MICROSTRIP DISK CAVITIES FILTER USING GAP CAPACITANCES COUPLING

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ABSTRACT

In this paper a microstrip disk cavities bandpass filter using gap capacitances coupling is proposed and tested. The advantages of this filter are its excellent electrical performance, small size and its convenience for planar integration. Here a theoretical evaluation of the main capacitances and gap capacitances in a shielded microstrip multi-conductors system is accomplished. Thus the foundation for analysis and synthesis of this filter is established.

INTRODUCTION

In the microstrip bandpass filters, the parallel coupling lines or the stub lines configuration are usually used, in which its resonators are the quarter wavelength or half wavelength TEM mode transmission lines. This paper describes another type of filter,its resonators are the microstrip circular disks operating in TM_{110} mode and the coupling elements are the gaps between disks. This type of filter could be formed in C-band and L-band. Using suitable substrate with high dielectric constant(ε_r=38.) the microstrip disk cavity has higher quality factor Q. The important advantages of this filter are its small size, narrow passband,convenience for planar integration and excellent electrical performance, in addition its spurious passbands are far from the main passband. Here we shall present analysis, synthesis and experiment result of this filter.

CONFIGURATION AND SYNTHESIS OF THE FILTER

The structure of microstrip disk cavities filter to be considered here is shown in Fig.(1a). There are several disks(the amount of which depend on filter performance specification) and two gradual microstrip lines which are used to cause enough coupling capacitances between input or output and the disk. The characteristic impedance of other two ends is 50Ω, which is easy to connect with microstrip-coaxial connector.

We will consider a filter with 5 cavities (n=5) as an example. Equivalent circuit of Fig.(1a) is shown in Fig.(1b), in which $C_{i,i+1}$ (i=0,1,2,...5) is the gap capacitance of two neighbouring conductors and C_{ib} is the main capacitance of the ith disk(the capacitance between the disk and the shielded box). The gap capacitance can be equivalent to a parallel circuit of two $C_{i,i+1}$ and one $J_{i,i+1}$ transformer shown in Fig.(1c). So the circuit shown in Fig.(1b) can be equivalent to the tipical filter circuit shown in Fig.(1d). The main capacitance C'_{ib} of the resonator can be expressed as follows

$$C'_{ib}=C_{ib}+C_{i-1,i}+C_{i,i+1} \quad (1)$$

By using the following formulas[1], the synthesis of the filter can be accomplished.

$$\frac{J_{i,i+1}}{\sqrt{\mathcal{B}_i \mathcal{B}_{i+1}}}=\frac{W}{\sqrt{g_i g_{i+1}}},\ \frac{J_{01}}{\sqrt{\mathcal{B}_1}}=\sqrt{\frac{WG_A}{g_1}},\ \frac{J_{56}}{\sqrt{\mathcal{B}_5}}=\sqrt{\frac{WG_B}{g_5}} \quad (2)$$
$$i=1,\cdots 4$$

where $J_{i,i+1}=2\pi f_0 C_{i,i+1}$, $\mathcal{B}_i=2\pi f_0 C'_{ib}$, f_0 is the center frequency of the passband,i.e the resonant frequency of the resonator in Fig(1d). G_A, G_B are the characteristic admittances of the gradual lines which link the first and the last disks respectively. $W=\Delta f/f_0$ is the relative bandwidth and $g_1 \ldots g_5$ are the values of the normalized elements of the lowpass prototype.

DETERMINATION OF PARAMETERS OF THE ELEMENTES

Determination of the resonant frequency f_0 and C_{ib} ,$C_{i,i+1}$ is the key to synthesis of this filter.

(1)Determination of the center frequency

The center frequency f_0 of passband of the filter depends on the resonant frequency f'_0 of the circular disk cavity and the gap capacitance. Under the condition of the ideal magnetic wall the resonant frequency f'_0 of ith circular disk operating in TM_{110} mode may be written as follows

$$f'_0=CX_{11}/2\pi R_i\sqrt{\varepsilon_r} \quad (3)$$

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where $C=3\times10^{10}$ cm/sec, $X_{11}=1.841$, R is the radius of the circular disk and $\mathcal{E}_r$ is relative dielectric constant of the substrate.

