ANALYSIS AND DESIGN OF SPURLINE BANDSTOP FILTERS

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ABSTRACT

The chain matrices of spurline bandstop filters employing asymmetrical two lines and symmetrical three lines in an inhomogeneous medium were derived and used for accurate filter design. One-section spurline bandstop filters at 26.5 to 40 GHz have been designed and tested. There is an excellent agreement between the experimental results and those predicted theoretically.

INTRODUCTION

Recent advances in microwave and millimeter wave integrated circuits have created a demand for compact, bandstop filters. Spurline bandstop filters (Figure 1) are most promising; they are compact structures, with a significantly lower radiation loss than conventional shunt-stub and coupled-line filters(1).

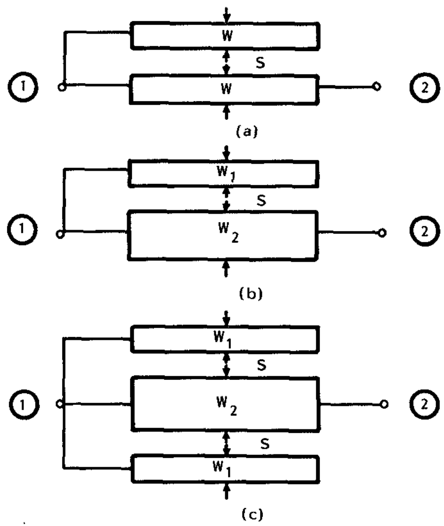

Figure 1. Spurline bandstop filter configurations.

A basic spurline bandstop filter, consisting of two identical parallel conductors (Figure 1a) built in stripline configuration, was first introduced by Schiffman and Matthaei (2). Bates adapted this technique in microstrip medium by assuming the same phase velocities for even and odd modes (1). Later, Nguyen et al. analyzed the structure, taking into account the different even- and odd-mode phase velocities (3). None of the papers published on this subject, however, analyze spurline filters using asymmetrical two lines (Figure 1b) and symmetrical three lines (Figure 1c).

The principal advantages of the asymmetric two-line filter are its ability to act as a symmetrical two-line filter combined with an impedance transformer, and to be designed to achieve a wider stop-bandwidth. The symmetrical three-line filter has significant advantages over asymmetrical and symmetrical two-line filters because it can offer a much wider bandwidth, in addition to a higher stop-band rejection in a comparable size.

It is the intent of this paper to provide an analysis and performance of such spurline bandstop filters in an inhomogeneous medium.

SPURLINE BANDSTOP FILTERS

The structures of two nonidentical and three symmetric coupled lines embedded in an inhomogeneous medium support, respectively, two and three quasi-TEM propagation modes. The impedance matrices of these structures have been obtained for a general case in (4) and (5). For lossless coupled-line structures with nonmagnetic dielectric, they can be derived in terms of the elements of the per-unit-length capacitance matrices of the structures with and without the presence of dielectric. These impedance matrices are used to derive the chain matrices of the spurline bandstop filters by applying the appropriate boundary conditions.

Two-Conductor Spurline Filter

Figure 2 shows the schematic of a single section of the spurline bandstop filter employing two coupled lines. With the knowledge of the impedance matrix of the corresponding four-port parallel coupled-line network, the ABCD matrix parameters of this two-port spurline network can be derived as

$$A = \frac{\cos\theta_c \cos\theta_\pi (R_c - R_\pi)}{R_c(1-R_\pi)\cos\theta_\pi - R_\pi(1-R_c)\cos\theta_c}$$

$$C = \frac{j}{R_c(1-R_\pi)\cos\theta_\pi - R_\pi(1-R_c)\cos\theta_c}$$

$$\left[\frac{(1-R_c)^2\cos\theta_c}{R_c Z_{01\pi}\csc\theta_\pi} - \frac{(1-R_\pi)^2\cos\theta_\pi}{R_\pi Z_{01c}\csc\theta_c}\right]$$

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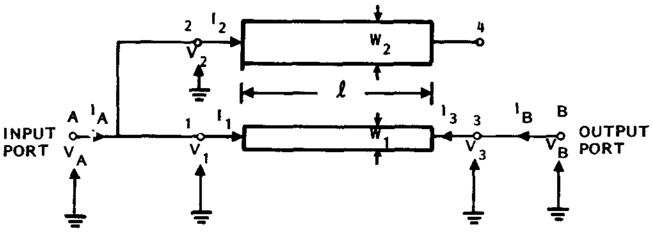

Figure 2. Schematic of two-conductor spurline section.

