Temperature Characteristics of Combline Resonators and Filters

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***Abstract* — Temperature characteristics of combline resonators and filters are investigated with a full wave simulation. For a given combline resonator, perfect temperature compensations may be achieved at two different resonant frequencies by adjusting the tuning screws. A 4 GHz 8-pole filter is designed and tested. Satisfactory temperature compensation is obtained.**

I. INTRODUCTION

Rapid development of satellite and terrestrial wireless communications resulted in increasing demand on efficient utilization of the assigned frequency spectrum. Reducing the guard bands between adjacent channels and improving the useful channel bandwidth maximize communication capacities and throughputs. This demand imposed stringent requirements on low cost, light weight, but high performance filters with sharp selectivity and temperature stable frequency responses.

Combline filters [1]-[5] have compact size, relatively low loss, and easy manufacturing and tuning, which made them widely used in various communications systems. Simple temperature compensation techniques, utilizing different types of metals for filter housing, resonator rods, and tuning screws, have been used to stabilize the frequency responses over temperature variations [6][7]. However most temperature compensation designs were achieved empirically, which is very time consuming. Recently, a rigorous mode matching method in conjunction with perturbation technique was applied to model and simulate resonant frequency changes over temperature of the combline resonators with the resonant rods consisting of two different materials [8].

In this paper, the previously developed full wave method [5] is used to analyze the temperature characteristics of the combline resonators consisting of different materials for housing, resonator rods, and tuning screws. It is found that for a combline resonator with given dimensions of the housing and the resonator rod, the equivalent temperature coefficient of frequency variation of the resonator changes with the depth of the tuning screw, and perfect temperature compensations can be achieved at two different resonant frequencies if the materials for the resonator rod are properly selected. As an application, a 4 GHz temperature compensated 8-pole filter was designed, constructed, and tested. An equivalent temperature coefficient of -2.8 PPM/^{o}C was achieved for the filter.

II. NUMERICAL INVESTIGATION

The general configuration of the combline resonator under consideration is given in Fig. 1. For temperature compensation purpose, the resonator horsing, the resonator rod, and the tuning screw could have different materials with the coefficients of thermal expansions τ_h, τ_r, and τ_s, respectively.

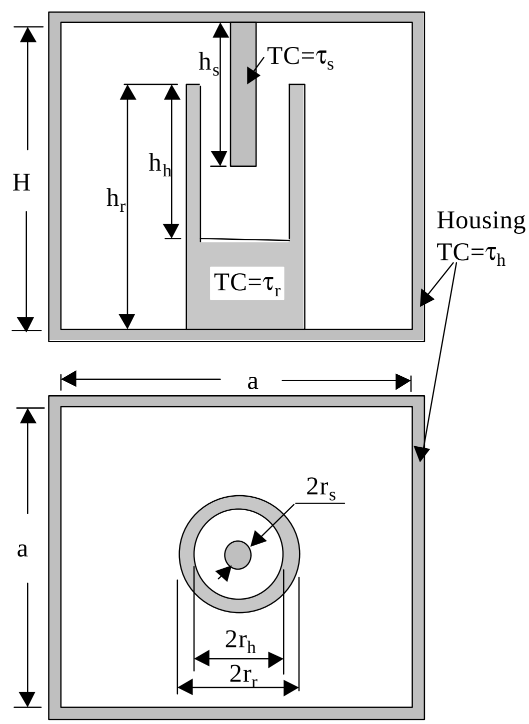

Fig. 1 A general configuration of a combline resonator

To maintain the design flexibility, the resonator rod can be made of one material or two different materials. For the latter case, the equivalent coefficient of thermal expansion τ_r of the rod is related to the properties and lengths of the two different materials by

$$t_r h_r = t_{r1} h_{r1} + t_{r2}(h_r - h_{r1}) \quad (1)$$

where τ_{r1} and τ_{r2} are the coefficients of thermal expansion of the two materials, respectively; and h_{r1} is the length of the potion of the rod made of material 1.

The dimensions of the combline resonator change with the operating temperature, resulting in resonant frequency shift. The shift can be simulated by the previously developed full wave model [5]. The basic idea of the temperature compensation for a combline resonator is to provide a change of the open-end capacitance, formed between the rod and the tuning screw as well as the housing, to compensate for the change of the resonator rod length so that the resonant frequency remains nearly constant.

