THEORETICAL AND EXPERIMENTAL CHARACTERIZATION OF RADIAL-RESONATOR WAVEGUIDE MOUNTING STRUCTURES

Andrew Ko and Bevan D. Bates

Department of Electrical and Electronic Engineering
The University of Melbourne, Parkville, Victoria 3052, Australia.

Abstract

Further development of millimeter wave computer-aided design methods requires accurate analysis and measurement techniques. This paper provides a useful source of experimental data for verification of a systematic computer-based analysis for a radial-resonator diode-mounting structure. The measurements are processed through an accurate de-embedding technique for this radial-waveguide device.

Introduction

The problem of modeling a diode post-mounting structure has been under study for many years. Eisenhart and Khan [1] carried out an extensive analysis, using a Dyadic Green's function approach with an extension of the induced EMF method, to obtain expressions for the driving-point impedance. An equivalent circuit was presented for the single-gap mount. This approach was then applied to the analysis of a single-post two-gap mount and correlation has been established between a coaxial-waveguide junction and post-gap structure by Eisenhart [2].

Recently, Williamson [3,4,5] has suggested an approach which used a magnetic-current excitation to obtain admittance expressions from summation of the infinite series resulting from the images together with appropriate boundary conditions. Bialkowski [6] has applied the image method of Williamson to accurately account for the effect of the waveguide environment including either matched and short-circuited waveguide terminations, provided the disc is not too large compared with the waveguide width.

Bates [7] extended Bialkowski's approach to the analysis of a wide variety of diode mount configurations by the use of a multi-modal Y-parameter representation of the regions within the mounts. Application to mounts with multiple radial steps was achieved through the use of a coupling-coefficient matrix determined by mode-matching at the boundaries of the radial regions. His systematic approach could also be applied to the dual diode structure such as that of Talwar [8] and a varactor-tuned oscillator with two diodes mounted on a single post [9].

To assess the accuracy of the formulations presented above, extensive comparisons of theoretical and experimental results need to be undertaken. However, the sources of experimental data used in these comparisons have been limited. Williamson [3,4,5] obtained verification of theoretical results from the experimental studies carried out by Eisenhart and Khan [1,2]. Bialkowski [6] also compared numerical results with previously published experimental and theoretical data [3,5].

This paper provides a useful source for experimental verification of theoretical analysis. An accurate de-embedding method is developed for vector network measurements for a wide range of diode mounting structures (Fig. 1).

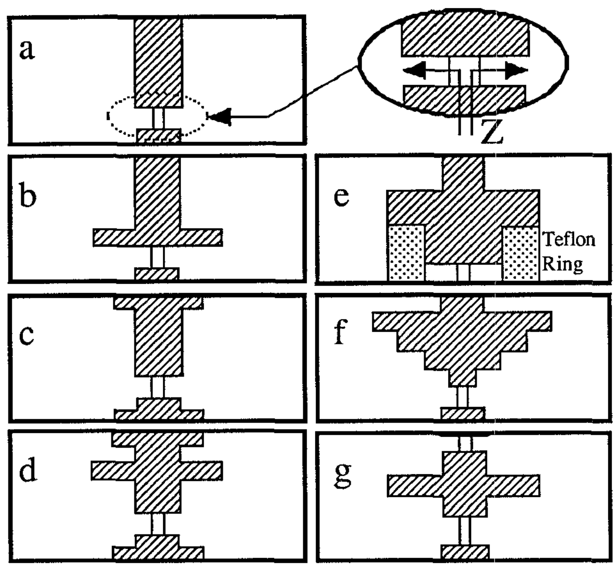

Fig. 1 *Radial resonator waveguide diode mounts*
a. Post mount
b. Resonant-cap mount
c. Post mount with lower and upper step
d. Resonant-cap mount with lower and upper step
e. Dielectric-loaded mount
f. Multiple-step mount
g. Talwar power combiner

Mount Analysis Program

MARGARET (Modal Analysis of Radial Guide And Resonators with External Terminations) is a user-oriented computer-aided design (CAD) program for the design of millimeter-wave circuits using semi-conductor devices mounted in waveguiding structures. Being developed from a previously-reported modal analysis [7], *MARGARET* determines the driving-point impedance of a wider range of waveguide diode mounting structures using radial resonators. An example of the type of mount that can be analysed is the resonant-cap mount widely used in GUNN and IMPATT oscillators. The program allows the user to easily vary mount dimensions, dielectric constants and waveguide short positions so that design optimization can be achieved for a particular frequency range of operation. The program also analyses multiple-step and dual-gap configurations.

