BANDPASS FILTERS USING PARALLEL COUPLED STRIP-LINE STEPPED IMPEDANCE RESONATORS

Mitsuo Makimoto and Sadahiko Yamashita
Matsushita Research Institute Tokyo, Inc.
Ikuta, Tama-ku, Kawasaki, Japan

ABSTRACT

Design formulae for bandpass filters using parallel coupled strip-line stepped impedance resonators (S.I.R.) are derived. The formulae take into account the arbitary coupling length as well as quarter-wavelength coupling. One of the important advantages of this filter is its ability to control spurious response by changing the structure of the resonator.

Using the design formulae an experimental bandpass filter was designed and fabricated and its performance closely matched design data.

Introduction

The center frequency of the second passband of bandpass filters with half-wave length resonators is two or three times of that of the fundamental frequency. This causes poor harmonic suppresion when used as output filters in oscillators or amplifiers. To overcome this problem, the use of non-uniform transmission line resonators as a filter element was considered.[1]

This paper describes a stepped impedance resonator (S.I.R.)[2] used as a non-uniform transmission line resonator and its application to bandpass filters.

Firstly, fundamental parameters such as resonance characteristics of an S.I.R. and slope parameters are derived. Secondly, the design formulae of a bandpass filter was derived from the admittance inverter which is in a coupling circuit with arbitary coupled electrical length. Finally, an experimental bandpass filter was designed and fabricated. The experimental performance data is shown to be in close agreement with the design data.

Stepped Impedance Resonator

Resonator Condition

The resonator structure of an S.I.R. to be considered here is shown in Fig. 1. The resonator has two different impedance lines, Z_1 and Z_2. The design equation is simple and practical when the electrical length of each line is chosen as shown in Fig. 1.

The admittance of the resonator from the open end, Y_i is given as

$$Y_i = jY_2 \cdot \frac{2\,(1+K)\cdot(K-\tan^2\theta)\cdot\tan\theta}{K-2\,(1+K+K^2)\cdot\tan^2\theta+K\tan^4\theta} \qquad (1)$$

where $Y_2 = 1/Z_2$, K = Impedance Ratio = Z_2/Z_1

Resonance condition can be obtained from the following:

$$Y_i = 0 \qquad (2)$$

Then, using the fundamental frequency fo and corresponding electrical length θ_0,

$$\tan^2\theta_0 = K$$
$$\theta_0 = \tan^{-1}\sqrt{K} \qquad (3)$$

It becomes clear that θ_T is a function of the impedance ratio K and

$$\theta_T < \pi \quad \text{when } K < 1$$
$$\theta_T > \pi \quad \text{when } K > 1 \qquad (4)$$

When K = 1, this corresponds to a uniform impedance line resonator and it becomes $\theta_T = \pi$.

Next consider the spurious response. Taking the spurious resonance frequency to be f_{sn} (n = 1,2,...) and corresponding θ with θ_{sn} (n=1,2,...), we obtain from Equation (1)

$$f_{s_1} = \frac{\theta_{s_1}}{\theta_0}\cdot f_0 = \frac{\pi}{2\theta_0}\cdot f_0$$
$$f_{s_2} = \frac{\theta_{s_2}}{\theta_0}\cdot f_0 = (2f_{s_1}-1)\cdot f_0 \qquad (5)$$
$$f_{s_3} = \frac{\theta_{s_3}}{\theta_0}\cdot f_0 = 2\cdot f_{s_1}$$

The above result is shown in Fig. 2 as a function of the impedance ratio K.

Admittance Slope Parameters

To design bandpass filters, the slope parameters must be derived. The admittance slope parameter b of an S.I.R. is defined as,

$$b = \frac{\omega_0}{2}\cdot\left.\frac{dB}{d\omega}\right|_{\omega=\omega_0} = \frac{\theta_0}{2}\cdot\left.\frac{dB}{d\theta}\right|_{\theta=\theta_0} \qquad (6)$$

where $Y_i = jB$.

