Filter-Like Design and Optimization of NRD-Guide Mode Suppressors

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Abstract

A new compact NRD-guide mode suppressor is proposed in this paper for wideband applications in NRD integrated circuits. Rigorous field-theoretical analysis and optimum design are carried out to determine frequency response of the proposed mode suppressor using a filter-like scheme. It is found that the transmission loss of a three-section mode suppressor is better than -30dB over the frequency band of interest. In addition, the length of the whole resulting mode suppressor becomes shorter than its counterpart using the choke metallic pattern by 20%.

Introduction

One of the key issues in successful applications of the NRD-guide technology [1,2] is how to suppress effectively or at least diminish the propagation of unwanted modes. This is really a complex problem because mode propagation and mode spectrum of NRD-guide may have coupled-mode effects or mode-degenerating problems. Generally speaking, modes of the NRD-guide are usually classified into LSM and LSE modes according to its geometry. Since the LSM_{01} is selected as the operating mode due to its lowest transmission loss, the LSE_{01} mode that has a lower cut-off frequency than the wanted operating mode needs to be suppressed in most cases. Therefore, the mode suppressing technique using the mode suppressor has been proposed and used to suppress the unwanted LSE_{01} mode. In [3], a $\lambda/4$ choke pattern has been suggested for suppressing the parasitic modes. For instance, the transmission energy can be suppressed below 20 dB by means of a five-stage mode suppressor.

This paper presents a new class of mode suppressors which can be called the filter-like pattern mode suppressor. It is essentially based on a technique of controlling out-of-band characteristics of the TEM mode low-pass filter. Hence, the design issue of mode suppressor is effectively transformed into a design problem of low-pass filter with specific attention on out-of-band property. The resulting mode suppressor presents obviously advantages of shorter dimensions and better rejection characteristics of spurious modes than its previous counterpart [3]. In this work, the spectral domain approach (SDA) is first used to calculate propagation characteristics of the proposed transmission structure. Then the frequency-domain transmission-line matrix (FDTLM) technique is applied to determine frequency-dependent S-parameters of the entire mode suppressor including two discontinuities that are responsible for mode conversion between the LSE_{01} and TEM mode. The cut-off frequency of the low-pass filter is designed and optimized such that the characteristics of the upper stop-band is adjusted to provide the best rejection (suppressing) of LSE_{01} mode. The results are verified by experments.

Theoretical Modeling and Design Procedure

A cross-section of NRD-guide in Fig. 1(a) which shows a copper foil sandwiched in the middle of the dielectric strip with metal plates serving as the ground planes. The complete geometry can be viewed as a symmetrical multilayer planar transmission line with

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cascaded discontinuities. To begin with, a standard SDA is used to calculate propagation characteristics and characteristic impedance of such a structure. This is usually important in the design of a low-pass filter based on conventional low- and high-impedance line design technique. Fig. 2 gives the calculated curves of dispersion and impedance for different width of the central conductor. As expected, the dispersion diagrams of λ_g and Z_0 are almost linear functions of frequency. With these results, a loss-pass filter can be designed for suppressing the TEM mode transmission under the context of NRD-guide.

The frequency-dependent S-parameters of the complete mode suppressor are determined by using a FDTLM algorithm. This field-theoretical approach is a space discretization technique which has been documented in [4,5]. Sketched in this paper is a brief procedure with respect to the application of such a technique to this particular problem. As demonstrated in Fig. 1(b), the discontinuities of a complete mode suppressor can be effectively divided into a series of sequential subsections such as step discontinuities and homogeneous NRD-guides interconnecting these discontinuities which form the input and output ports. The low- and high-impedance lines and two step discontinuities responsible for the mode conversion are first calculated individually, and the whole structure can then be modeled as an equivalent cascaded two-port network. In this way, the overall filtering characteristics can be determined by combining all S-parameters of the related subsections. Since frequency-dependent S-parameters of various discontinuities become available, a polynomial curve fitting technique can effectively be applied to further improve frequency response of such a filtering structure, and subsequently the mode suppressor.