Experimental Setup

A versatile mount device (Fig. 2), in which a wide range of mount structures can be installed, has been designed to extend the experimental study by Eisenhart and Khan [1]. It consists of ten simple disc mounts with a maximum diameter of 15mm, a thick disc mount with a teflon ring, a multiple step mount and a disc mount for Talwar 2-port power combiner. The positions of the mount holder and K-cable holder can be adjusted to create a upper step and a lower step to enhance the variety of measurements. The mount device is flexible and its dimensions can be changed to accomodate different waveguides. For the present measurements, only the X-band waveguide (22.86mm x 10.16mm) has been used. A set of waveguide direct short, offset shorts (4.758mm, 9.573mm, 14.364mm) and match can be applied for different waveguide terminations.The subminature K coaxial cable and connector provide excellent performance up to 46 GHz and compatibility with SMA and APC-3.5 [10].

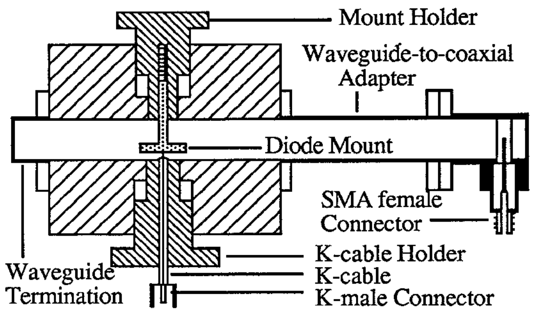

Fig. 2 *The versatile mount device with a radial resonator*

Equivalent Circuit Model

To enable accurate de-embedding for the parameters of the desired mounting structure from the measured S-parameters, the connection interfaces were modelled by an equivalent circuit. The forward and reverse transmission models (Fig. 3) consisted of the K-connector and cable, the coaxial-to-radial transistion, the device under test, and the waveguide-to-coaxial adapter.

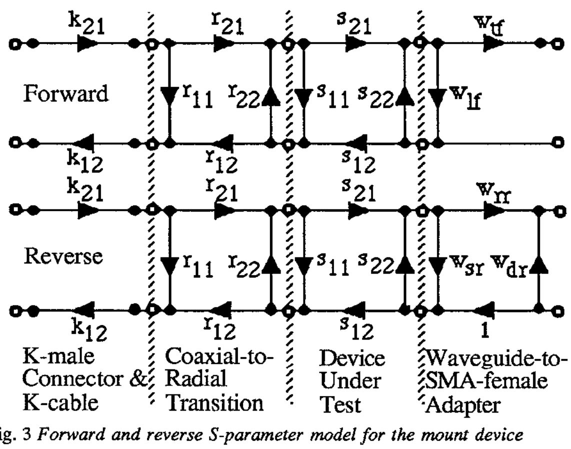

Fig. 3 *Forward and reverse S-parameter model for the mount device*

De-embedding Parameters

1. *Waveguide-to-coaxial adapter*

With the application of a 2-port calibration technique, the model of waveguide-to-coaxial adapter has been determined. With another coaxial-to-waveguide adapter, measurements were taken at same frequency points as that of the mount device. Reflection measurements (Fig. 4a) were taken with X-band waveguide direct short and offset short precision terminations (4.758mm, 9.573mm). Similarly, reflection and transmission measurements (Fig. 4b) were taken with a through connection. The directivity (w_{df}), source match (w_{sr}), load match (w_{lf}), reflection and transmission frequency response (w_{rr} and w_{tf}) were then extracted (Fig. 4c).

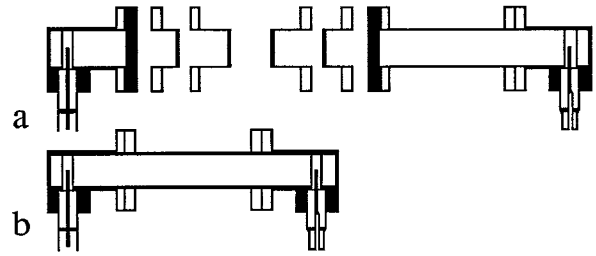

Fig. 4 *Waveguide-to-coaxial adapter*
a. Reflection measurements with direct and offset shorts
b. Reflection and transmission measurements with through connection

2. *K-cable and connector*

A section of a known length of K-cable with connectors has been assembled. Applying a known APC-3.5 offset short standard, the equivalent K-cable length, l_C, of each connector was estimated. As the reflections due to the K-to-APC-3.5 connector interface were negligible in this frequency range, the model of the K-connector and cable of a known length, l_L, was simplified to an equivalent length of line (Fig. 5).

