800 MHz Band Dielectric Channel Dropping Filter Using TM_{110} Triple Mode Resonance

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ABSTRACT

High power and temperature stable "Channel Dropping Filters" for Transmission Multiplexers of base stations have been miniaturized to almost 1/3 the size of the dielectric TM_{010} resonator filter by using triple mode resonance, and we reported on this at the last symposium. The triple mode resonator works as resonators of three independent one-section filters. The isolation level between each two filter was about 40dB.

INTRODUCTION

Recently within the category of mobile communication systems, cellular systems have been put into practical use, and the number of base stations has increased. Channel filters are used for transmission multiplexers in these base stations, and their technical requirements are increasing to a high level. The most important characteristics required of conventional filters are physical size reduction and low cost.

$TE_{01\delta}$ mode dielectric resonators with improved temperature stability and shielded by metal cases were used in order to miniaturize filters.[1] After that TM_{010} mode dielectric resonators and filters with metal cases were reported.[2] These resonators are smaller than $TE_{01\delta}$ mode resonators, but the essential problem of frequency stability was not solved until 1984 when we cleared it up.[3]

Recently a method by which space can be used effectively using the TM_{110} dual mode of two block dielectric resonators has been reported.[4] We developed the TM_{110} triple mode method with one block dielectric resonators in order to use cavity space more effectively. Three dominant modes are multiplexed in common space where their resonant energies are independent of each other. Each dominant mode is a TM_{110} dielectric resonator in a rectangular cavity, and the resonant axes of the three modes are orthogonal to each other. Three independent one-section filters were constructed in a common ceramic cavity where each filter has a different center frequency from all others, and the size of the filters is reduced to almost 1/3. Now, we succeeded in developing a small size 800 MHz band channel dropping filter by using the effective method mentioned above.

CONSTRUCTION

The construction of the dielectric channel dropping filter is shown in Figure 1. The "jack-shaped" hexapod dielectric (with ϵ_r of 37.5) is fixed in a cubic electromagnetic shielding and made of ceramic material with the same thermal expansion coefficient as the inner dielectric resonator. The electrode of the cavity is a thin film of fired silver. The surface resistance of the electrode is about 10% larger than the theoretical value of silver. The small rod on the axis is used for tuning the center frequency. Slant metal screws are used for adjusting zero coupling between triple modes. These pairs of connectors are fixed to the face of the case to which they are connected and to two adjacent sides perpendicular to that face. Three pairs of external coupling loops are coupled to each of the three resonator modes independently.

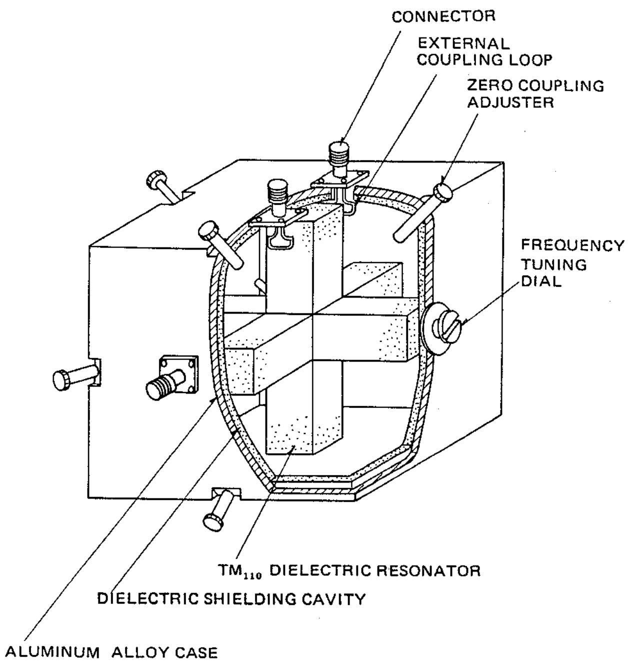

Figure 1. The construction of dielectric channel dropping filter

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Table 1. Properties of the ceramic materials