Results and Discussion

Based on the above theoretical synthesis procedure, the complete transmission characteristics of the mode suppressor with the conventional choke metallic pattern are obtained and compared very well with the measurements as displayed in Fig. 3. This indicates that the theoretical modeling presents a very accurate prediction of electrical performance of these complex structures.

Based on the well-established approximate design criteria for NRD-guides [1], a Ka-band Teflon NRD-guide should be chosen such that the spacing between two cover metal plates a = 4.0 mm and the dielectric width b = 1.5 mm. Under this design, the LSE_{01} nonradiative mode can only propagate between 34-36 GHz frequency band. With the calculated curves using the SDA (see Fig. 2), a low-pass filter can be readily designed and optimized by the application of the low- and high-impedance line approach. To do so, a 50 ohm central conducting strip is chosen as the input and output ports of the filter. Fig. 4 shows the predicted electrical performance of the low-pass filters with three- and five-elements. The cutoff frequency is designed to be 18 GHz to provide a better attenuation (rejection) at the desired suppressing band of frequency for the LSE_{01} mode. Clearly, the three-elements filter presents no better performance than five-elements counterpart in this case. It should be reminded that the filtering characteristics are looked at the input TEM mode instead of the LSE_{01} mode. Note that, in this preliminary design, the discontinuities responsible for the mode conversion at the input and output ports are not considered. It is worthwhile mentioning that only the mode suppressor is really looked at while the filter design is an intermediate consideration in the optimized design procedure. As a matter of fact, the discontinuities at the input and output ports bring some additional reactance that will cause a frequency shift. Considering all these factors, a new mode suppressor is designed with three-elements low-pass filter pattern. In this case, the cutoff frequency is specified at 24 GHz such that an excellent out-of-band rejection of the filter appears. This is clearly described in Fig. 5 indicating that a very good compact three-element mode suppressor can be realized with the band rejection performance of more than 30 dB over full band of frequency. This is also confirmed by measurements.

Conclusions

A new class of NRD-guide mode suppressors are proposed for wideband applications of NRD integrated circuits. It is found that the theoretical prediction and experimental results are in excellent agreements for a large number of structures. With the proposed design technique, a three-section mode suppressor is designed and optimized to achieve a transmission loss better than 30 dB over the full frequency band of interest. This interesting characteristics are also confirmed by measurements. The results presented in this work indicate that a compact high-performance mode suppressor can be realized.

References

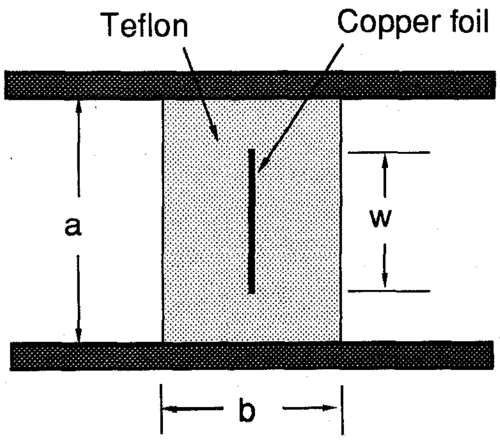
[1] T. Yoneyama, "Nonradiative dielectric waveguide," *in Infrared and millimeter-waves*, vol.11, pp.61-98, K.J. Button Ed., Academic Press, New York,1984.

[2] T. Yoneyama, "Recent development in NRD-guide technology," *Ann. Télécommun.*, 47, no. 11-12, pp. 508-514, 1992.