Differentiating Equation (1) by θ, we obtain

$$b = \frac{\theta_0}{2}\cdot 2\,(1+K)\,Y_2\cdot\frac{2}{1+K} = 2\theta_0\cdot Y_2 \qquad (7)$$

Admittance Inverter Expression for a Parallel Coupled Section of an Arbitary Electrical Length

For designing bandpass filters with S.I.R. in which lines are coupled in parallel, it is necessary to obtain the equivalent filter including an inverter and coupled lines having arbitary coupling length θ.

Figure 3 (a) shows even and odd mode impedance Zoe, Zoo of a coupled line of electrical length θ and the equivalent circuit is expressed by two single transmission lines of electrical length θ, impedance Zo and admittance inverter parameter J. The ABCD matrix for (a) and (b) can be expressed as

$$[Fa] = \begin{bmatrix} \frac{Zoe+Zoo}{Zoe-Zoo}\cos\theta & j\,\frac{(Zoe-Zoo)^2+(Zoe+Zoo)^2\,(\cos^2\theta)}{2\,(Zoe-Zoo)\,\sin\theta} \\ j\,\frac{2\sin\theta}{Zoe-Zoo} & \frac{Zoe+Zoo}{Zoe-Zoo}\cos\theta \end{bmatrix} \qquad (8)$$

$$[Fb] = \begin{bmatrix} (JZo+\frac{1}{JZo})\sin\theta\cdot\cos\theta & j\,(JZo^2\sin^2\theta-\frac{1}{J}\cos^2\theta) \\ j\,(\frac{1}{JZo^2}\sin^2\theta-J\cos^2\theta) & (JZo+\frac{1}{JZo})\sin\theta\cdot\cos\theta \end{bmatrix} \qquad (9)$$

Then equalizing each corresponding matrix element, we can obtain:

$$\frac{Zoe}{Zo} = \frac{1 + (\frac{J}{Yo}) \operatorname{cosec}\theta + (\frac{J}{Yo})^2}{1 - (\frac{J}{Yo})^2 \cot^2\theta}$$

$$\frac{Zoo}{Zo} = \frac{1 - (\frac{J}{Yo}) \operatorname{cosec}\theta + (\frac{J}{Yo})^2}{1 - (\frac{J}{Yo})^2 \cot^2\theta} \qquad (10)$$

when $\theta = \pi/2$, $J/Yo = Zo/K$ (K is the impedance inverter parameter), Equation (8) coincides with Cohn's Equation.(3)

Admittance Inverter Parameters for Bandpass Filters

The fundamental configuration of a n-stage bandpass filter considered here is shown in Fig. 4. When element values g_i and relative bandwidth ω are given as fundamental design parameters of a bandpass filter,(4) the admittance inverter parameter J_j, J_{j+1} can be expresses as

$$J_{01} = \sqrt{\frac{Yo \cdot b_1 \cdot \omega}{g_0\, g_1}} = Yo \cdot \sqrt{\frac{2\omega\theta}{g_0\, g_1}}$$

$$J_{j,j+1} = \omega \cdot \sqrt{\frac{b_j \cdot b_{j+1}}{g_j \cdot g_{j+1}}} = Yo \cdot \frac{2\theta_0\,\omega}{\sqrt{g_j \cdot g_{j+1}}} \quad (j = 1 \sim n\text{-}1) \qquad (11)$$

$$J_{n,n=1} = \sqrt{\frac{Yo \cdot b_n \cdot \omega}{g_n \cdot g_{n+1}}} = Yo \cdot \sqrt{\frac{2\omega\theta}{g_n \cdot g_{n+1}}}$$

Using the results obtained in the previous section, the design data for coupling lines can be obtained. It is then possible to design a bandpass filter with S.I.R.

Performance of an Experimental Filter

On the basis of the derived formulae of Equation (8) and (9), an experimental bandpass filter was designed and fabricated using the following parameters:

Center Frequency	$f_O = 1.00$ GHz
Number of Resonators	N = 4
Response	Chebyshev
Passband Ripple	R = 0.01 dB
Relative Bandwidth	w = 0.04

The impedance ratio K was chosen as

K = 0.5

so as to obtain spurious response above 2.5 · fo. The spurious response was thus:

$$f_{S_1} = \frac{\pi}{2\theta_0} \cdot fo = 2.55 \cdot fo$$

$$f_{S_2} = (2f_{S_1} - 1)\, fo = 4.10 \cdot fo \qquad (12)$$

The filter was fabricated with a substrate having a dielectric constant of $\varepsilon_r = 2.6$, and a triplate strip-line structure in which the distance between ground planes is 3.15 mm. The arrangement of a filter is shown in Fig. 5, and Fig. 6 and 7 show the attenuation characteristics and the spurious response, respectively.

