RE-ENTRANT FILTER DESIGN USES MICROSTRIP-TO-SLOTLINE TRANSITIONS

This innovative filter design is based on even-odd-mode microwave circuit-analysis techniques.

RE-ENTRANT filters feature a simple architecture that is suitable for low- and medium-density microwave integrated circuits (MICs). In making this design approach practical, it is necessary to develop an effective means of modeling the transition between two different transmission media: microstrip and slotline. Fortunately, a set of design equations has been derived for such predictions, with excellent agreement with experimental results.

Slotline has long been considered as an alternative transmission line to microstrip and stripline in MICs.[1-4] Slotline offers a unique combination of a planar-type geometry and a transverse-electromagnetic (TE) dominant mode similar to the dominant mode in rectangular waveguide. Slotline on one side of a design can be combined with microstrip on the other side of a dielectric substrate to create interesting possibilities for realizing miniature microwave devices such as filters, couplers, and complete microwave circuits.[5-6]

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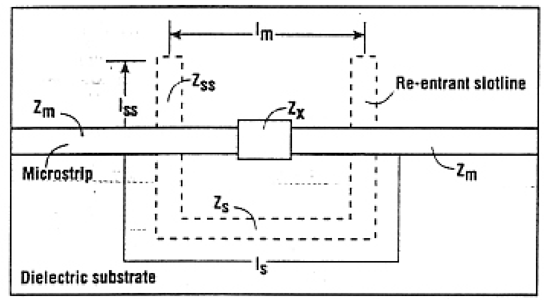
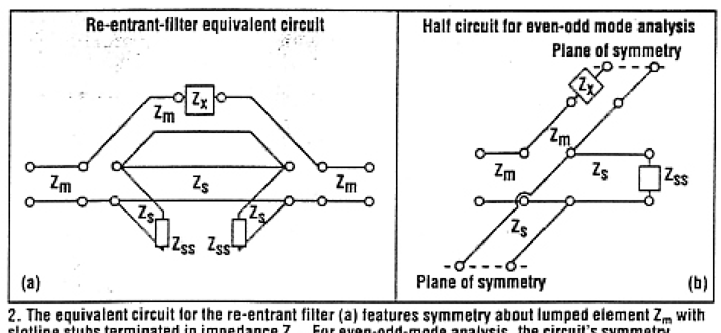


1. A novel re-entrant filter design includes a transition between the slotline and microstrip line.

Using this combination of slotline and microstrip, it was possible to create a novel structure for the design of a re-entrant filter circuit (Fig. 1). Simulations of the performance of this filter circuit, based on the design equations below, are well-supported by actual vector-analyzer measurements made across a frequency range of 1 to 10 GHz.

When a microstrip line and a slotline of equal characteristic impe-



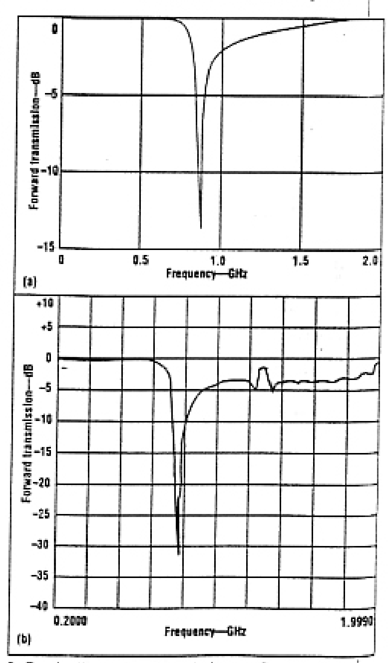
2. The equivalent circuit for the re-entrant filter (a) features symmetry about lumped element Z_m with slotline stubs terminated in impedance Z_{ss}. For even-odd-mode analysis, the circuit's symmetry allows one-half of the circuit to be scrutinized (b).

dance cross each other at right angles (and extend a quarter wavelength beyond the crossing point), coupling between the two lines is strong and a transition covering approximately 30-percent bandwidth is possible. This type of transition has been investigated, with theoretical and experimental results well-documented.[7-10]

FILTER LAYOUT

The basic layout of the re-entrant filter consists of a microstrip transmission line of length l_m with a lumped element of impedance Z_m in its path and a slotline of length l_s in the ground plane crossing the microstrip line at two different locations, which are symmetric with respect to the location of the lumped element. At the crossover points, the slotlines extend an arbitrary length l_{ss} beyond the crossing points and are then terminated with shorts.