Part	Material	ϵ_r	α(ppm/°C)	1/tanδ
Resonator	$(Zr \cdot Sn)TiO_4$	37.5	6.5	35000
Shielding Cavity	$2MgO \cdot SiO_2 - ZrO_2 \cdot SiO_2$		6.5	

DIELECTRIC MATERIALS OF THE FILTER

The ceramic materials used for the filter are listed in Table 1. The changes of the resonant frequency of the high ϵ_r material versus temperature are shown in Figure 8. The frequency temperature coefficient "η_{f_0}" of the dielectric material is defined as follows:

$$\eta_{f_0} \equiv -\frac{1}{2}\eta_{\epsilon_r} - \alpha = \frac{1}{f_0}\frac{\partial f_0}{\partial T} \qquad (1)$$

where η_{ϵ_r} is the temperature coefficient of ϵ_r and α is the thermal expansion coefficient. The second equal sign of the equation is realized when the electromagnetic energy is perfectly confined in the dielectric material. Therefore, the value of η_{f_0} is independent of the shape of the ceramics and their resonant mode.

DESIGN

Each electromagnetic field of this triple mode is orthogonal to each other in this construction. Then these three modes are multiplexed in a common space. This method of using cavity space effectively reduces the size of the channel dropping filter.

Required characteristics

Required characteristics of the filter are shown in Table 2.

Equivalent circuit and isolation between channels

The equivalent circuit of three one-section filters using TM_{110} triple mode is shown in Figure 2. These resonators are expressed ideally in lumped inductors and capacitors. Coupling coefficients "k_{ij}" in the figure are expressed in mutual inductances and make the isolation level between channels lower. The electromagnetic fields of this triple mode which expresses the three resonators

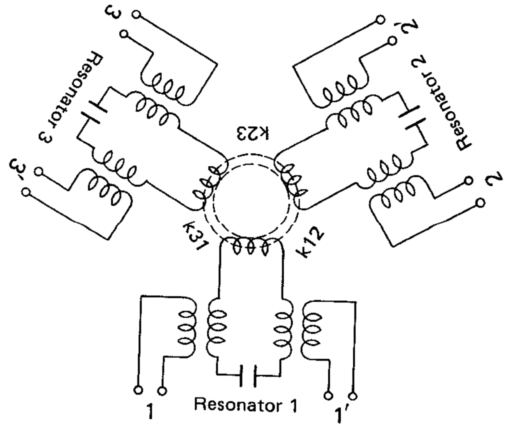


Figure 2. Equivalent circuit of three one-section filters

Table 2. Required characteristics

Center frequency	880MHz
Frequency adjustable range	from 875MHz to 885MHz
Attenuation at fo±0.6MHz	9.5dB (Q≅1,500)
Insertion loss	1.8dB max. (Qo≥8,000)
Operating power	30W min.
Operating temperature	from -30°C to +80°C
Outer dimension (Volume)	70 70X70 mm (343cc)
Weight	750 g

in the equivalent circuit are orthogonal to each other in this construction. But the orthogonality is not perfect because of deviation in dimensions. This deviation results in coupling coefficient between modes "k_{ij}". The value of k_{ij} will be about 0.1% in usual machinable size accuracy for the dielectric cavity resonator. An adjuster which reduces the coupling coefficient between resonators is necessary. An example of the mechanism which adjusts the coupling coefficient between resonator 1 and resonator 2 is shown in Figure 3. Inserting one of two screws into the cavity increases the resonant frequency of even mode composed of resonator 1 and resonator 2, and inserting the other increases the odd mode resonator frequency. As the result, we obtain $k_{ij} \cong 0$. We can easily control $k_{ij} \cong \pm 0.5\%$ by adjustment of screws of 5.0mm in diameter.