Conclusions

A method of designing bandpass filters suitable for strip-line with stepped impedance resonators (S.I.R.) was established and the fabricated filter performance closely coincided with the design data.

A feature of this filter is that the spurious response can be controlled by the impedance ratio K of the resonator.

Acknowledgements

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References

(1) C.P. Womack, IRE Trans. on MTT, vol. 10, no. 3, p. 124, March 1962.

(2) M. Makimoto and S. Yamashita, Proc. IEEE, vol. 67. p. 16, Jan. 1979.

(3) S.B. Cohn, IRE Trans. on MTT, vol. 6, no. 2, p. 233, April 1958.

(4) G.L. Matthaei et al, Microwave Filters, Impedance-Matching Networks and Coupling Structures, New York, McGrow-Hill 1964.

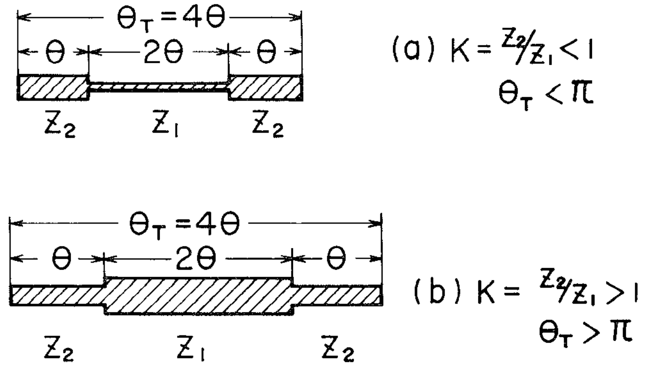

Fig. 1 Stepped Impedance Resonator (S.I.R.)

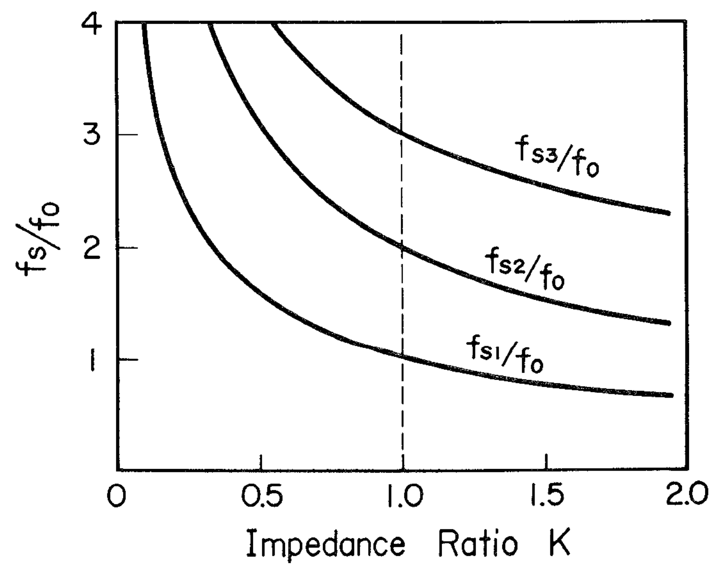

Fig. 2 Spurious Response Frequency of a S.I.R.