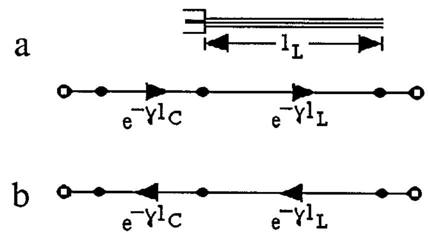

Fig. 5 *K-cable and connector*
a. A known length of K-cable with connector
b. S-parameter model

3. *Coaxial-to-radial transition*

Applying Williamson's equivalent circuit [11], the Z-parameters of the 2-port network was calculated. The S-parameters were obtained through Z-S transformation (Fig.6).

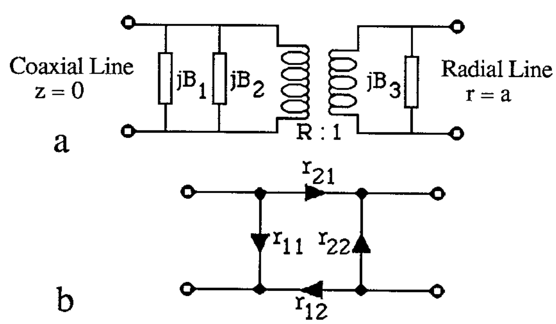

Fig. 6 *Coaxial-to-radial transition*
a. Williamson 's equivalent circuit
b. Equivalent S-parameter model

Measurements and De-embedding

Using an automatic vector network analyzer system, error-corrected measurements were taken for all S-parameters over the frequency range of interest (7.5 to 12.5GHz). The selection of APC-3.5 mm male and female connection made the calibration possible with normal 3.5 mm calibration kit of offset open, offset short, match and thru, thus avoiding the unavailable radial calibration standards [12] and a specific waveguide-to-coaxial adapter [13]. The waveguide-to-coaxial adapter, the K-connector and cable and the coaxial-to-radial transition parameters were de-embedded from the measurements. Then the S-parameters for the device-under-test could be obtained to calculate the driving-point impedance of diode mounting structures.

Experimental Verification

Fig. 7 describes the parameters of a general 2-port multiple-step diode mount and Fig. 8 shows that the results computed with *MARGARET* agree very well with the experimental results for a variety of mounting structures. In all figures, the data clearly show the zeros and poles as predicted by *MARGARET*, providing the verification desired. For Fig. 8g, the disc might not be exactly horizontal and could have misalignment as it was only supported by the center conductors of K-cable holders. For the rest of the figures, the correlation between the measured data and results of MARGARET is excellent.

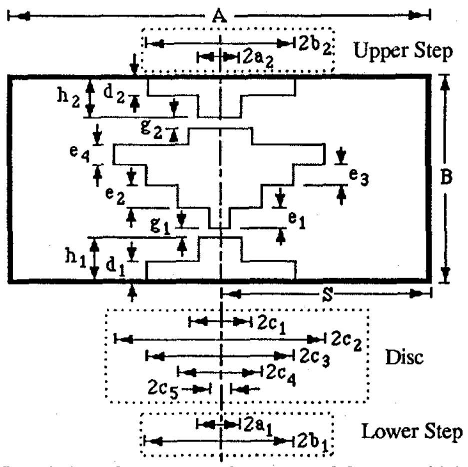

Fig. 7 *Description of parameters for a general 2-port multiple-step diode mount*

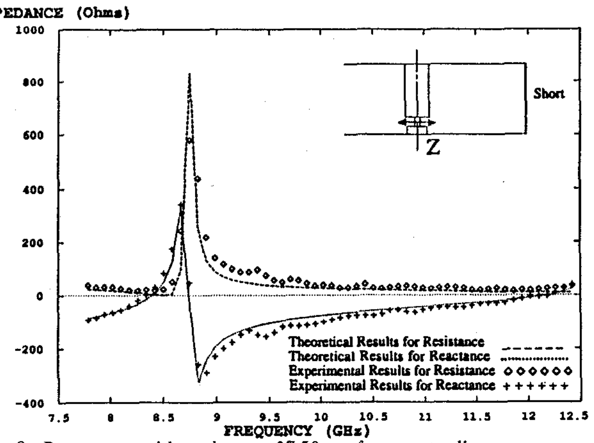

Fig. 8a *Post mount with a short at 27.50mm from center-line*
$a_1 = b_1 = 1.51$, $a_2 = b_2 = c_1 = c_2 = c_3 = c_4 = c_5 = 1.65$, $d_1 = d_2 = 0$, $g_1 = 1.66$, $g_2 = 0$, $h_1 = 1.14$

