MINIATURIZED DIPLEXER FOR LAND MOBILE COMMUNICATION
USING HIGH DIELECTRIC CERAMICS

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ABSTRACT

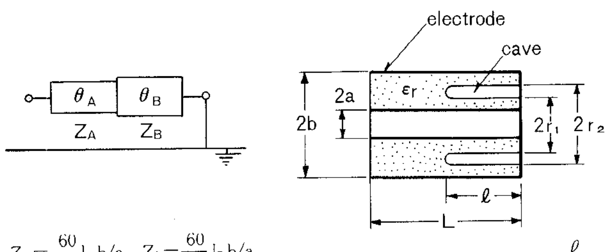
Miniaturized Diplexer for 800 MHz land mobile communication system has been developed using dielectric quarter wavelength resonator having high permittivity of 37 and 90. The physical volume of diplexer is about 48 cc. The Spurious responses of quarter wavelength resonator were shifted to the higher frequencies by stepping the effective permittivity of the resonator material.

Introduction

Half wavelength transmission line bandpass filter[1] using (Zr-Sn)TiO_4 ceramics with high permittivity of 37.5 and smaller sized quarter wavelength dielectric Diplexer[2] using ($CaTiO_3$-$MgTiO_3$) ceramics with permittivity of 21 were reported. However the required physical size of the Anttena diplexer for land mobile communications are getting smaller and smaller. In order to miniaturize the diplexer less than 50 cc, we used the dielectric ceramics[3] with permittivity of both 37.5 and 90 for coaxial quarter wavelength resonator. The spurious responses of ordinary quarter wavelength TEM resonator with high permittivity are excited almost exactly at the odd multiple frequencies of dominant mode response. It was reported that the spurious responses of the second and the third harmonics could be suppressed by using composite resonator of half wavelength which had two kinds of permittivities.
We applied the similiar but the simpler method to the quarter wavelength resonator, where the cylindrical cave in the short circuited side of the resonator makes the extremely lower effective permittivity for TEM electro-magnetic field.

Ceramic materials

Two kind of ceramic materials are used for diplexer. The first ceramics is (Zr-Sn)TiO_4 and used for both transmitting filter and receiving filter. The second ceramics is the mixture of TiO_2, (BaPb)TiO_3 and $Nd_2Ti_2O_7$ and used for receiving filter. The first ceramics is low loss dielectric materials which has Q of over 20,000 at the frequency under 1 GHz, while the second ceramics shows fair low Q. But at 800 MHz the Q is about 6,000 and this value is good enough for TEM resonators of receiving filter. The permittivities of these ceramics are 37.5 and 90 respectively.



$$Z_A = \frac{60}{\sqrt{\varepsilon_r}} \ln b/a, \quad Z_B = \frac{60}{\sqrt{\varepsilon_s}} \ln b/a \qquad \eta = \frac{\ell}{L}$$

$$\theta_A = \frac{2\pi}{\lambda_0}\sqrt{\varepsilon_r}\,(L-\ell), \quad \theta_B = \frac{2\pi}{\lambda_0}\sqrt{\varepsilon_s}\,\ell$$

$$\text{where} \quad \varepsilon_s \simeq \frac{\varepsilon_r \ln b/a}{\ln b/a + (\varepsilon_r - 1)\ln r_2/r_1}$$

Fig 1 CONSTRUCTION AND EQUIVALENT CIRCUIT OF CAVED COAXIAL RESONATOR

Properties of dielectric caved resonator

The construction and the equivalent circuit of caved resonator are shown in Figure 1. The axial length of the cylindrical cave is ℓ, which is measured from short circuited side.

As the electric field of TEM mode is radial direction, the effective permittivity(ε_s) at the caved region in transmission line is extremely lower than ceramic permittivity(ε_r). The effective permittivity is calculated approximately in assuming electrostatic field as shown in the same figure. When the width of the cave is half of the thickness of ceramic and the permittivities are 90 and 37.5. The ratios of effective permittivities to their original values are 0.036 and 0.084 respectively. The resonant frequency of dielectric caved resonator is given by solving next equation;

$$\sqrt{\frac{\varepsilon_s}{\varepsilon_r}} = \tan[\theta(1-\eta)]\cdot\tan[\theta\sqrt{\frac{\varepsilon_s}{\varepsilon_r}}\,\eta] \quad ; \quad \theta = \frac{2\pi}{\lambda_0}\sqrt{\varepsilon_r}\,L \qquad (1)$$

The resonant characteristics of the dominant mode and the third harmonics are shown in Figure 2. Ordinate is normalized resonant frequency and Abscissa is normalized length (η) along the axial direction of the resonator. When η = 0.4, change of resonant frequency of dominant mode is less than 5 percents, on the other hand, that of the third harmonics changes about 20 percents. Therefore it is expected that the frequency ratio of the third harmonics to the dominant mode is over 3.4.

