MICROWAVE BANDPASS FILTERS CONTAINING DIELECTRIC RESONATORS WITH IMPROVED TEMPERATURE STABILITY AND SPURIOUS RESPONSE

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Abstract

The development of dielectric resonator superior to invar cavity on temperature stability as the result of our research made the usage of the miniature bandpass filter practical, and the method to set up temperature coefficient was established well.

I. Introduction

The microwave bandpass filter with high Q dielectric resonators has been reported several times since 1965 by W. H. Harrison, S. B. Cohn and others. Since the major advantage of utilizing dielectric resonators is the physical space reduction, because of its high dielectric constant, to match with the size of other related components, rutil (TiO_2) resonators were used for bandpass filters as reported in the past.

However, this dielectric material is very sensitive to temperature variation thus causing frequency to drift extensively.

Recent progress of material science has brought about various kind of material system and then followed the sintering technique of the materials related to the system so developed in controlling temperature cofficient including 0 PPM/$^{\circ}$C. The ceramics developed in such a way have relative permitivity of approximately 38, and a characteristics of high Q such as 6500 (at 7.5 GHz).

Moreover, we also developed the circuit technique which gives satisfactory temperature stability of filter as well as improved sprious response.

II. Temperature variation of resonant frequency.

Approximate solution by variation method

To discuss the temperature variation of resonant frequency, the solution of eigenvalue equation must be obtained. The approximate solution obtained by magnetic wall assumption is accompanied by the inevitable error of 10 %, more or less. As a countermeasure to this problem, we applied the variation method described as follows; the TE_{01} scaler potential with an assumption of imperfect magnetic wall having a certain finite value of the degree of freedom of the wall impedance is considered as a trial function within a cylindrical area including dielectric resonator of the resonant system shown in Fig.1.

Trial function:

$$h_s < z < h_s + L \qquad \phi_1 = J_0(k_r r)\cos(\beta_g(z - \tfrac{L}{2} - h_s) + \theta) \tag{1}$$

$$0 < z < h_s \qquad \phi_1 = \frac{\cos(\frac{1}{2}\beta_g L - \theta)}{\sinh \xi_0' h_s} J_0(k_r r)\sinh \xi_0' h_s \tag{2}$$

$$h_s + L < z < 2h_0 + L \quad \phi_1 = \frac{-\cos(\frac{1}{2}\beta_g L + \theta)}{\sinh \xi_0 h_u} J_0(k_r r)\sinh \xi_0 (z - L - 2h_0) \quad (2h_0 = h_u + h_s) \tag{3}$$

In the above case, the resonant frequency can be obtained by substituting the value of k_r into next equation,[1]

$$\beta_g L = \cot^{-1}\frac{\beta_g}{\xi_0}\tanh \xi_0 h_u + \cot^{-1}\frac{\beta_g}{\xi_0'}\tan \xi_0' h_s \tag{4}$$

where
$$\xi_0' = 2\pi\sqrt{(k_r/2\pi)^2 - \varepsilon_s (1/\lambda_0)^2} \tag{5}$$

Since the axial component of magnetic field has a certain value, the stationary value of the resonant frequency is obtained by the variation of wall admittance. The wall admittance is defined as

$$Y_\omega = H_z / E_\theta = k_r^2 \phi_1 / j\omega\mu \partial_r \phi_1 \Big|_{r=a} \tag{6}$$

from (6)

$$\Delta k_r = \frac{j\omega\mu J_1^2(k_r a) \quad \Delta Y_\omega}{k_r a J_1^2(k_r a) - J_0(k_r a) J_1(k_r a) + k_r a J_0(k_r a) J_1'(k_r a)} \tag{7}$$

When the axial components of magnetic field of inside and outside cylindrical area are expressed by Hz_1, Hz_2 respectively, the stationary condition[2] is

$$\int_S (H_{z2} - H_{z1}) E_{\theta 1} dS = 0 \tag{8}$$

so the value of admittance must be given by next equation.

$$Y_\omega = \int_S H_{z2} E_{\theta 1} dS \Big/ \int_S E_{\theta 1}^2 dS \tag{9}$$

The outside solution ot scaler potential is given by the complete set, corresponding to TE_0

$$\phi_2 = \sum_{n=1}^{\infty} F_n H_0^{(1)}(r\sqrt{k_0^2 - k_{zn}^2}) \sin k_{zn} z \tag{10}$$

$$\left(k_{zn} = \frac{n\pi}{2h_0 + L}\right).$$

Hz_2 is expressed using $E_{\theta 2}$ obtained from (10), thus Hz_2 is given

$$H_{z2}(a,z) = \frac{2j}{\omega\mu(2h_0+L)} \sum_n \left\{ \sqrt{k_0^2 - k_{zn}^2} \frac{H_0^{(1)}(a\sqrt{k_0^2 - k_{zn}^2})}{H_1^{(1)}(a\sqrt{k_0^2 - k_{zn}^2})} \int_0^{2h_0+L} E_{\theta 2} \sin k_{zn} z' dz' \right\} \sin k_{zn} z \tag{11}$$

Setting the external electric field obtained from equal to the electric field given by the trial function at the boundary surface, Hz_2 can be expressed by the trial function.

