MINIATURE STUB AND FILTER DESIGNS USING THE MICROSHIELD TRANSMISSION LINE

T. M. Weller and L. P. Katehi

The Radiation Laboratory, EECS Dept.
The University of Michigan
Ann Arbor, MI 48109-2122

Abstract — This paper presents new CPW-type stub and filter configurations which are useful approaches for compact microwave circuit design. It is shown that conventional open- and short-end quarter wavelength stubs can be shortened by a factor of three by folding the center conductor. Also, narrowband open-end stubs are demonstrated which have thin-film overlay capacitors integrated across the stub sections. In this work the circuits have been implemented using microshield transmission line, a geometry in which a 1.4 μm-thick dielectric membrane supports coplanar conducting lines virtually in free-space. The new stub configurations, however, are also suitable for standard substrate-supported CPW.

I. INTRODUCTION

Compact layout is an important issue in microwave circuit design and it is primarily influenced by circuit crosstalk and component size. In the case of CPW (coplanar waveguide) based stub designs, crosstalk and parasitic radiation can be minimized by using series stubs which are patterned in the center conductor, as opposed to a shunt stub configuration. These types of stubs are useful for switches [1], filters [2, 3], and DC and LO blocks. At low frequencies or on low permittivity substrates, however, they tend to occupy considerable amounts of space since they are often designed to be a quarter-wavelength long. As a solution to this problem, the concept of *folded* series stubs is introduced herein. It will be demonstrated that these miniature configurations provide a narrower bandwidth than the conventional geometries and are only one third as long. Also presented in this paper is a new technique for designing narrowband stubs by combining a distributed element stub with lumped element, MIM (metal-insulator-metal) capacitors. Measured 3-dB bandwidths of around 16% have been obtained using circuits which are $\lambda/4$ in length, demonstrating a significant reduction over the 100% bandwidth of a comparable series open-end stub.

The circuits to be discussed have all been implemented using the microshield transmission line [4]. Microshield is a partially shielded geometry which is micromachined in a silicon (or GaAs) substrate and uses a 1.4 μm-thick dielectric membrane to support coplanar conducting lines essentially in free-space (Figure 1). The new stub and filter designs, however, are adaptable to standard substrate-supported coplanar waveguide, as has been verified by the authors using a full-wave analysis.

II. FOLDED SERIES STUBS

A. Short-End Stubs

A standard short-end series stub in CPW is designed by deforming the center conductor with two shorted slots which are connected to the center conductor-to-ground plane slots (Figure 2). At the resonant frequency, these inner slots are a quarter wavelength long and thus the short-circuit at point A is transferred to an open-circuit at point B, resulting in a bandstop response. Using the new approach, the inner slots are simply folded back upon themselves two times (Figure 3). This effectively reduces the stub length from $\lambda/4$ to $\lambda/12$, while achieving the same open-circuit effect at the input port. To demonstrate, the performance of a 25 GHz folded short-end stub is compared to a similar 30 GHz non-folded stub in Figure 4. The behavior of the two stubs is nearly the same except that the 3-dB bandwidth is reduced from 70% to 40% by using the folded design.

The configuration shown in Figure 3 is one of three possible means of interleaving the fingers to achieve the double-folded design, and two other configurations exist for a single-folded approach. A comparison between the bandwidth, resonant frequency and symmetry of the electrical response of these designs will be presented at the conference.

B. Open-End Stubs

The open-end series stub is identical to the short-end stub except that the center conductor slots on either side are connected to each other. This creates an open-circuit at the ends of the slots, which transfers to a short circuit at the input port at the resonant frequency and gives a bandpass response. The folding technique has also been applied here to reduce the effective stub length to $\lambda/12$ (Figure 5), and the performance remains essentially unchanged from that of the non-folded design. A comparison between a 25 GHz folded stub and a 30 GHz non-folded stub is shown in Figure 6, and it is seen that the only significant change with the folded design is a reduction of the 3-dB bandwidth from 100% to 85%. The passband insertion loss for the folded and non-folded designs is 0.4 and 0.5 dB, respectively.

The one alternative configuration for the double-folded open-end stub takes the form of a 7-finger CPW interdigitated capacitor (see [5]). The capacitors are typically used below their first resonance, however, and not in tuning stub applications. A comparison between these two double-folded designs and a single-folded version will be presented at the conference.