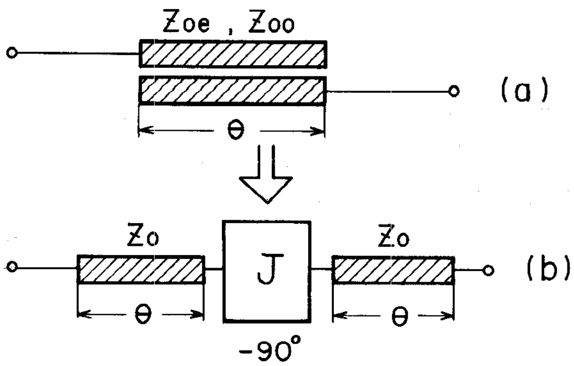

Fig. 3 Parallel Coupled Line and Its Equivalent with an Inverter

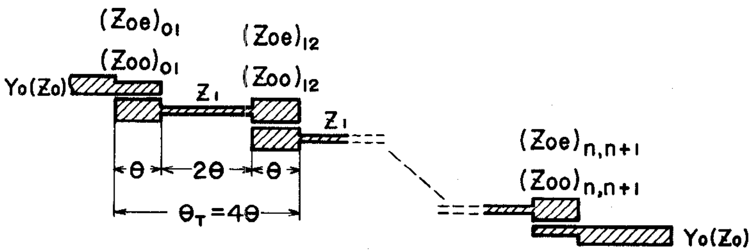

Fig. 4 Bandpass Filter Structure Using S.I.R.

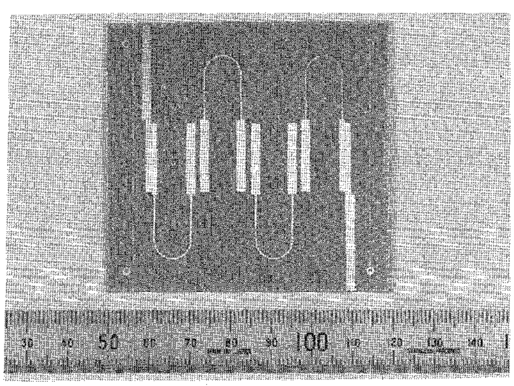

Fig. 5 Experimental S.I.R. Bandpass Filter
(f_0 = 1.0 GHz, K = 0.5)

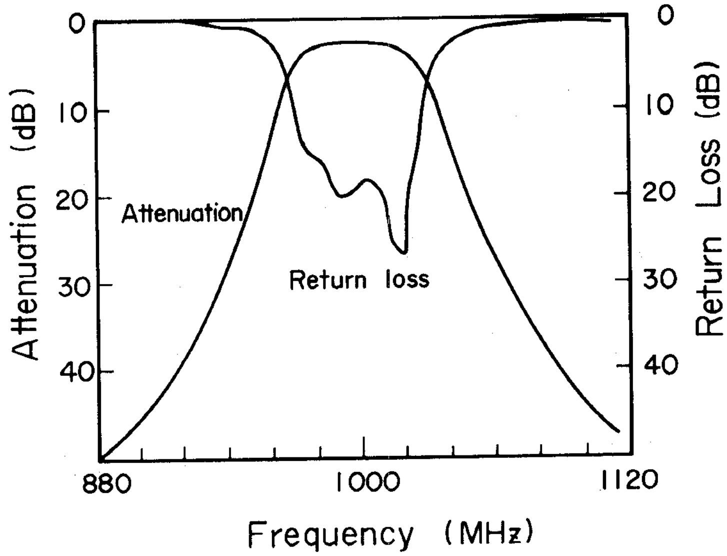

Fig. 6 Measured Frequency Response of a Four-stage Filter

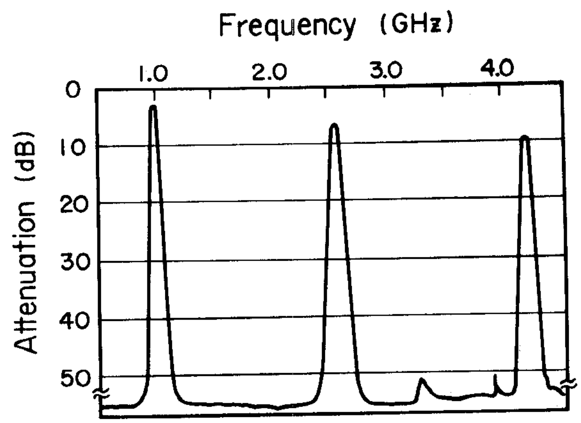

Fig. 7 Measured Spurious Response of the S.I.R. Filter