In practice the "edge effect" of the disk must be taken into consideration. As a result the R and $\mathcal{E}_r$ should be substituted by the effective radius R_{ef} and $\mathcal{E}_e$ in(3). The R_{ief} and $\mathcal{E}_{ie}$ of the ith disk are defined as follows

$$R_{ief}=(C_{ib}\,h/\pi\varepsilon_0\varepsilon_{ie})^{\frac{1}{2}}$$
$$\varepsilon_{ie}=C_{ib}/C^{(a)}_{ib} \qquad (4)$$

where $C^{(a)}_{ib}$ denotes the main capacitance of ith disk with air as dielectric, h is the thickness of substrate, $\mathcal{E}_0=1/3.6\pi$ (pf/cm).

Hence the formula (3) may be written

$$f'_o=4.6328/\sqrt{C_{ib}\,h} \quad (GHz) \qquad (3-a)$$

where the units of C_{ib} and h are (pf) and (cm) respectively.

It must be noticed that each resonator of the filter in Fig(1d) associates with one main capacitance of disk and two neighbouring gap capacitances(to see formula(1)). Hence the resonant frequency of the filter's resonator should be modified as follows

$$f_o=4.6328/\sqrt{C'_{ib}\,h} \quad (GHz) \qquad (3-b)$$

(2)Determination of C_{ib} and $C_{i,i+1}$

The five cavities filter with shielded box is shown in Fig(2) and the dimension 2a,2b,h,B are shown too. Five circular disks and two gradual microstrip lines are shaped symmetrically to axes X and Y of the coordinates. If we neglect the influence of non-neighbouring conductors, the static charge of ith disk may be expressed [2]

$$Q_i=C_{ib}V_{ib}+C_{i,i-1}V_{i,i-1}+C_{i,i+1}V_{i,i+1} \qquad (5)$$

where C_{ij} and V_{ij} denote the capacitance and voltage between the ith disk and the jth conductor respectively. V_{ib} is the voltage between the ith disk and the box.

Formula (5) may be simplified, if we take some suitable driving, and the C_{ib}, $C_{i,i+1}$ will be determined. For example, let the potential of the box be zero, and let the potential of the disks 0,1,2,...6 be 1.0 volt, the charge on disks 1,2and 3 must be

$$\begin{aligned} Q_1 &= C_{1b}\times 1.0 \\ Q_2 &= C_{2b}\times 1.0 \qquad (5-a) \\ Q_3 &= C_{3b}\times 1.0 \end{aligned}$$

If we arrange the potential of the box and the disks 0,2,4,6 be zero, and the potential of other disks be 1.0, the charges of disks 1,2,3 should be expressed,

$$\begin{aligned} Q'_1 &= C_{1b}+C_{10}+C_{12} \\ Q'_2 &= -C_{21}-C_{23} \qquad (5-b) \\ Q'_3 &= C_{3b}+C_{32}+C_{34}=C_{3b}+2C_{32} \qquad (5-b) \end{aligned}$$

It may be seen from (5-a) and(5-b) if the Q_i and Q'_i are determined,the C_{ib} and $C_{i-1,i}$ (i=1,2,3) are obtained immediately.

It is obvious that the Q_i can be determined by the integral

$$Q_i=\iint_{D_i}\sigma(x',y')\,dx'dy' \qquad (6)$$

where $\sigma(x',y')$ is the surface charge density, D_i is the area of ith disk, $\sigma(x',y')$ must be solved from the following integral equation:

$$\int_{-a}^{a}\int_{-b}^{b}\sigma(x',y')G(x,y,x',y')\,dx'dy'=V(x,y) \qquad (7)$$

where $V(x,y)$, $G(x,y,x',y')$ are respectively the potential function and Green's function on the surface of the substrate, (x,y) and (x',y') denote the field point and source point respectively.

According to the boundary conditions on the walls of the box and the interface of the substrate the Green's function may be written

$$\begin{aligned} G(x,y,x',y') &= \sum_{m,n}(S(m,n)/\varepsilon_0 ab)\varphi_{mn}(x,y)\varphi_{mn}(x',y') \\ \varphi_{mn}(x,y) &= \sin(K_m x+K_m a)\cdot\sin(K_n y+K_n b) \qquad (8) \\ S(m,n) &= \frac{sh(K_{mn}B)\,sh(K_{mn}h)}{(sh(K_{mn}h)\,ch(K_{mn}B)+\varepsilon_r\,sh(K_{mn}B)\,ch(K_{mn}h))K_{mn}} \\ K_m &= m\pi/2a;\ K_n=n\pi/2b;\ K_{mn}=(K^2_m+K^2_n)^{\frac{1}{2}} \end{aligned}$$

V(x,y) can be determined by solving its Laplace's equation numerically under the boundary conditions of the box and disks.