The unloaded Q of caved resonator is given by the following equations;

$$\frac{1}{Q_0} = \tan\delta + \frac{1}{Q_c} \qquad (2)$$

$$Q_c = \frac{\omega\mu}{R_s}\,\frac{b\,\ln b/a}{(1+b/a) + \frac{2b}{L}\ln b/a}\,[1+\Delta] \qquad (3)$$

$$\Delta = \frac{(1-\eta)\frac{2b}{L}\ln b/a \cdot \left[\frac{1}{\sin^2\theta_A + \frac{\varepsilon_s}{\varepsilon_r}\cos^2\theta_A} - 1\right]}{(1+b/a)\left[\eta + \frac{1-\eta}{\sin^2\theta_A + \frac{\varepsilon_s}{\varepsilon_r}\cos^2\theta_A}\right] + \frac{2b}{L}\ln b/a} \ll 1 \qquad (4)$$

Qc caused by the current loss is almost same as the homogeneous quarter wavelength resonator. In the equation (3), Δ is the correction of the non-caved resonator and is usually less than 3 percents.

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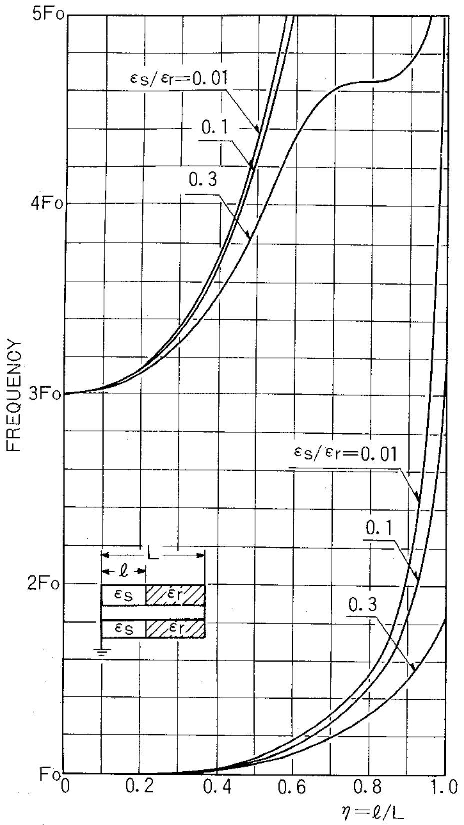

Fig. 2 RESONANT CHARACTERISTICS OF DOMINENT MODE AND THE THIRD HARMONICS

The construction and equivalent circuits of capacitive and inductive coupling portions between resonators are expressed in Figure 3. Cs and Ce in the figure store the electric energy of TM mode excited at the boundary surface between resonator and coupling capacitor. Le in the same figure stores the magnetic energy of TE mode excited at the Inductive film electrode.

Construction

The construction of the dielectric diplexer and its equivalent circuit in Figure 4. Transmitting filter has 5 pieces of resonators of 37.5 in dielectric constant and 15 millimeter in diameter. Four resonators among them are coupled capacitively in one port and