In order to demonstrate the application of the folded open-end stub, a five-section bandpass filter was developed with the aid of a full-wave analysis. The design consists of five series stubs with the dimensions shown in Figure 5, with the 2^{nd} and 4^{th} stubs reversed relative to the others. Including some small inter-stub spacing, the total filter length is $\lambda/2$ (6 mm) at the center frequency of 25 GHz, whereas the length would be 1.3 λ (15.6 mm) using the non-folded geometry. As shown in Figure 7, the passband insertion loss is 2 dB and the 3-dB bandwidth is 32%. Improvements in the loss performance are expected to be made by utilizing a higher impedance line. This is based on results in [6] which showed that the conductor loss in microshield drops from 0.05 dB/mm to 0.025 dB/mm when the characteristic impedance increases from 75 Ω to 100 Ω. The impedance used here is 70 Ω.

III. NARROWBAND STUB DESIGNS

In addition to the folded stub configurations, a different design approach has been developed which emphasizes bandwidth reduction. It is based on the use of lumped element MIM capacitors integrated with distributed element, series stubs. The capacitors are thin-film overlay designs with a silicon monoxide ($\epsilon_r = 6$) insulator, and only the conventional (non-folded) open-end stubs have been used to date. It is noted that different variations of combining lumped and distributed elements for filter applications have been presented previously, e.g. [7, 8].

The configuration of interest consists of two cascaded stubs, with the second stub reversed relative to the first. By using an equivalent circuit which was proposed by Dib et al. [2], it was found that an appropriate increase in the shunt capacitance resulted in narrowband bandpass resonances. Furthermore, these resonances occurred at frequencies much lower than the natural quarter-wavelength frequency of an isolated stub, leading to electrically short designs.

The preliminary testing of these narrowband stubs has proven that the necessary shunt capacitance can be obtained by integrating MIM capacitors along the length of the stubs. As an example, a circuit which uses 450 x 20 μm^2 capacitors, positioned 480 μm from the ends of each stub, is shown in Figure 8. The measured insertion loss is 1.25 dB and the 3-dB bandwidth is 16% (Figure 9). Furthermore, the total circuit length is only $\lambda/4$ at the center frequency of 30 GHz. The significant reduction in bandwidth is seen by comparing these results to the performance of the non-folded $\lambda/4$ stub shown in Figure 6. Further research on these narrowband stubs will examine the bandwidth versus insertion loss tradeoff and the development of a design/analysis methodology.

IV. ACKNOWLEDGEMENT

This work is supported by the Jet Propulsion Laboratory under contract number PF-399. The authors would also like to thank Jim Kulman for his advice and assistance regarding dielectric thin-film deposition.

V. REFERENCES

[1] P. A. R. Holder, "X-band microwave integrated circuits using slotline and coplanar waveguide," *The Radio and Electronic Engineer*, Vol. 48, No. 1/2, January/February 1978, pp. 38-42.

[2] N. Dib, P. Katehi, G. Ponchak and R. Simons, "Theoretical and Experimental Characterization of Coplanar Waveguide Discontinuities for Filter Applications," *IEEE Trans. MTT*, pp. 873-882, May 1991.

[3] D. F. Williams and S. E. Schwarz, "Design and Performance of Coplanar Waveguide Band-Pass Filters," *IEEE Trans. MTT*, vol. MTT-31, pp. 558-566, July 1983.

[4] N. Dib, W. Harokopus, P. Katehi, C. Ling, and G. Rebeiz, "Study of a Novel Planar Transmission Line," *1991 IEEE MTT-S Digest*, pp. 623-626.

[5] G. Kibuuka, R. Bertenburg, M. Naghed and I. Wolff, "Coplanar Lumped Elements and Their Application in Filters on Ceramic and Gallium Arsenide Substrates," *Proceedings of the 1989 European Microwave Conference*, pp. 656-661.

[6] T. M. Weller, L. P. Katehi and G. M. Rebeiz, "High Performance Microshield Transmission Line Circuits," *To appear in IEEE Trans. MTT, March 1995.*

[7] T. Ishizaki, M. Fujita, H. Kagata, T. Owano and H. Miyake, "A Very Small Dielectric Planar Filter for Portable Telephones," *IEEE Trans. MTT*, vol. MTT-42, pp. 2017-2022, November 1994.

[8] R. Pregla, "Microwave Filters of Coupled Lines and Lumped Capacitances," *IEEE Trans. MTT*, vol. MTT-18, pp. 278-280, May 1970.

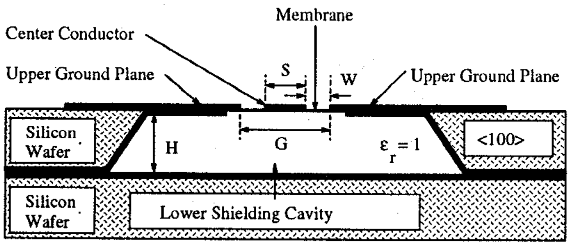

Figure 1: The microshield transmission line geometry (not to scale). The dark lines indicate metallization, which is typically 1-2 microns thick.

