DISCRETE SELF-SIMILAR WAVEGUIDES FOR THE DESIGN OF SELECTIVE MICROWAVE FILTERS

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ABSTRACT

The frequency response of self-similar waveguiding structures exhibits sharp transmission peaks inside high-attenuation frequency-bands. We take advantage of this property for designing selective microwave filters in metallic waveguide and in planar technologies. The role of descriptors (the similarity dimension, the lacunarity and the stage of growth) of such self-similar structures is investigated and it is shown that they are key design parameters. As modified periodic band-gaps structures, self-similar filters exhibit sharp peaks within forbidden frequency band-gaps. In planar technology, the self-similar distribution of step-discontinuity along the propagation axis may provide lower insertion loss than a periodic distribution.

1 - INTRODUCTION

Self-similar stratified media or *fractal superlattices* [1] present photonic band-gap structures and consequently, lead to the hope of many potential applications as, for example, the design of anti-reflective coatings and dielectric mirrors.

The research work reported here explores the frequency response of discrete self-similar (fractal) waveguides and investigates the design of microwave filters based on such multi-scale structures. Two configurations are considered here : (1) the self-similar distribution of dielectric slabs in metallic waveguides and, (2) the self-similar distribution of discontinuities along the propagation axis of planar transmission lines. We show that the transmission spectrum of these two configurations may exhibit sharp peaks within forbidden frequency band-gaps. We take advantage of this property for designing selective microwave filters. The similarity dimension, the lacunarity and the stage of growth of such self-similar waveguides are used as key parameters in the design. Numerical and experimental results are presented and discussed.

2 - SELF-SIMILAR METALLIC WAVEGUIDES : DESCRIPTION, RESULTS AND DISCUSSION

Self-similar stratified media inserted in a waveguide may be designed by alternating dielectric slabs (see Fig.1) of two different dielectric permittivities according to an iterative process [2]. The stage S of the process consists in N replica of one obtained at the previous stage $S - 1$, each replica being reduced by a given reduction factor ρ. As S tends to infinity, the similarity dimension D_S associated with the resulting discrete self-similar structure is then found to be $ln(N)/ln(1/\rho)$. Two self-similar structures, with the same dimension D_S, may differ from the size of the outermost slab (normalized to the total length L) at the first stage of growth. As suggested in [3] this geometric spacing provides a measure of the *lacunarity* of the structure. Thus, in addition to the fractal dimension D_S and stage of growth S, the lacunarity provides a third fractal descriptor of the studied self-similar waveguide.

As illustrative example, numerical results are given for a WR28 metallic waveguide filled with three-gap Cantor distribution at stage 3 of fused quartz slabs. Two self-similar structures, with the same similarity dimension are studied: a structure with a low lacunarity (Fig.2a) and, a structure with an high lacunarity (Fig.2b). The computation of the transmission coefficient of the TE_{10}-mode (in the monomodal frequency band) has been performed by using the iterative process recently reported in [4]. Sharp transmission peaks have been obtained in the attenuation band: they correspond to the second resonant frequency f_0 of the air-cavity located at the centre of the structure and may be controlled by adjusting the lacunarity of the self-similar waveguide. As seen in Fig. 3, this parameter has two major advantages: it allows (1) to adjust the transmission peak location and (2) to generate numerous peaks in high attenutation frequency bands.