This result gives the value of Y_ω by substituting (11) to (9), then Δk_r is obtained as (12) by relating Y_ω to (7) as follows,

$$\Delta k_{d_{i-1}} = \frac{-4 J_1(k_r a) \sum_n D\sqrt{k_0^2 - k_{zn}^2} \frac{H_0^{(1)}(a\sqrt{k_0^2 - k_{zn}^2})}{H_1^{(1)}(a\sqrt{k_0^2 - k_{zn}^2})} \left[\int_0^{(2h_0+L)/D} \bar{E}_{\theta 1} \sin k_{zn} z \, d(\frac{z}{D}) \right]^2}{(2h_0+L)/D \quad (k_d J_1^2 - 2J_0 J_1 + k_d J_0 J_1') \int_0^{(2h_0+L)/D} \bar{E}_{\theta 1}^2 d(\frac{z}{D})} + \frac{2 k_d J_1 J_0}{k_d J_1^2 - 2J_0 J_1 + k_d J_0 J_1'} \Bigg|_{\substack{k_0 = k_{0\,i-1} \\ k_r = k_{r\,i-1} \\ J_n = J_n(k_{r_{i-1}} a) \\ \bar{E}_{\theta 1} = D\partial_r \phi_1(\lambda_{0_{i-1}}, k_{r_{i-1}})}} \tag{12}$$

$$i \geq 1 \quad k_{d_i} = k_{d_{i-1}} + \Delta k_{d_{i-1}} \quad (k_{d_i} = k_{r_i} D)$$
$$i = 0 \quad k_{d_0} = 4.81 \tag{13}$$

Substituting k_r compensated by (12) and (13) to (4), the compensated frequency can be obtained. Where i is a number of compensation. The calculation curve is shown in Fig.1.

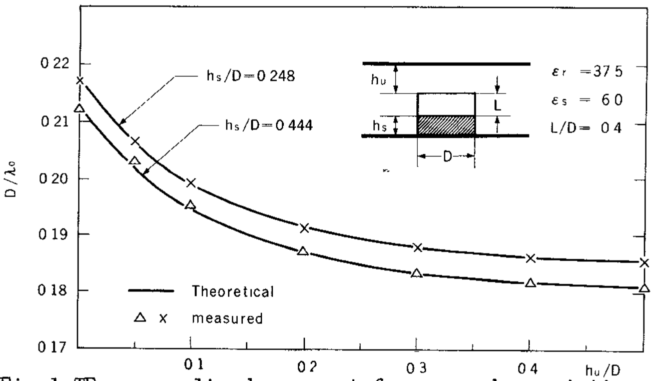

Fig.1 TE_{01} normalized resonant frequency by variation method

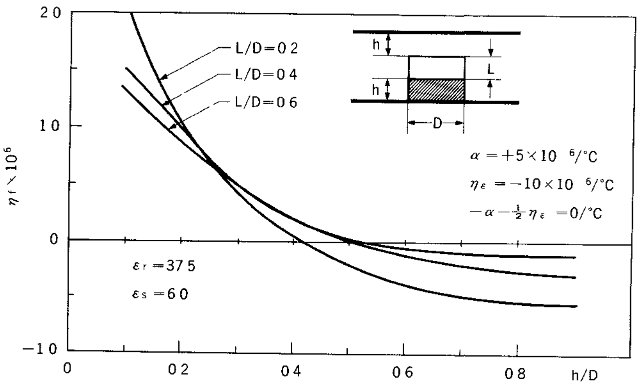

Fig.2 The deviation of η_f from compensated value.

