IMPROVEMENT OF SPURIOUS PERFORMANCE OF COMBLINE FILTERS

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ABSTRACT

Methods to improve the spurious performance of combline filters are investigated. The first spurious passband of a conventional combline filter with uniform rods can be pushed to a higher frequency by using stepped rod resonators or suppressed by a careful design of the coupling slots without a noticeable sacrifice of filter insertion loss. Experiments verify the theory.

I. INTRODUCTION

Combline filters [1]-[4], with the merits of low cost, small size, relatively low loss, and good spurious response, are now widely used in many communications systems as input and output filters. For both applications, particularly for the output filter applications, it is desired that the filters have a wide stop-band to reject the first few harmonics of a transmitter or an oscillator. Traditional analysis based on the TEM mode transmission line theory predicts that the first spurious passband of a combline filter occurs at $3f_0$ for 90^o resonators and at $5f_0$ for 45^o resonators [1], where f_0 is the center frequency of the filter. In practice, the first spurious band of a combline filter often differs from the TEM mode prediction and occurs around $3f_0$. For more accurate control of the spurious performance of a combline filter, new resonant structures need to be investigated and a rigorous analysis of such structures is essential.

In this paper, a stepped rod combline resonator, which is an extension of the concept of the stepped impedance resonators introduced in [5] to improve the stop-band characteristics of dielectric filled coaxial filters, is studied analytically and experimentally. A full wave model similar to the one proposed in [6] is applied to calculate the dominant mode as well as higher order mode resonant frequencies and coupling coefficients. Numerical investigation is performed to find the effect of stepped resonator parameters on the spurious characteristics

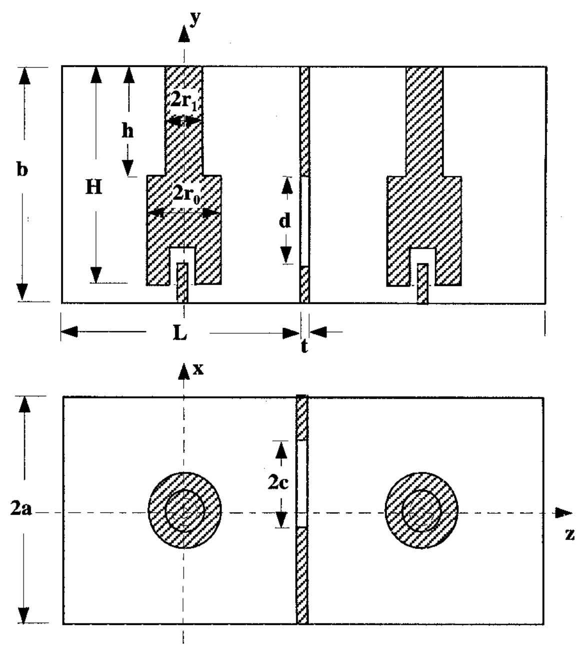


Fig. 1 Configuration of coupled combline cavities with stepped rod resonators.

and to show the different behavior of slot couplings of the dominant mode and the first higher order mode. Ways to further improvement of combline filter's spurious performances are proposed based on the analysis. As an application and a validation, an experimental five-pole Tchebyscheff filter with different resonant rods is designed and tested. The expected improvement of the spurious response is obtained.

II. ANALYSIS

The general structure of the combline resonators under consideration is shown in Fig. 1. The key for an accurate characterization of the structure, including calculation of resonant frequency and coupling coefficient for a given mode, is to solve the generalized scattering parameters $[S^r]$ of a cylindrical object, representing the resonant rod, in a rectangular waveguide. As discussed in the previous papers [6]-[8], $[S^r]$ can be obtained by mode matching technique in conjunction with the orthogonal expansion method [9][10] by introducing an artificial cylindrical boundary at $r = a$. The boundary divides the problem into a radial waveguide discontinuity problem and a problem of a rectangular waveguide discontinuity with a cylindrical boundary. Under this treatment, the resonant rod shown in Fig. 1 can be viewed as a cascade of several radial waveguide discontinuities. The procedure for matching the artificial boundary is independent on the rod structure.

With the knowledge of $[S^r]$, the characteristic equations for a single cavity and two coupled cavities can be acquired by applying proper termination conditions at the end walls of the cavities [6]. The resonant frequencies and the coupling coefficients can therefore be obtained by solving the equations.

III. NUMERICAL INVESTIGATION

Using the model discussed above, the higher order mode characteristics of combline cavities are investigated.

Fig. 2 shows the variations of the first higher order mode frequencies of stepped combline resonators, with different step length h, tuned at 55^o and 64^o, respectively; where the electrical length is defined as $\theta = k_0 H$; f_0 is the dominant mode frequency; f_1 is the first higher order mode frequency. $h/H = 0$ and $h/H = 1$ represent the uniform rods with radius of r_0 and r_1, respectively. As can be seen there exists an optimum step length at which the first higher order mode is pushed to the highest possible frequency. The optimized step length changes with the change of electrical length of the resonator.