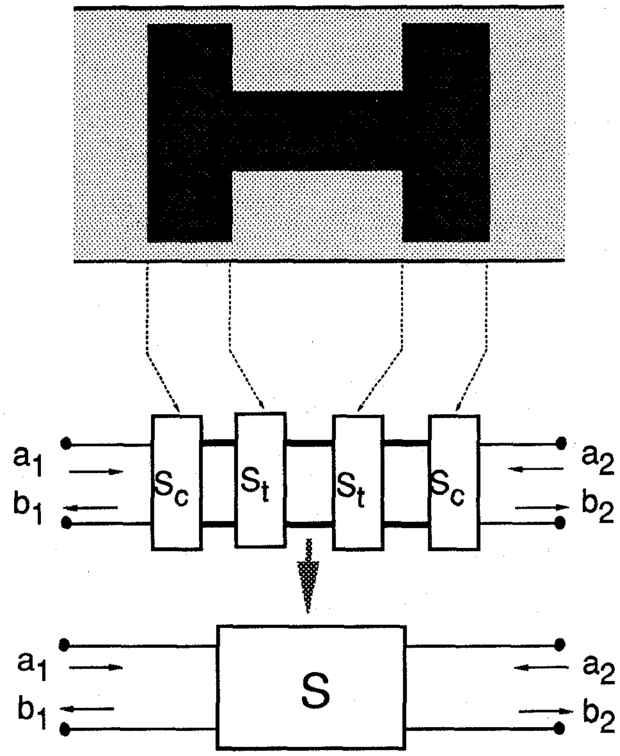
[3] T. Yoneyama, "Millimeter-wave transmitter and receiver using the nonradiative dielectric waveguide", *Digest of 1989 IEEE International Microwave Symposium*, Long Beach, USA, PP. 1083-1086, 1989.

[4] H. Jin and R. Vahldieck, "The frequency-domain TLM method - A new concept", *IEEE Trans.Microwave Theory and Tech.* vol. 40, No. 12, Dec. 1992, PP. 2207-2218.

[5] J. Huang, R. Vahldieck and H. Jin, "Fast frequency-domain TLM analysis of 3D circuit discontinuities," *In the 9th Annual Review of Progress in Applied Computational Electromagnetics Symposium*, Monterey, CA, March 22-26, 1993.



(a)



(b)

Fig.1 (a) Cross section of the NRD-guide with a copper foil in the centre of the dielectric strip. (b) Longitudinal section of the NRD-guide and its derivation of the s-parameters for discontinuity region.

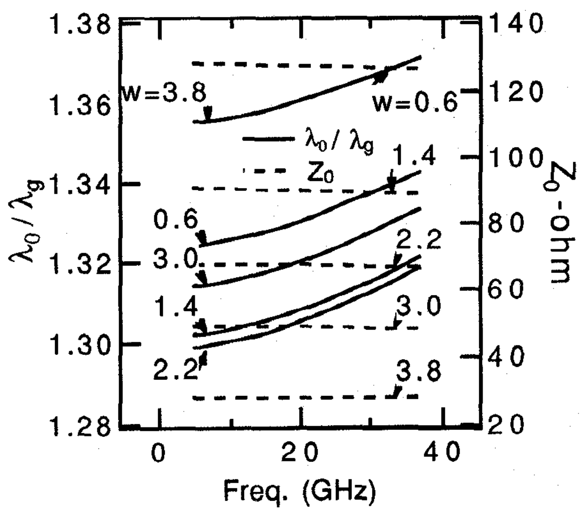


Fig. 2 Propagation characteristics for the structure of Fig.1(a) (a=4.0 mm, b=1.5 mm, ε_r=2.04).

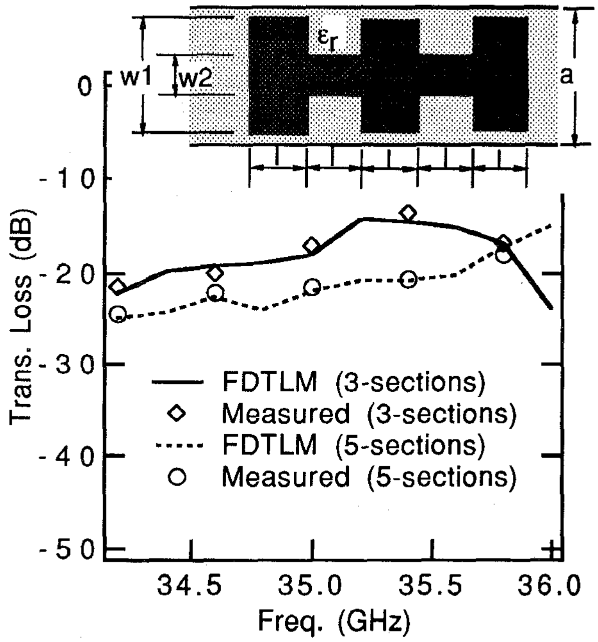


Fig. 3 Transmission loss characteristics of the LSE_{01} choke mode suppresor (a=4, w1=3.8, w2=1, b=l=1.5 mm, ε_r=2.04).

