The Temperature Compensation of the Dielectric Resonator Devices

Mihailo Crnadak
University of Banja Luka, Electrical Engineering Dept.

Abstract

The overall frequency stability of a resonant structures, employing dielectric resonators, has been examined. The results presented prove feasibility of resonant structures design to a specific value of frequency stability by proper choice of the materials and dimensions of the mechanical counterparts and of the temperature coefficient of the dielectric resonator itself.

1. Introduction

It is well known that resonant devices employing dielectric resonator (DR) have many advantages comparing it to cumbersome and expensive metal cavities and low-Q transmission line resonators. However, a DR has a few disadvantages such as the difficulty of manufacturing a large number of dielectric pieces having uniform characteristics and the variability of the resonant frequency due to variations of temperature. Accordingly, it is necessary to adjust for resonant frequency tolerances (by means of frequency tuning mechanism) and to compensate for resonant frequency shift due to variations in temperature.

In practice, DR doesn't come as an isolated dielectric body. It is surrounded with mechanical parts like metal housing, resonator supporting member, coupling mechanism, tuning mechanism etc. These elements, depending on dimensions, materials and position relative to DR influence basic resonator parameters: frequency, Q-factor and temperature stability.

With relation to temperature stability the aim is to reduce temperature coefficient of frequency or alternatively to extend temperature range without reducing the advantages of the conventional DR. There are a few methods of compensating for the resonant frequency variation due to temperature, depending on specific stability requirements. For example one may choose between analog and digital technique [1, 2] or make use of an oven [3]. However for any circuit containing DR we intend to make it as stable as possible without implementing any of the methods causing device to be more complicated and expensive. If one is able to design such structure that would inherently be stable to a specific value of frequency, say in the vicinity of 1 ppm/°C, then, firstly many practical cases regarding stability would be already solved, and, secondly employing some of the aforementioned compensation methods on such "prestabilized" circuit would be much easier and more efficient. It is the aim of this paper to show how to provide frequency stabilized DR device with additional care and no penalty in cost.

2. Temperature Compensation of the DR's Resonant Structure

In order to accomplish the above objective let us analyze frequency stabilized DR device, which is composed of a DR element (1), a frequency tuning element (2) manually controlling the resonant frequency of the DR device, a supporting member (3) and a housing (4), Fig. 1.

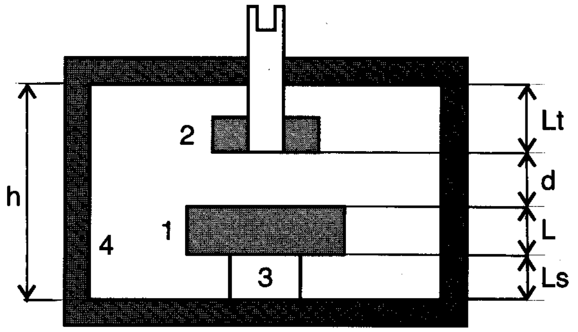

Fig. 1. Resonant structure with axially suspended dielectric resonator

In the construction by manually changing the distance d between tuning element (another dielectric body) and upper surface of the DR, without changing the temperature, the resonant frequency is changed as shown in Fig. 2.

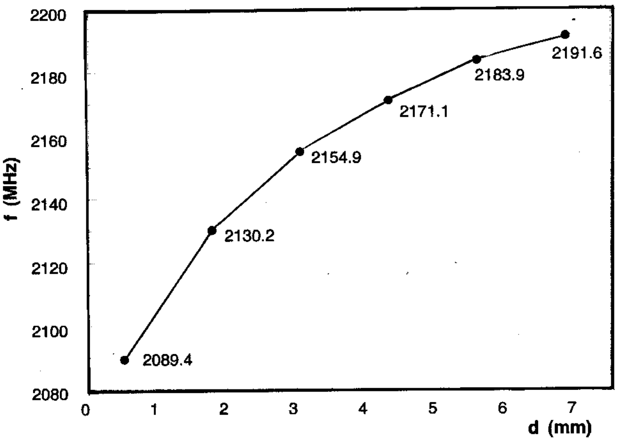

Fig. 2. Frequency vs. distance d change for the structure from Fig. 1.

In the embodiment shown, the materials and dimensions are determined in such a way that the change in resonant frequency of the DR itself due to temperature variations can be compensated for by automatically changing the relative distance d on the basis of thermal expansion. The simplified form of the temperature stability is

$$\frac{\Delta f}{\Delta T} = \frac{\Delta f_r}{\Delta T} + \frac{\Delta f_d}{\Delta d}\ \frac{\Delta d}{\Delta T} \qquad (1)$$

Equating (1) with zero, we have the condition

$$\frac{\Delta f}{\Delta T} = -\frac{\Delta f_d}{\Delta d} \cdot \frac{\Delta d}{\Delta T} \qquad (2)$$

where

ƛf=total frequency shift of the device due to the change of temperature

ƛf_d=frequency shift of the device due to the change h in the relative distance

ƛf_r=frequency shift of the DR element itself

The relative distance change, ƛd, depends on the thermal expansion coefficients of the construction members in the vertical direction and its temperature variation is given by

$$\frac{\Delta d}{\Delta T} = \alpha_h h - \alpha_s L_s - \alpha_L L - \alpha_t L_t \qquad (3)$$

where h, L_s, L and L_t designate the lengths in the vertical direction of the housing, supporting member, dielectric resonator pack and the tuning element, respectively. The coefficients α_h, α_s, α_L and α designate the corresponding thermal expansion coefficients, and ƛT designates thermal variation.

