J-6

PRECISE MEASUREMENT METHOD FOR TEMPERATURE COEFFICIENT OF MICROWAVE DIELECTRIC RESONATOR MATERIAL

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ABSTRACT

A precise measurement method for the temperature coefficient of dielectric resonator material was developed. The error of measurement was decreased from 0.5ppm/℃ to 0.05 ppm/℃ compared with the conventional method. This measurement method made techniques for improving stability possible, such as for filters, multiplexers and oscillators.

INTRODUCTION

For filters and oscillators, a precise measurement technique for temperature coefficient has been needed in order to achieve improved temperature stability [1]. Recently, dielectric resonator materials with extremely small dielectric loss and better, more stable temperature coefficient were developed [2]. The requirement for a precise method of measuring the temperature coefficient was satisfied to the level of ±0.05ppm/℃. Also, because the linearity of the temperature coefficient of the dielectric constant K is one of important factors for achieving high temperature stability, there has been an added impetus to creating a precise method for temperature coefficient measurement.

Conventionally, temperature coefficients of dielectric resonator materials were measured with a dielectric rod resonator TE_{011} mode, short-circuited at both ends by two parallel conducting plates [3]. However, this method is not fit for measurement of improved dielectric loss material. The precision of this type of measurement decreases because the unloaded Q of this measuring method is low compared with the Q factor of the material, and because the dimensional accuracy required is so high that it is impossible to achieve.

In this paper, we propose a precise measurement method using a $TE_{01\delta}$ mode dielectric resonator. The precision of this temperature coefficient measuring method can satisfy the requirement of ± 0.05 ppm/℃ because the unloaded Q of the measurement is as high as the Q factor of the dielectric materials.

CONSTRUCTION OF MEASURING INSTRUMENT

A cross section of the measuring instrument is shown in Figure 1. The dielectric resonator is fixed to the support in the center of the cavity.

Figure 1-a shows the measuring instrument of a brass metal cavity of which the thermal expansion coefficient, α is 18 ppm/℃. An Invar metal cavity of which α is 0 ppm/℃ is also used.

The shielding cavity, shown in Figure 1-b, are made of metalized ceramic material having the same α as the dielectric resonator. The support is made of a ceramic

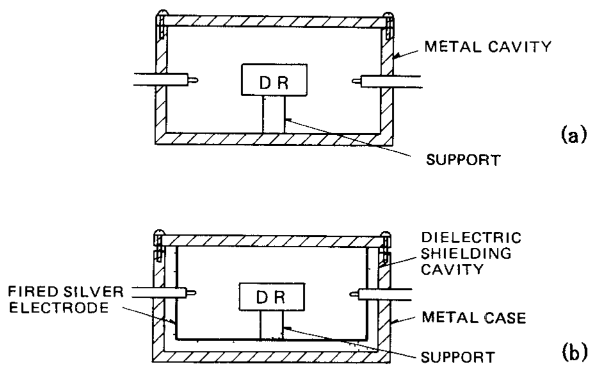

Figure 1 The cross sectional view of measuring instrument ; (a) metal cavity (b) ceramic cavity

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tube which also has the same α . α of the cavity and support material ($2MgO{\cdot}SiO_2$ -$ZrSiO_4$) can be controlled from between 4 ppm/℃ to 10 ppm/℃ using a composition ratio of $2MgO{\cdot}SiO_2$ and $ZrSiO_4$. α of the ceramic material ($2MgO{\cdot}SiO_2$ -$ZrSiO_4$) is shown in Figure 2.

The difference of the thermal expansion caused by α of the dielectric resonator and the cavity is shown in Figure 3. The dimension ratio of the dielectric resonator and the metal cavity dimension was changed by the thermal expansion; however, this ratio, in the case of a ceramic cavity, was not changed by thermal expansion. Therefore, using a ceramic cavity, the temperature coefficient of the material can be measured without the effect of the thermal expansion.

