QUARTER WAVE DIELECTRIC TRANSMISSION LINE DIPLEXER FOR LAND MOBILE COMMUNICATIONS

Kikuo Wakino, Toshio Nishikawa, Haruo Matsumoto and Youhei Ishikawa
Murata Manufacturing Company Limited
Kyoto Japan

ABSTRACT

Small sized Diplexer with high selectivity and low insertion loss for 800 MHz band land mobile communication systems has been developed using two port quarter wave coaxial dielectric resonators. A couple of resonators including inductive film electrode construct a compact resonance unit of the Diplexer and it is coupled by capacitive air gap spacings which operates as a part of J-inverter.

Introduction

Half wave dielectric transmission line bandpass filters using (Zr-Sn)TiO_4 ceramics with an excellent temperature stability were reported.[1] Further development was realized later in that its construction was made smaller and simpler. Although a quarter wave resonator is smaller in size and better in spurious performance than the half wave resonator, the unloaded Q of the former is a little lower than that of the latter because of its Joul loss at the short circuit conductor. To avoid the Q degradation, we used ceramics which has a smaller dielectric constant and a little larger diameter. The unloaded Q of the quarter wave resonator was about 1700.

The requirements of Antenna Diplexer for land mobile communication systems are small size and low insertion loss, high selectivity and large endurance against shock or vibration. It has been reported[1][2][3] that the dielectric resonator filter generally fills the first two requirements. In order to obtain a high selectivity the amplitude of the higher order mode excited around the inverter has to attenuate itself sufficiently at the next inverter. TM_{01} mode in the coaxial resonator which has a dielectric constant of about 20 and a diameter of 20 mm is in a well cut-off condition.

The last two performances have been improved by the disappearance of adjustment part and of alignment work due to the simple construction.

Construction

Internal view of Dielectric Diplexer is shown in Figure 1. The 6-pole and 8-pole bandpass filters are connected by matching circuit of 50 ohm coaxial cable.

Each quarter wave resonator is coupled capacitively at the open end and inductively at the short end.

In general TM_{0n} dielectric rod line should be used in order to obtain a sufficient coupling capacitance between resonators. But when designing a narrow bandpass filter with relative bandwidth of a few percents we can use an air gap spacing which operates sufficiently as a part of compact and accurate J-inverter.

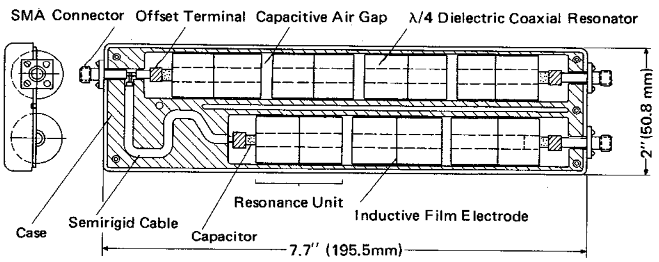

Fig. 1 Internal view of 800 MHz quarter wave dielectric diplexer (6-pole and 8-pole)

An inductive film electrode is inserted between two resonators.

Two resonators and an inductive film electrode inserted between them construct a basic element for the new Diplexer. The film electrode which operates as a part of K-inverter has 6 coupling windows and dominant mode is theoretically orthogonal to $TE_{1,n} \sim TE_{5,n}$ mode therefore, the transverse electric modes are not excited at the coupling windows and the responses are suppressed.

Equivalent circuit

The equivalent circuit of the dielectric two port resonator is shown in Figure 2. The series capacitance (Cs) and shunt capacitance (Ce) in the figure are due to the electric energy of cut-off TM_{0n} mode of air gap spacing and inside of dielectrics. When the axial component of real propagation vector of TM_{0n} mode is not large enough, the power is transmitted slightly by the cut-off modes. Ct in the figure is the capacitance corresponding to the energy flow of the higher order mode and is given by the equation below:

$$C_{tn} = \frac{\varepsilon_0 \cdot \varepsilon_r}{\sqrt{k_{rn}^2 - \left(\frac{2\pi}{\lambda_o}\right)^2 \varepsilon_r} \cdot \sinh\left(\sqrt{k_{rn}^2 - \left(\frac{2\pi}{\lambda_o}\right)^2 \varepsilon_r \cdot \ell}\right)} \quad (1)$$

where each k_{rn} fills the next boundary condition:

$$J_o(k_{rn}\, a)\, Y_o(k_{rn}\, b) - J_o(k_{rn}\, b)\, Y_o(k_{rn}\, a) = 0 \quad (2)$$

$$a = d/2 \;,\quad b = D_o/2$$

On the contrary, Le and Lt in the figure are inductance on the TEM transmission line and on the cut-off TM_{01} transmission line respectively. These are due to magnetic energy of cut-off $TM_{6n,m}$ mode and are coupled slightly through $TE_{6n,2}$ mode. When designing a bandpass filter we must introduce the following relation.

