MINIATURIZED MICROWAVE FILTER CONSTRUCTION
WITH DIELECTRIC-LOADED RESONATOR AND SPACE COUPLING

By Atsushi Fukasawa, Takuro Sato and Kenichiro Hosoda

Laboratory
OKI Electric Industry Company Ltd.
550-5 Higashi Asakawa, Hachioji City
Tokyo 193, Japan

ABSTRACT

A new filter construction is proposed in this paper to realize a highly miniaturized microwave band-pass filter. An element of resonator filter is composed of a square dielectric post and a round inner conductor. Each element of resonator is allocated in a housing similar to conventional combline filter, however, the length of a resonator is basically a quarter-wavelength long. The higher unloaded Q and a larger inter-resonator coupling were brought through two factors: open-boundary condition on the periphery along the dielectric post and the air spacing between resonators. Five-stages Tschebyshev response band-pass filters were developed at 800 MHz band to have 20 ~ 30 MHz pass-band and 0.8 ~ 1.0 dB insertion loss at the temperature range: −35 ~ +80°C. The volume and the weight of the filters are about 25 cm^3 and 60 gramms.

INTRODUCTION

The vehicular communications such as wideband mobile telephone systems are planned in practice using a lower microwave frequency band. Realization of a sufficiently miniaturized and extremely low-loss microwave filter contributes to reduce the volume and power consumption of a radio equipment. A compact filter-duplexer is in fact a fundamental component for these radio telephone equipment providing simultaneous talking and listening.

A conventional air- or dielectric-filled coaxial resonator filter was first introduced to present low insertion loss characteristics. It was made clear, however, not easy to reduce the volume to the extent. The authors has developed new filter configuration with resonators composed of a round dielectric rod and a central conductor [1][2]. This technology brought mainly higher resonator Q at a low price. Recently, a more progressive filter configuration is requested to realize smaller volume, wider bandwidth and small insertion loss. In this paper a highly miniaturized microwave filter configuration is introduced utilizing compact TEM resonator and a simple inter-resonator coupling through small air space placed between the dielectric posts.

THEORETICAL

Figure 1 (a) shows the basic configuration of the filter. Each element of resonators is allocated to have their short-and open-circuit terminals at the same sides in a filter housing.

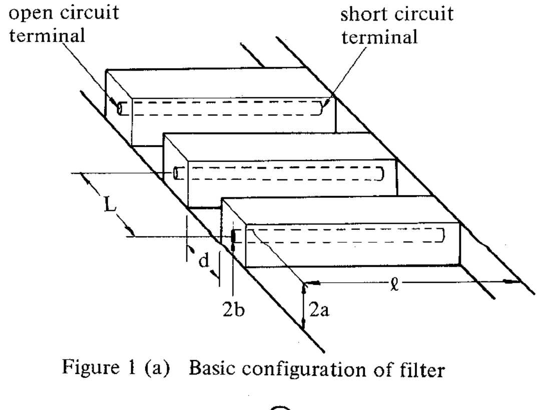

Figure 1 (a) Basic configuration of filter

The allocation of the element of resonators in a filter is apparently the same as the one in so-called combline filter. The length of resonators is a quarter-wavelength long in the case of this filter. 2a and 2b are the width of the square dielectric post and the diameter of the center inner conductor respectively. L and d are the pitch length of the adjacent resonators and the distance of the air space between the dielectric posts respectively.

The element of resonator is made up by the section of transmission line and the terminations of the resonator. Then the following study was conducted:

(1) Electromagnetic field and corresponding line parameters of the coupled infinitely long transmission line.

(2) Inter-resonator coupling coefficient of the transmission line with finite length, terminated by the characteristic impedances.

It must be notified that the coupling formula for a infinitely long transmission line is not applied to the resonators of this filter.