Coupling loop

The mechanism of the mode selective external coupling loop is shown in Figure 3. A pair of loops for input and output is set at each resonator for driving and probing. The value of external Q "Qex" is controlled by the cross section of the coupling loop and its position. The design value

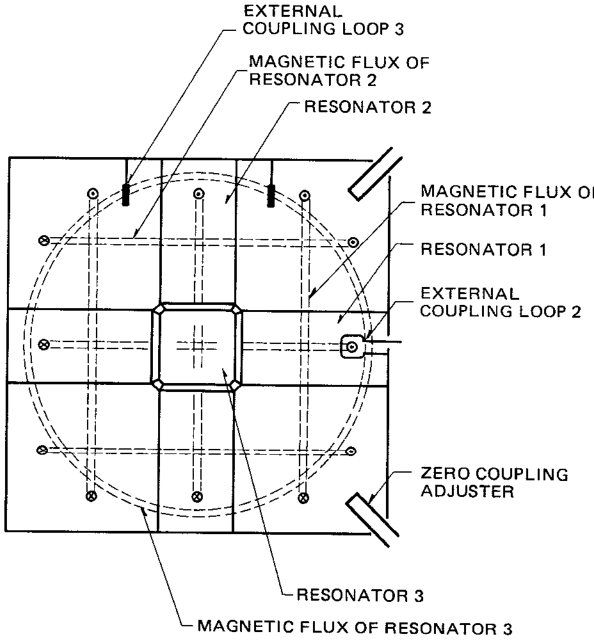


Figure 3. Mechanism of mode selective external coupling loops and zero coupling adjusters

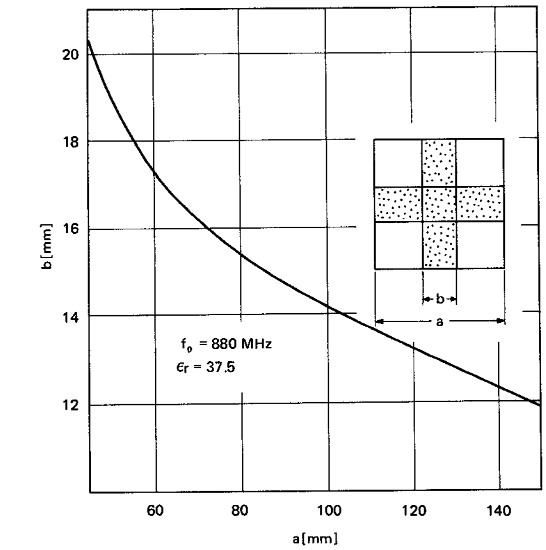


Figure 4. The outer dimendions of the inner dielectric resonator versus the inner dimension of the cavity resonator

of external Q "Qex" is decided by the loaded Q "Q_L" and unloaded Q "Qo" as follows,

$$\frac{2}{Q_{ex}} = \frac{1}{Q_L} - \frac{1}{Q_o} \qquad (2)$$

where Q_L and Qo are as listed in table 2.

Calculation of resonant frequency

"Vectorial Finite-Element Formulation without Spurious Modes for Dielectric Waveguides" was reported.[5] We applied this method to three-dimension analysis of this triple mode dielectric resonator. In this method the following Lagrangian is used.

$$\begin{aligned} \mathcal{L}(H) = & \frac{1}{2}\iiint_V (\nabla \times H)^* \cdot (\frac{1}{\epsilon_r}\nabla \times H) dV \\ & + \frac{1}{2}\iiint_V (\nabla \cdot H)^* (\nabla \cdot H) dV \\ & - \frac{1}{2} k_0^2 \iiint_V H^* \cdot H dV \end{aligned} \qquad (3)$$

