A TUNABLE, TEMPERATURE COMPENSATED HYBRID MODE DIELECTRIC RESONATORS

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Abstract

A thermal and an electromagnetic model of a tunable hybrid mode dielectric double resonator is introduced, and analyzed by the mode matching technique. Results of the analysis shows the temperature sensitivity of the structure as a function of the spacing between the double resonators as well as the other resonator parameters. A simple optimization procedure is described, which enables the design of the resonator to simultaneously have wide tunability range and good thermal stability of the resonant frequency.

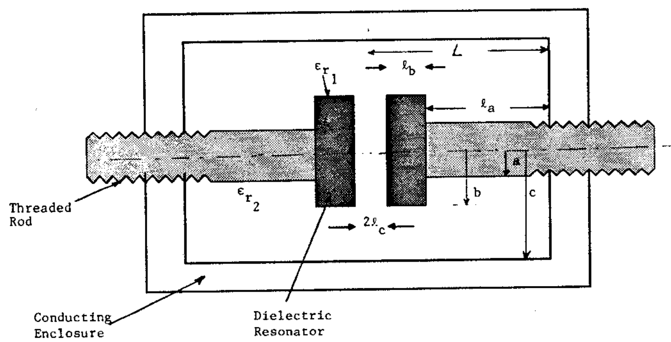

Fig.1 Tunable Double Dielectric Resonator.

I. Introduction

Dielectric resonators are being increasingly employed in a variety of microwave components and subsystems such as filters and oscillators. One of the most desirable resonator properties is simple tunability over a reasonably wide frequency band. The usual approach is to provide some means of perturbing the fields surrounding the resonator, such as tuning screw placed at a location of strong electric field or a tuning plunger that essentially varies the enclosures dimensions. Unfortunately, these approaches have two major limitations. First, they provide very narrow tunability ranges (if the unloaded Q's are to be maintained at a high value), because the fields are usually concentrated within the dielectric material due to its high relative permittivity, and the effect of perturbing the weak external fields on the resonant frequency of the structure is very small. If the tunability range is increased, the proximity of the conductors to the resonator causes severe degradation to the unloaded Q.

A novel structure which has the potential of providing a wide tunability range of the $TE_{01\delta}$ modes was introduced by Karp etal [1], and latter used by Fiedziuszko for oscillator applications [2]-[3]. This structure consists of two resonators placed axially in an enclosure. One of the resonators having the ability of being moved along the enclosures axis, so as to change the spacing between the two resonators. This structure will also maintain the high Q properties of the resonator, since no conductors are introduced near the resonator's fields.

The present paper extends the same principal to hybrid modes (nonaxially symmetric) in dielectric resonators, and analyzes the properties of such structures. In addition to wide tunability ranges, a principal factor in the practical applications of these resonators is temperature stability of the resonant frequency. Since there is a wide range of dielectric materials with varying thermal properties (i.e. linear coefficient of expansion and/or coefficient of dielectric constant variation with temperature) it is important to be able to optimize the parameters of the resonator so that the resonant frequency stability is maintained over the tunability range. Results of the analysis show how this optimization can be achieved.

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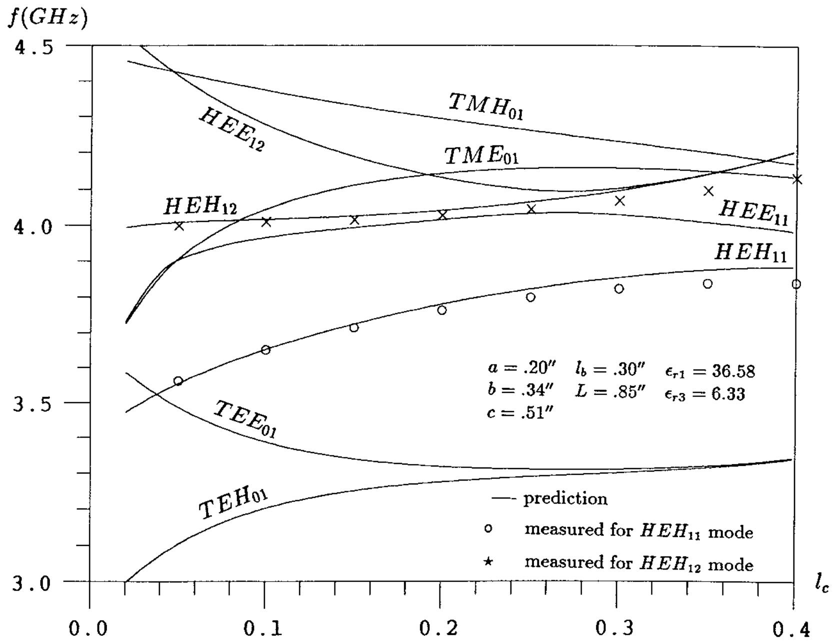

Fig.2 Variations of resonance with gaps between the double resonators.

