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DIELECTRIC HIGH-POWER BANDPASS FILTER USING QUARTER-CUT $TE_{01\delta}$ IMAGE RESONATOR FOR CELLULAR BASE STATIONS

Toshio Nishikawa, Kikuo Wakino, Kikuo Tsunoda, and Youhei Ishikawa

Murata Manufacturing Company Limited
Kyoto, Japan

ABSTRACT

A dielectric high-power bandpass filter using "Quarter-cut $TE_{01\delta}$ Image Resonators" has been developed. This resonator construction has a high unloaded Q over 7000 and also provides a sufficient thermal diffusion path to the metal housing.

The insertion loss and the attenuation level of the 8-pole elliptic function type filter are 0.37 dB and 95 dB respectively. The physical size of the dielectric filter is 280×135×65 (mm), one third to one fifth the volume of conventional cavity resonator filters.

INTRODUCTION

Recently 800 MHz band cellular systems have been put into practical use in mobile communication systems.

Transmitting high-power bandpass filters for their base stations must be compact and low cost.

The most important problems involved in to design a high-power dielectric transmitting filter are generally how to construct a high Q dielectric resonator system which has low dissipation power and how to provide the thermal diffusion path which suppresses the temperature increase of the resonator.

We proposed a new dielectric resonator filter construction which solves these problems.

The dielectric resonator construction of the filter is composed of one quarter of an original $TE_{01\delta}$ mode dielectric ring shaped resonator[1] and two metalized ceramic substrates for fixing the resonator. We named this the "Quarter-cut $TE_{01\delta}$ Image Resonator" (Q.T.I.R.).

Using this construction we succeeded in developing an 880 MHz 8-pole elliptic function type high-power filter with 20 MHz bandwidth. The size is reduced to about 1/3~1/5 of conventional cavity resonator filters.

This paper describes the unloaded Q estimation, the power and the thermal design and the performance of the new dielectric resonator filter.

CONSTRUCTION

The construction of the Quarter-cut $TE_{01\delta}$ Image Resonator (Q.T.I.R.) Filter is shown in Figure 1.

The Q.T.I.R. is fixed to the L-angle metalized ceramic substrates. The substrates are attached electrically to the metal housing walls which divide the space into one quarter that of the TE_{01} mode cut-off waveguide.

Resonators are inductively coupled to each other,and the two resonators at each end are coupled inductively to the external load. Input and output ports are type N connectors (female). The equivalent circuit of the direct coupled resonator filter corresponding to this construction is shown in Figure 1.

DESIGN

Outline of Required Characteristics

The required characteristics for the bandpass filter used for mobile communications systems at the 800 MHz band are listed in Table 1.

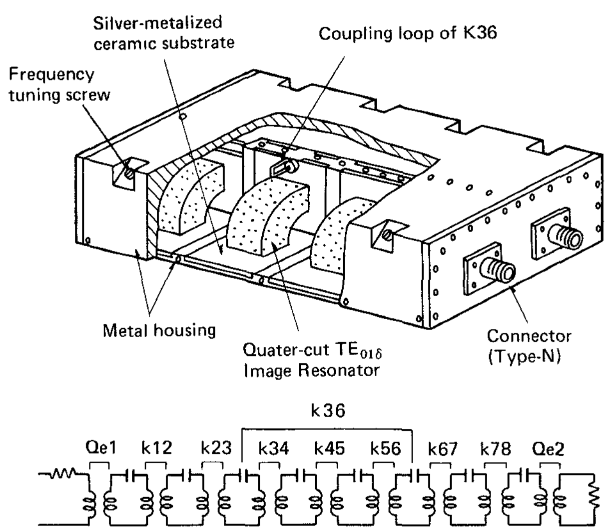

Fig. 1 Basic construction of "Quarter-cut $TE_{01\delta}$ Resonator Filter" and its equivalent circuit

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Table 1. Outline of required characteristics

Center frequency (f_0)	880MHz
Bandwidth (BW)	20 MHz
Attenuation (f_0-35MHz)	90 dB min
Insertion loss (at BW)	0.45 dB max
Input power	500 watts max
VSWR (at BW)	1.5 max
Volume	3.0ℓ max

Dielectric Materials

Dielectric materials of the Q.T.I.R. are listed in Table 2.

