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STRIP-LINE RESONATOR FILTERS HAVING MULTI-COUPLED SECTIONS

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ABSTRACT

The design criteria for microwave filters with multi-coupled strip-line have been developed. One of the advantages of this method is that it provides a line-spacing which is five times wider than with the conventional method. Higher production yield is therefore obtainable in designing wideband or millimeter-wave filters with the use of thin dielectric substrate.

Introduction

Parallel coupled strip-line resonator filters have been most commonly used in microwave integrated circuits(1). Wideband filter design using thin substrate usually requires the formation of coupled section with narrow line spacing. The conventional photo-lithographic technique is limited where the production of high performance filters is concerned and several efforts have been made to overcome this limitation(2)(3).

This paper presents a novel method of filter design which requires wider tolerance of geometric specifications for the spacing of coupled section with the use of multiply coupled lines. The first part of this paper discusses analytical relationships between single and multiply coupled lines. Secondly, the physical dimensions of a coupling section are calculated and discussed using microstrip doubly coupled lines.

Finally, the results of an experimental bandpass filter, which was designed and fabricated based on the previous design criteria, was reported.

The Relationships Between Singly and Multiply Coupled Lines

Fig. 1 (a) and (b) schematically show singly and the multiply coupled lines.

The electrical parameters of singly coupled lines are expressed by even and odd mode impedance, $(Z_{oe})_s$, $(Z_{oo})_s$ and the coupling angle θ_c, as shown in Fig. 1 (a). These parameters can be represented by equivalent circuit of two single lines with electrical length, θ_c, impedance, Z_s, and admittance inverter, J_s, as shown in Fig. 2 (a)(4). If the electrical length, θ_c, equal 90°, $(Z_{oe})_s$ and $(Z_{oo})_s$ can be expressed by,

$$\begin{cases} (Z_{oe})_s = Z_s\{1 + (J_s/Y_s) + (J_s/Y_s)^2\} \\ (Z_{oo})_s = Z_s\{1 - (J_s/Y_s) + (J_s/Y_s)^2\} \end{cases} \quad (1)$$

where $Y_s = 1/Z_s$

The admittance matrix $[Y]_s$ of Fig. 2(b) can be obtained by calculating total fundamental matrix $[F]_s$ as,

$$[F]_s = \begin{bmatrix} 0 & jZ_s \\ j/Z_s & 0 \end{bmatrix} \times \begin{bmatrix} 0 & -j/J_s \\ -jJ_s & 0 \end{bmatrix} \times \begin{bmatrix} 0 & jZ_s \\ j/Z_s & 0 \end{bmatrix} = \begin{bmatrix} 0 & jJ_sZ_s^2 \\ j/J_sZ_s^2 & 0 \end{bmatrix}$$

then,

$$[Y]_s = \begin{bmatrix} 0 & j/J_sZ_s^2 \\ j/J_sZ_s^2 & 0 \end{bmatrix} \quad (2)$$

Next, multiply coupled lines shown in Fig. 1 (b) can be considered. The unit coupling section has the same structure, and is expressed by even and odd mode impedance, $(Z_{oe})_p$ and $(Z_{oo})_p$, and coupling angle θ_c. As in the case of singly coupled lines, the equivalent circuit of unit coupling section can be expressed by Z_p, J_p and θ_c.

If no coupling exists between each coupling section, the total equivalent circuit can be obtained as shown in Fig. 2 (b). The total admittance matrix, $[Y]_p$ in this case, can be expressed by,

$$[Y]_p = \begin{bmatrix} 0 & j/J_pZ_p^2 \\ j/J_pZ_p^2 & 0 \end{bmatrix} + \begin{bmatrix} 0 & j/J_pZ_p^2 \\ j/J_pZ_p^2 & 0 \end{bmatrix} + \cdots\cdots + \begin{bmatrix} 0 & j/J_pZ_p^2 \\ j/J_pZ_p^2 & 0 \end{bmatrix} = \begin{bmatrix} 0 & jn/J_pZ_p^2 \\ jn/J_pZ_p^2 & 0 \end{bmatrix} \quad (3)$$

To find the relationship between singly and multiply coupled lines, a comparison of matrix $[Y]_p$ with $[Y]_s$ is convenient. By equalizing each corresponding matrix element, it is possible to obtain,

$$J_sZ_s^2 = J_pZ_p^2/n \quad (4)$$

or

$$(J_p/Y_p) = n \cdot (Z_s/Z_p) \cdot (J_s/Y_s) \quad (5)$$

The direct relationship between each line impedance can be derived as follows.
$(Z_{oe})_p$ and $(Z_{oo})_p$ are expressed by

$$\begin{cases} (Z_{oe})_p = Z_p\{1 + (J_p/Y_p) + (J_p/Y_p)^2\} \\ (Z_{oo})_p = Z_p\{1 - (J_p/Y_p) + (J_p/Y_p)^2\} \end{cases} \quad (6)$$

Using equation (1), (6) and (5),

$$\begin{aligned} (Z_{oe})_p - (Z_{oo})_p &= Z_p \cdot 2 \cdot (J_p/Y_p) \\ &= n \cdot \{Z_s \cdot 2 \cdot (J_s/Y_s)\} \\ &= n \cdot \{(Z_{oe})_s - (Z_{oo})_s\} \end{aligned} \quad (7)$$

The equation (5) and (7) are relationships between singly and n-stage coupled lines.