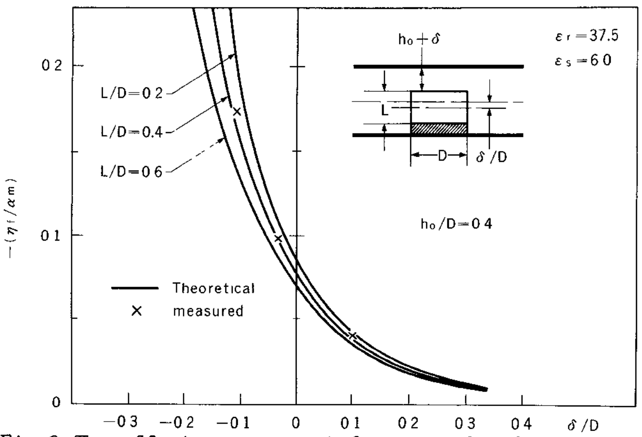

Fig.3 The effect on resonant frequency by thermal expansion of box

The effect of temperature dependency of resonator

The dielectric material we used as a resonator has a small temperature coefficient of the resonant frequency of 0 ± 1 PPM/°C. This cofficient was derived according to the measuring method described in the literature by Y. Kobayashi[3]. The theoretical curves shown in Fig.2 indicate to what exent the temperature coefficient of resonant frequency of dielectric resonator, compensated when covered by magnetic wall, deviates from 0 PPM/°C on the actual resonant system shown in the same Fig.

The frequency variation caused by other factors

The temperature coefficient of resonant frequency

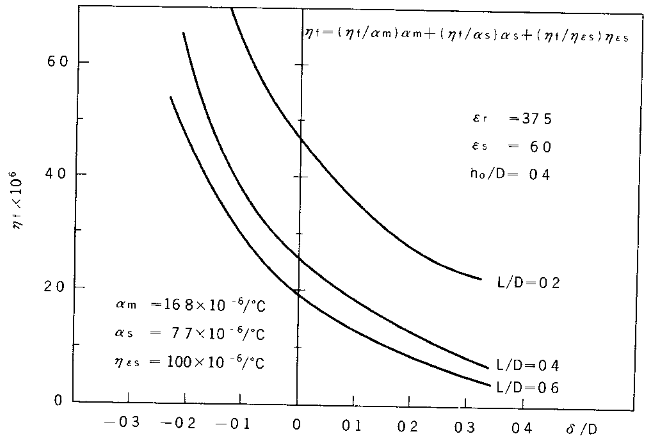

Fig.4 Simultaneous effect of α_m, α_s, $\eta_{\varepsilon s}$ on η_f

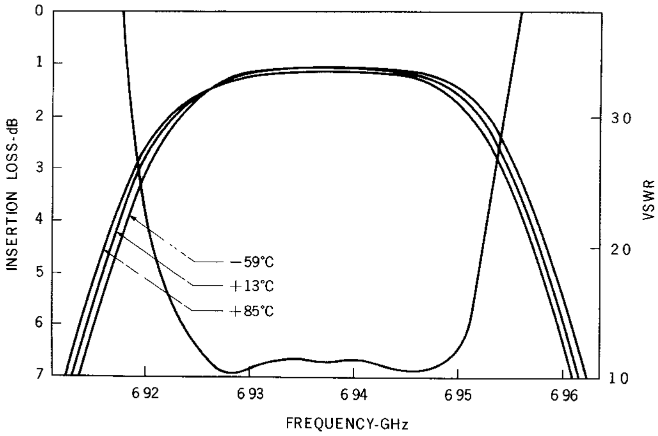

Fig.5 Frequency deviation of pass band

depends mainly on α_m, α_s and $\eta_{\varepsilon s}$ except for resonator itself. Where

α_m ; thermal expansion coefficient of housing or guide

α_s ; thermal expansion coefficient of support or substrate

$\eta_{\varepsilon s}$; temperature coefficient of dielectric constant of support or substrate

Theoretical curve shown in Fig.3 is the effect of which is the largest among the above.

Considering the effect of other factors together with α_m, we estimate the theoretical value of temperature coefficient of resonant frequency assuming that the box is made of brass (α_m = 16.8 PPM/°C) and the dielectric support is forsterite ($2\,MgO{\cdot}SiO_2$ ε_s = 6.0 $\eta_{\varepsilon s}$ = + 100 PPM/°C, α_s = 7.7 PPM/°C).
The effect of the temperature coefficients of various materials which surround the resonator is illustrated in Fig.4.

Therefore, by using the resonator with temperature coefficient which offsets the whole effect of the above mentioned temperature coefficients, we can obtain 0 PPM/°C as a total resonant system.

III. Bandpass filter with improved temperature stability

Design

This bandpass filter was designed with the characteristics of the following parameters.

Center frequency	6937.5 MHz
Response	Butter worth
3 dB band width	40.0 MHz
Number of resonator	3
Material of resonator	Resomics R-71C (Murata)
Support of resonator	$2MgO \cdot SiO_2$
Box dimension	60 x 24 x 13 (mm)
Box material	Brass

Temperature characteristics

The deviation of pass band in accordance with temperature variation is shown in Fig.5. The frequency drift is 1.51 MHz under temperature variation from $-59^{\circ}C$ to $85^{\circ}C$.
The changing rate of the resonant frequency is $-1.5 \times 10^{-6}/^{\circ}C$.
This small value of changing rate is equivalent or superior to the filter built with invar.

