (8).

The wavelength in a stub can be computed from the following formula for wavelength in single ridge unilateral fin line on substrates with $\varepsilon_r = 2.22$:

$$\lambda_g/s = a_1 + a_2(s/\lambda) + a_3(s/\lambda)^2 + a_4(s/\lambda)^3 \tag{16}$$

where $a_1 = 150.4 + 24.29\ (d/s)$ (17)

$$a_2 = -9092 - 2098\ (d/s) \quad (18)$$

$$a_3 = 236500 + 64900\ (d/s) \quad (19)$$

$$a_4 = -2269000 - 690800\ (d/s) \quad (20)$$

This formula is accurate to ±1 percent over the same ranges as (14) and (15) and for

$$s/a < 0.1$$

The wavelength in the stub is the same as the wavelength in a single ridge unilateral fin line when the gap is equal to half the stub width.

CONCLUSION

S-parameter measurements were made to derive expressions for the parameters of open- and short-circuited series stubs in single ridge unilateral fin line. The expressions include losses and show the effect of fin line gap, stub length, and frequency and are valid for a complete waveguide bandwidth, for a specified range of low fin line gap ratios, and for a specified range of narrow substrate thicknesses.

REFERENCES

[1] Hofmann, H.: "MM-Wave Gunn Oscillator with Distributed Feedback Fin-Line Circuit", Proc. 1980 IEEE MTT-S International Microwave Conference, pp. 59-61.

[2] Meier, P.J.: "Wideband Subharmonically Pumped W-Band Mixer in Single-Ridge Fin-Line", 1982 IEEE MTT-S Digest, pp. 201-203.

[3] Souza, J.R. and Talboys, E.C.: "S-Parameter Characterization of Coaxial to Microstrip Transition", IEEE Proc., Vol. 129, Pt. H., No. 1, Feb. 1982, pp. 37-40.

[4] Gupta, K.C., Garg, R., and Chadha, R.: "Computer-Aided Design of Microwave Circuits", Artech House, 1981, pp. 319-321.

[5] Kruppe, W. and Sodomsky, K.F.: "An Explicit Solution for the Scattering Parameters of a Linear Two-Port Measured with an Imperfect Test-Set", IEEE Trans. MTT, Jan. 1971, pp. 122-123.

[6] Mason, S.J.: "Feedback Theory-Further Properties of Signal Flow Graphs", Proc. IRE, 1956, 44, pp. 920-926.

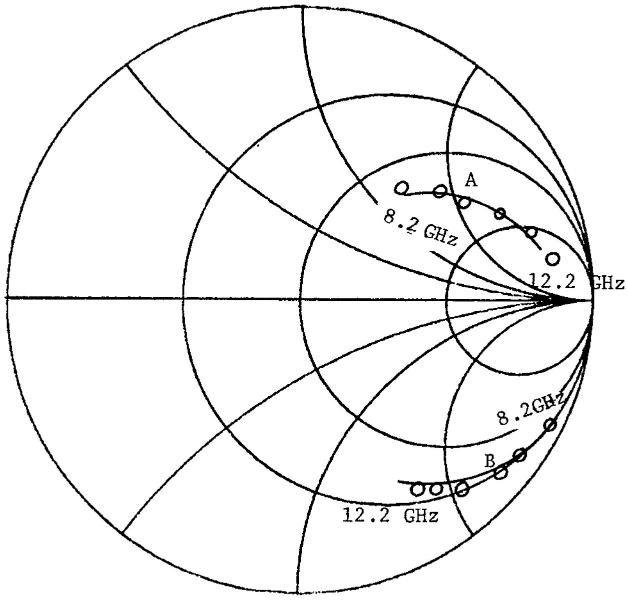

Fig. 3 Comparison of measured data (circles) to fitted curves (continuous lines) for (A) a short circuited stub and (B) an open circuited stub. Each stub is 4 mm long and in a single ridge unilateral fin line with fin line gap of 0.85 mm.