Table 2. Ceramic materials

	Resonator	Substrate
Material system	(Zr, Sn)TiO_4	$2MgO \cdot SiO_2-ZrSiO_4$
Dielectric permittivity (ϵr)	37.5	8.5
Dissipation factor ($\tan\delta$)	2.5×10^{-5} at 800 MHz	
$\frac{1}{\tan\delta}\cdot\frac{\Delta\tan\delta}{\Delta T}$	2% / 10°C	
Temperature coefficient (η_{f_0})	2ppm / °C	
Thermal expansion coefficient (α)	6.5ppm / °C	6.5ppm / °C
Thermal conductivity (K)	0.02 Joul / cm·deg·sec	

Resonant Frequency And Coupling Coefficient

The electromagnetic field distribution of the Q.T.I.R. is completely the same as that in the filter using axially coupled original $TE_{01\delta}$ mode resonators.

Accurate design method of the filter is reported by Y.Kobayashi et.al.[2] So both resonant frequency and coupling coefficient of the newly designed filter can be analytically obtained with high accuracy using this method. $TM_{01\delta}$, $HE_{11\delta}$ and $EH_{11\delta}$ modes are not excited in the new resonator as shown in Figure 2 because of the existence of the two electric walls. So the spurious response of the Q.T.I.R. filter can be expected to be far superior to the original $TE_{01\delta}$ mode filter.

Unloaded Q of Q.T.I.R.

The unloaded Q analysis of the original $TE_{01\delta}$ mode resonator ($Q_{o\ original}$) is reported by Y.Kobayashi.[3]

However, in order to estimate the unloaded Q of the Q.T.I.R., we must calculate the optional conductor losses on the two electric walls.

The conductor losses (1/Q') and unloaded Q (Q_0) are given as follows:

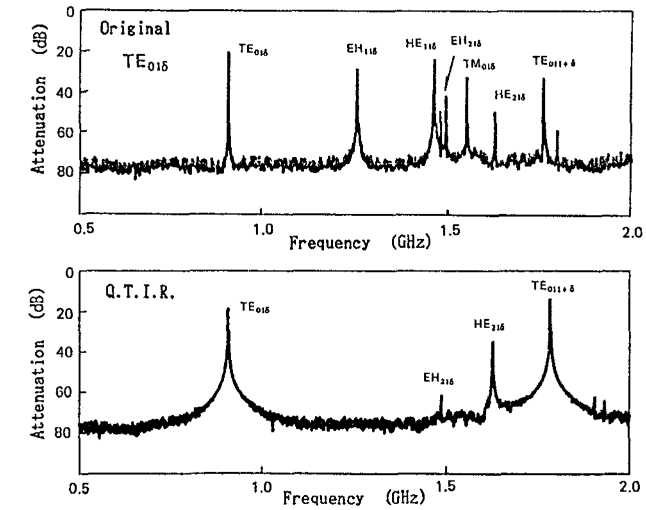


Fig. 2 Measured resonant characteristics of original $TE_{01\delta}$ mode resonator and Quarter-cut $TE_{01\delta}$ Image Resonator

$$Q' = \frac{\pi\mu_0\omega}{4R_s}\cdot\langle r\rangle \qquad (1)$$

$$\frac{1}{Q_0} = \frac{1}{Q'} + \frac{1}{Q_{0\,original}} \qquad (2)$$

$$\text{where} \quad \langle r\rangle = \frac{\int rH^2\,drdz}{\int H^2\,drdz} \qquad (3)$$

The average extent of the magnetic field (<r>) is calculated by F.E.M. according to the definition of Equation(3). The effect of small inner radius (Rx) is to expand the <r> as shown in Figure 3.

When the construction parameters are given as in the same figure, theoretical and measured values of unloaded Q are 7500 and 7100 respectively.