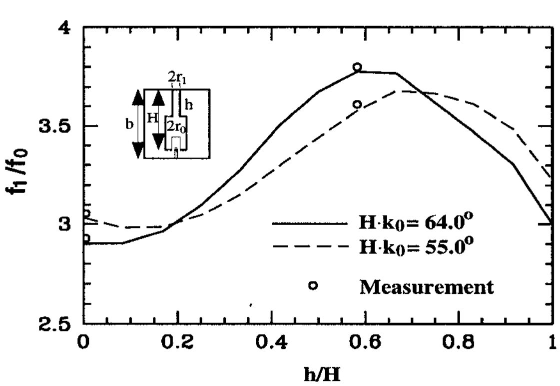


Fig. 2 Variations of the first higher order mode frequencies of a stepped rod combline resonator with different step length. $2a = L = 1.6$", $b = 2.7$", $r_1 = 0.4r_0 = 0.1$", and $H = 2.4$".

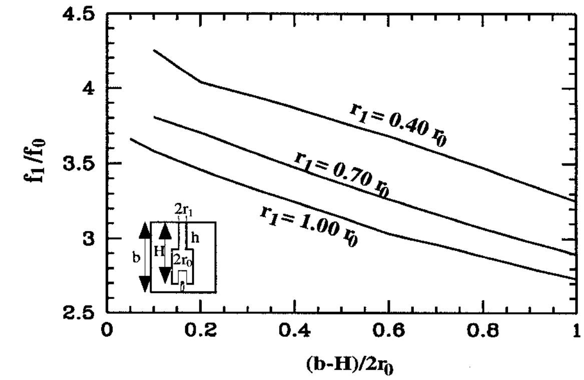
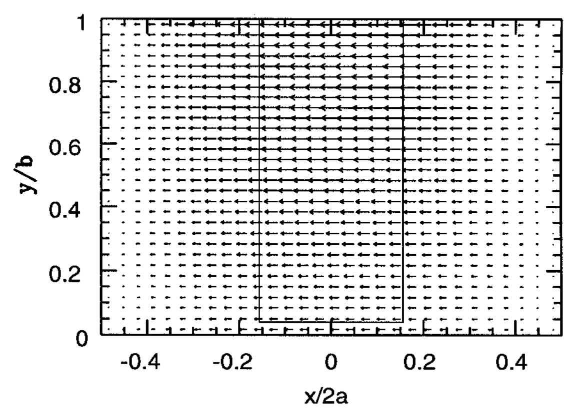
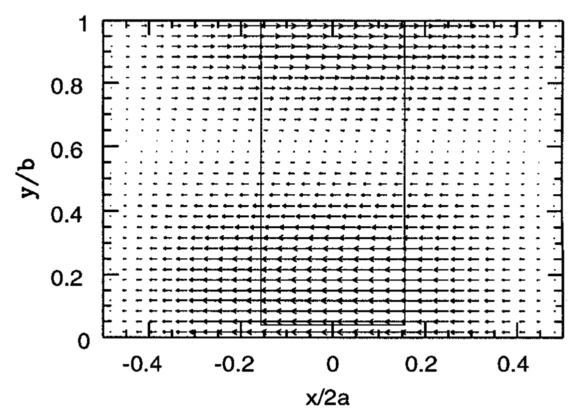


Fig. 3 Variations of the first higher order mode frequencies of a stepped rod combline resonator with different gaps. $2a = L = 1.6$", $r_0 = 0.25$", $h = 1.6$", and $H = 2.4$".



(a)



(b)

Fig. 4 Magnetic field distributions of a combline resonator in a cross section parallel to the resonator rod for (a) dominant mode and (b) the first higher order mode.

Fig. 3 presents the shift of the first higher order mode frequency with respect to the change of the gap between the rod and the end wall of the cavity for different radius ratio of stepped rods. The cavities are numerically tuned at the same frequency with the rod electrical length of 55°. For a given radius ratio, f_1/f_0 increases with the decrease of the gap. As a limit, the transmission line theory applies when the gap tends to infinitely small. This results in $f_1/f_0 \rightarrow 1 + \frac{180^o}{\theta}$ for an uniform rod with the gap approaching to zero. However, it may not be practical to move away the first spurious mode of a combline cavity by significantly reducing the gap due to structure limitation and power handling consideration. As shown in the figure, a practical way is to use stepped rods. The larger the radius ratio is, the further the first higher order mode is pushed to.