Using the model for the microstrip-to-slotline transition, the re-entrant filter may be modeled by an



3. For the filter with shorted element Z_{ss}, the theoretical (a) and measured (b) values of forward transmission (S_{21}) agree closely.

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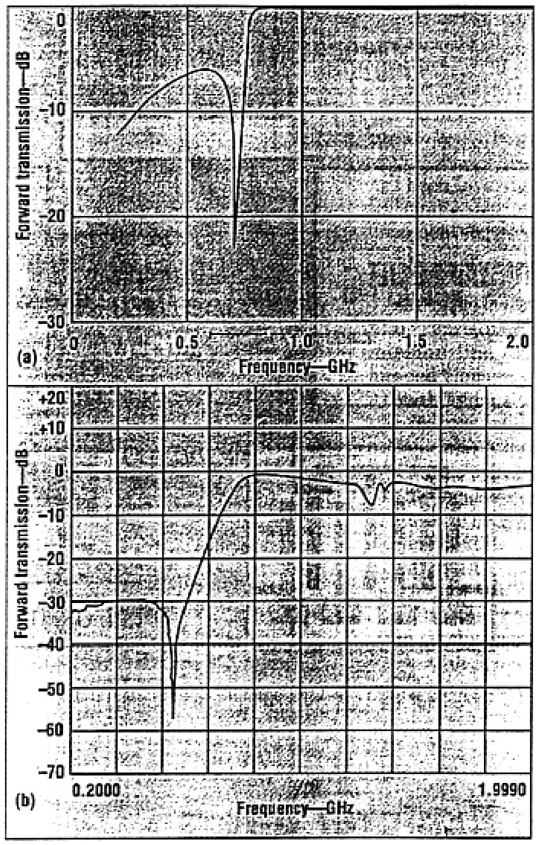


4. When filter element Z_{ss} is assigned a capacitive value of 0.1 pF, the theoretical (a) and measured (b) transmission values still agree closely.

equivalent circuit (Fig. 2a). In this model, the slotline stubs have been terminated with an impedance of Z_{ss} for analysis of a general case. In the special case of the novel re-entrant filter, Z_{ss} is set to zero for analysis purposes.

The symmetry of the generalized network is then exploited by using even-odd-mode techniques such that only one-half of the equivalent circuit is actually considered (Fig. 2b).[11] In this technique, the input waveform is broken into an even and odd mode, while the vector amplitudes of the various arms are computed from the sums or differences of the reflection or transmission coefficients. The transfer function of the filter (S_{21}) is computed by:

$$S_{21} = 0.5(\Gamma_e - \Gamma_o) \quad (1)$$

where:

$$\Gamma_e = [(A_e Z_{ss} - D_e Z_o) + (B_e - C_e Z_{ss} Z_o)]/(A_e Z_{ss} + D_e Z_o + B_e + C_e Z_{ss} Z_o) \quad (2)$$

$$\Gamma_o = [(A_o Z_{ss} - D_o Z_o) + (B_o - C_o Z_{ss} Z_o)]/(A_o Z_{ss} + D_o Z_o + B_o + C_o Z_{ss} Z_o) \quad (3)$$

where:

Γ_e = the even-mode reflection coefficient,

Γ_o = the odd-mode reflection coefficient,

$[A_e B_e C_e D_e]$ = the even-mode [ABCD] matrix,

$[A_o B_o C_o D_o]$ = the odd-mode [ABCD] matrix,

Z_{ss} = the load impedance, and

Z_o = the generator impedance.