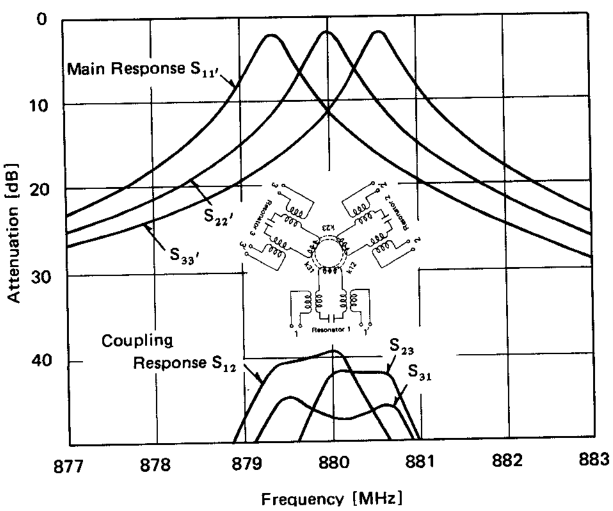
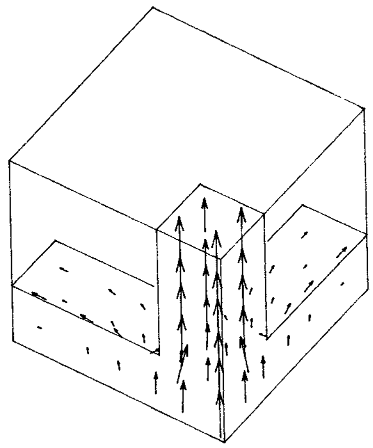


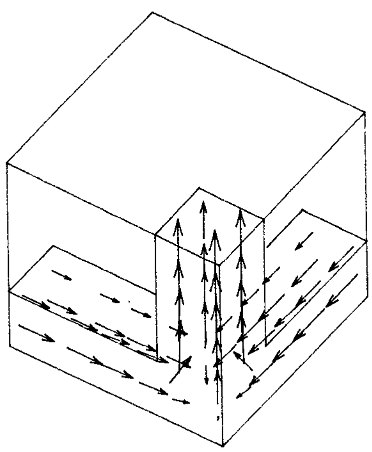
Figure 5. The attenuation characteristics and the isolation characteristics of the dielectric channel dropping filter

where
 H : magnetic field in the cavity
 ϵ_r : relative dielectric constant
 k_0 : $2\pi / \lambda_0$

The electric displacement vector in Figure 6 is obtained by F.E.M. This figure shows the field of the space equalling 1/8 of the cavity resonator. (A) is dominant mode (TM_{110}) and (B) is next higher order mode (TM_{111}). In Figure (A) the electric energy is concentrated in one resonator and the dielectric permittivity of the other two resonators does not work effectively. The bottom surface of Figure (A) is an electric wall. These facts indicate that triply degenerated modes exist and electromagnetic field distribution of each resonant mode resembles that of the TM_{010} single mode dielectric resonator cavity which we reported in 1984. The electric displacement vector in Figure (B) is also like that of the TM_{111} mode of cavity resonator without dielectrics. Then the solutions obtained by F.E.M. are expected to derive meaningful results. The resonator frequency was computed by F.E.M. The outer dimensions of the inner dielectric resonator "b" is decided by Figure 4 when the inner size of the cavity resonator "a" is given. As the required outer dimensions of the filter are 70X70X70mm, dimension "a" must be smaller than 56mm, and dimen-



(A) dominant mode (TM_{110})



(B) next higher order mode (TM_{111})

Figure 6. Electric displacement vector of resonant mode computed by F.E.M.