PRINCIPLES

We considered the measurement of the temperature dependence of resonant frequency. When the measuring instrument of Figure 1-b is used, the normalized resonant frequency is that shown in the following equation,

$$\frac{2\pi D}{\lambda_0} = F(K_1, K_2, L/D, d_1/D, d_2/D, \ell_1/D, \ell_2/D) \qquad (1)$$

where, λ_0 is resonant wavelength in free space, K_1 and K_2 are dielectric constant of a resonator and a suport. If the small linear changes $\Delta D, \Delta K_1, \Delta K_2, \Delta L, \Delta d_1, \Delta d_2, \Delta \ell_1, \Delta \ell_2, \Delta f$ in (1) are caused by the temperature change ΔT℃ of the instrument, the following equation is derived.

$$\eta_f = \frac{1}{F}\frac{\partial F}{\partial K_1}\frac{\Delta K_1}{\Delta T} + \frac{1}{F}\frac{\partial F}{\partial K_2}\frac{\Delta K_2}{\Delta T} + \frac{1}{F}\sum_i \frac{\partial F}{\partial X_i}\frac{\Delta X_i}{\Delta T} - \frac{1}{D}\frac{\Delta D}{\Delta T} \qquad (2)$$

where

$$\eta_f = \frac{1}{f}\frac{\Delta f}{\Delta T},\quad X_i = L/D, d_1/D, d_2/D, \ell_1/D, \ell_2/D \qquad (3)$$

Here, η_f is the temperature coefficient of resonant frequency. If α of a resonator, a cavity, and a support are all equal, then $\Delta X_i = 0$ in (2). Therefore the following equation is derived from (2).

$$\eta_f = \frac{1}{F}\frac{\partial F}{\partial K_1}\frac{\Delta K_1}{\Delta T} + \frac{1}{F}\frac{\partial F}{\partial K_2}\frac{\Delta K_2}{\Delta T} - \alpha \qquad (4)$$

where

$$\alpha = \frac{1}{D}\frac{\Delta D}{\Delta T} \qquad (5)$$

$\frac{1}{F}\frac{\partial F}{\partial K_i}\frac{\Delta K_i}{\Delta T}$ is the change ratio of resonant frequency which is caused by the temperature coefficient of K. The change ratio is shown in the following equation[4].

$$\frac{1}{f_0}\frac{\Delta f}{\Delta T} = -\frac{1}{2} A \frac{1}{K}\frac{\Delta K}{\Delta T} \qquad (6)$$

where, A is the ratio of the electric energy stored in the dielectric rod in proportion to the total electric energy in the cavity.

The following equation is derived from (4),(6).

$$\eta_f = -\frac{1}{2}(A_1 \eta_{K_1} + A_2 \eta_{K_2}) - \alpha \qquad (7)$$

where

$$\eta_{K_i} = \frac{1}{K_i}\frac{\Delta K_i}{\Delta T} \qquad (8)$$

If all electric energy is stored in the dielectric rod, $A_1=1$ and $A_2=0$ in (7). η_{f_0} defined when $A_1=1$ and $A_2=0$, is shown in the following equation.

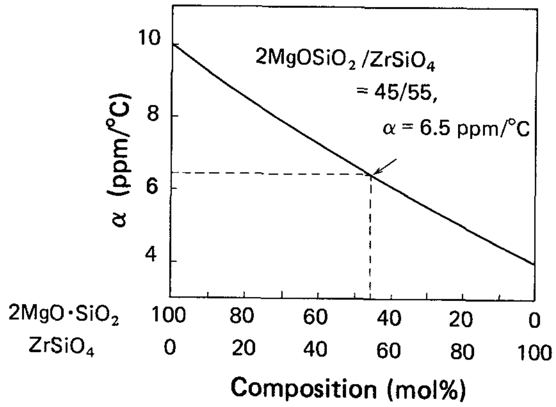

Figure 2 The thermal expansion coefficient of the ceramic material

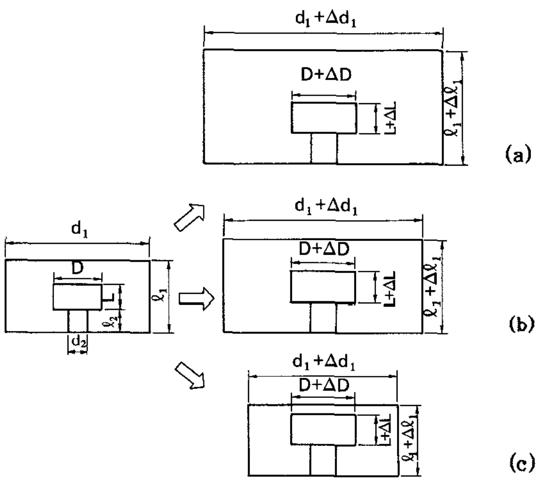

Figure 3 The thermal expansion of the dielectric resonator and the cavity ; (a) brass cavity, (b) ceramic cavity, (c) Invar cavity