$$L_t\omega \leq L_e\omega \ll \frac{1}{C_t\omega} \quad (3)$$

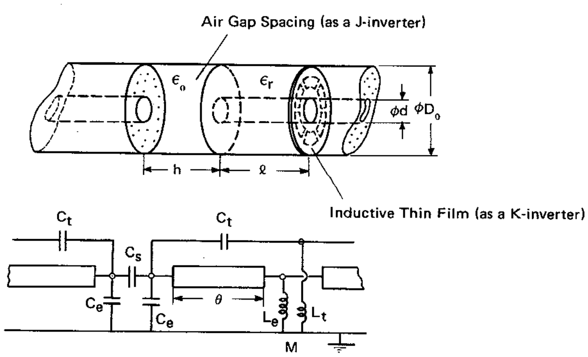

Fig. 2 Dielectric two port resonator which is coupled alternately by K and J inverter, and its equivalent circuit

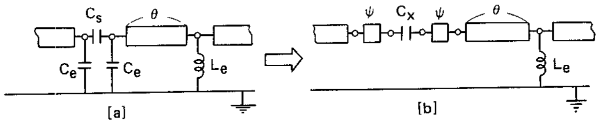

Fig. 3 Simplified equivalent circuits of Fig. 2 for practical filter design

Under this condition, Ct is transferred to the shunt capacitance in Figure 2 and the equivalent circuit is simplified as shown in Figure 3.

The series and shunt capacitances are obtained exactly by mode matching method as shown in Figure 4. The electrical length and coupling capacitance shown in Figure 3-(b) which are more convenient parameters for filter design are given by the following transformation.

$$\Psi=\mathrm{Cos}^{-1}\frac{1}{\sqrt{\left(\frac{Ce+Cs}{Cs}\right)^2+\left(\frac{1}{Zo\omega Cs}\right)^2}}-\tan^{-1}\frac{1}{(Cs+Ce)\omega Zo} \quad (4)$$

$$Cx=\frac{Cs\ \mathrm{Cos}^2\Psi}{1+\omega CsZo\ \mathrm{Sin}2\Psi} \quad (5)$$

TEM transmission line coupled to 50 ohm coaxial line and its equivalent circuits for external Q calculation are shown in Figure 5. The axial symmetric configration in the figure makes it easy to calculate equivalent constants (Ro, Co) and protects the adjacent non-axial symmetric mode (TE_{11}) from getting excited. The equivalent constants of Figure 5 obtained by mode matching method are shown in Figure 6.

Design of Diplexer

The equivalent circuit of single bandpass filter is given by connecting two kinds of equivalent circuit of Figure 3 and Figure 5. This filter is constructed using two port quarter wave-length resonators which are coupled alternately by K and J-inverters.

(1) Coupling capacitance and inductance

When coupling coefficient and external Q are given, the necessary capacitance and inductance are determined by the following relations:(4)

$$Cx_{j,j+1}=\frac{J_{j,j+1}}{\{1-(J_{j,j+1}/Yo)^2\}\,\omega o}\ ;\ J_{j,j+1}=\frac{\pi}{4}Yo\,k_{j,j+1} \quad (6)$$

$$Le_{j,j+1}=\frac{K_{j,j+1}}{\{1-(K_{j,j+1}/Zo)^2\}\,\omega o}\ ;\ K_{j,j+1}=\frac{\pi}{4}Zo\,k_{j,j+1} \quad (7)$$

The capacitance for external Q is given by the following

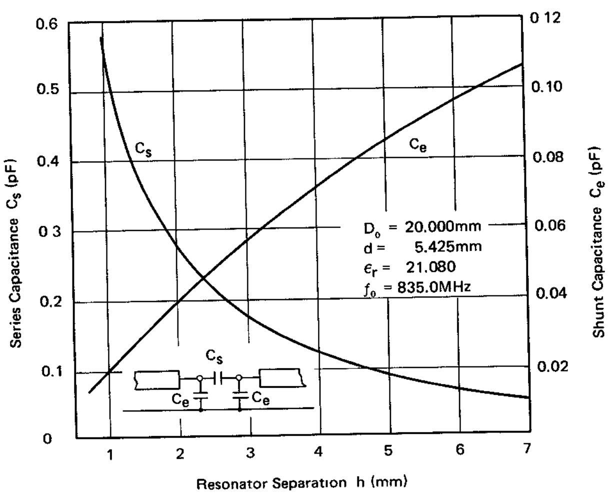

Fig. 4 Equivalent series and shunt capacitance of air gap spacing computed by mode matching method