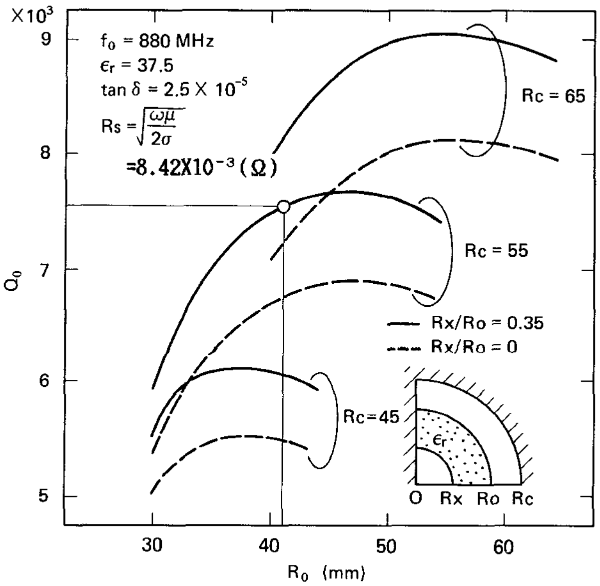


Fig. 3 Unloaded Q of Quarter-cut $TE_{01\delta}$ Image Resonator

Power Design

The most sensitive characteristics of the dielectric filter under high-power operation seems to be the third order inter-modulation.

The electromagnetic energy stored in each resonator under high-power operation, as shown in Figure 4, is obtained from the equivalent circuit. The F.E.M field analysis of the $TE_{01\delta}$ mode resonator gives maximum electric field strength in the dielectrics when the stored energy is known, as shown in the same figure.

Then we developed a measurement system which evaluates the distortion level of the Q.T.I.R. using two small RF power sources as shown in Figure 5.

The field intensity in the dielectrics obtained by this measurement system is calculated to be 44 V/mm which is equivalent when the filter input power is 1.45 KW. It will be low enough for Q.T.I.R. because the available field intensity of para-electric material is generally about a few KV/mm. The measured distortion level of the new dielectric resonator at field intensity of 44 V/mm is less than -120 dB as shown in Figure 6.

Thermal Design

The thermal energy, which was caused by the dissipation factor of the dielectrics, flows to the electric walls which work as heat sinks.

Assuming that the thermal diffusion is only due to the thermal conductivity (K) of the ceramic dielectrics and assuming a magnetic wall model of dielectric resonator, the stationary temperature is given by two dimensional analysis. Thermal source $q(r_0, \varphi_0)$ is expressed by total R.F. loss power (P_{DLOSS}) and electric field distribution as follows.

$$q(r_0\,\varphi_0) \simeq 2P_{DLOSS}\, J_1^2\left(u_{01}\frac{r_0}{R_0}\right) \Big/ \pi L \int_{R_x}^{R_0} r J_1^2\left(u_{01}\frac{r}{R_0}\right) dr \qquad (u_{01} = 2.401) \quad (4)$$

The temperature distribution is given using two dimensional Green's function as follows.

$$G^{I}(r\varphi; r_0\varphi_0) = \frac{2}{K\pi}\sum_{n=1} \frac{\left[1+\left(\frac{r_0}{R_0}\right)^{4n}\right]\sin 2n\varphi \cdot \sin 2n\varphi_0}{n\left[1+\left(\frac{R_x}{r_0}\right)^{4n}\right]\left[2-\left(\frac{r_0}{R_0}\right)^{4n}-\left(\frac{R_x}{r_0}\right)^{4n}\right]} \cdot \left[\left(\frac{r}{r_0}\right)^{2n} + \left(\frac{R_x}{r_0}\right)^{4n}\left(\frac{r_0}{r}\right)^{2n}\right] \quad (5)$$

$$G^{II}(r\varphi; r_0\varphi_0) = \frac{2}{K\pi}\sum_{n=1} \frac{\sin 2n\varphi \cdot \sin 2n\varphi_0}{n\left[2-\left(\frac{r_0}{R_0}\right)^{4n}-\left(\frac{R_x}{r_0}\right)^{4n}\right]} \cdot \left[\left(\frac{r_0}{r}\right)^{2n} + \left(\frac{r_0}{R_0}\right)^{4n}\left(\frac{r}{r_0}\right)^{2n}\right] \quad (6)$$