$$D = \left\{\cos\theta_c\cos\theta_\pi\left[R_\pi^2(1-R_c)^2 + R_c^2(1-R_\pi)^2\right] + R_cR_\pi\sin\theta_c\sin\theta_\pi\left[\frac{Z_{01c}}{Z_{01\pi}}(1-R_c)^2 + \frac{Z_{01\pi}}{Z_{01c}}(1-R_\pi)^2\right] - 2R_cR_\pi(1-R_c)(1-R_\pi)\right\} \Big/ (R_c-R_\pi)\left[R_c(1-R_\pi)\cos\theta_\pi - R_\pi(1-R_c)\cos\theta_c\right]$$

and

$$B = \frac{1}{C}\,(AD-1)$$

where Z_{0ik} ($i = 1,2$ and $k = c,\pi$) is the characteristic impedance of line i for mode k; $R_{c,\pi}$ and $\theta_{c,\pi}$ are the ratios of voltages on the lines and electrical lengths of the line for the two modes c and π, respectively. These parameters can be obtained in terms of the elements of the per-unit-length capacitance matrices of the structure with and without the presence of dielectric. For the special case of a spurline structure consisting of two identical coupled lines, the above equations reduce to those obtained in (3).

Three-Conductor Spurline Filter

A single section of a spurline bandstop filter consisting of three symmetrical coupled lines is illustrated in Figure 3. From the impedance matrix of the corresponding six-port coupled-line network, the chain matrix of this spurline network can be obtained as

$$\begin{bmatrix} V_A \\ I_A \end{bmatrix} = \frac{1}{M}\begin{bmatrix} L & (LN-M^2)/E \\ E & N \end{bmatrix}\begin{bmatrix} V_B \\ -I_B \end{bmatrix}$$

where

$$E = -\frac{2j}{R_d}\left[Z_{02b}\cot\theta_b(2-R_{2b}) - Z_{02c}\cot\theta_c(2-R_{2c}) + \frac{1}{2}R_{2c}Z_{01b}\cot\theta_b\right]$$

$$L = -\frac{1}{R_d^2}\left\{2(Z_{02b}\cot\theta_b - Z_{02c}\cot\theta_c)^2 + R_{2c}Z_{01b}\cot\theta_b(R_{2b}Z_{02b}\cot\theta_b - R_{2c}Z_{02c}\cot\theta_c)\right\}$$

$$N = -\frac{2}{R_d^2}\left\{\left[Z_{02b}\csc\theta_b(R_{2b}-1) - Z_{02c}\csc\theta_c(R_{2c}-1)\right]^2 + \left[R_{2b}Z_{02b}\cot\theta_b - R_{2c}Z_{02c}\cot\theta_c\right]\left[Z_{02b}\cot\theta_b(2-R_{2b}) - Z_{02c}\cot\theta_c(2-R_{2c}) + \frac{1}{2}R_{2c}Z_{01b}\cot\theta_b\right]\right\}$$

and

$$M = -\frac{1}{R_d^2}\,(2M_1M_4 + M_2M_3)$$

with

$$M_1 = Z_{02b}\cot\theta_b(1-R_{2b}) - Z_{02c}\cot\theta_c(1-R_{2c})$$

$$M_2 = 2Z_{02b}\cot\theta_b - 2Z_{02c}\cot\theta_c + R_{2c}Z_{01b}\cot\theta_b$$

$$M_3 = R_{2b}Z_{02b}\csc\theta_b - R_{2c}Z_{02c}\csc\theta_c$$

$$M_4 = Z_{02b}\csc\theta_b - Z_{02c}\csc\theta_c$$

$$R_d = R_{2b} - R_{2c}$$

Z_{0ik} ($i = 1,2,3$ and $k = a,b,c$) is the characteristic impedance of line i for mode k; $\theta_{a,b,c}$ and $R_{2b,c}$ are the electrical lengths of the line and the ratios of voltage on the i^{th} to the voltage on the first lines, respectively. These parameters can be derived in terms of the elements of the per-unit-length capacitance matrices of the structure with the dielectric in place and removed.

EXPERIMENTAL RESULTS

To validate the theory of spurline bandstop filters developed, single-section spurline bandstop filters at 26.5 to 40 GHz were fabricated on suspended stripline and tested. To minimize the discontinuity and obtain a very compact structure, these filters have been computer-optimized to fit within the width of transmission lines. The responses of these filters are shown in Figure 4 and 5. It can be seen that there are good agreements

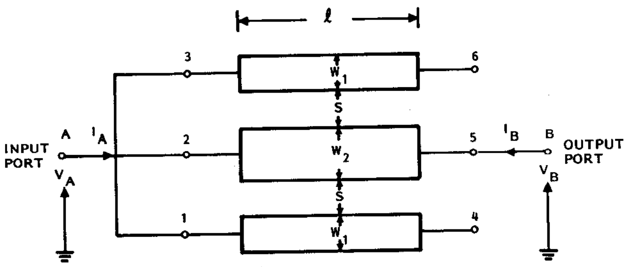

Figure 3. Schematic of three-conductor spurline section.

