A Two-Path Multimode Bandpass Filters Using The NonRadiative Dielectric (NRD) Waveguide Technology

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Abstract

A new class of two-path multimode bandpass filters are proposed in this paper for stringent requirement of NRD integrated circuits. Rigorous field-theoretical analysis and CAD procedure are developed to determine frequency response of the proposed structure. It is shown that the two-path multimode filter presents a better electrical performance over its one-path counterpart. In addition, the proposed geometry provides also more freedom of choosing filter parameters in the design and optimization of bandpass filters.

Introduction

The high-quality filters are always the key elements for communication systems. Since the NRD technology is well suitable for millimeter-wave applications, NRD-guide filtering structures are in particular attractive. A class of NRD-guide bandpass filters [1-3] have successfully been realized by different coupling mechanism. The simplest topology [1] was based on an air-gap coupled resonator approach which has shown a poor stopband performance. The metal window-coupled NRD-guide filter [2] exhibits the advantages of shorter size and steeper out-of-band rejection characteristics compared to the air gap-coupled counterpart. Recently, A experimental investigation on a class of NRD-guide dual-mode filters has been done in [3]. For dual-mode purposes, square dielectric resonators are used to form degenerate orthogonal resonant modes. However, the relevant coupling and tuning mechanisms are very complicated to predict theoretically, thereby limiting its practical applications. In order to retain the advantages of the dual mode elliptical behavior, this paper proposes a two-path coupled resonant NRD circuits. In such a configuration, the LSE and LSM modes can be excited simultaneously and coupled from a single NRD-guide. Since each path can support simultaneously both LSE and LSM modes, which are coupled to each other. In doing so, the structure can be tuned such that the resonance of two-path circuits is able to provide zero insertion loss at a given frequency. At the same time, the attenuation pole is made at another frequency. Clearly, this is attributed to the interference of multimodes from both circuits.

To design this new type of filters, the frequency domain transmission line matrix (FDTLM) method is used. The algorithm is first developed to calculate S-parameters of a three-port discontinuity network. Since frequency-dependent S-parameters of various discontinuities are available, the whole filter can be modeled as an equivalent cascaded network. In this way, an effective and fast curve fitting technique [4] can be applied to determine the frequency response of the filtering structure.

Theory

TH
3F

Fig. 1 shows the top view of a typical three-port coupling structure for this new bandpass filter. At port 1, there exists only the NRD-guide operating mode (LSM_{01}). As is known, nondegenerate orthogonal modes (LSE modes and LSM modes), by introducing appropriate offset asymmetries, can be excited simultanesouly on both port 2 and port 3. This forms a multi-mode network. In order to obtain the coupling coefficients or S-parameters, a network S-parameter extraction technique is developed. the formulation is an extension of the technique described in [5], which provides scattering parameters of the operating mode as well as higher order modes. The structure of Fig. 1 consists of a discontinuity region and three attached semi-infinity NRD-guides. The intrinsic scattering matrix S^I and R_1, R_2, R_3 are first found by the FDTLM space discretization and 2D eigenvalue analyses. The incident and reflected waves at the interfaces between the discontinuity region and three attached NRD-guides are related to each other as follows:

$$\begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix} = \begin{pmatrix} S^I_{11} & S^I_{12} & S^I_{13} \\ S^I_{21} & S^I_{22} & S^I_{23} \\ S^I_{31} & S^I_{32} & S^I_{33} \end{pmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \quad (1)$$

and

$$a_1 = R_1 \cdot b_1 \quad (2)$$

$$a_2 = R_2 \cdot b_2 \quad (3)$$

$$a_3 = R_3 \cdot b_3 \quad (4)$$

Then the system is excited by injecting appropriate mode field distribution at the interfaces. For instance, assuming that a_{1i} , b_{1i} mode field distribution be incident at the interface between port 1 and the discontinuity region, the reflected wave b_{1r} associated with the reflected modes at port 1 and the reflected waves b_2 and b_3 associated with the transmitted modes in port 2 and 3 are found from