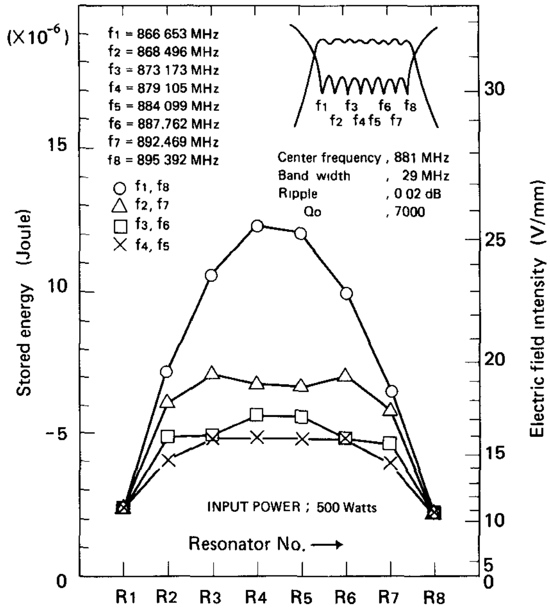


Fig. 4 Calculated stored energy and electric field intensity of each resonator

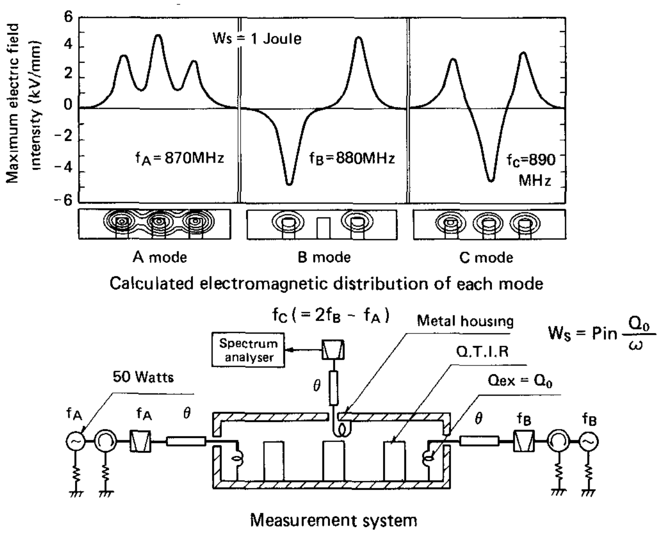


Fig. 5 The measurement method of the third order inter-modulation

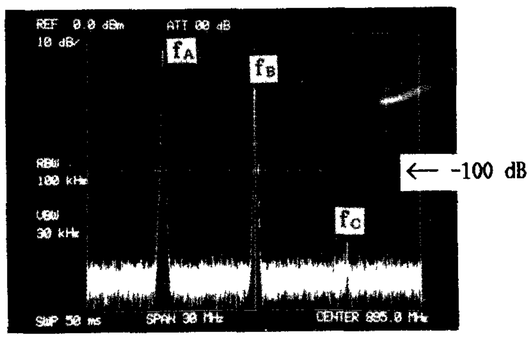
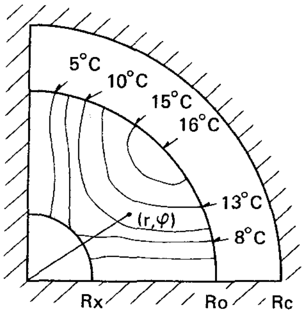


Fig. 6 The third order inter-modulation of Q.T.I.R.