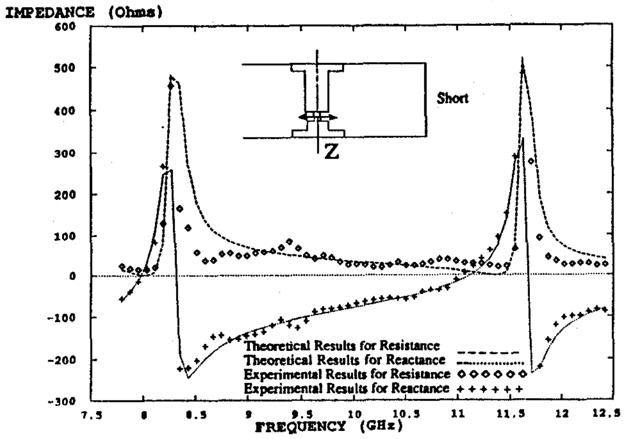

Fig. 8b *Post mount with a lower and upper step and a short at 32.26mm from center-line*
$a_1 = 1.51$, $b_1 = 3.48$, $a_2 = 1.65$, $b_2 = 3.48$, $c_1 = c_2 = c_3 = c_4 = c_5 = 1.65$, $d_1 = 1.03$, $d_2 = 0.95$, $g_1 = 1.66$, $g_2 = 0$, $h_1 = 2.17$

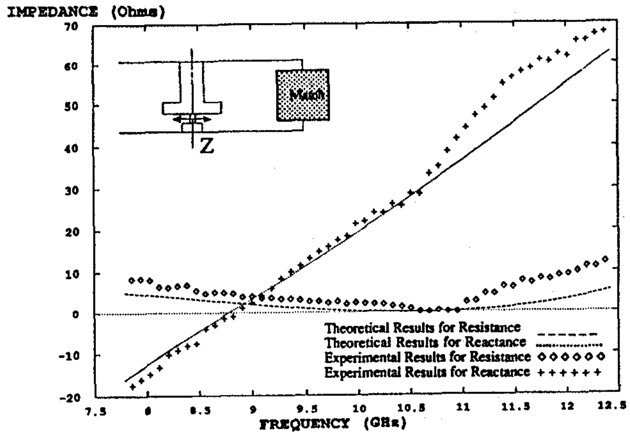

Fig. 8c *Resonant-cap mount with a match*
$a_1 = b_1 = 1.51$, $a_2 = b_2 = c_1 = c_3 = c_4 = c_5 = 1.65$, $c_2 = 4.00$, $d_1 = d_2 = 0$, $e_1 = e_2 = e_3 = 0$, $e_4 = 1.50$, $g_1 = 1.66$, $g_2 = 0$, $h_1 = 1.14$

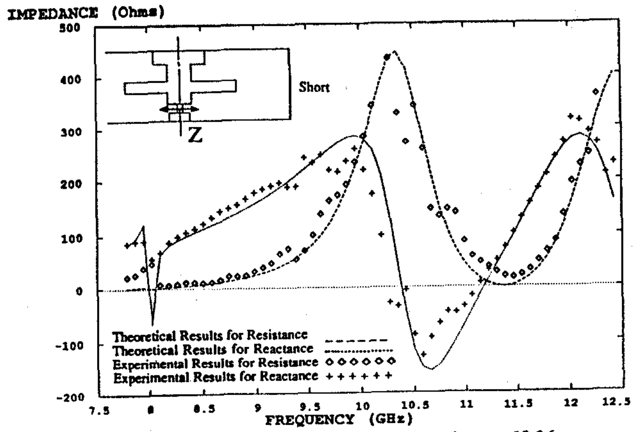

Fig. 8d *Resonant-cap mount with a upper step and a short at 32.26mm from center-line*
$a_1 = b_1 = 1.51$, $a_2 = 1.65$, $b_2 = 3.48$, $c_1 = c_3 = c_4 = c_5 = 1.65$, $c_2 = 7.50$, $d_1 = 0$, $d_2 = 1.91$, $e_1 = e_2 = 0$, $e_3 = 2.50$, $e_4 = 1.50$, $g_1 = 1.66$, $g_2 = 0$, $h_1 = 1.14$