Fig. 2 presents the simulated equivalent temperature coefficients of frequency variation of a combline resonator with the resonator rod made of Titanium with τ_r=8.5 PPM/^{o}C, Invar with τ_r=1.0 PPM/^{o}C, and combination of two different materials with equivalent τ_r=4.0 PPM/^{o}C, respectively. To minimize weight and cost, aluminum and steel are used for the filter housing and the tuning screw, respectively.

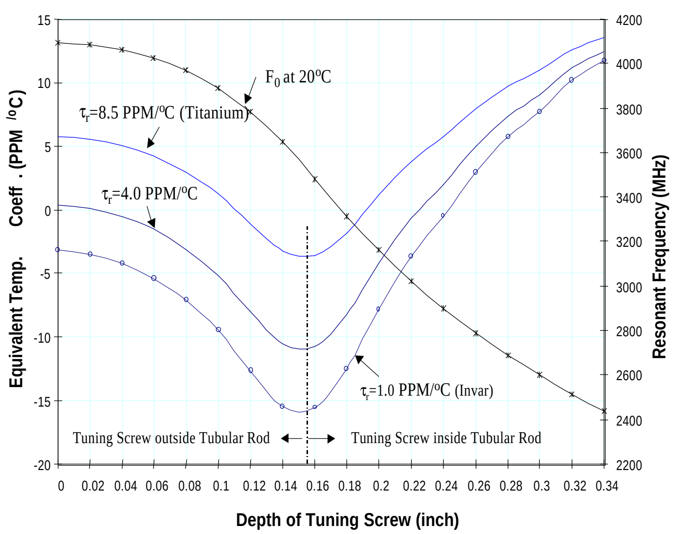

Fig. 2 Resonant frequency and equivalent temperature coefficient of frequency variation of a combline resonator with resonator rod made of different materials with a=1.0", H=0.63", h_r=0.475", h_h=0.325", r_r=0.13", r_h=0.08", and r_s=0.043".

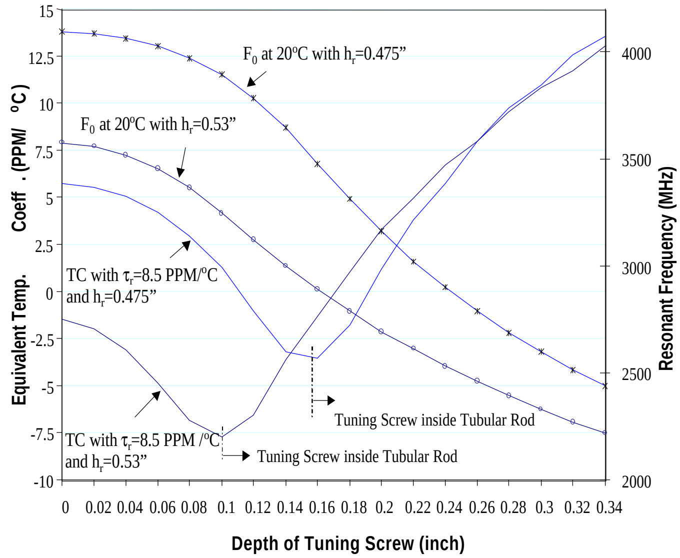

Fig. 3 Resonant frequency and equivalent temperature coefficient of frequency variation of combline resonators with different lengths of resonator rods with a=1.0", H=0.63", h_h=0.325", r_r=0.13", r_h=0.08", and r_s=0.043".

As can be seen, prefect compensations may be achieved at two different depths of the tuning screw if the material for the resonator rod is properly selected. In general, the equivalent temperature coefficient of the combline resonator decreases, even to negative range, with increasing the depth of the tuning screw before the screw is tuned in the tubular resonator rod; the equivalent temperature coefficient of frequency variation starts to increase once the tuning screw is inside the tubular rod. For a given combline resonator, one can always find a desired coefficient of thermal expansion for the resonator rod, either by using available material or by combining two different materials based on equation (1) so that the resonator can be exactly compensated at two different frequencies. In other words, two temperature compensation designs exist for a desired resonant frequency, one with higher unload Q and the other with smaller size. When high unloaded Q is desired, the compensation point with very small tuning screw depth can be selected. For small filter size, one may select the compensation point with deeper tuning screw. Usually, the first compensation point is less sensitive to the tuning screw position.