THEORETICAL ANALYSIS BY RELAXATION METHOD

The TEM mode is assumed for theoretical analysis of the electromagnetic field in the transmission line. The fundamental parameters, unloaded Q, characteristic impedance, coupling coefficient, and equivalent permittivity of the transmission line were obtained by numerical calculation based on relaxation method.

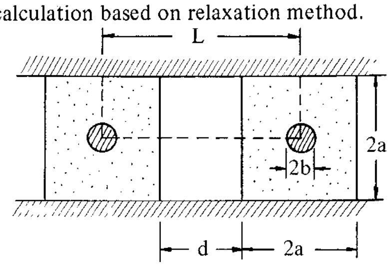

Figure 1 (b) Cross-sectional view for analysis

The cross-section is used for the analysis shown in Fig. 1 (b). Recently, the authors have been studied of the relaxation analysis for the coupled cylindrical dielectric waveguide[1][2]. The above results, has been analyzed as two dimensional model of infinite waveguide.

RELAXATION METHOD Figure 2 shows the potentials to meet the Maxwell equation in a homogeneous region. The solution of the TEM mode potential is obtained for each lattice point to minimize the residual error R_0 specified by the following:

$$R_0 = \phi_0 - \frac{1}{4}(\phi_1 + \phi_2 + \phi_3 + \phi_4) \quad \text{(1)}$$

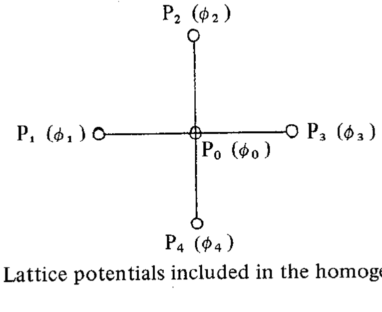

Figure 2 Lattice potentials included in the homogeneous region

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where, the potentials $\phi_0 \sim \phi_4$ are real potentials in the case of a homogeneous medium. When a lattic point include a boundary between a metal, air, and a dielectric material, the pseudo potential of each point is introduced into the equation (1) instead of the real potentials. Table 1 shows the pseudo potential of the lattice point including metal-dielectric and dielectric-air boundary.

DETERMINATION OF INITIAL POTENTIAL It is important to consider the optimum initial potentials to converge relaxation process. Figure 3 shows axial system used to determine the initial potentials. The initial potentials are classified as following.

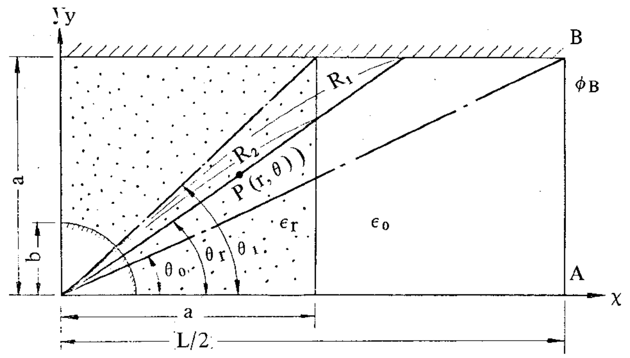


Figure 3 Axial system of the waveguide

The radius and angle of point P is expressed as:

$$r = \sqrt{x_p^2 + y_p^2} \qquad \theta_r = \tan^{-1}\left(\frac{y_p}{x_p}\right) \quad \cdots\cdots (2)$$

(a) Odd mode potential:

The zero potential is given to the potential ϕ_B on boundary AB.