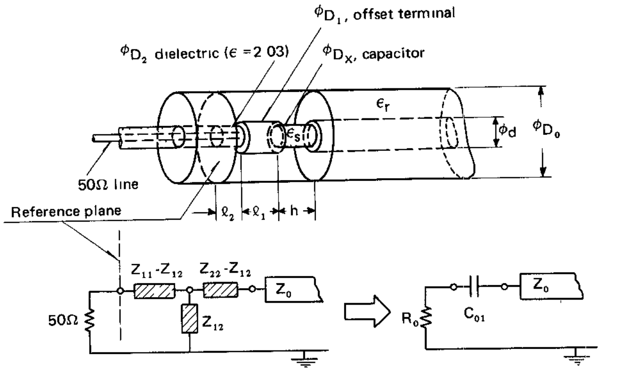

Fig. 5 TEM transmission line coupled to 50 ohm coaxial line and its simplified equivalent circuits for external Q calculation

equation:

$$Co_1=\frac{1}{\omega o}\sqrt{\frac{\frac{\pi}{4}Yo}{Ro\left(Qex-\frac{\pi}{4}YoRo\right)}} \quad (8)$$

(2) Electrical length of each resonator

To determine the physical length and tuning frequency of each resonator we must calculate the electrical length of the TEM resonator.

These are given by the following equations:

$$\theta j=\frac{\pi}{2}-\tan^{-1}(J_{j,j+1}/Yo)-\Psi_{j,j+1}-\tan^{-1}(K_{j-1,j}/Zo) \quad (j=2,4,6 \ldots n-2) \quad (9)$$

$$\theta j=\frac{\pi}{2}-\tan^{-1}(J_{j-1,j}/Yo)-\Psi_{j-1,j}-\tan^{-1}(K_{j,j+1}/Zo) \quad (j=3,5, \ldots n-1) \quad (10)$$

$$\theta_1=\frac{\pi}{2}-\tan^{-1}\frac{2\omega ZoCo_1}{1+Co_1^2\omega^2(R_o^2-Z_o^2)}-\tan^{-1}(K_{12}/Zo) \quad (11)$$

$$\theta n=\frac{\pi}{2}-\tan^{-1}\frac{2\omega\ Zo\ C_{n,n+1}}{1+C_{n,n+1}^2\omega^2(R_{n+1}^2-Z_o^2)}-\tan^{-1}(K_{n-1,n}/Zo) \quad (12)$$

In the former two equations Ψ is a small electrical length to compensate the stray capacitance between line and ground.

(3) Diplexer

In order to construct a Diplexer using two bandpass filters which are designed by the method mentioned above the coaxial cable length between reference plane shown in Figure 5 and T-junction must be determined for the matching property. When the input impedance of the filter is Z_{in} on the reference plane at the center frequcncy of another bandpass filter, the electrical length of the

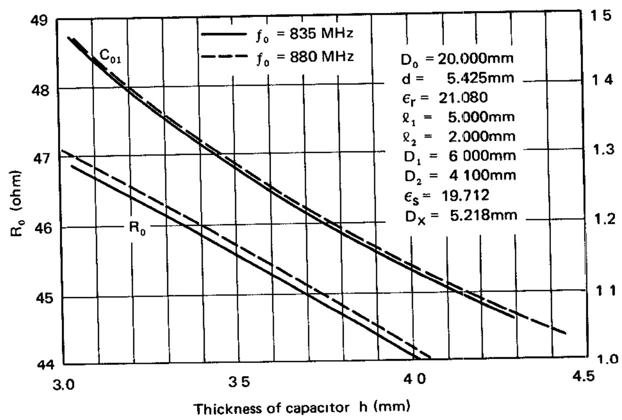

Fig. 6 Theoretical curves of capacitance and resistance loaded to dielectric resonator which is shown in Figure 5

cable at the same frequency is given by the equation below:

$$\theta_{\text{cable}} = \frac{\pi}{2} - \tan^{-1}(\text{ImZin}/50) \qquad (13)$$

Performance

We made 800 MHz quarter wave dielectric Diplexer as a trial. Each filter has 20 MHz band width of 0.01 dB Chebychef ripple. Performances of the Diplexer are shown in Figure 7, Figure 8 and Figure 9. The insertion loss at the center frequency of the diplexer is 0.9 dB for 835 MHz filter and 1.3 dB for 880 MHz filter.

The temperature stability of the diplexer is almost decided by the temperature coefficient of ceramic dielectrics because the resonant energy is well concentrated in the dielectrics. The temperature deviation of center frequency was about -1.5 PPM/degree C.

The response of unsymmetrical TE_{11} mode was not observed as expected. This Diplexer was tested under 50G in shock and 10G in vibration as general requirement for mobile communication, and then the electric characteristics did not change.