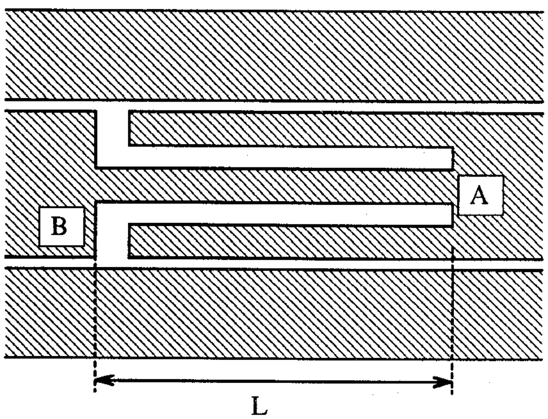

Figure 2: Metallization pattern for a conventional, non-folded series short-end stub. At the resonant frequency, the length L is approximately $\lambda/4$.

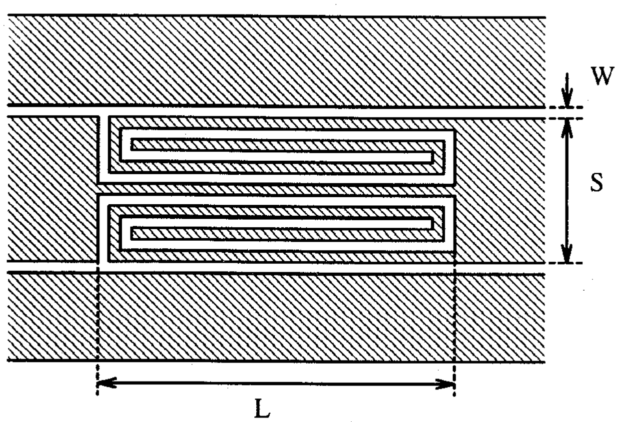

Figure 3: Metallization pattern for the microshield folded short-end stub (f_c = 25 GHz). The dimensions are L=1.14, W=0.02, S=0.26 and the finger width and spacing are 0.02 (millimeters).

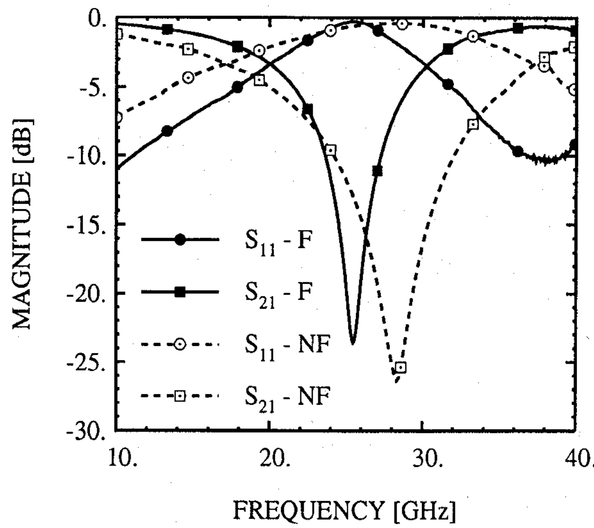

Figure 4: Measured performance of the folded short-end stub shown in Figure 3 (F) compared to the measured performance of a similiar non-folded microshield stub (NF).

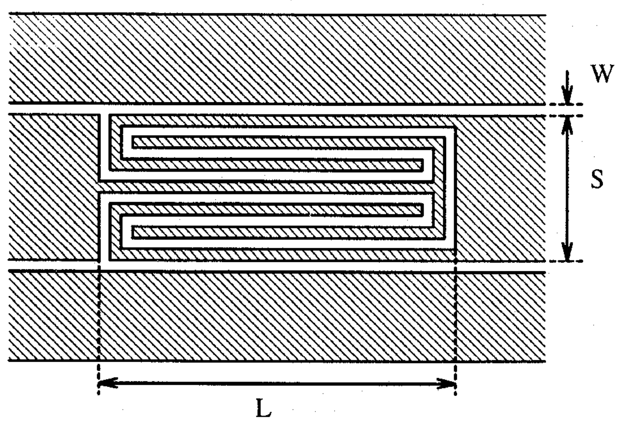

Figure 5: Metallization pattern for the microshield folded open-end stub (f_c = 25 GHz). The dimensions are L=1.02, W=0.02, S=0.26 and the finger width and spacing are 0.02 (millimeters).