$r \leqq b; \phi_p = 1$ volt

In case of $\theta_r \geqq \theta_1$ and $r > b$

$$\phi_p = 1 + \frac{\ln\left(\frac{b}{r}\right)}{\ln\left(\frac{R_1}{b}\right)} \quad \cdots\cdots (3)$$

In case of $\theta_0 \leqq \theta_r \leqq \theta_1$

and $b < r \leqq R_2$

$$\phi_p = 1 + \frac{\ln(b/r)}{\ln(R_2/b) + \epsilon_r \ln(R_1/R_2)} \quad \cdots\cdots (4)$$

and $R_2 < r \leqq R_1$

$$\phi_p = \frac{\epsilon_r \ln(R_1/r)}{\ln(R_1/b) + \epsilon_r \ln(R_1/R_2)} \quad \cdots\cdots (5)$$

In case of $\theta_r < \theta_0$, the same equations are derived by the above method.

(b) Even mode potential:

In case of $\theta_r \geqq \theta_0$, the equations are equal to equations (3) ~ (5).

In case of $\theta_r < \theta_0$, the open boundary condition is given to the potential ϕ_B on boundary AB.

$r \leqq b; \qquad \phi_p = 1$ volt $\cdots\cdots (6)$

$$b < r \leqq R_2; \quad \phi_p = 1 + \frac{(1-\phi_B)\ln\left(\frac{b}{r}\right)}{\ln\left(\frac{R_2}{b}\right) + \epsilon_r \ln\left(\frac{R_1}{R_2}\right)} \quad \cdots\cdots (7)$$

$$r > R_2; \qquad \phi_p = \phi_B + \frac{\epsilon_r(1-\phi_B)\ln\left(\frac{R_1}{r}\right)}{\ln\left(\frac{R_2}{b}\right) + \epsilon_r \ln\left(\frac{R_1}{R_2}\right)} \quad \cdots\cdots (8)$$

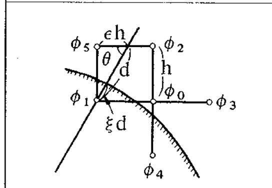
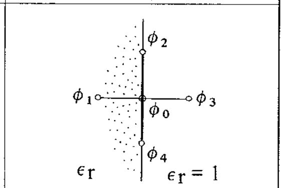
(1)	(2)
	
$\phi'_1 = \frac{\phi_1 - \{\phi_5 + \epsilon(\phi_2 - \phi_5)\}}{1-\xi}$ $\epsilon = h \cdot \cot\theta$	$\phi'_3 = \frac{2}{\epsilon_r + 1}\phi_3$ $\phi'_1 = \frac{2\epsilon_r}{\epsilon_r + 1}\phi_1$

Table 1 The classification of the lattice point group including a boundary

TRANSMISSION LINE PARAMETERS Fundamental parameters are obtained using the potential distribution which is calculated by relaxation method[2]. Figure 4 shows the theoretical values of unloaded Q of resonator. Figure 5 shows the calculated impedances Zeven and Zodd.

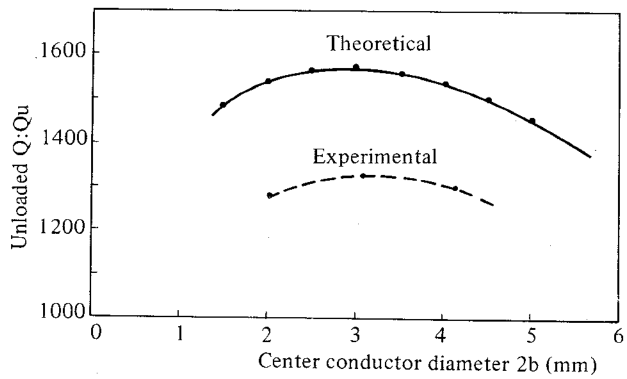


Figure 4 Unloaded Q versus center conductor diameter at 2a = 12 mm, ϵ_r = 20, tanδ = 0.5 x 10^{-4}