Considering Z_{ss} equal to zero (a short), the B and D terms of the even- and odd-mode matrices are then only of interest for the calculation of S_{21}. From transmission-line theory:

$$B_o = jZ_s \sin[2\pi(l_{ss}/\lambda)] \times [1 + \{Z_m/\tan[\pi(l_m/\lambda)]\} \times \{\tan[\pi(l_s/\lambda)]/Z_s\}] + \{Z_m/j \tan[\pi(l_m/\lambda)]\} \times \cos[2\pi(l_{ss}/\lambda)] \quad (4)$$

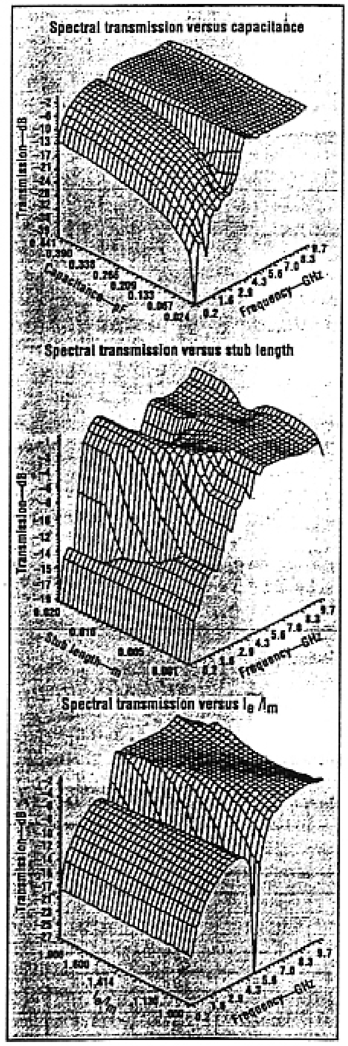
$$D_o = -\tan[\pi(l_s/\lambda)] \times \sin[2\pi(l_{ss}/\lambda)] + \cos[2\pi(l_{ss}/\lambda)] \quad (5)$$

$$B_o = jZ_s \sin[2\pi(l_{ss}/\lambda)] \times [1 + Z_m\{Z_x + jZ_m \tan[\pi(l_m/\lambda)]\} \{(jZ_m - Z_xZ_s \times \tan[\pi(l_m/\lambda)]) \times \tan[\pi(l_s/\lambda)]\}^{-1}] + \cos[2\pi(l_{ss}/\lambda)] \times Z_m[\{Z_x + jZ_m \times \tan[\pi(l_m/\lambda)]\} \{Z_m + jZ_x \times \tan[\pi(l_m/\lambda)]\}^{-1}] \quad (6)$$

$$D_o = [\{\sin[2\pi(l_{ss}/\lambda)]\} \times \{\tan[\pi(l_s/\lambda)]\}^{-1}] + \cos[2\pi(l_{ss}/\lambda)] \quad (7)$$

To verify that these theoretical derivations predict the behavior of the filter, experiments were conducted on actual re-entrant filter designs. Two re-entrant filter circuits were fabricated on Teflon dielectric substrates with a dielectric constant of 2.33. The experimental results clearly confirmed the theoretical findings. Dimensions of the slotlines were calculated from published slotline approximations.[12] The circuits were then tested on an HP 8720B automatic vector network analyzer from Hewlett-Packard Co. (Palo Alto, CA).

The measured transfer function of these filter circuits closely matches the values predicted by theory when the impedance element in the micro-strip line is shorted through (Figs. 3 and 4). Similarly, the theoretical transfer function of the filters when the lumped element is chosen to be a capacitor (with a value of 0.1 pF) closely matches the measured results for the fabricated filters at frequencies up to 2 GHz. The particular design appears to perform well as a highpass filter. The experimental results demonstrate a good order of accuracy and agreement with the first-order theoretical analysis presented above.



5. The filter's spectral transmission characteristics are plotted as a function of capacitance (top), stub length (middle), and transmission-line-length ratio (l_s/l_m) (bottom).

Figure 5 shows the theoretical spectral transmission characteristics of a highpass configuration as a function of capacitance (Z_x), stub length (l_{ss}), and transmission-line-length ratio (l_s/l_m). These plots are invaluable in providing circuit designers with an accurate understanding of the performance of these filters under circuit-element parameter-value variations.

In conclusion, by taking advantage of an effective microstrip-to-slotline transition, the re-entrant filter design can be realized as an extremely compact and reproducible format. The basic design can be easily configured to provide a number of spectral responses in filters, couplers, and other microwave components. ••

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