Calculated Results of Physical Dimensions

Physical dimensions of coupled lines having impedances of Z_{oe} and Z_{oo} can be determined by the transmission line synthesis method(5).

The calculated values of the ratio of line spacing, S, to substrate thickness, H, for doubly coupled section as a function of inverter parameter, J_s/Y_s, are shown in Fig. 3. In this case, the line structure consists of microstrip formed on a substrate of relative dielectric constant ϵ_r of 2.50.

It is clearly seen from Fig. 3 that the S/H ratio of doubly coupled lines is larger than that of singly coupled lines. This indicates that the use of multiply coupled lines for filter design allows wider geometrical tolerance during the fabrication process. In addition the wider line spacing of the doubly coupled lines enables the use of a substrate with a lower relative dielectric constant of less than 8.0.

Application of Doubly Coupled Lines to Bandpass Filter

An experimental bandpass filter was designed and fabricated on the basis of the previous design criteria according to the following design specifications.

Center frequency	:	4.0 GHz
Number of resonator	:	4
Response type	:	Butterworth
3-dB bandwidth	:	800 MHz

The line structure consists of microstrip formed on a substrate with dielectric constant ϵ_r of 2.33, and thickness H of 1.5 mm.
Table-1 (a) shows design parameters for singly coupled lines. The line spacing of the input and output coupling section for this case is 0.052 mm.
The parameters for doubly coupled lines for input and output coupling are listed in Table-1 (b).
Where impedance Z_P is 100Ω, the designed line spacing of doubly coupled lines is 0.252 mm, which is approximately 5 times wider than that of singly coupled lines.

A picture of the experimental filter is shown in Fig. 4. Fig. 5 shows the calculated and measured response. Although the measured bandwidth tends to be slightly narrower than the designed value, relatively good agreement between calculated and measured results has been obtained.

In this design example the relative bandwidth w was chosen to be 20%, but a wide-band filter in which w is up to 50% can be easily realizable using the same substrate (ϵ_r = 2.33, H = 1.5 mm).

Conclusion

A novel method of designing bandpass filter having multiply coupled strip-lines was developed. The fabricated filter performance based on the design criteria showed close coincidance with the designed data. The important features of this method are that it allows a greater geometrical tolerance for the formation and use of thinner dielectric substrate as compared to the conventional method.

It is expected that the multiply coupled strip-line concept will provide manufactures with an effective design tool to obtain higher production yield with the use of thin dielectrid substrate during both wideband and millimeter-wave filter design.

References

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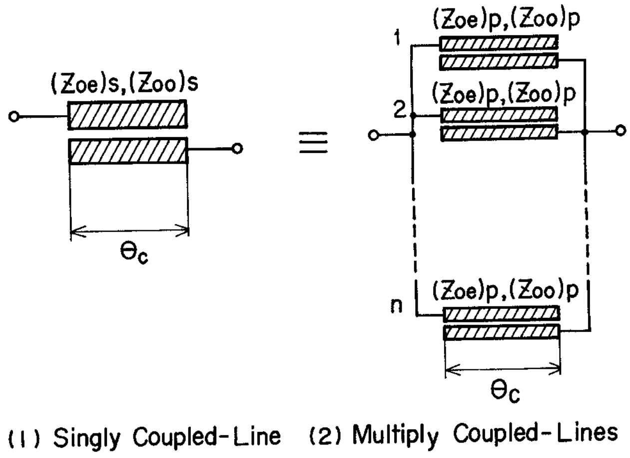