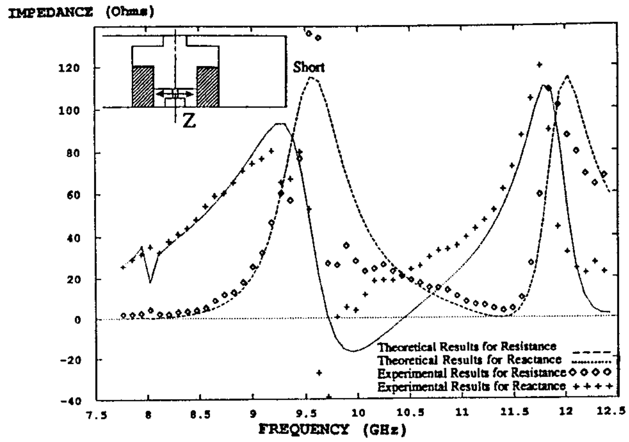

Fig. 8e *Dielectric-loaded mount with a short at 32.26mm from center-line*
$a_1 = b_1 = 1.51$, $a_2 = b_2 = c_1 = 1.65$, $c_2 = 6.00$, $c_3 = c_4 = c_5 = 3.00$, $d_1 = d_2 = 0$, $e_1 = e_2 = 0$, $e_3 = 3.0$, $e_4 = 3.00$, $g_1 = 1.45$, $g_2 = 0$, $h_1 = 0.40$, $\varepsilon_r = 2.1$

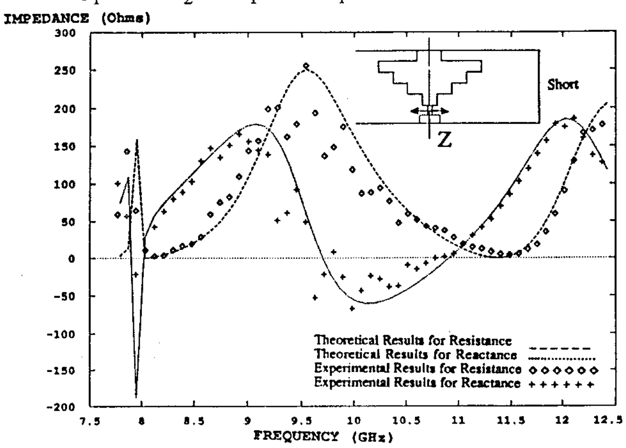

Fig. 8f *Multiple-step mount with a short at 32.26mm from center-line*
$a_1 = b_1 = 1.51$, $a_2 = b_2 = c_1 = 1.65$, $c_2 = 7.00$, $c_3 = 5.00$, $c_4 = 3.00$, $c_5 = 1.00$, $d_1 = d_2 = 0$, $e_1 = e_2 = e_3 = e_4 = 1.50$, $g_1 = 1.73$, $g_2 = 0$, $h_1 = 1.14$

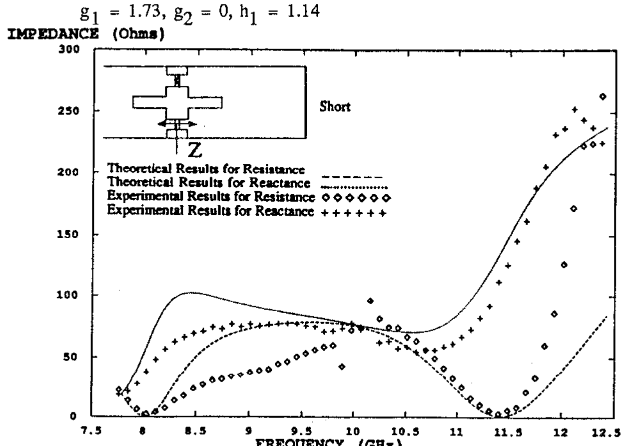

Fig. 8g *Talwar power combiner with a 50-ohm termination at gap 2 and a short at 32.26mm from the center-line*
$a_1 = b_1 = a_2 = b_2 = 1.51$, $c_1 = c_3 = c_4 = c_5 = 1.65$, $c_2 = 6.00$, $d_1 = d_2 = 0$, $e_1 = e_2 = 0$, $e_3 = e_4 = 1.50$, $g_1 = 2.24$, $g_2 = 1.88$, $h_1 = 1.14$, $h_2 = 0.40$

Fig. 8 *Theoretical and experimental results of the driving-point impedance as a function of frequency*
For all cases, dimensions in mm, A = 22.86, B = 10.16, S/A = 0.5

Conclusion

The experimental measurements give a high degree of confidence in the theoretical results obtained using *MARGARET* indicating that the program can be used in the design millimeter-wave circuits such as oscillators, (e.g. [7]), amplifiers, mixers and filters. The de-embedded measurements over a wide range of diode mounting structures provide an useful source for experimental verification of theoretical analyses. This paper also demonstrates the development of an accurate de-embedding technique for a device in which it is not possible or convenient to define calibration standards, for example, a radial-waveguide device.

Acknowledgements

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