The contribution of temperature coefficient of resonant frequency of -1.5 PPM/$^{\circ}$C should be

the effect of $\eta_{\varepsilon s}$ ----- -1.20 PPM/$^{\circ}$C

the effect of α_s ----- -0.10 PPM/$^{\circ}$C

the effect of α_m ----- -1.26 PPM/$^{\circ}$C

and further we must include the mean value of temperature coefficient of three resonators and the deviated value in Fig.2:

the mean temperature coefficient of resonators

----- $+0.63$ PPM/$^{\circ}$C

(the temperature coefficients of resonators are $+0.5$, $+0.7$ and $+0.7$ PPM/$^{\circ}$C)

the deviation from compensated value

----- $+0.25$ PPM/$^{\circ}$C

Summing up these 5 terms, the changing rate of resonant frequency is theoretically -1.68 PPM/$^{\circ}$C.

Insertion loss

Measured value of insertion loss at the center frequency is 1.1 dB as shown in Fig.5. In this measured value, about 0.2 dB is due to the OSM type coaxial connectors. The resultant 0.9 dB loss corresponds to the unloaded Q of resonators. By S. B. Cohn's formular we can estimate the mean value of unloaded Q.

Spurious response

At the center of dielectric resonator, the electric field strength of dominant mode is very weak contrary to that of ajacent HE_{11} mode. The ratio of resonant frequency of TE_{01} and HE_{11} mode is approximately between 1 : 1.2 and 1 : 1.3 for the cylindrical resonator. Using similar sized ring shaped resonator, the ratio of resonant frequency is of two modes like 1 : 1.5 was obtained. The ring shaped respnators we used for the filter have inside diameter of 0.35 times smaller than outside diameter. So, we obtained the spurious response of 6.9 GHz bandpass filter shown in Fig.7.

When inside diameter is too large as compared with outside diameter, the resonant frequency of not only HE_{11} mode but also dominant mode drift to higher frequency drastically. The effect of the resonant frequency of dominant mode by expanding inside diameter is shown in Fig.6.

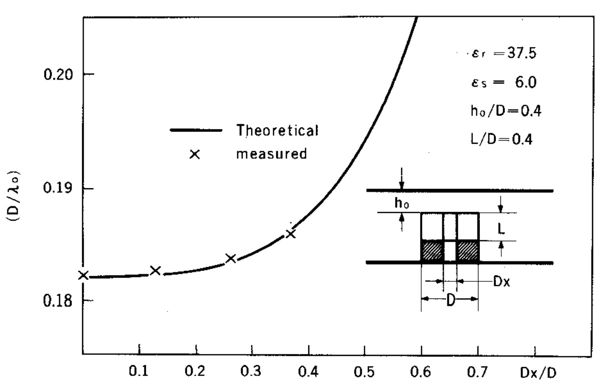

Fig.6 Effect on resonant frequency of TE_{01} by expanding inside diameter.

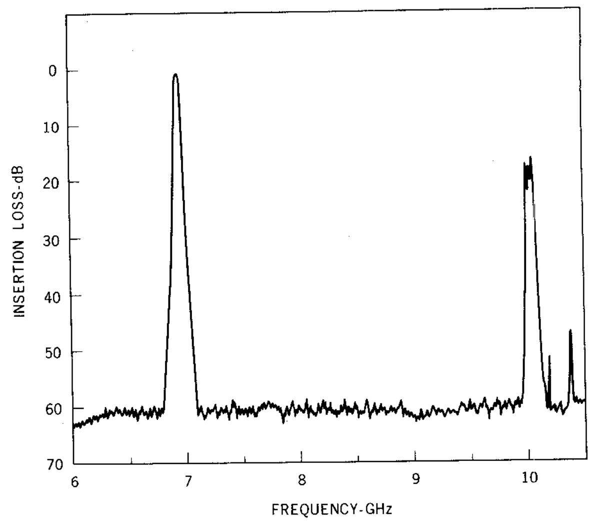

Fig.7 Measured dominant and sprious response of 6.9 GHz filter

IV. Conclusion

The development of new ceramics with many advantageous properties at microwave frequency has made the temperature stability of bandpass filter better than that of the filter made of invar cavities. The temperature variation of the resonant frequency is not determined only by temperature coefficient of the resonator. In addition, the effects on resonant frequency by other factors like α_m which can be detected quantitively by differentiation of the theoretical should also be considered in determining the temperature variation of the resonant frequency. Furthermore, the spurious response was improved by using ring shaped resonators.

V. Aknowledgement

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NOTES