It must be noticed that the $\sigma(x',y')$ is an even function of x' and y' in the two driving, and the odd terms of $G(x,y,x',y')$ are even function too. As a result in (8) only the odd terms for m and n are necessary for the integral in (7). Substituting (8) into (7) and changing the orders of the integral and sum, the equation (7) becomes

$$\begin{aligned} \frac{4}{\varepsilon_0 ab}\sum_{m',n'}S(m',n')\varphi_{m'n'}(x,y)\tilde{\sigma}(m',n') &= V(x,y) \\ \tilde{\sigma}(m',n') &= \int_0^a dx'\int_0^b \sigma(x',y')\varphi_{m'n'}(x',y')\,dy' \qquad (9) \\ m'=2m-1, \quad n'=2n-1 \quad & m,n=1,2,3\cdots \end{aligned}$$

where $\tilde{\sigma}(m',n')$ is the Fourier integral of $\sigma(x',y')$.

Using the orthogonal property of the trigonometric function,we can obtain from (9)

$$\begin{aligned} (1/\varepsilon_0)S(m',n')\tilde{\sigma}(m',n') &= \tilde{V}(m',n') \\ \tilde{V}(m',n') &= \int_0^a dx\int_0^b V(x,y)\varphi_{m'n'}(x,y)\,dy \qquad (10) \end{aligned}$$

Obviously

$$\tilde{\sigma}(m',n')=\varepsilon_0\tilde{V}(m',n')/S(m',n') \qquad (11)$$

Then

$$\sigma(x', y') = (4/ab) \sum_{m'} \sum_{n'} \tilde{\sigma}(m', n') \varphi_{m'n'}(x', y') \quad (12)$$

Substituting (12) into formula (6), the charge of disks 1,2,3 may be derived

$$Q_3 = \frac{16}{ab} \sum_{m'} \sum_{n'} \tilde{\sigma}(m', n') I(m', n')$$

$$Q_2 = \frac{16}{ab} \sum_{m'} \sum_{n'} \tilde{\sigma}(m', n') I(m', n') \cos(K_{m'}(S_{23} + 2R)) \quad (13)$$

$$Q_1 = \frac{16}{ab} \sum_{m'} \sum_{n'} \tilde{\sigma}(m', n') I(m', n') \cos(K_{m'}(S_{23} + S_{12} + 4R))$$

$$I(m', n') = (-1)^{m+n} \frac{\pi R}{2} (0.5 + \sum_{k=1}^{\infty} \frac{(-1)^k (K_{m'n'} R)^{2k}}{2K!! (2K+2)!!})$$

in which S_{12} and S_{23} are the gap widthes between disks 1,2 and disks 2,3 respectively.

The relationship of C_{3b}, C_{23} with respect to S_{23} is shown in Table(1). The values of parameters are: R=0.34cm, h=0.15cm, ε_r=38, 2a=5.0cm, 2b=1.5cm, B=0.85cm.

Table (1)

S_{23}(mm)	C_{3b} (pf)	C_{23} (pf)
0.2	8.66116	0.44924
0.4	8.73458	0.37389
0.6	8.81234	0.29842
0.8	8.90566	0.22021
1.0	9.00214	0.15684
1.5	9.16748	0.06821
2.0	9.20594	0.04946
2.5	9.20904	0.04787

From table(1) it can be seen that the C_{3b} is about 20% greater than the ideal capacitance of parallel planes.

$$(C_{ideal} = \varepsilon_0 \varepsilon_r \pi R^2 / h = 8.1348 (pf))$$

It must be noticed that the values of C_{ib} and $C_{i,i+1}$ evaluated in this section are static capacitances. Since our filter operates in TM_{110} mode, the C_{ib} and $C_{i,i+1}$ in formula (2) should be dynamic capacitances.

In this paper the relationships between dynamic and static capacitances for C_{ib} and $C_{i,i+1}$ are as follows [3]

$$C_{ib,dyn} = 0.3525\, C_{ib,stat} \quad \text{for } TM_{110} \text{ mode}$$

$$C_{i,i+1,dyn} = 0.3525\, C_{i,i+1,stat} \quad \text{for } TM_{110} \text{ mode} \quad (14)$$

$$C_{01,dyn} = C_{01,stat},\ C_{56,dyn} = C_{56,stat}$$

$$i = 1, 2, 3, 4$$

THE MEASUREMENT OF THIS FILTER

The configuration of our developed filter is shown in Fig(3). The dimension of the substrate is 60×15×1.5 mm^3, and ε_r=38.0. Fig(4) is the frequency response curve of the filter shown in the screen of 8566A Spectrum Analyzer (HP). The frequency response curves of the multi-channel filters are shown in Fig(5).