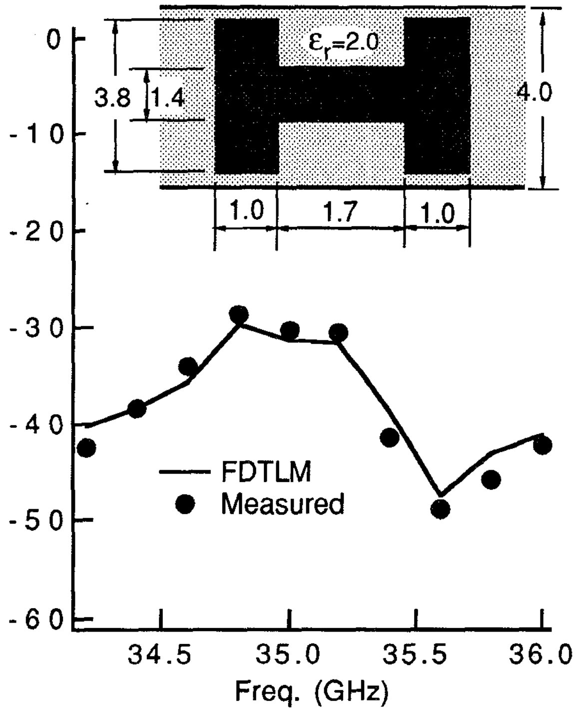


Fig. 5 Transmission loss characteristics of the LSE_{01} choke mode suppresor.

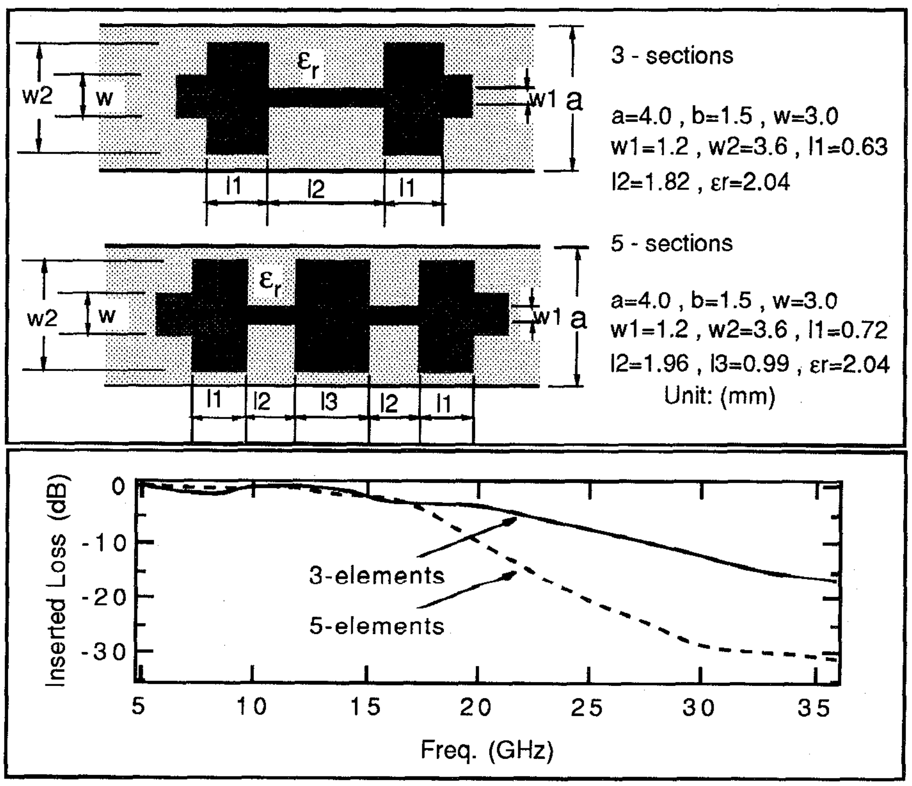


Fig. 4 Low-pass filter circuit layout and predicted frequency response.