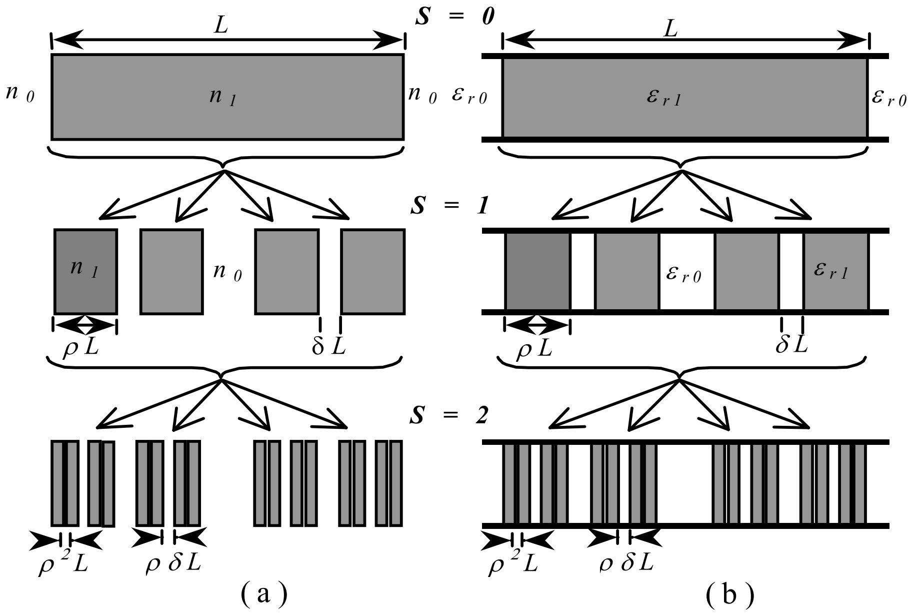

Fig. 1. (a) Generation of a polyadic Cantor set and (b) the resulting self-similar filter in waveguide technology (longitudinal view)

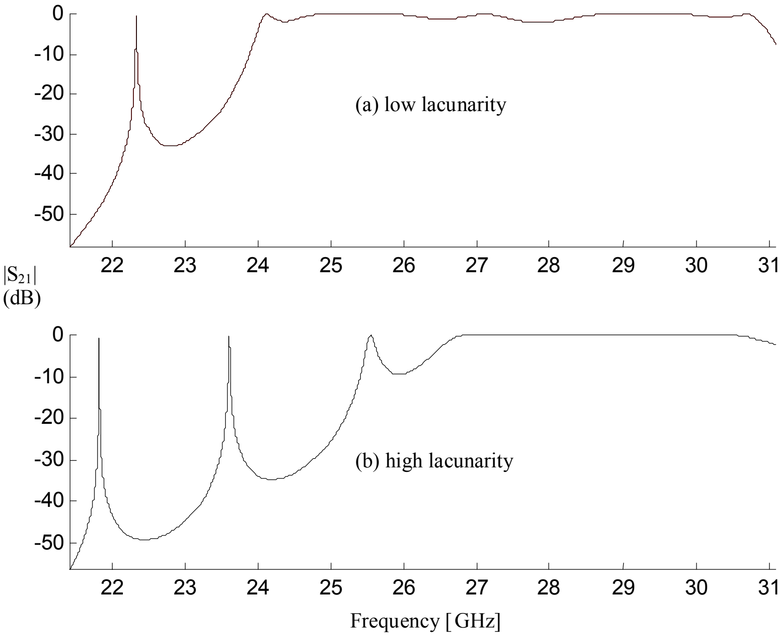

Fig. 2. Transmission coefficient of a WR28 waveguide filled with three-gap Cantor distribution ($N=4$, $\rho=1/6.85$, $S=3$) for (a) low lacunarity and (b) high lacunarity.

3 - SELF-SIMILAR PLANAR WAVEGUIDES : DESCRIPTION, RESULTS AND DISCUSSION

As an illustrative example, the Fig. 3 sketches the design of a self-similar planar structure for which step-discontinuities are located on a Cantor set (at a finite stage of growth) along a microstrip line. Microstrip technology is adopted in this paper but the proposed design has also been applied by the authors to other types of transmission lines (e.g., coplanar lines or slotlines). Step-discontinuities have been chosen here but other types of discontinuities (e.g., gaps, air bridges or via holes) could be investigated and advantageously exploited. Moreover, self-similar structures may be designed on the basis of a great variety of discrete self-similar (fractal) supports but Cantor sets are probably the most simple to handle in this context.