Obviously having Eq. 2. satisfied, the device will be compensated at the specific distance d i. e. at one specific frequency. For the rest of frequencies in the tuning range it will be either overcompensated or undercompensated. in order to have structure stable over entire tuning range, one has to adjust ƛd/ƛT to be of small value (as close to zero as possible). From there the thermal expansion coefficient of the supporting member, $\mapsto_s$, may be determined leading to the selection of the supporting member material. By equating (3) with zero, we have

$$\alpha_s = \frac{1}{L_s}(\alpha_h h - \alpha_L L - \alpha_t L_t) \qquad (4)$$

If the material with thermal expansion coefficient calculated by (4) is not available, one should choose material with large value of α_s and make the length of the supporting element, proportionally shorter.

3. The Experimental Results

The device shown in Fig. 1. has been assembled and tested to verify its predicted stability. Fig. 3. shows the experimental characteristic of the frequency temperature coefficient with distance d variation. The resonant device from which the characteristic shown in Fig. 3. is obtained, is designed as follows

- Resonating mode: $TE_{01\square}$
- Frequency tuning range: 2100 - 2200 MHz
- Dielectric resonator: (Murata Erie)
- DRD 248 UC 108, ($\leftrightarrow_f$ = 0 2 10^{-6} 1/°C)
- DR supporting member
    - -material: rexolite (α_s = 72 10^{-6} 1/°C)
    - -dimensions: ∅8 x 12 mm
- DR tuning element: (Murata Erie)
  DRD 200 U 040 C 086
- Tuning element support:
    - -fused silica, (α = 0,6 10^{-6} 1/°C)
- Housing:
    - -material: aluminum (α_h = 24 10^{-6} 1/°C)
    - -dimensions: ∅50 x 40 mm

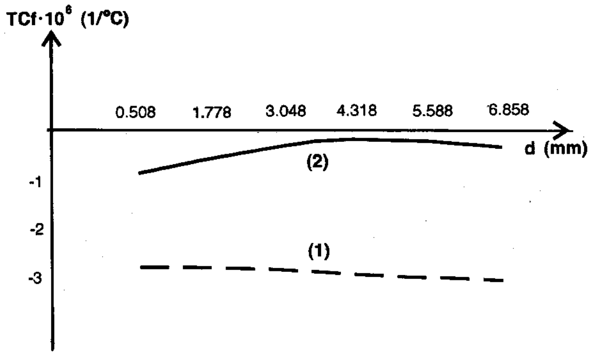

Fig. 3. Frequency temperature coefficient change over the resonator tuning range

The inside diameter of the cylindrical metal enclosure is twice as much dielectric resonator diameter, and has only a minor influence to the resonant frequency. For that reason the presence of the cylinder enclosing dielectric resonator has been ignored.

According to Eq. 4. it was found that temperature coefficient of the DR supporting member should be $\alpha_s = 67 \quad 10^{-6}$ 1/°C. Since such material was not found, the rexolite ($\alpha_s = 72 \quad 10^{-6}$ 1/°C) was used instead. As the result the device was overcompensated. By means of experiment it was found that the supporting member of 12 mm length should have expansion coefficient of 42 10^{-6} 1/°C. Such supporting member was realized by stacking two cylinders of the same diameter on each other: one made of brass length 7 mm and the other one (next to DR) made of rexolite, length 5 mm. The discrepancy between calculated (67 ppm/°C) and measured (42 ppm/°C) value for $\mapsto_s$ is attributed to the coupling mechanism (a small capacitive probe - not shown) placed close to the dielectric resonator in order to realize strong coupling. Besides, all data concerning expansion coefficients were taken from data sheets and data books.

At the low frequency end (d≈1mm, f=2100MHz) it was measured ƛf =–250 kHz at ƛT =40°C, and at the high frequency end (d≈6,8mm, f=2100MHz) ƛf =–285 kHz at ƛT =40°C. These results correspond to frequency temperature coefficients of –2,97 10^{-6} 1/°C, and –3,24 10^{-6} 1/°C respectively - curve (1) in Fig. 3.

It can be seen that dielectric resonator itself should have temperature coefficient somewhere between 2 10^{-6} 1/°C and 4 10^{-6} 1/°C. When resonator DRD 248 UC 108, ($\leftrightarrow_f = 0\ 2 \quad 10^{-6}$ 1/°C) was replaced by resonator DRD 248 UE 108 ($\leftrightarrow_f = 2\ 2 \quad 10^{-6}$ 1/°C) the results shown by curve (2) in Fig. 3. were obtained, i. e. frequency temperature coefficient was within 1 ppm/°C range.

4. Conclusion

The analysis and experiments have shown the feasibility of the temperature stable resonant structure design containing dielectric resonator. The stability is obtained over entire tuning range by providing dielectric resonator supporting member to be made of proper materials and dimensions and by the choice of frequency temperature coefficient of the dielectric resonator itself.

References

[1] Lee J., J. E. Andrews, K. W. Lee and W. R. Day, "Digital and Analog Frequency - Temperature Compensation of DRO", IEEE MTT-S Digest, pp 277-279, 1984.

[2] T. Higarski and T. Makino, "Resonant frequency stability of the dielectric resonator on a dielectric substrate", IEEE Trans. On MTT, Vol. MTT-29, pp 1048-1052, October 1981.

[3] E. Fridler and Z. Bogan, "The frequency stability of a cylindric dielectric resonator in MIC", 13th European Microwave Conference, 1983