Fig.-1 Structure of Parallel-Coupled Strip-Lines

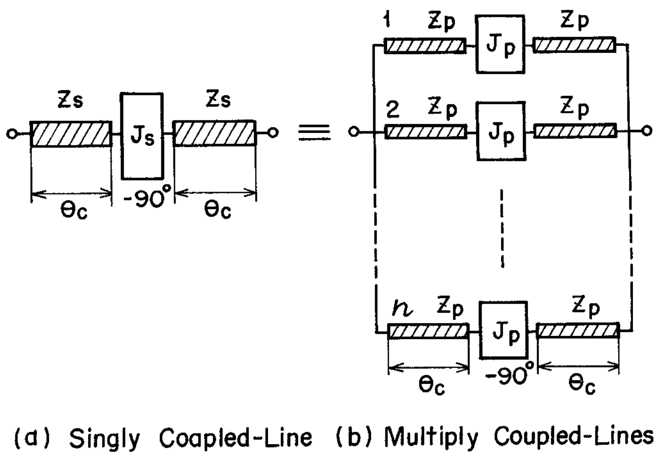


Fig.-2 Equivalent Circuits with J-Inverters

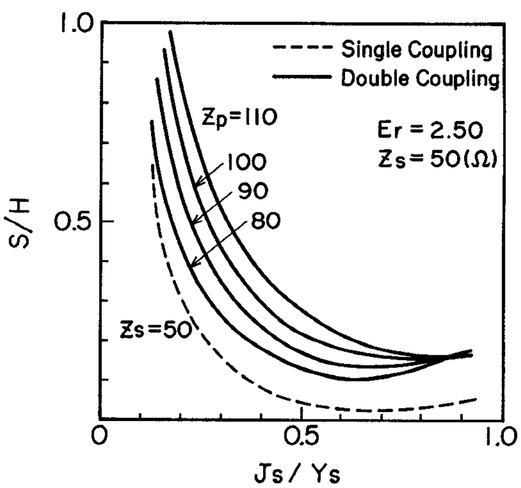
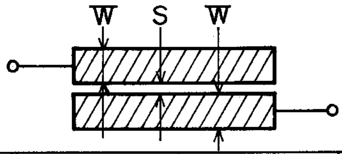


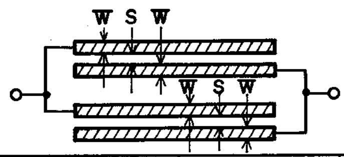
Fig.-3 Calculated S/H of Microstrip Lines



εr = 2.33
H = 1.50 (mm)
Z_s = 50 (Ω)

J, J+1	$J_{j,j+1}/Y_s$	$(Z_{oe})_{s\,j,j+1}(\Omega)$	$(Z_{oo})_{s\,j,j+1}(\Omega)$	W_j (mm)	$S_{j,j+1}$ (mm)
0, 1 (4,5)	0.6407	102.6	38.5	2.11	0.052
1,2 (3,4)	0.2642	66.7	40.3	3.78	0.312
2,3	0.1700	60.0	43.0	4.21	0.761

(a) Singly Coupled - Lines



εr = 2.33
H = 1.50 (mm)

Z_p (Ω)	J_p/Y_p	$(Z_{oe})_p$ (Ω)	$(Z_{oo})_p$ (Ω)	W (mm)	S (mm)
80	0.8008	195.4	67.2	0.591	0.177
90	0.7118	199.7	71.5	0.546	0.210
100	0.6407	205.1	77.0	0.472	0.252

(b) Doubly Coupled-Lines for Input and Output Coupling

Toble-1 Design Parameters of Coupled Section

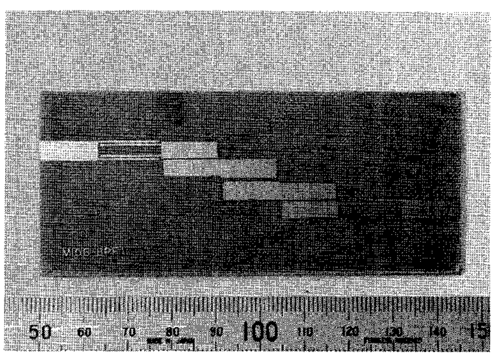


Fig.-4 Photograph of the Experimental Filter

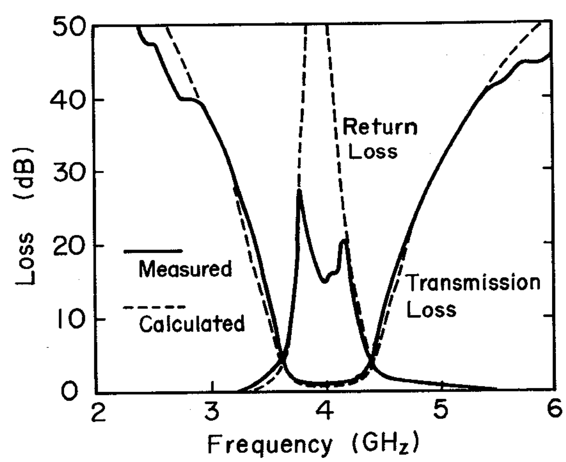


Fig.-5 Measured and Calculated Response of the Experimental Filter