Results are given in the case of triadic Cantor planar waveguide ($\rho = 1/3$ and $N = 2$) at the second stage of growth ($S=2$), i.e. a transmission line presenting discontinuities that are located on a triadic Cantor set along the propagation axis. The characteristics of the dielectric substrate are the following : 10.4 of relative permittivity, $3\ 10^{-3}$ of loss tangent and a thickness of 1.4mm. The Fig. 4 displays the frequency response of this filtering structure. We have observed a large forbidden band-gap (between 2GHz and 5.5GHz) with a sharp transmission peak (at f_0=3.2GHz). This peak corresponds to the first resonance of the center cavity of the structure. And so, in the case of a Cantor triadic, it can be easily determine from the length of the structure (L_T), the reduction factor (ρ) and the effective dielectric constant (ε_{reff}) by the relation :

$$f_0 = \frac{c}{2L_T(1-2\rho)\sqrt{\varepsilon_{reff}}} \tag{1}$$

where c designates the free-space celerity of light.

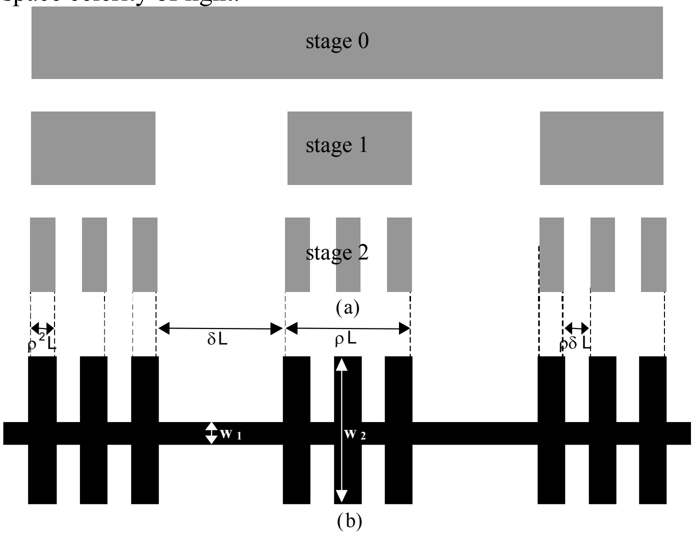

Fig. 3. (a) Generation of a triadic Cantor set and (b) the resulting self-similar filter in planar technology (longitudinal view)

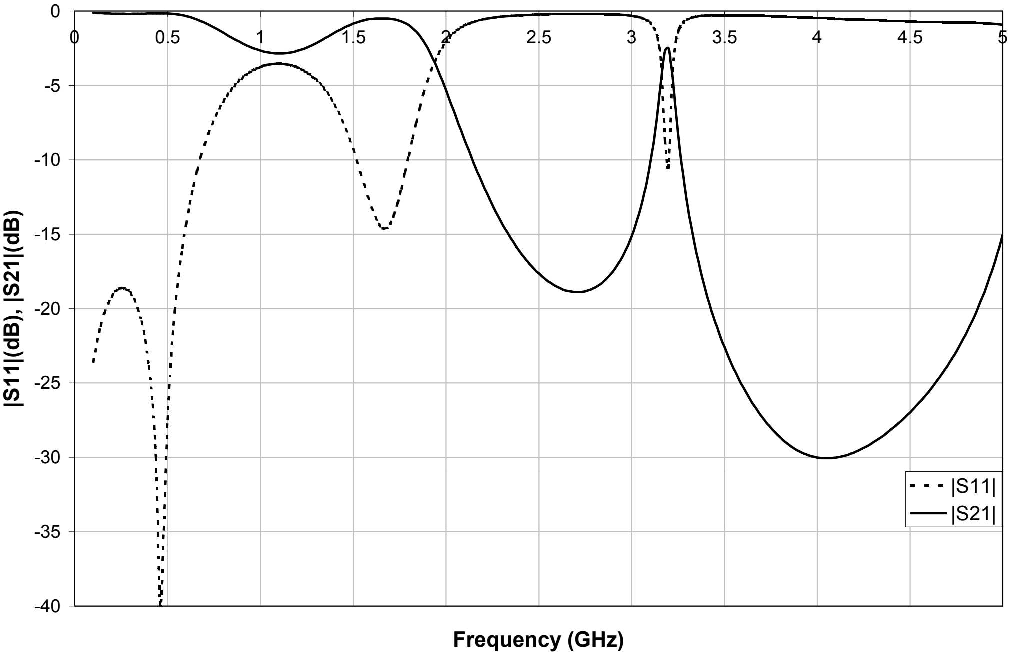

Fig. 4. Frequency response of a self-similar planar filter with N=2, ρ=1/3, S=2.