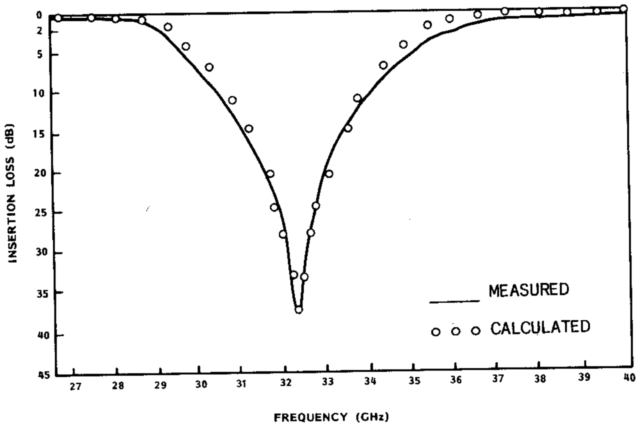

Figure 4. Transmission loss for single-section two-line spurline filter.

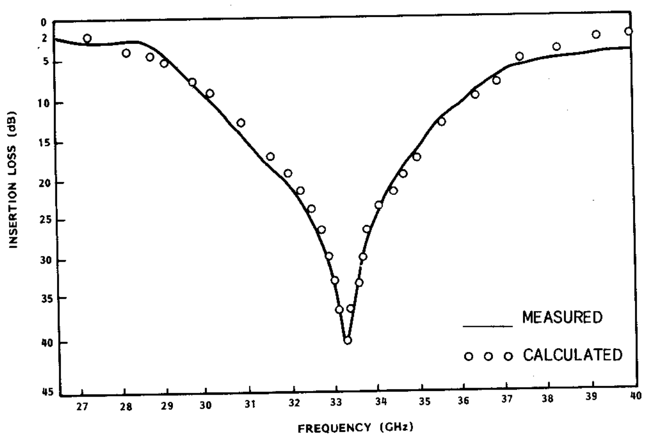

Figure 5. Transmission loss for single-section three-line spurline filter.

between calculated and measured responses. Figures 6 and 7 are photographs of these filters.

CONCLUSIONS

The chain matrices of the spurline bandstop filters consisting of two asymmetrical and three symmetrical coupled lines in an inhomogeneous medium have been derived. The experimental results obtained on two- and three-conductor spurline bandstop filters were found to be in good agreement with the computed results. The results obtained should be

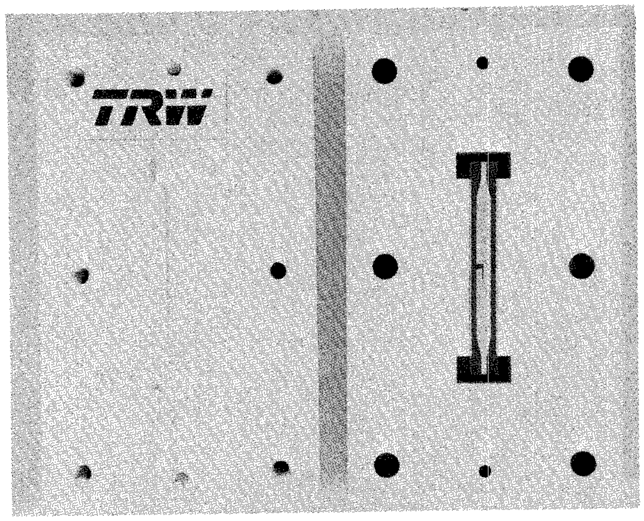

Figure 6. Photograph of the two-line spurline filter.

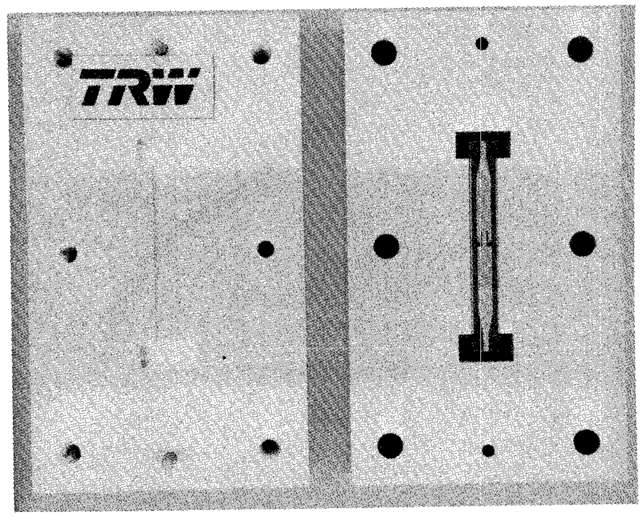

Figure 7. Photograph of the three-line spurline filter.

useful in designing spurline bandstop filters in an inhomogeneous medium (homogeneous medium is a special case).

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