The resonant frequencies and the equivalent temperature coefficients of a combline resonator with different lengths of the resonator rod are shown in Fig. 3. Again, aluminum housing and steel tuning screw are assumed in the simulation. As expected, the resonant frequency of the resonator with a longer rod is lower than the one with a shorter rod. The figure exhibits similar performances of equivalent temperature coefficient as shown in Fig. 2.

Fig. 4 shows the resonant frequencies and the equivalent temperature coefficients of two combline resonators which have different cavity dimensions and rod lengths, but the same resonant frequency when the tuning screws are completely backed out. The resonator rods are made of Titanium, while the housings and the screws are made of aluminum and steel respectively.

In practice, the coefficient of thermal expansion of a given material may vary around its nominal value due to the different production conditions. The unknown variation may result in an inaccurate temperature compensation design with full wave simulations. Fig. 5 presents the sensitivity of the equivalent temperature coefficient of frequency variation of a combline resonator to the coefficient of thermal expansion of the resonator housing. As can be seen, the variation of the resonator equivalent temperature coefficient is less than the variation of the thermal expansion coefficient of its housing.

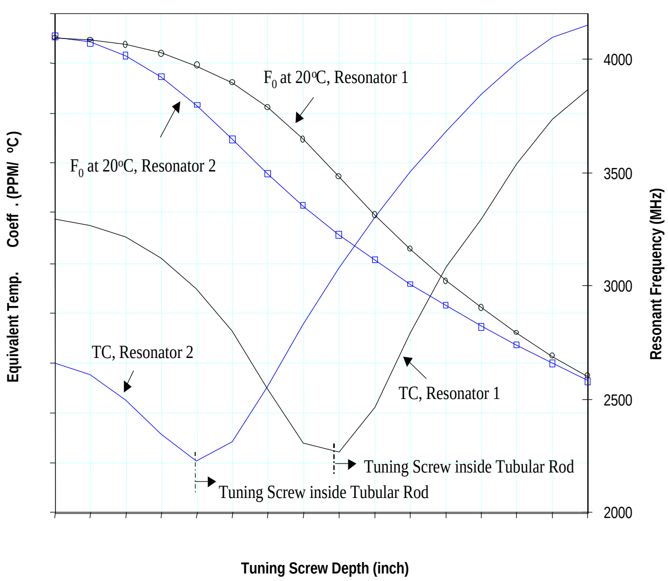

Fig. 4 Resonant frequency and equivalent temperature coefficient of frequency variation of different combline resonators with the same starting resonant frequency. Resonator 1: a=1.0", H=0.63", h_r=0.475", h_h=0.325", r_r=0.13", r_h=0.08", and r_s=0.043"; Resonator 2: a=1.0", H=0.5", h_r=0.41", h_h=0.26", r_r=0.13", r_h=0.08", and r_s=0.043"; τ_r=8.5 PPM/^{o}C.

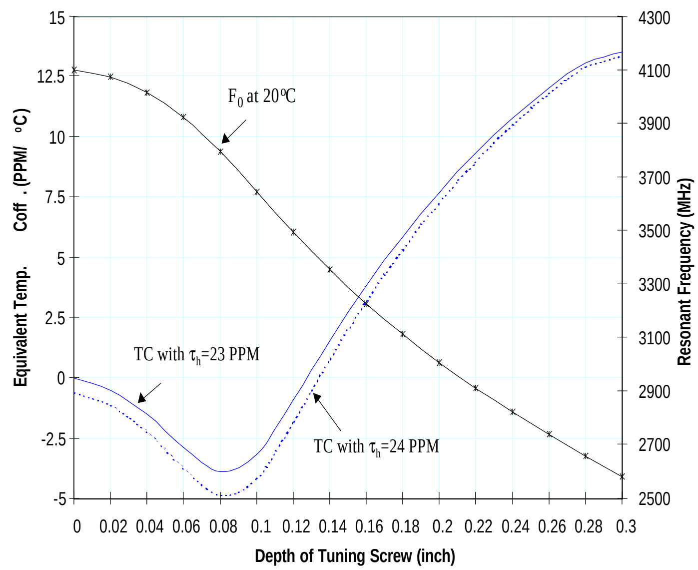

Fig. 5 Sensitivity of equivalent temperature coefficient of frequency variation of a combline resonator to the coefficients of thermal expansion of the housing with a=1.0", H=0.5", h_r=0.41", h_h=0.26", r_r=0.13", r_h=0.08", r_s=0.043", and τ_r=8.5 PPM/^{o}C (Titanium rod).