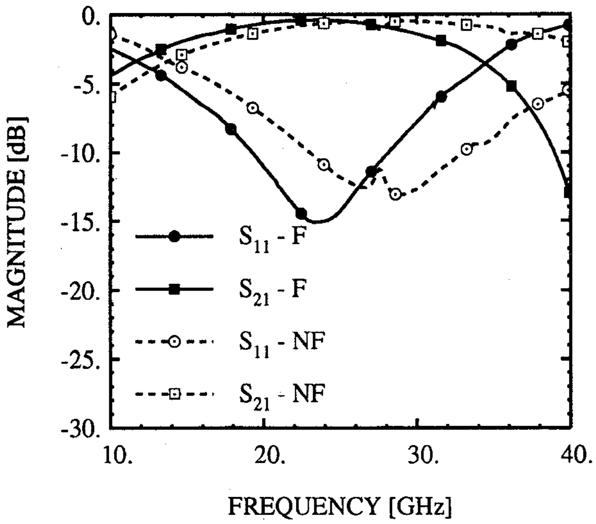

Figure 6: Measured performance of the folded open-end stub shown in Figure 5 (F) compared to the measured performance of a similiar non-folded microshield stub (NF).

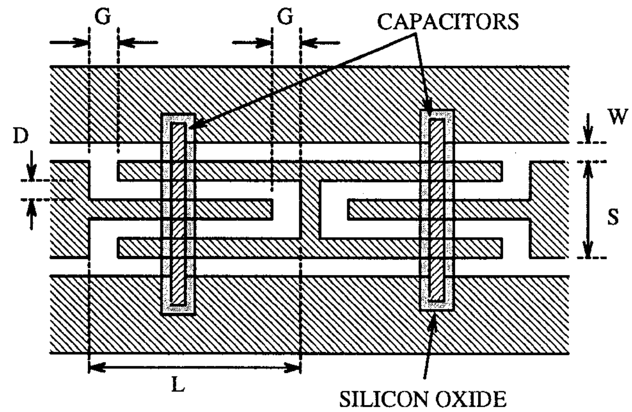

Figure 8: Metallization pattern for the microshield 2-section open-end stub with overlay capacitors. The dimensions are L=1.29, W=0.02, S=0.26, D=0.025, and G=0.1 (millimeters). One micron-thick films of silicon monoxide (ϵ_r = 6.0) are used for the capacitor dielectric.

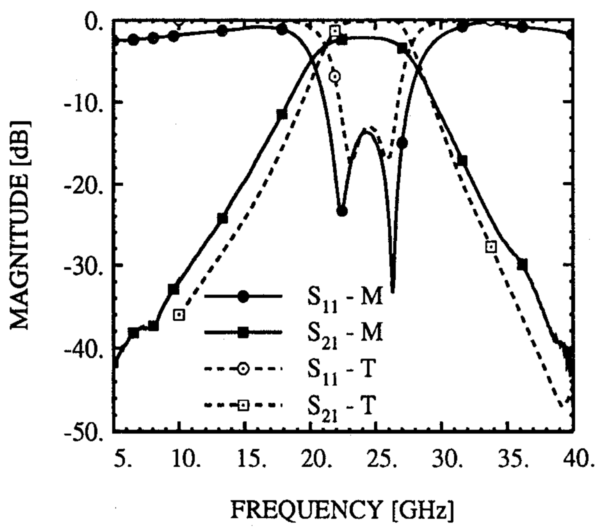

Figure 7: Measured performance of a 5-section bandpass filter which uses the folded open-end stub shown in Figure 5 (M). Also shown is the theoretical performance predicted by a full-wave analysis (T).

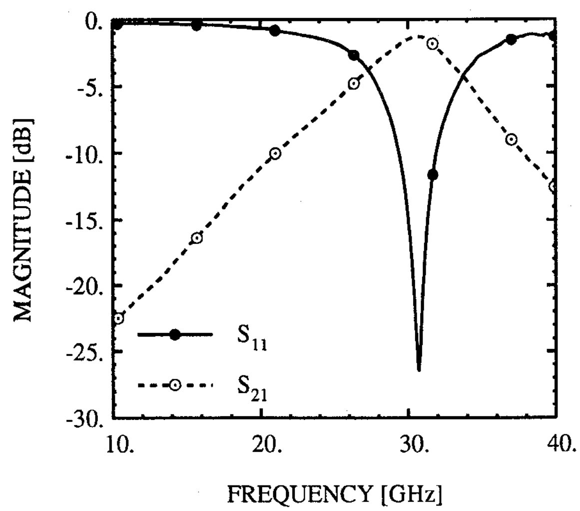

Figure 9: Measured performance of the compact open-end stub shown in Figure 8.