$$b_{1r} = (R_1 \cdot V_1 - 1)^{-1} \cdot (R_1 - V_1) \cdot a_{1i} \quad (5)$$

$$b_2 = T_2 \cdot (a_{1i} + R_1 \cdot b_{1r}) \quad (6)$$

$$b_3 = T_3 \cdot (a_{1i} + R_1 \cdot b_{1r}) \quad (7)$$

where

$$V_1 = S^I_{11} + S^I_{12} \cdot R_2 \cdot T_2 + S^I_{13} \cdot R_3 \cdot T_3$$

$$V_2 = (1 - S^I_{22} \cdot R_2)^{-1}$$

$$V_3 = (1 - S^I_{33} \cdot R_3)^{-1}$$

$$T_2 = (1 - V_2 \cdot V_3 \cdot S^I_{32} \cdot R_2)^{-1}$$

$$\cdot (V_2 \cdot S^I_{21} + V_2 \cdot S^I_{23} \cdot R_3 \cdot V_3 \cdot S^I_{31})$$

$$T_3 = V_3 \cdot S^I_{31} + V_3 \cdot S^I_{32} \cdot R_2 \cdot T_2$$

Thus, the corresponding S-parameters of different mode can be extracted [5] from the equation (5) ~ (7).

Results and Discussion

Based on the above described theoretical procedure, S-parameters of the proposed structure (Fig. 1) are calculated for Polystyrene (ε_r=2.58) strips with a height of 13 mm and a width of 14 mm. As long as the LSM_{01} mode is excited on port 1 of the NRD-guide, the LSE_{01} and LSM_{01} modes are simultaneously coupled onto port 2 and port 3. Due to the vertical symmetry of the topology, only the half structure is needed for discretization. Fig. 2 shows the coupling S-parameters of the LSE_{01} and LSM_{01} modes between the port 1 and port 2, where S_{12} is the coupling coefficient of LSE_{01} modes on port 1 and port 2, respectively; S_{13} is the coupling coefficient between the LSE_{01} mode on port 1 and LSM_{01} mode on port 2; and S_{23} is the coupling coefficient related LSE_{01} mode to LSM_{01} on port 2. It is found that S_{12} presents in most situations dominant characteristics over other coupling.

The design of a two-path multimode NRD-guide filter is followed next. The input and output of the NRD-guide are the single NRD strip supporting only the LSM_{01} operating mode. Fig. 3 is the top view of a two-path multimode NRD-guide filter using Polystyrene strips with a height of 13 mm and width of 14 mm. Considering the vertical symmetry of structure, a half of the structure for the equivalent multimode network is calculated. Thereafter, an efficient and fast optimization procedure is carried out by using the multi-variable Powell method together with a 2D curve fitting technique [4]. Fig. 4 shows a calculated response of one-path and two-path NRD-guide filters. The computed transmission loss is better than 0.5 dB for the two-path topology, while an attenuation pole is expected in the off-passband higher than the designed central frequency. This is extremely useful in most diplexer design in which a steep cutoff is needed for one side of each filter, with a relatively low selectivity requirement on the other side.

Conclusions

A new nonradiative dielectric waveguide bandpass filter is proposed by using the two-path multimode coupling mechanism. The method is based on the FDTLM algorithm which is effectively extended to the modeling and analysis of multiport networks. The expected filter performance are readily achieved as shown in the theoretical predictions. The filter prototypes are currently being fabricated which will be used to compare the theoretical results with measurements.

References

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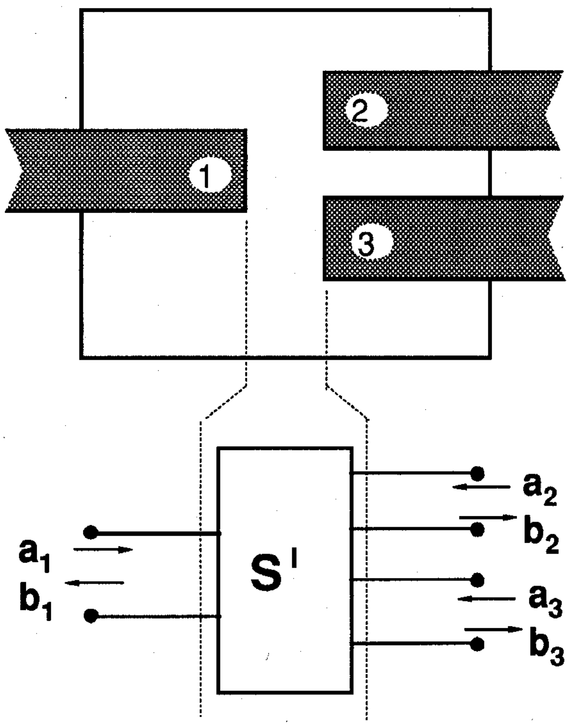


Fig. 1 The top view of a three-port NRD-guide gap discondinuity and its equivalent network.