The result given by practical measurement denotes that all the spurious passbands are separated from the main passband by more than 2GHz, and the insertion lose in the passband is only about 2dB. Such performance of the filter is good enough for general engineering application.

REFERENCES

[1] G.L.Matthaei, L.Young and E.M.T.Jones, "Microwave Filters, Impedance Matching Networks and Coupling Structures", Now York, McGraw-Hill (1964)

[2] John David Jackson "Classical Electrodynamics"

[3] Wolff and N.Knoppik, IEEE Trans. MTT vol-MTT 22 (1974) p857

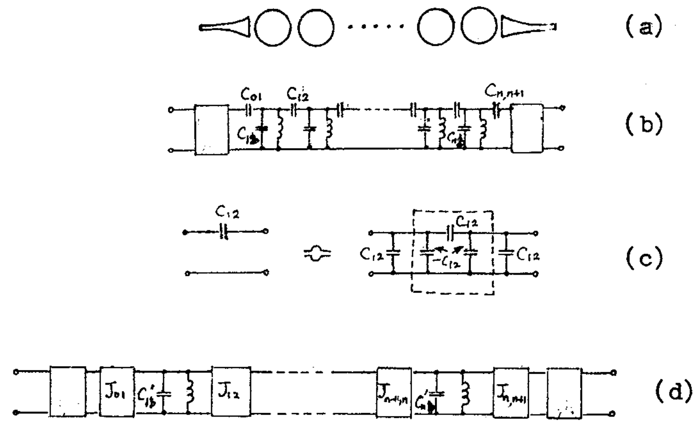

Fig.(1)

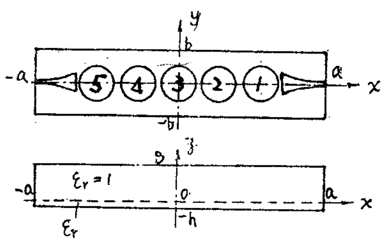

Fig.(2)

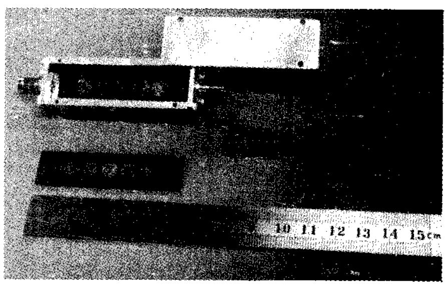

Fig.(3)

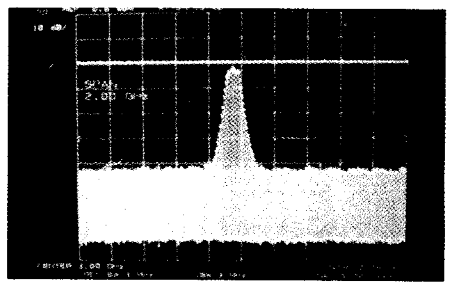

Fig.(4)

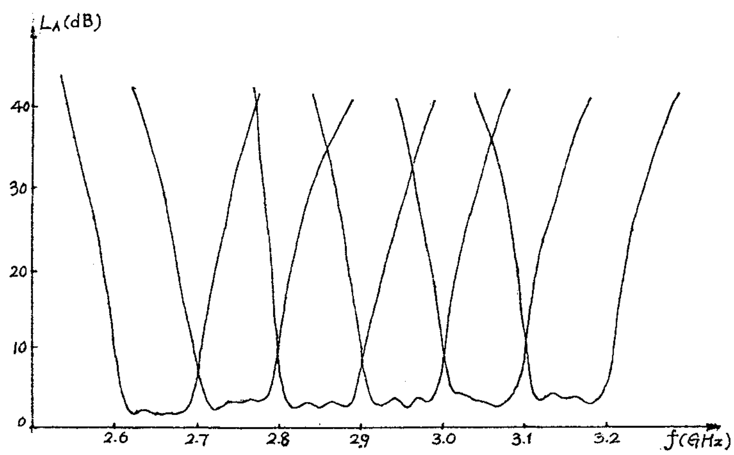

Fig.(5)