A 250-GHz Microshield Bandpass Filter

Thomas M. Weller, *Student Member, IEEE,* Linda P. Katehi, *Senior Member, IEEE,* and Gabriel M. Rebeiz, *Senior Member, IEEE*

***Abstract*—A four-section, planar bandpass filter has been designed, fabricated and tested at 130–360 GHz. The filter is based on the microshield line, a half-shielded transmission line in which the conducting lines are supported on a 1.4-μm-thick dielectric membrane. The insertion loss of the filter is less than 1.5 dB with a 58% relative bandwidth at 250 GHz, demonstrating the excellent performance of the microshield geometry. Also, a Monte Carlo routine was developed in conjuction with a semi-empirical/semi-analytical model to allow the S-parameters of the filter to be derived from scalar power measurements.**

I. Introduction

The potential for high performance planar circuits which are implemented in conventional substrate-supported microstrip or coplanar waveguide is severely limited at sub-millimeter wave frequencies. This shortcoming is primarily due to dielectric and radiation losses, and the most common solution is to utilize waveguide-based designs [1]. One quasi-planar transmission line which can overcome these difficulties is the microshield line. Introduced in 1991 [2], microshield is a half shielded geometry, similar to CPW, which uses a thin (around 1.4 μm) dielectric membrane to support the conducting lines and upper ground planes above a metallized shielding cavity. It is characterized by low loss, broad band TEM propagation and has previously been demonstrated in circuits operating at Ka-band [3], [4] and W-band [5]. In the work presented here, microshield is utilized to fabricate the first planar bandpass filter at 250 GHz. This paper also describes a quasi-optical measurement technique which was developed in order to determine the filter S-parameters in the presence of reflections at the filter input and output ports, due to the receiving antenna and the microbolometer used for power detection, respectively.

II. Bandpass Filter

The bandpass filter consists of a compact configuration of open-end series stubs which provides both low loss and longitudinal symmetry. Application of the open-end stub to filter design has been examined in previous publications, in which it was noted that the location of the stub within the center conductor leads to greater field confinement and thus lower radiation loss than is characteristic of straight gap-coupled resonators or stubs with lateral extension [6], [7]. The design applied here utilizes four quarter-wavelength stubs which are resonant at 250 GHz, with the second and fourth stubs reversed relative to the first and third (Fig. 1).

Manuscript received November 11,1994. This work was supported by the NASA Center for Space Terahertz Technology and the Office of Naval Research.

The authors are with The Radiation Laboratory, University of Michigan, Ann Arbor, MI 48109-2122 USA.

IEEE Log Number 9410021.

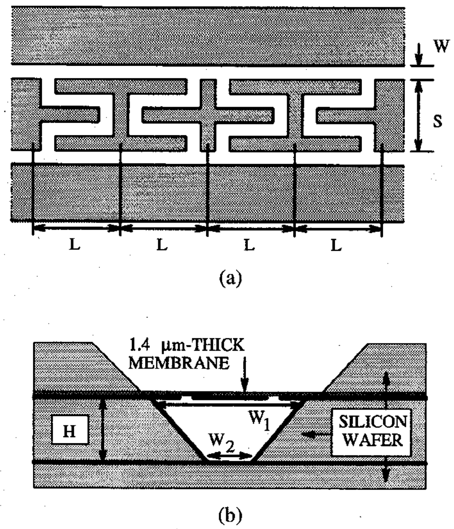

Fig. 1. The four-section microshield bandpass filter (not to scale). The metallization pattern is shown in (a), where L = 250, S = 50, and W = 10. A cross-sectional view is shown in (b), where H = 200, W_1 = 320, and W_2 = 40. The geometry is comprised of three silicon wafers which are used to support the membrane and filter metallization, form the cavity sidewalls, and complete the lower ground plane, respectively. In (b), metallization is indicated by the dark lines. All dimensions are in μm.

III. Measurement Technique

At frequencies above 115 GHz, there are currently very few options available for microwave circuit characterization. Electrooptic sampling and waveguide-based approaches are possible techniques, but were not available for this project. Therefore, an alternative technique based on quasi-optical methods was developed which uses a semi-empirical/semi-analytical model to extract the circuit S-parameters.