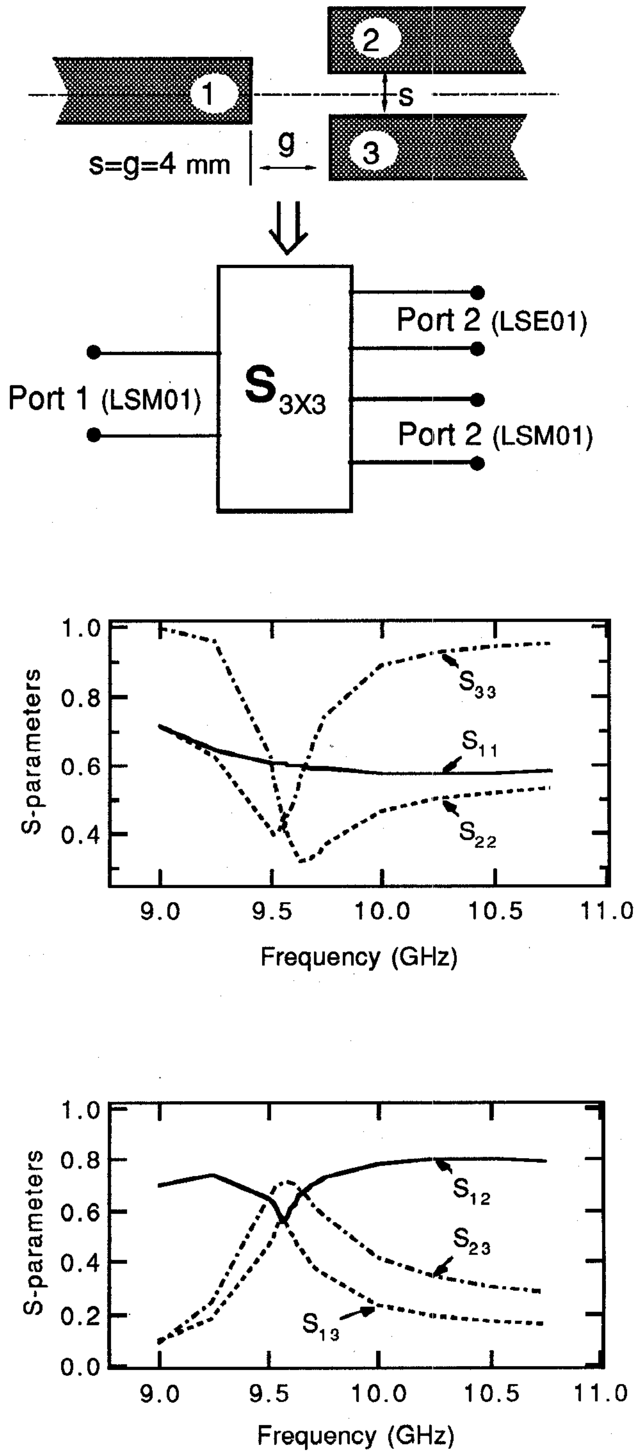


Fig. 2 The coupling S-parameters of the LSM_{01} and LSE_{01} modes between the port 1 and port 2.