On the other hand, the first higher order mode of a combline resonator usually has the same field distributions as that of the dominant mode in the transverse cross section and therefore can be viewed as a quasi TEM mode in the rod direction. The magnetic field distributions of the dominant mode and the first higher order mode in a cross section parallel to the rod are shown in Fig. 4. This figure implies that it is possible to carefully design a coupling structure which provides the required coupling to dominant mode, but minimizes the coupling of the first higher order mode. In this way, the first spurious passband of a combline filter can be suppressed or killed, and the spurious response is improved.

IV. EXPERIMENTS

As an application and validation of the analysis, a five pole Tchebyscheff combline filter with the center frequency of 836.5 MHz and the bandwidth of 25 MHz is designed and tested for its spurious performance.

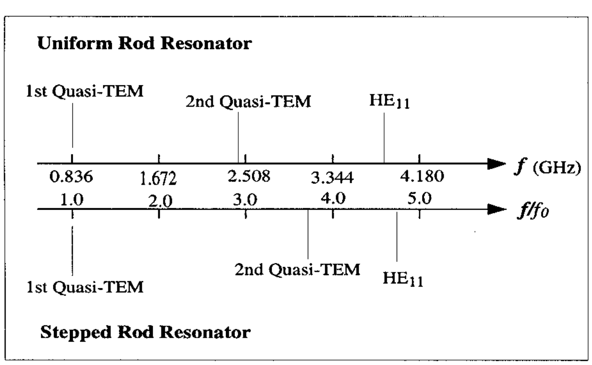


Fig. 5 The calculated resonances of the combline filter resonator with the uniform rod and the stepped rod, respectively.

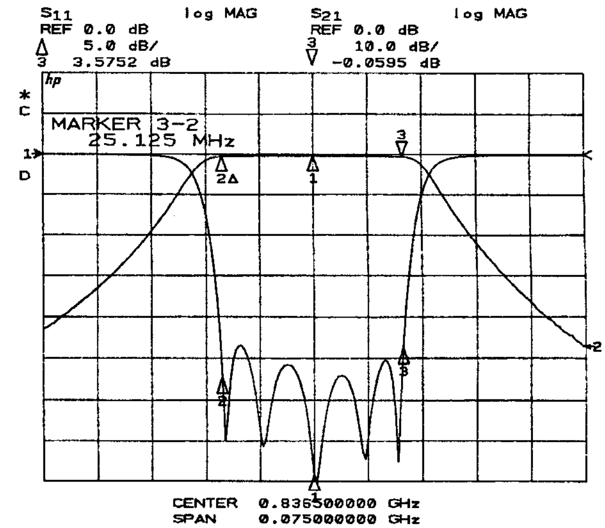


Fig. 6 A typical measured passband response of the filter.

The filter is constructed with 61^o uniform rods, stepped rods, and their different combinations, respectively. The stepped rods have the parameters as $r_1/r_0 = 0.4$ and $h/H = 0.583$. The slots, which are opened from the open ends of the resonators, are designed based on the uniform rods, and tuning screws are used to get correct coupling for the other cases. The calculated mode charts of the combline cavity with the uniform rod and the stepped rod are given in Fig. 5.

The typical passband response of the filter is presented in Fig. 6. The wideband responses of the filter with all uniform rods and all stepped rods are shown in

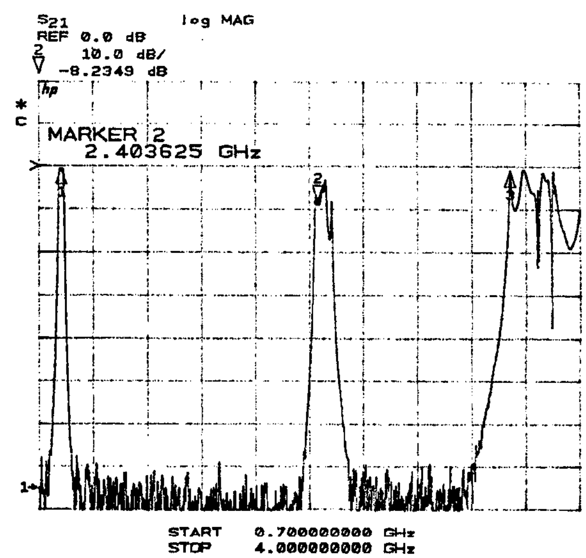


Fig. 7 The measured wideband response of the filter with all uniform rod resonators.

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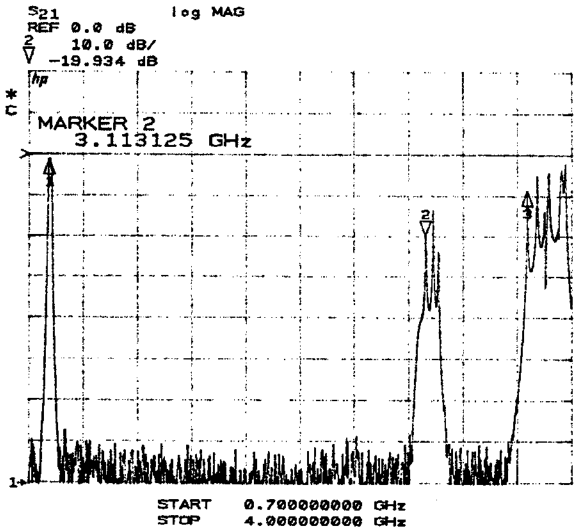

Fig. 8 The measured wideband response of the filter with all stepped rod resonators.

