APPLICATION NOTE

No. 831: Temperature Coefficients of Dielectric Resonators

Introduction

Our previous Tech-Brief1 detailed some of the advantages of the substitution of conventional microwave resonators by dielectric resonators (D.R.s). Better circuit performance with respect to temperature variations was mentioned among others. The design of D.R. temperature compensated circuits involves an understanding of the relationship between the different temperature coefficients. The purpose of this Tech-Brief is to present an introduction to the definitions, properties and measurements of the temperature coefficients of cylindrical D.R.s.

Definitions

There are four temperature coefficients (T.C.): T.C. of dielectric constant, T.C. of the cavity, T.C. of thermal expansion, and T.C. of resonant frequency which is a function dependent on the other three. Their definitions are (relative to Figure 1)

$$\tau\epsilon = \frac{1}{\epsilon\tau}\frac{\Delta\epsilon\tau}{\Delta T}\ldots$$

T.C. of dielectric constant

$$\tau_c = \frac{1}{L}\frac{\Delta L}{\Delta T}\ldots$$

T.C. of the cavity

$$\alpha_L = \frac{1}{H}\frac{\Delta H}{\Delta T} = \frac{1}{D}\frac{\Delta D}{\Delta T}\ldots$$

T.C. of thermal expansion

$$\tau_f = \frac{1}{f_o}\frac{\Delta f_o}{\Delta T}\ldots$$

T.C. of resonant frequency

where Δf_0 is the total frequency variation corresponding to the temperature shift ΔT, $\Delta\varepsilon_T$, is the variation of the dielectric constant, ΔL the cavity expansion and ΔH, ΔD the resonator material linear expansions.

The usual units employed in the measurement of any of the above coefficients is 10^{-6}/°C or ppm/°C.

Temperature Coefficient of Resonant Frequency τf

As mentioned previously[1], the resonant frequency of cylindrical D.R.s depends on the resonator's geometric and physical parameters as well as the environment surrounding it. Therefore, the computation of the overall effect of temperature variation will have to include the variations of all the materials employed to hold and shield the D.R.

For the configuration shown in Figure 1, the effects of the holder can be neglected if it is manufactured of a material with low dielectric constant and low coefficient to thermal expansion (such as fused silica). If the effects of radial expansion are also neglected (only true for cavities which are large relative to the D.R.), the relationship between the temperature coefficients and τ_f is:

$$\tau_f \;\; i = 3/4\,(A\tau\varepsilon + B\alpha_L + C_\tau c) \qquad (5)$$

where A ~ 1/2, B ~ 1. C is dependent on the position of the D.R. relative to the top and bottom cavity walls. The typical range of values for C is between 0.05 and 1.0.

Figure 2 shows a typical variation of resonant frequency as a function of cavity length. Note how the same variation in the cavity dimension, $\Delta L_1 = \Delta L_2$, can lead to different frequency variations, $\Delta f_1 = \Delta f_2$. This change depends on the initial cavity size. This feature, together with the availability of materials with an appropriate range of $\tau\varepsilon$'s can lead to the desired value of τ_f via a careful choice of the parameters in Equation 5.

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Measurement

The measurement of τ_f can be easily performed in any test setup capable of precise resonant frequency measurements. A resolution of at least seven digits read out in the GHz range is required. Figure 3 is an example using the impedance method to track the change in resonant frequency of the D.R. with temperature. The microwave signal is coupled to the D.R. located in a cylindrical test cavity via a H-field probe.

Values of τ_f given in Trans-Tech specifications bulletins are measured on test samples of 0.500" dia. by 0.200" thickness. The sample is centered in a cavity of 1.500" dia. by 1.050" height. The room temperature resonant frequency of the cavity plus D.R. is about 4.2 GHz. A practical example of the strong effect of the top and bottom cavity walls on the temperature coefficient of resonant frequency is given for Trans-Tech dielectric resonator type D-8512. In a parallel plate cavity with the metallic walls in contact with the D.R., a τ_f of +9 ppm/°C is obtained. When measured in the quality control standard cylindrical cavity described above, the value of τ_f is reduced to +4.0 ppm/°C. It is worthwhile noting that manufacturers measure the Q of dielectric resonators at different frequencies. A general phenomenological equation can be utilized to estimate the Q at any frequency.

$$f_0 \bullet Q = 40{,}000 \qquad (6)$$

where f_0 is the resonant frequency. For example, a material with a Q of 10,000 at 4 GHz will have a Q of 5,000 at 8 GHz.

In summary, care must be exercised in selecting a D.R. material of correct value to obtain overall device temperature stability.

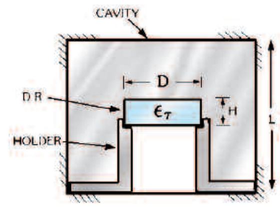

Figure 1

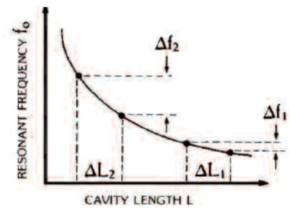

Figure 2

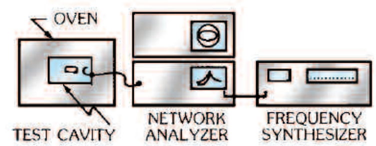

Figure 3

Trans-Tech compliments its product line of Dielectric Resonators by offering materials with various temperature coefficients of Resonant Frequency, abbreviated τ_f. The purpose of offering a variety of τ_f is to allow the designer control of frequency drift vs. temperature.

The τ_f is expressed in ppm/°C. In this context, the meaning is 1 Hz change for each MHz of operating frequency. For example, if an oscillator running at 10,750 MHz (10.750 GHz) decreases in frequency by a total of 1.5 MHz over a -20 °C to + 70°C temperature range, the temperature coefficient of the oscillator circuit, T_C, is

$$t_c = \frac{-1.5 \text{ X } 10^6 \text{ Hz}}{10750 \text{ MHz}} \text{ X } \frac{1}{(70- -20)}$$

$$= -1.55 \text{ ppm/°C}$$

This oscillator could be compensated for near-zero temperature drift by changing the tf of the dielectric resonator by + 2ppm/°C.

TTI recommends that first design iterations begin with zero coefficient, $\tau_f = 0$.

References:

(1) Tech-Brief No. 821 - An Introduction to Dielectric Resonators.