III. APPLICATION

As an application, a temperature compensated 8-pole elliptic function filter was designed. The filter housing is made of aluminum for light weight and low manufacturing cost. The resonator rods and the tuning screws are made of Titanium and steel, respectively. The electric (negative) couplings in the filter are realized by coupling probes and all the magnetic (positive) couplings are provided by coupling slots. The filter is designed at the center frequency of 4 GHz with bandwidth of 36 MHz. To minimize the inband loss variation, the resonators are designed to provide the correct resonant frequency and temperature compensation with slightly tuning the screws in the housing. The filter has been constructed and tested. The realized unloaded Q estimated based on measurements is greater than 3500. Fig. 6 shows the measured responses of the filter at 25^{o}C and 40^{o}C. Fig. 7 presents the enlarged inband loss variations. The overall equivalent temperature coefficient of frequency variation of the filter, evaluated based on the center frequency shift, is about -2.8 PPM/^{o}C. The slight over compensation is probably due to the uncertainty of material thermal expansion coefficients and the slightly

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higher resonant frequency designed for each resonator as tuning margin to overcome the different loading condition of each resonator.

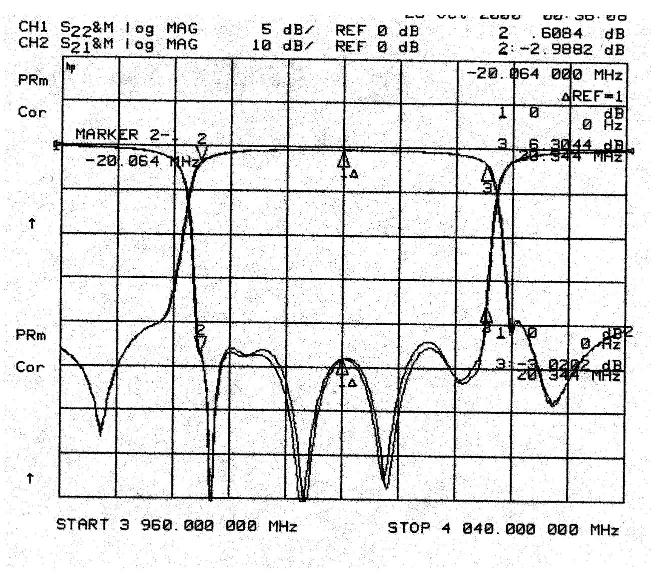

Fig. 6 Measured filter responses at 25^{o}C and 40^{o}C

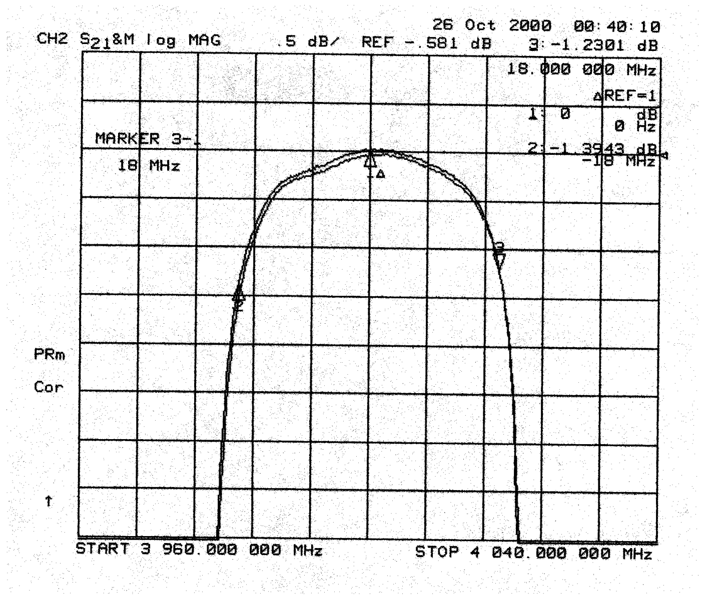

Fig. 7. Enlarged measured filter inband responses at 25^{o}C and 40^{o}C

IV. CONCLUSION

Temperature characteristics of combline resonators are investigated using full wave simulations. Perfect temperature compensations may be achieved at two different resonant frequencies for a given resonator if the materials for the resonator are properly selected. A temperature compensated 8-pole elliptic function filter is designed and tested. An equivalent temperature coefficient of -2.8 PPM/^{o}C is achieved for the filter.

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