$$\eta_{f_0} \equiv -\frac{1}{2}\eta_{K_1} - \alpha \quad (9)$$

Finally, the temperature coefficient of frequency is given by the following equation derived from (7),(9).

$$\eta_f = \eta_{f_0} - \frac{1}{2}(1 - A_1)\eta_{K_1} + \frac{1}{2}A_2\eta_{K_2} \quad (10)$$

MEASURED RESULTS

The measuring system is shown in Figure 4. Temperature coefficient for the dielectric resonator of K = 37.6, D = 10.1 mm and L = 4.9 mm was measured by using the Invar cavity, the ceramic cavity, and the brass cavity. $\Delta\eta_f$, the measured value deviation of η_f from η_{f_0} is shown in Table 1. ; its mean-square errors are about 0.05 ppm/℃. The histogram of measured $\Delta\eta_f$ is shown in Figure 5. $\Delta\eta_f$ in Table 1 is measured with the dielectric rod in the center height of the cavity; however, $\Delta\eta_f$ has dependence on the resonator position in the metal cavity because of the difference between the thermal expansion of the ceramics and the metal. The $\Delta\eta_f$ dependence on the resonator position is shown in Figure 6. By increasing the support length, $\Delta\eta_f$ measured in the Invar cavity increased and $\Delta\eta_f$ measured in the brass cavity decreased. $\Delta\eta_f$ can be measured without the dependence on the resonator position in the ceramic cavity.

The temperature coefficient of the three materials (K=30.0, 37.6, 89.0) were measured using the conventional method and this newly developed method. The measured results are shown in Table 2. The measured unloaded Q, Qo of the conventional method are higher than the one of this newly developed method. The mean-square error is decreased from 0.5 ppm/℃ to 0.05 ppm/℃ compared with the conventional method.

Table 1. Measured $\Delta\eta_f$ of three cavities

Cavity material	Invar	Ceramic	Brass
α of cavity(ppm/℃)	0.0	6.5	18.0
Measured $\Delta\eta_f$ (ppm/℃)	-0.1±0.05	-0.1±0.05	-1.0±0.05

(Measuring condition)