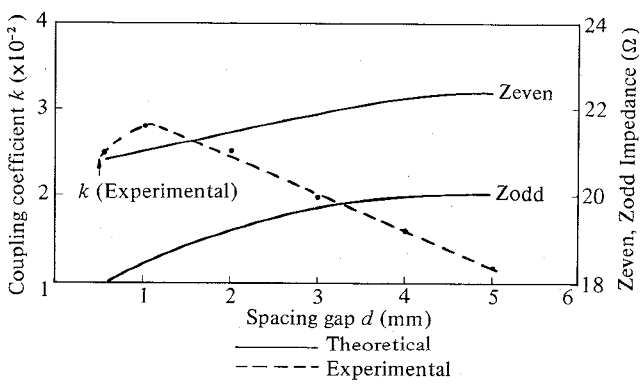


Figure 5 Inter-resonator coupling versus spacing gap

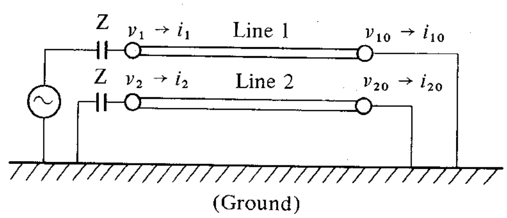


Figure 6 Equivalent transmission line circuit of filter

INTER-RESONATOR COUPLING CONSIDERATION

Figure 6 shows the equivalent transmission line circuit of this filter composed of two elements of resonator. The coupling between parallel resonators is estimated to solve the transmission line equation including the specified terminate conditions. The transmission line equation is derived as follows:

$$\begin{bmatrix} v_1 \\ v_2 \\ i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} \cos\beta\ell & 0 & Z_{11} j\sin\beta\ell & Z_{12} j\sin\beta\ell \\ 0 & \cos\beta\ell & Z_{12} j\sin\beta\ell & Z_{11} j\sin\beta\ell \\ Y_{11} j\sin\beta\ell & Y_{12} j\sin\beta\ell & \cos\beta\ell & 0 \\ Y_{12} j\sin\beta\ell & Y_{11} j\sin\beta\ell & 0 & \cos\beta\ell \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ I_{10} \\ I_{20} \end{bmatrix} \quad \ldots (9)$$

As each transmission line is supposed to be symmetry,

$$\begin{matrix} Z_{11} = Z_{22} \\ Y_{11} = Y_{22} \end{matrix} \quad \ldots\ldots (10)$$

where Z_{11} and Z_{22} are input and output impedance, Y_{11} and Y_{22} are input and output admittance of the circuit. β is the propagation constant of the TEM transmission line. The propagation loss is neglected.

The voltage and the current coupling coefficient are derived as follows:

$$\frac{v_2}{v_1} = \frac{\text{Zeven} - \text{Zodd}}{\text{Zeven} + \text{Zodd} + j\dfrac{2\,\text{Zeven}\,\text{Zodd}}{Z}\tan\beta\ell} \quad \ldots\ldots (11)$$

$$\frac{i_2}{i_1} = -\frac{\text{Zeven} - \text{Zodd}}{\text{Zeven} + \text{Zodd} - j2Z\cot\beta\ell} \quad \ldots\ldots (12)$$