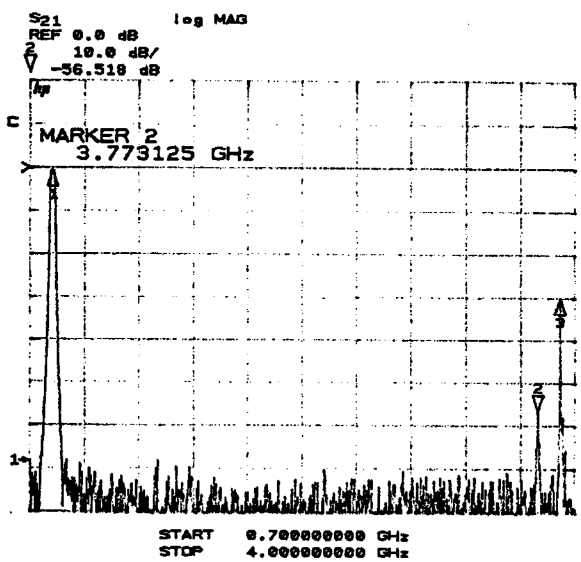

Fig. 9 The measured wideband response of the filter with the rod combination of **U-S-S-S-U** and with the first spurious band suppressed by adjusting the slot tuning screws.

Fig. 7 and Fig. 8, respectively. As expected, the first spurious passband corresponds to the calculation and occurs around $2.9f_0$ for all uniform rod filter and $3.7f_0$ for all stepped rod filter. The mid-band insertion losses of the two filters are 0.327 dB and 0.375 dB corresponding to the unloaded Q of 2550 and 2300, respectively. With mixing the uniform rods and the stepped rods, the spurious passbands appear, in general, around both $2.9f_0$ and $3.7f_0$, but with lower levels.

As discussed in the last section, the real levels of the spurious passbands depend on how the resonators are coupled. For the filter using the stepped rods, the first higher order mode coupling is minimized when the coupling tuning screws are tuned very deep; therefore the spurious passband due to the first higher order mode is suppressed. Fig. 9 shows the wideband response of the filter with the combination of **U-S-S-S-U**, where **U** represents a cavity with uniform rod and **S** indicates a cavity with stepped rod, when the first spurious band is suppressed by adjusting the coupling tuning screws.

V. CONCLUSION

The spurious performance of combline filters is investigated. The first spurious passband of a combline filter can be either shifted to a higher frequency by using stepped rods or suppressed by a careful design of the coupling structure to minimize the coupling of the first higher order mode. Numerical analysis is verified by experiments.

REFERENCES

[1] G. L. Matthaei, "Comb-line band-pass filters of narrow or moderate bandwidth," *Microwave J.*, vol. 6, pp. 82-91, Aug. 1963.

[2] E. G. Cristal, "Coupled circular cylindrical rods between parallel ground planes," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-12, pp. 428-439, July 1964.

[3] R. Levy and J. D. Rhodes, "A comb-line elliptic filter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 26-29, Jan. 1971.

[4] R. J. Wenzel, "Synthesis of combline and capacitively loaded interdigital bandpass filters of arbitrary bandwidth," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 678-686, Aug. 1971.

[5] M. Sagawa, M. Makimoto, and S. Yamashita, "A design method of bandpass filters using dielectric-filled coaxial resonators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, pp.152-157, Feb. 1985.

[6] H.-W. Yao, K. A. Zaki, A. E. Atia, and R. Hershtig, "Full wave modeling of conducting posts in rectangular waveguide and its applications to slot coupled combline filters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-43, pp. 2824-2830, Dec. 1995.

[7] H.-W. Yao, C. Wang, and K. A. Zaki, "Quarter wavelength ceramic combline filters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-44, Dec. 1996. (to be published)

[8] H.-W. Yao, C. Wang, and K. A. Zaki, "Effects of tuning structures on combline filters," *26th EuMC Dig.*, pp. 427-429, 1996, Prague, Czech Republic.

[9] R. Gesche and N. Löchel, "Scattering by a lossy dielectric cylinder in a rectangular waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-36, pp. 137-144, Jan. 1988.

[10] X.-P. Liang and K. A. Zaki, "Modeling of cylindrical dielectric resonators in rectangular waveguides and cavities," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-41, pp. 2174-2181, Dec. 1993.

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