Resonator ; D=10.1mm, L=4.9mm, K=37.6, η_{f_0}=0.25ppm/℃

Cavity ; d_1=32.3mm, l_1=14.3mm

Support ; d_2=5.0mm, l_2=4.8mm, K=8.5, η_f=-60ppm/℃

Frequency ; fo=5.1GHz

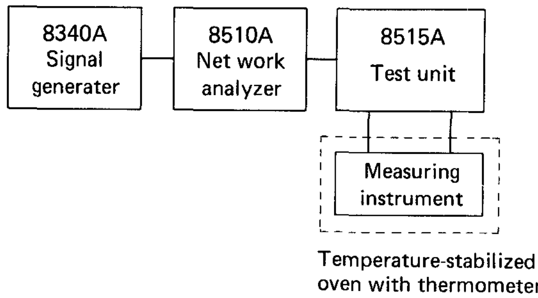

Figure 4 The measuring system

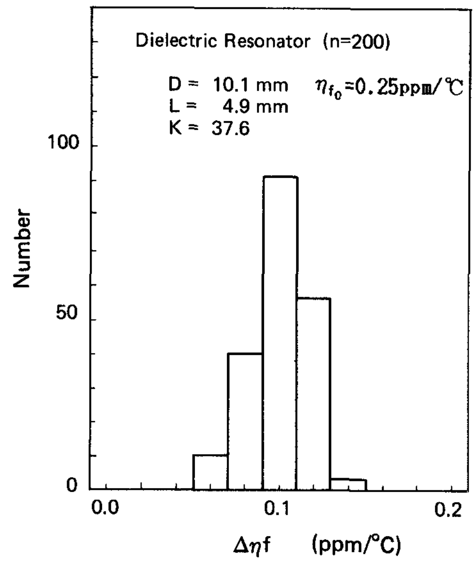

Figure 5 The histogram of measured $\Delta\eta_f$

Table 2. Measured η_f of three resonators

Resonator material	A	B	C
K of resonator	30.0	37.6	89.0
α of resonator (ppm/℃)	10.5	6.5	8.5
Conventional method; η_f (ppm/℃) Frequency (Qo)	2.00±0.50 6.0 (3500)	0.10±0.50 5.3 (3000)	-5.00±0.50 3.5 (1200)
Developed method; η_f (ppm/℃) Frequency (Qo)	2.10±0.05 5.8 (12000)	0.15±0.05 5.1 (9000)	-4.92±0.05 3.4 (2000)

(Measuring condition)

Resonator; D=10.1mm, L=4.9mm

CONCLUSION

The precise measurement method for temperature coefficient of dielectric resonator materials was developed. The measuring instrument is shown in Figures 7 and 8.

This method is suitable for measuring the temperature coefficient of the low-loss dielectric material for high selective filters [5].

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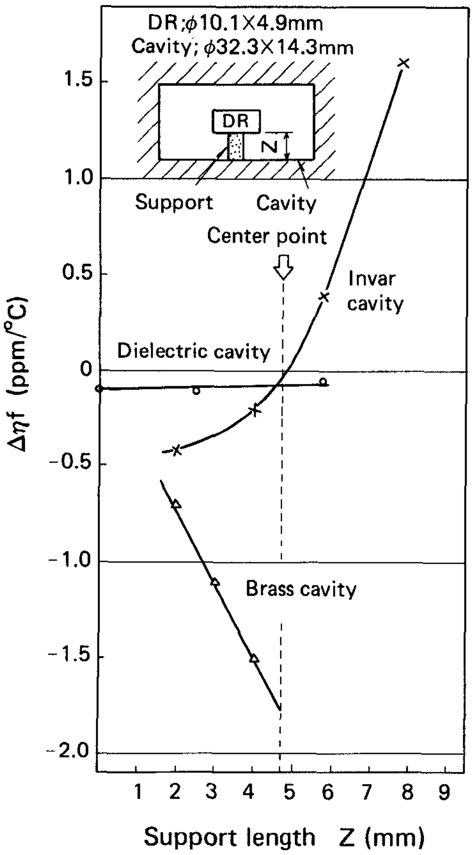

Figure 6 The measured results of $\Delta\eta_f$

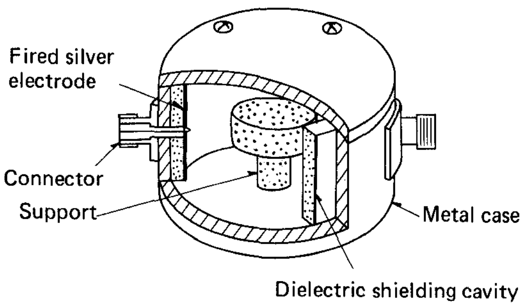

Figure 7 The measuring instrument

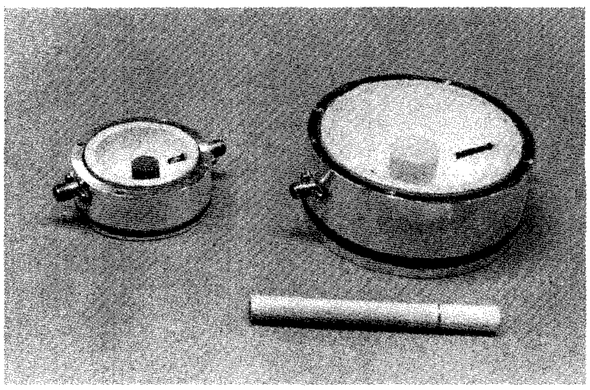

Figure 8 The photograph of the measuring instrument