II. Analysis

The double resonator structure is shown in Fig.1. It consists of two dielectric resonators of relative dielectric constant ϵ_{r_1}, radius b and length ℓ_b. Each of the resonators is connected to a threaded rod of radius a and length ℓ_a. The rod is taken as a dielectric with low loss and lower dielectric constant (ϵ_{r_1}) than the resonator. The spacing between the two resonators is $2\ell_c$. The resonators are placed coaxially and symmetrically in a conducting enclosure of radius c.

Due to its uniformity in ϕ, electromagnetic fields existing on this structure will have the same angular variation $e^{\pm jn\phi}$. For any such mode, the two resonators can be considered as a single system or as two coupled individual resonators. In either case, the resonant frequency can be computed for modes which have zero transverse electric fields in the symmetry plane $z = 0$ (even modes with electric wall boundary condition) and modes which have zero transverse magnetic field in the symmetry plane (odd modes with magnetic wall boundary condition). The calculation can be carried out using a mode matching technique as described in [4]. The calculation yields the typical tuning curves shown in Fig. 2. If the even HE_{11} mode is considered the desired resonance of the system. It is clear that its frequency changes by a sizable magnitude (about 10% tuning range) when the spacing ℓ_c changes by approximately .3″.

Thermal stability of the resonant frequency of the structure as it is tuned is also important. Idealy, the resonant frequency at any separation ℓ_c should not be affected by temperature changes. Although the resonator materials could be chosen within a range of thermal coefficient of frequency variation, the effects of the temperature change on other elements of the structure (i. e. enclosure and tuning rods) may produce pronounced resonant frequency changes. To quantitatively investigate these effects a simple thermal model of the structure is analyzed. This model predicts the various dimensions and dielectric constants of the structure as a function of deviation (ΔT) of the temperature from an ambient temperature (T_0). Thus:

$$\ell_a = \ell_{a0}\,(1 + \alpha_a \Delta T)\,; \quad a = a_0\,(1 + \alpha_a \Delta T) \qquad (1)$$

$$\ell_b = \ell_{b0}\,(1 + \alpha_b \Delta T)\,; \quad b = b_0\,(1 + \alpha_b \Delta T) \qquad (2)$$

$$L = L_0\,(1 + \alpha_c \Delta T)\,; \quad c = c_0\,(1 + \alpha_c \Delta T) \qquad (3)$$

$$\epsilon_{r_1} = \epsilon_{r_{10}}\,(1 + \tau_b \Delta T)\,; \quad \epsilon_{r_3} = \epsilon_{r_{30}}\,(1 + \tau_a \Delta T) \qquad (4)$$

$$\ell_c = (L_0 - \ell_{b0} - \ell_{a0}) + \Delta T\,(\alpha_c L_0 - \alpha_b \ell_{b0} - \alpha_a \ell_{a0}) \qquad (5)$$

where $\alpha_a, \alpha_b, \alpha_c$ are the linear temperature coefficient of expansions of the tuning rod, the dielectric resonator and the enclosure respectively, $\ell_{a_0}, a_0, \ell_{b_0}, b_0$ and L_0, c_0 are the lengths and radius of the tuning rods, dielectric resonators and enclosures respectively, at the ambient temperature T_0. The equations in (1) to (5) above are used to determine the dimensions and relative permittivities of the structure at any temperature deviation ΔT from T_0. These parameters are used in the mode matching program to determine the resonant frequency of the structure at that temperature. Approximately, the temperature stabilities of resonant frequency for the whole structure are affected by two factors, 1) the inherent temperature coefficient of the dielectric resonators τ_f :

$$\tau_f = -(\frac{1}{2}\tau_\epsilon + \alpha) \tag{6}$$

where τ_f is empirically determined by its linear thermal coefficient of expansions α as well as the temperature coefficient of dielectric constant τ_ϵ, 2)variations of the gaps (ℓ_c) between the double resonators with temperature, which are, however, mainly determined by the linear thermal expansion coefficients of the enclosure and the tuning rod. From equation(5), if the materials for the enclosure and the tuning rod are chosen such that the second term of equation(5) cancelled, then the variation of the gap length becomes equal to zero and the sensitivity of the resonant frequency with the gap length is minimized.

By changing the parameters and/or the materials from a selection of available sources, an optimum configuration can be obtained that produces the widest possible tuning range of the resonant frequency, and the least temperature sensitivity. This process is illustrated in the results shown in the next section.