Input power = 500 watts
PDLOSS = 1.75 watts
f = 866.65 MHz
Resonator No. ; R4
L (thickness of resonator) = 18.2mm
R_0 = 41mm
Rx = 14.4mm
Rc = 55mm

Fig. 7 Temperature distribution of Quarter-cut $TE_{01\delta}$ Image Resonator

$$\theta(r\varphi) = \int_0^{\frac{\pi}{2}}\int_{R_x}^{r} G^{II}(r\varphi; r_0\varphi_0)\, q(r_0\varphi_0) r_0 dr_0 d\varphi_0 + \int_0^{\frac{\pi}{2}}\int_{r}^{R_0} G^{I}(r\varphi; r_0\varphi_0) q(r_0\varphi_0) r_0 dr_0 d\varphi_0 \quad (7)$$

The highest temperature point in the dielectrics is the center of the outer circumference, and its calculation and experimental value are 16 degrees and 20 degrees centigrade higher than the heat sink respectively as shown in Figure 7. The insertion loss increase by temperature rise of the dielectrics of the filter under 500 W RF power operation should be about 0.03 dB.

PERFORMANCE

The performance of this filter is shown in Table 3, Figure 8 and Figure 9. This performance sufficiently satisfies the required characteristics shown in Table 1.

Table 3. Performance of the filter

Center frequency (f_0)	880 MHz
Bandwidth (BW)	20 MHz
Attenuation (f_0- 35MHz)	95 dB
Insertion loss (at BW)	0.37 dB
VSWR (at BW)	1.37
Size	280 X 135 X 65mm (2.46ℓ)

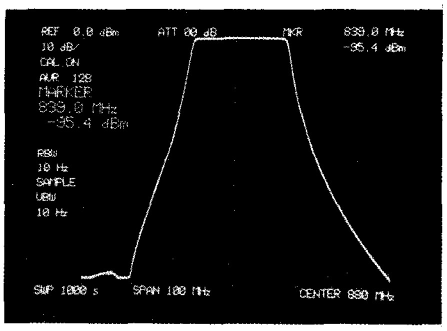


Fig. 8 Attenuation characteristics

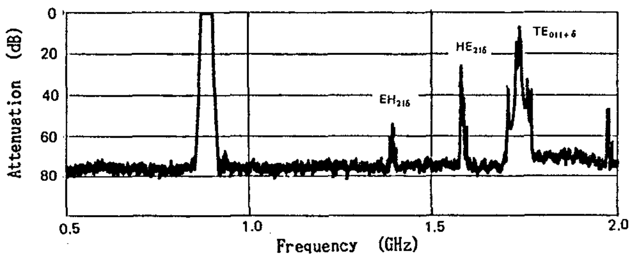


Fig. 9 Spurious response characteristics

CONCLUSION

We have developed 800 MHz dielectric high-power bandpass filter with 20 MHz bandwidth using "Quarter-cut $TE_{01\delta}$ Image Resonators".

Low insertion loss of 0.37 dB is obtained by high unloaded Q of 7100, and high attenuation of 95 dB is obtained by 8-pole elliptic function type filter design. Stable power characteristics of the filter are guaranteed by the new measurement method to evaluate the harmonic distortion of the dielectric resonator. The dimensions of the filter are 280×135×65mm, about from one third to one fifth the size of the cavity resonator filters. This is expected to be applicable to 800 MHz use in cellular base station.

REFERENCES

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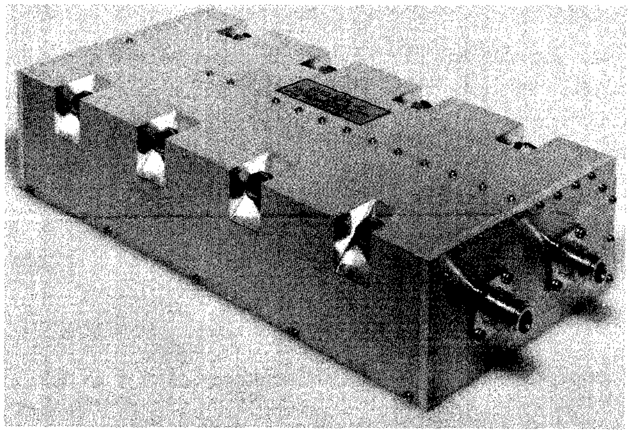

Fig. 10 Outview of Quater-cut $TE_{01\delta}$ Image Resonator Filter