Conclusion

The quarter wave length dielectric Diplexer using compact resonance unit which is constructed by two ceramics and one film electrode was developed for application to land mobile communication systems.

Their requirements are well satisfied. Design performance and reproduction of electric performance are excellent because of the simple construction of axial symmetry so that all parameters can be calculated accurately.

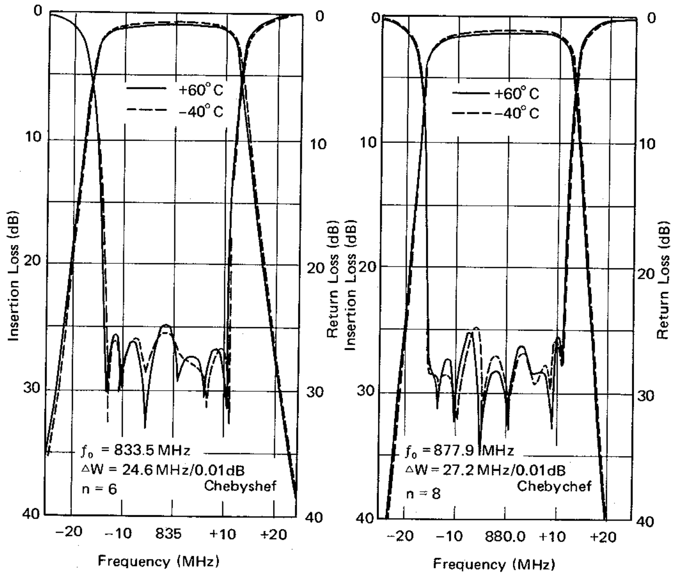

Fig. 7 Measured curves of insertion and return loss at pass band region

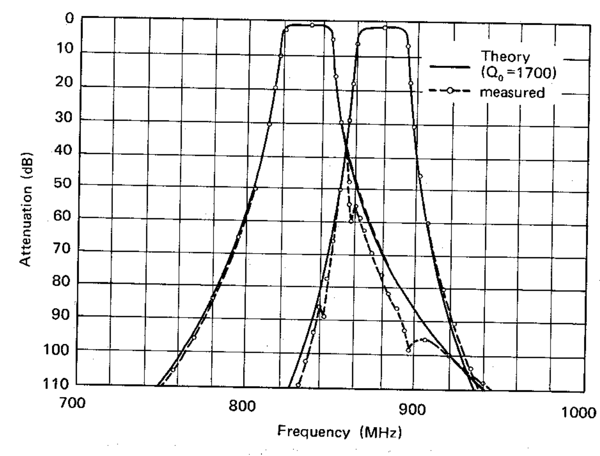

Fig. 8 Measured and theoretical attenuation response

Acknowledgement

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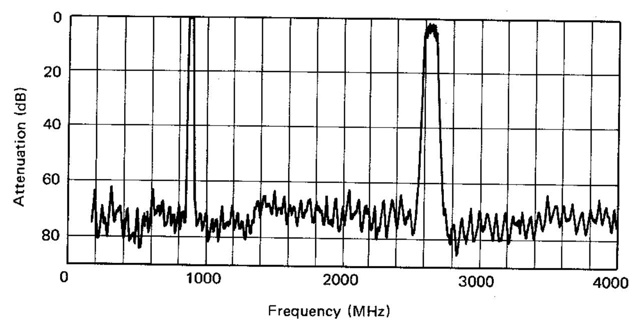

Fig. 9 Measured dominant and spurious response of quarter wave dielectric diplexer (8-pole response)

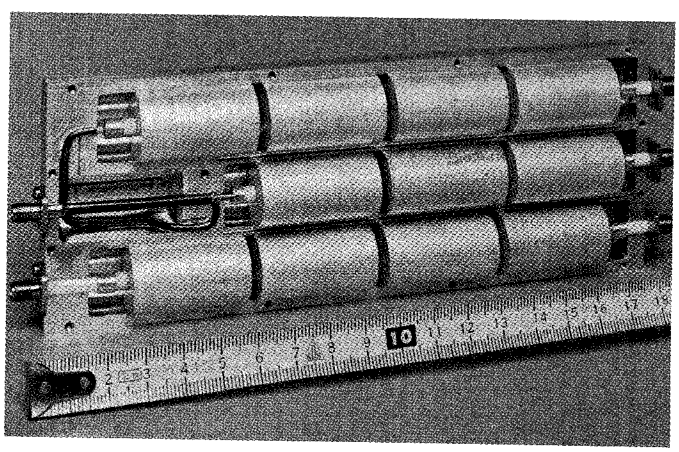

Fig. 10 Exploded view of 800 MHz Dielectric Triplexer (6-pole, 8-pole x 2)