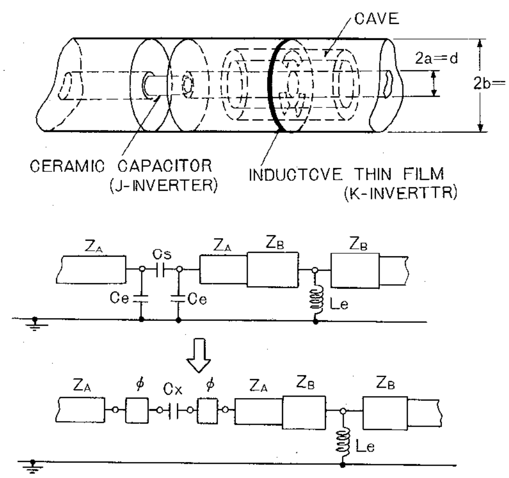

Fig.3 CONSTRUCTION AND EQUIVALENT CIRCUITS OF CAPACITIVE AND INDUCTIVE COUPLING PORTIONS BETWEEN RESONATORS

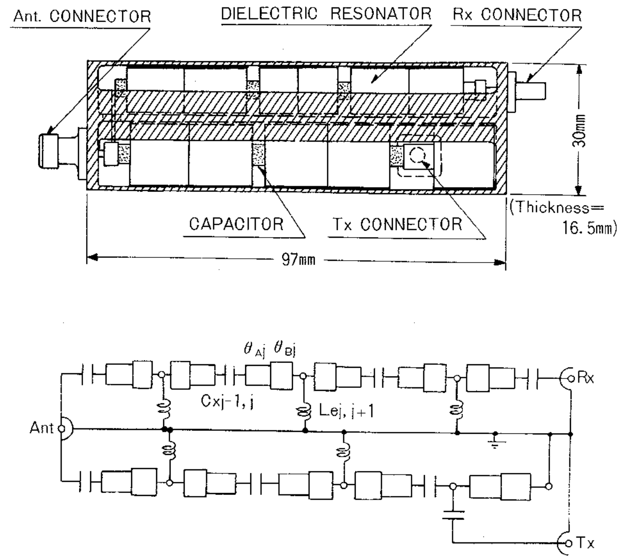

Fig. 4 CONSTRUCTION OF DIELECTRIC DIPLEXER AND ITS EQUIVALENT CIRCUIT

inductively in the other port respectively. The other one is coupled capacitively in both ports. Receiving filter has 6 pieces of resonators of 11 millimeter in diameter. Two resonators among them have permittivity of 90 and the other four have that of 37.5. They are coupled capacitively and inductively by turns. These resonators in both filters are aliened along the axial direction and in the axial symmetry. For this reason, responses of higher order mode can be suppressed small level, and compact J and K invertors can be constructed. Resonator of high permittivity ceramics makes small leakage of electromagnetic energy from it, so it enables to handle this filter like a lumped circuit. The equivalent circuit of the filter is given by connecting the circuit of transmission line and inverter circuit.

Design

The electrical design parameters are shown in Table 1. Each bandpass filter has band width of 20 MHz with 0.01 dB tchebyscheff ripple.

(1) Coupling capacitance and inductance

When coupling coefficient($k_{j\,j+1}$) and external Q(Qex) are given, the necessary capacitance($Cx_{j\,j+1}$) and inductance($Le_{j\,j+1}$) are determined(4) as follows;

$$C_{x\,j,j+1}=\frac{J_{j,j+1}}{\omega_0\{1-(J_{j,j+1}\cdot Z_A)^2\}} \quad ; \quad J_{j,j+1}=k_{j,j+1}\sqrt{b_j\cdot b_{j+1}} \qquad (8)$$

$$C_{x\,0,1}=C_{x\,n,n+1}=\frac{J_{01}}{\omega_0\sqrt{1-(J_{01}R)^2}} \quad ; \quad J_{0,1}=\sqrt{\frac{b_1}{Q_{ex}R}} \qquad (9)$$

$$b_j=\frac{1}{Z_A}\cdot\frac{(Z_B\theta_B^\circ+Z_A\theta_A^\circ)\tan\theta_B+(Z_B\theta_A^\circ+Z_A\theta_B^\circ)\tan\theta_A}{2(Z_A\tan\theta_B^\circ+Z_B\tan\theta_A^\circ)} \qquad (10)$$

$$L_{e\,j,j+1}=\frac{K_{j,j+1}}{\omega_0\{1-(K_{j,j+1}/Z_B)^2\}} \quad ; \quad K_{j,j+1}=k_{j,j+1}\sqrt{\chi_j\chi_{j+1}} \qquad (11)$$

$$\chi_j=Z_B\frac{(Z_A\theta_A^\circ+Z_B\theta_B^\circ)\tan\theta_A+(Z_A\theta_B^\circ+Z_B\theta_A^\circ)\tan\theta_B}{2(Z_A\tan\theta_B^\circ+Z_B\tan\theta_A^\circ)} \qquad (12)$$

where θ_A° and are the electrical angle of uncoupled resonator.

(2) Electrical angle of the resonator

Electrical angles of the resonator are calculated by the following equations;

	Fo (MHz)	n	ΔW (MHz)	I. Loss (BAND WIDTH)	Isolation (dB)
Tx	831	5	20	1.5	65 (821～841MHz)
Rx	876	6	20	2.6	45 (866～886MHz)

TABLE 1 DESIGN PARAMETERS OF DIPLEXER

$$\theta_{Aj}=\theta^{\circ}_{A}-\tan^{-1}(J_{j,j+1}Z_A) \tag{13}$$

$$\theta_{Bj}=\theta^{\circ}_{B}-\tan^{-1}(K_{j,j+1}/Z_B) \tag{14}$$

$$\theta_{A1}=\theta_{An}=\theta^{\circ}_{A}-\tan^{-1}\left[\frac{2J_{01}Z_A\sqrt{1-(J_{01}R)^2}}{1-(J_{01}Z_A)^2}\right] \tag{15}$$

j=5 (Tx port)

$$\theta_{A5}=\theta^{\circ}_{A}-\tan^{-1}(J_{4,5}Z_A)-\tan^{-1}\left[\frac{2J_{01}Z_A\sqrt{1-(J_{01}R)^2}}{1-(J_{01}Z_A)^2}\right] \tag{16}$$

$$\theta_{B5}=\theta^{\circ}_{B} \tag{17}$$

Performances

Performances of the diplexer we made as a trial are shown in Figure 5 and Figure 6.