III. Results

Figure 3 shows a typical result for a C-band resonator. It shows the computed frequency shift of in MHz, versus temperature T for different resonators material. The parameters of the structure analyzed are: $a_0 = 0.2'', b_0 = .34'', c_0 = .51''$, $\ell_{b_0} = 0.3''$ and $L_0 = .85''$. The enclosure material is Aluminum with $\alpha_c = 24.3 \times 10^{-6}/°C$. The tuning rod is chosen as material with $\alpha_a = 10 \times 10^6/°C$ and $\epsilon_{r_{30}} = 6.33$ and $\tau_a = 107 \times 10^{-6}/°C$. Commercially available resonator materials were utilized. Fig.3 shows the variations of resonant frequency with temperature for different materials. Experimental results for D8513, which shows very good agreement with the analysis, are also included in the same figure. According to the analysis, resonator material D8516 shows the least temperature coefficient of variation of the structure's resonant frequency. When these materials are used and the tuning plunger is moved to vary ℓ_c, the resulting temperature coefficients of the resonant frequency are shown in Fig.4. It is seen in this figure that for $\ell_c = .15''$ the structure's resonant frequency has no temperature variation. Over the tuning range $\ell_c = .01''$ to $.2''$ the frequency can be varied more than 300 MHz, with frequency stability better than $10 \times 10^{-6}/°C$, which is quite acceptable for most practical applications. By utilizing tuning rods with higher expansion coefficients comparable with those for the enclosures, the temperature stability of the system is expected to be much better.

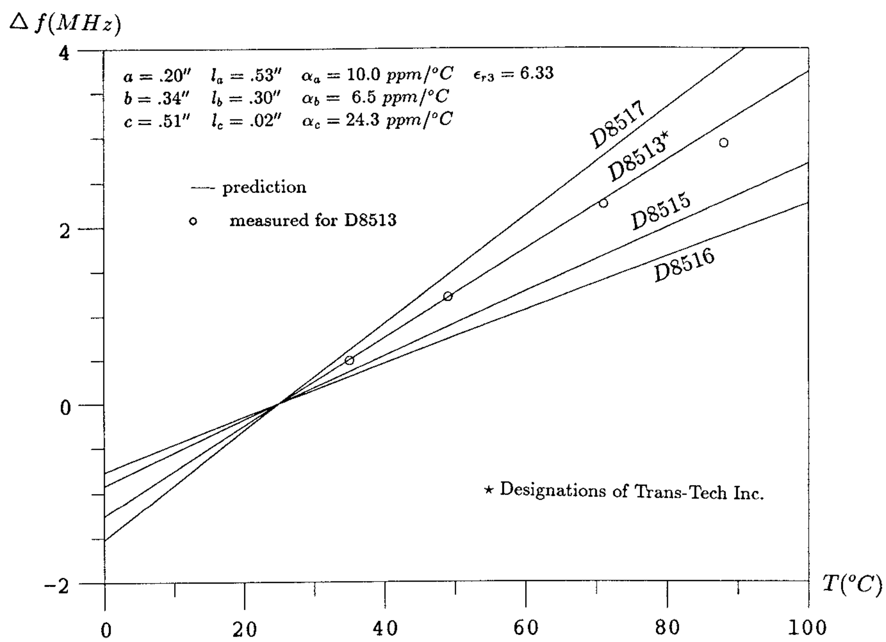

Fig.3 Deviations of resonance with temperatures for different materials.

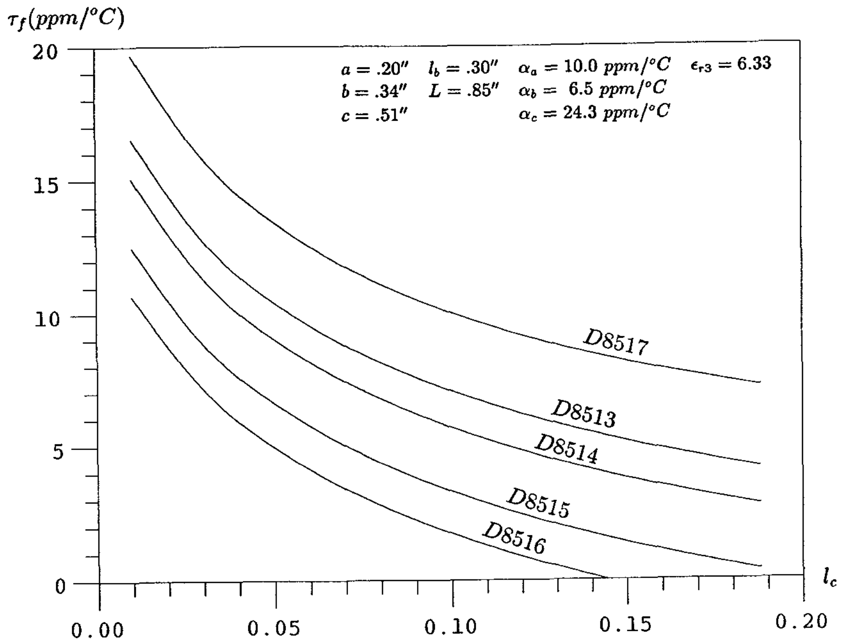

Fig.4 Variations of temperature coefficients of resonance with gaps between the double resonators.

IV. Conclusion

The tunable double resonator structure analyzed resonates in hybrid (HE_{11}) mode, is simple and provides adequate tuning range with good temperature stability. The optimization process described is based on rigorous analysis of the structure using mode matching. The choice of the optimum parameters is based on parametric analysis that depicts all the relevant sensitivities to the designer.

Experimental verification of the analytical results has been demonstrated and good agreement has been achieved.

References

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