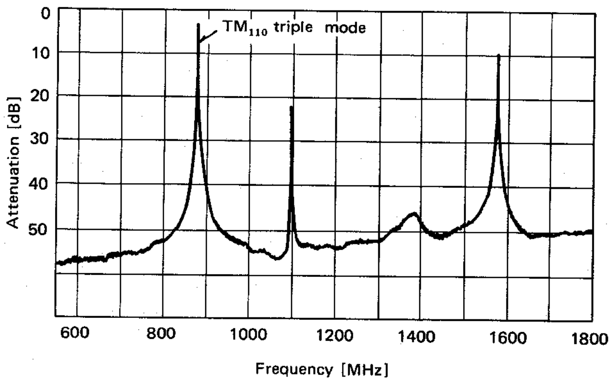


Figure 7. The spurious characteristics of the dielectric channel dropping filter

sion of 17.6mm are obtained for "b". In this case the experimental value of unloaded Q of the resonator was 8,500.

PERFORMANCE

The attenuation characteristics and isolation characteristics of the filter we made as a trial are shown in Figure 5. The center frequencies of three independent one-section filters are at 0.6MHz separation. The unloaded Q of the resonator was about 8,500 and insertion loss at the center frequency was 1.7dB when loaded Q was 1,500. The isolation between channels was more than 39dB. The spurious characteristics of the filter are shown in Figure 7. We observed the spurious mode at about 1,100MHz. The frequency of this spurious mode shows agreement with the frequency of the resonant mode in Figure 7. The temperature coefficient of the dielectric material and the filter are shown in Figure 8. The temperature rise of the inner part of the filter caused by applied power of 30 watts to each input port is about 35°C from the temperature on the surface of the filter.

CONCLUSION

A small sized channel dropping filter using TM_{110} triple mode resonator was developed. The outer dimensions shown in Figure 9 were 70X70X70 mm (343cc). The isolation between channels were about 40dB. The unloaded Q of the resonator was about 8,500 and insertion loss at the center frequency was 1.7dB when loaded Q is 1,500. As the temperature coefficient of the filter was almost the same as that of the material, the high stability of the center frequency was easily obtained. This stable and reduced-size channel dropping filter is suitable for smaller sized mobile telecommunications equipment.

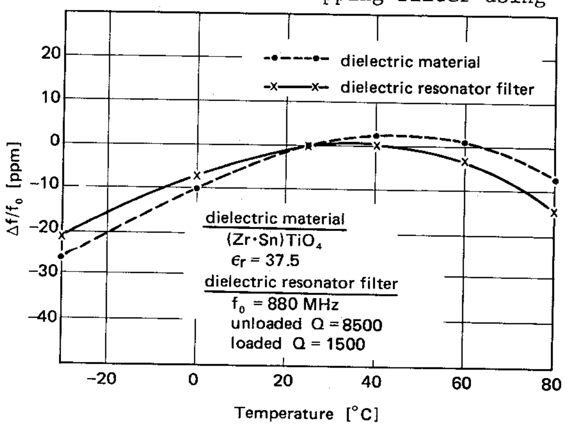


Figure 8. The temperature coefficient of the dielectric material and of the dielectric channel dropping filter

ACKNOWLEDGEMENT

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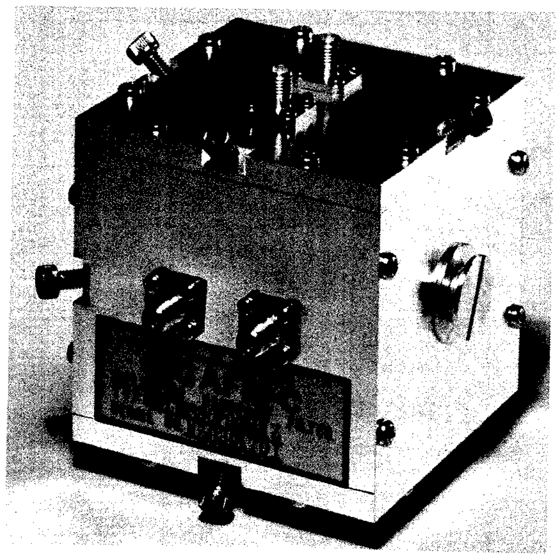

Figure 9. Dielectric channel dropping filter