The objective of the quasi-optical measurement is to determine the amount of power transmitted through the filter as a function of frequency, using the circuit shown in Fig. 2. In this figure, RF power is supplied from a Gunn diode/tripler pair and coupled into the circuit through a CPW-fed, double folded-slot antenna [8]. A thin-film bismuth microbolometer detector [9] is placed at the output of the filter, in parallel with an RF short which is positioned approximately a quarter-wavelength away (L_4). The RF short is a silicon oxide (SiO) thin-film capacitor which allows DC biasing of the bolometer detector and presents an open circuit at the output of the filter. The power measurement is made by modulating the RF signal with a 1 KHz square wave and using a lock-in amplifier to

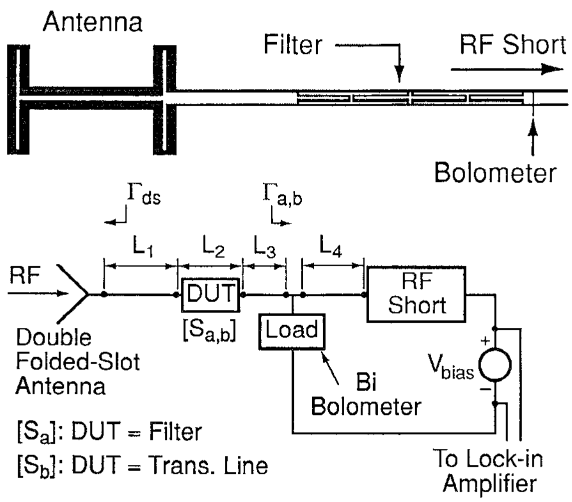

Fig. 2. Diagram of the circuit used in the quasi-optical measurement, where DUT stands for device under test. The upper illustration shows a circuit which has a bandpass filter as the DUT. The reflection coefficients Γ_a and Γ_b may be different, in general, to allow for fabrication tolerances between the bolometers of the filter circuit and the transmission line circuit.

detect the 1 KHz voltage across the bolometer. As a means of calibration, a similar circuit is utilized in which the filter is replaced by a straight length of microshield transmission line. Using the measured absolute responsivity (in Volts/Watt) of the bolometers in each circuit, one can determine the ratio of the power received through the filter (P_{filt}) to that received through the transmission line (P_{TL}).

IV. S-Parameter Extraction

The remaining step involved in characterizing the filter is to extract its S-parameters using the experimental values for $P_{\text{filt}}/P_{\text{TL}}$. An equation which relates the scalar power measurement data and all the pertinent vector quantities in the system is derived from the circuit model in Fig. 2

$$\begin{aligned} P_{\text{filt}}/P_{\text{TL}} = &|S_{21,a}|^2 \, |1 - \Gamma_{ds}\Gamma_b e^{-2\gamma(L_1+L_2+L_3)}|^2 \\ &\cdot \left(\frac{1-|\Gamma_a|^2}{1-|\Gamma_b|^2}\right) \\ &\times |1 + (S_{11,a}^2 - S_{21,a}^2)\Gamma_{ds}\Gamma_a e^{-2\gamma(L_1+L_3)} \\ &- S_{11,a}(\Gamma_{ds}e^{-2\gamma L_1} + \Gamma_a e^{-2\gamma L_3})|^{-2} \end{aligned} \quad (1)$$

where γ is the propagation constant of the microshield line. In order to resolve the unknowns in (1), a Monte Carlo routine (MCr) has been implemented which uses a combination of empirical and analytical data for initial values. Estimates for Γ_a and Γ_b are computed using measured values for the bolometer DC resistance and values for γ extrapolated from 10–40 GHz measurements. Initial values for the antenna reflection coefficient (Γ_{ds}), on the other hand, have been determined using a full-wave analysis [8]. After specifying upper and lower limits for all the parameters in (1), the MCr is then used to fit them to the model. An important point is that the initial range for the magnitude of the filter S-parameters is between 0 and 1, i.e. they are unconstrained. However, the quantity $|S_{11,a}|^2 + |S_{21,a}|^2$ is restricted to a range which encompasses the expected overall filter loss. Also, the range

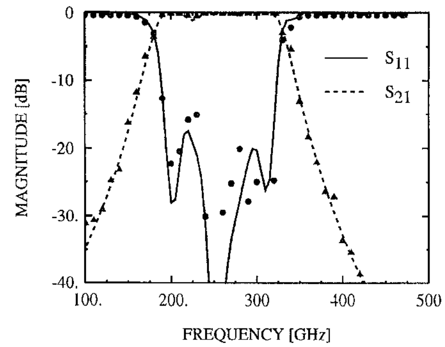

Fig. 3. Comparison between the MCr-extracted values (markers) and the "exact" predicted filter response from a full-wave analysis (lines), using a hypothetical set of system parameters to compute $P_{\text{filt}}/P_{\text{TL}}$