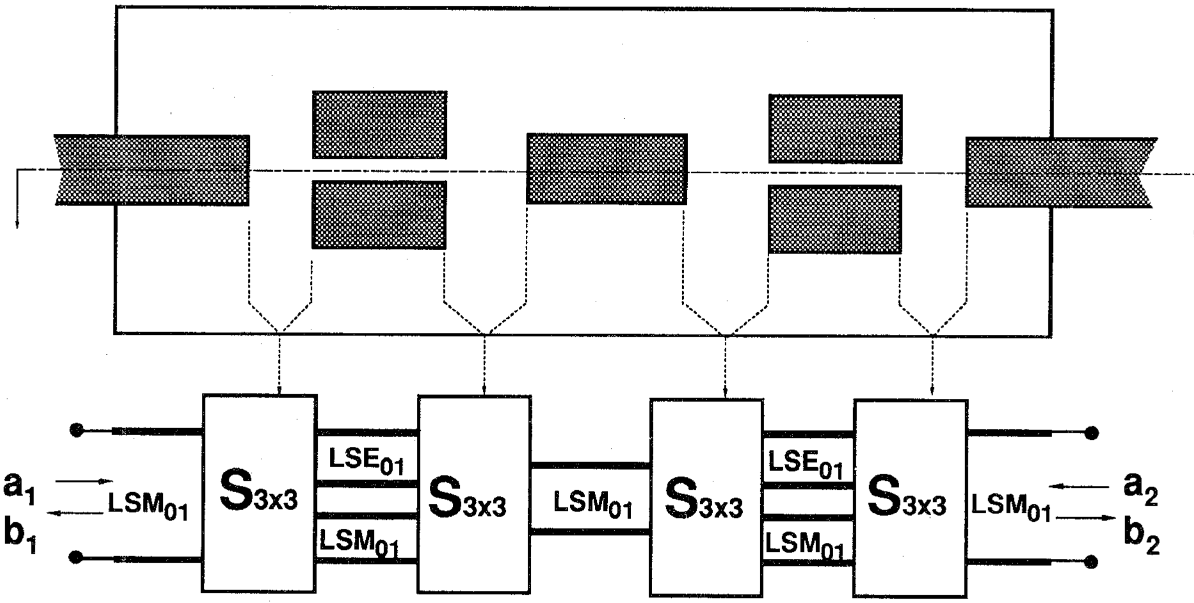
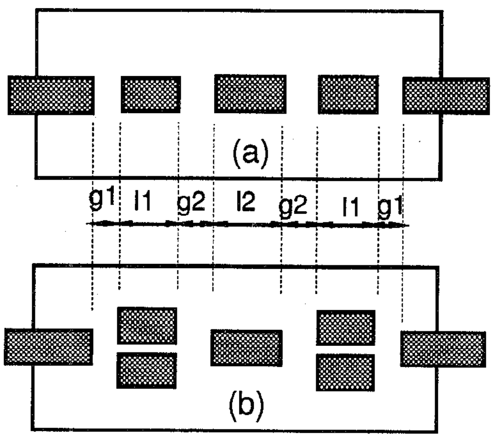


Fig. 3 The top view of a two-path multi-mode NRD-guide filter and its equivalent circuit for the calculation of the S-parameters.



Dimensions (a=13.0, b=14.0, εr=2.56)

(a) One-path filter
g1=4.6, g2=9.6, l1=8.7, l2=8.5.

(b) Two-path filter
g1=7.6, g2=12.5, l1=9.0, l2=9.3, s=6.6 (mm)

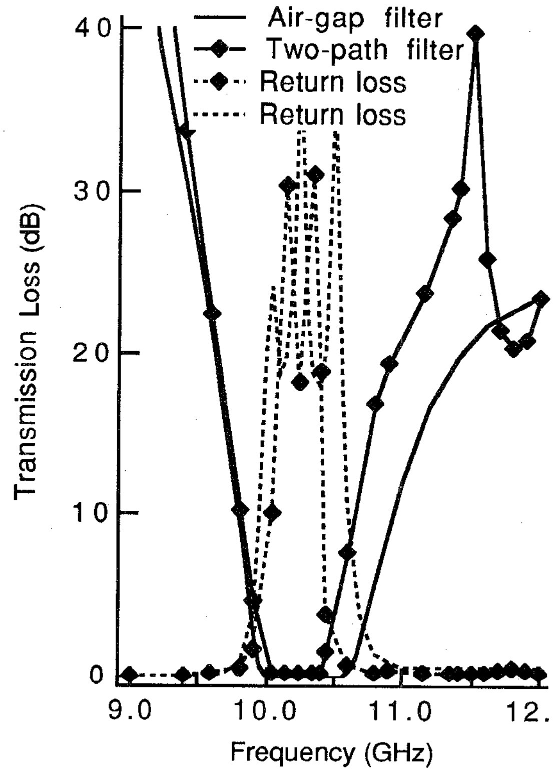


Fig. 4 Frequency response of the one-path and two-path bandpass NRD-guide filters.