The insertion loss of the diplexer was 1.35 dB for transmitting filter and 2.3 dB for receiving filter. The isolation level between Tx port and Rx port was 72 dB at the frequency from 821 MHz to 841 MHz and 49 dB at the frequency from 866 MHz to 886 MHz. The resonant characteristics of the dielectric caved resonator was reflected to the spurious performance of the diplexer. The response of the third harmonics shifted up to the higher frequency. In addition, the axial-symmetrical construction well suppressed the unsymmetrical TE_{11} mode of the dielectric coaxial resonator as we expected.

Conclusion

Resonator was miniaturized by using high permittivity ceramics and diplexer of 48 cubic centimeter for land mobile telecommunication was developed. Spurious response for third harmonics of the filter using quarter wavelength resonator was suppressed by developed coaxial resonator having cylindrical cave. This diplexer has insertion losses of 1.35 dB in transmitting side and 2.3 dB in receiving side, and isolations of 72 dB in transmitting band and 49 dB in receiving side.

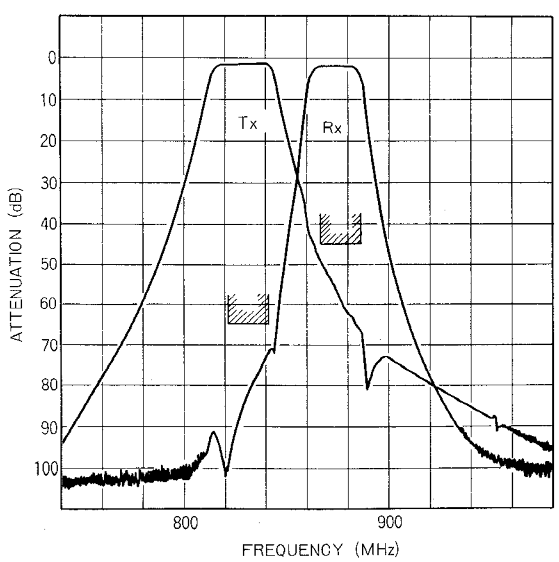

Fig.5 MEASURED ATTENUATION RESPONSES OF THE DIPLEXER

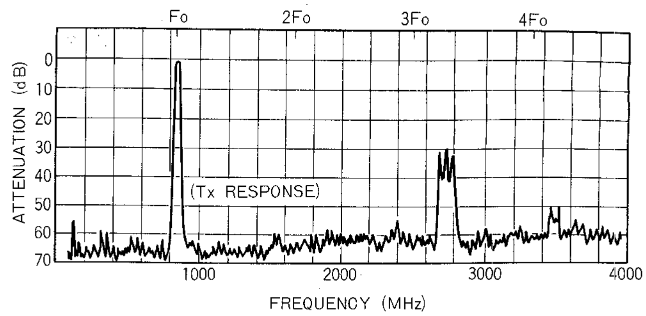

Fig. 6 MEASURED DOMINANT AND SPURIOUS RESPONSE OF DIPLEXER

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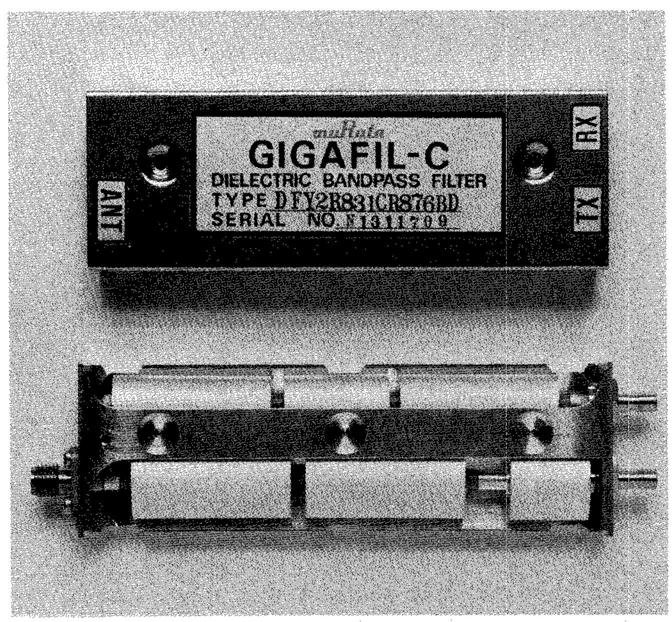

Fig. 7 Internal view of 800 MHz DIPLEXER