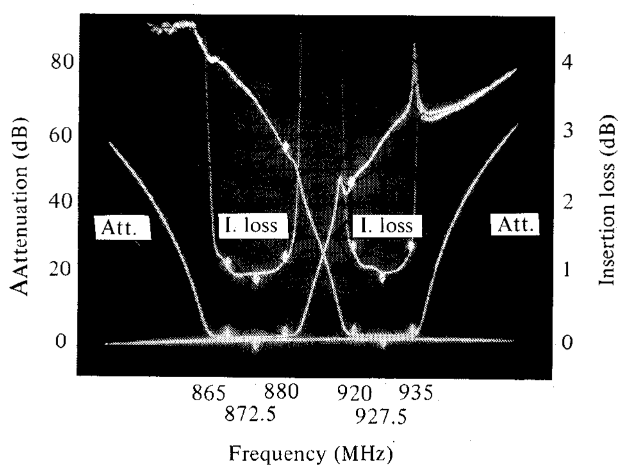


Photo 1 Characteristics of a filter-duplexer

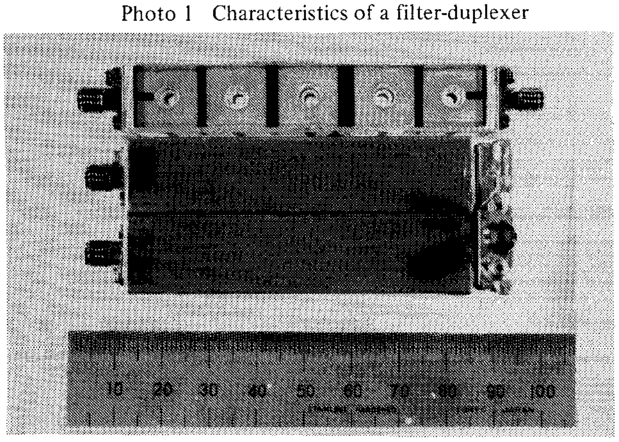


Photo 2 Inside view of B.P.F. and outside view of a filter-duplexer

When the load impedance Z of a resonator has a large value, the total coupling is expected to be so small, because the voltage and current coupling coefficient are nearly equal and have opposite signs. The above condition of impedance Z is corresponds to the case of the length of a resonator is nearly a quarter-wavelength long. At the case of a combline filter the length of a resonator ℓ is chosen shorter than a quarter-wavelength long to bring a larger coupling coefficient. On the contrary, the characteristic impedances Zeven and Zodd is understood to be chosen to increase the coupling by introducing air spacing into resonators.

EXPERIMENTAL

The cross-sectional dimension of a resonator 2a was chosen 12 mm and the center conductor diameter 2b was varied. The measured unloaded Q:Qu of a resonator is shown in Figure 4. (2a = 12 mm, ϵ_r = 20, $\tan\delta$ = 0.5 x 10^{-4}) The optimum diameter to present the maximum Q was 2b $\approx$ 3 ~ 4 mm. The measured Q was corresponding to 80 ~ 85 percents of the theoretical values. The inter-resonator coupling was measured[3] against the air spacing between two resonators as shown in Figure 5. (2b = 4 mm, ϵ_r = 20) The maximum values of k was appeared against the air spacing $d \approx$ 1 mm. The measured k was well in agreement with the theoretical values. The effective dielectric constant ϵ_{eff} of the resonator was also measured at about $\epsilon_{eff} \approx 18$ against the resonant and matched termination conditions.

A miniaturized band-pass filter was designed at 800 MHz band to have 2 ~ 3 percents pass-band. The insertion loss of five-stages Tschebyshev response filter was about 1.0 dB at the temperature range −35 ~ +80°C. The volume and weight of the filter is about 25 cc and 60 gramms respectively.

DISCUSSION AND CONCLUSION

At the first step of analytical studies, round and rectangular inner conductors are introduced. The current density on the surface of the inner conductor is calculated. The results of calculations and experiments show that a round inner conductor gives an approximately 30% higher unloaded Q and is more suited to miniaturization of the resonator than a rectangular inner conductor.

Using the results of the field calculation, fundamental values of the transmission line parameters were obtained. The unloaded Q ; Qu, effective dielectric constant ϵ_{eff}, and coupling coefficient[3] are calculated supposing dielectric constant ϵ_r = 20 and $\tan\delta$ = 0.5 x 10^{-4}. The new waveguide construction presents a very small and low-loss filter, being available for vehicular communications in the microwave frequency band below 2 GHz.

REFERENCE

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[2] A. Fukasawa et al., "Analysis and application of a new waveguide structure with dielectric loading", IEEE MTT-S, pp.453-455 May, 1980.

[3] S.B. Cohn, et al., "Direct-Coupled-Resonator Filters," IRE-45, pp.187-196 Feb., 1957.