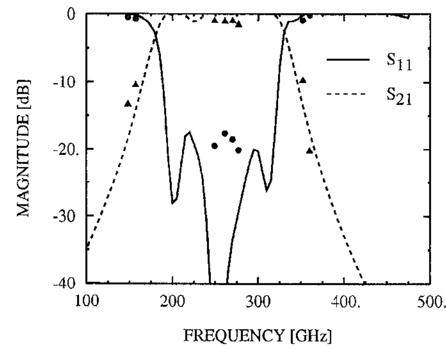

Fig 4 Comparison between the results extracted from raw measured data (markers) and the predicted filter response from the full-wave analysis (lines).

for the phase is 80° about the values predicted by a full-wave analysis of the filter.

In order to investigate this method of solution, the filter S-parameters from the full-wave analysis were used along with randomly generated values for the remaining unknowns to compute exact values for $P_{\text{filt}}/P_{\text{TL}}$. The MCr was then applied to this hypothetical data set and the accuracy proved to be very good. As shown in Fig. 3, the MCr-extracted $|S_{21,a}|$ follows the true distribution almost exactly and the maximum passband error is about 0.45 dB. As a consequence of the weaker dependence of (1) on $|S_{11,a}|$ it is more difficult to resolve this parameter. Likewise, it is only possible to determine the phase of the S-parameters when the magnitude of the respective unknown is quite large. Even then, due to the rapid phase variation in the 4-element filter, the results can only approximate the overall distribution.

V. Results and Conclusion

Using the measurement technique described in Section III and the S-parameter extraction technique described in Section IV, the performance of the filter was measured at eight frequencies from 130–360 GHz. Due to the limited RF power and the low responsivity of the bolometers (typically around 2 V/W), the dynamic range is limited to approximately 20 dB. As shown in Fig. 4, the S-parameters extracted from the raw measured data are very close to the predicted response from the full-wave analysis, which takes radiation loss into account. The measured pass-band insertion loss for this four-section filter is around 1.5 dB and the relative bandwidth is 58%. It is also seen that the low frequency stop-band provides excellent rejection. These results confirm that high-performance, planar circuits are realizable at millimeter- and submillimeter-wave frequencies using the microshield line configuration.

ACKNOWLEDGMENT

The authors would like to thank Sanjay Raman and Steve Gearhart for their help in making the measurements and Dan Ross for discussions regarding the Monte Carlo routine.

REFERENCES

[1] L. Q. Bui, D. Ball, and T. Itoh, "Broad-band millimeter-wave E-plane bandpass filters, " *IEEE Trans. Microwave Theory Tech.*, pp. 1655–1658, Dec. 1984.

[2] N. Dib, W. Harokopus, P. Katehi, C. Ling, and G. Rebeiz, "Study of a novel planar transmission line," in *1991 IEEE MTT-S Dig.*, pp. 623–626.

[3] T. M. Weller, G. M. Rebeiz, and L. P. Katehi, "Experimental results on microshield transmission line circuits," in *1993 IEEE MTT-S Dig.*, vol. 2, pp. 827–830.

[4] T. M. Weller, L. P. Katehi, and G. M. Rebeiz, "High performance microshield line components," to appear in *IEEE Trans. Microwave Theory Tech.*, Mar. 1995.

[5] S. V. Robertson, L. P. Katehi, and G. M. Rebeiz, "W-band microshield low-pass filters," in *1994 IEEE MTT-S Dig.*, vol. 2, pp. 625–628.

[6] D. F. Williams and S. E. Schwarz, "Design and performance of coplanar waveguide band-pass filters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 558–566, July 1983.

[7] N. Dib, P. Katehi, G. Ponchak, and R. Simons, "Theoretical and experimental characterization of coplanar waveguide discontinuities for filter applications," *IEEE Trans. Microwave Theory Tech.*, pp. 873–882, May 1991.

[8] T. M. Weller, L. P. Katehi, and G. M. Rebeiz, "Single and double folded-slot antennas on semi-infinite substrates," submitted to *IEEE Trans. Antenn. Propagat.*

[9] D. P. Neikirk, W. W. Lam, and D. B. Rutledge, "Far-infrared microbolometer detectors," *Int. J. Infrared Millimeter Waves*, vol. 5, no. 3, pp. 245–278, 1984.