Next we have defined a lacunarity-related parameter in case of discrete self-similar planar waveguides (with N=3 and ρ=1/5) and the role of this parameter in the design of microwave selective filters has been investigated. We illustrate in Fig.5 the fact that this fractal descriptor may be used as a key design parameter for controlling the location of the transmission peaks in forbidden band-gaps. Experimental results confirm these predicted frequency responses and will be presented at the conference.

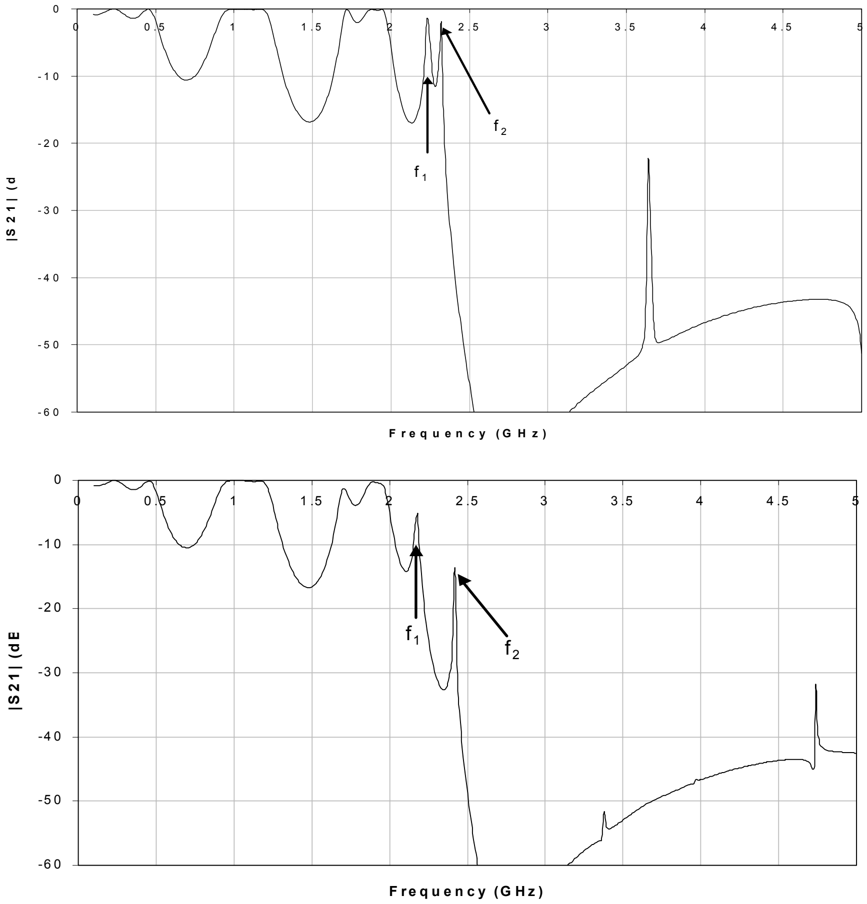

Fig. 5. Frequency responses of self-similar planar waveguides based on a Cantor set (N=3, ρ=1/5, S=2) for various lacunarities: (a) very low lacunarity and (b) medium lacunarity. Total length of the filtering structure : L_T=150mm.

4 - CONCLUSION

Two types of self-similar waveguides have been investigated: (1) a metallic waveguide filled with self-similar and lacunar multi-slab media and, (2) a planar line with discontinuities that are located on a discretely self-similar set along the propagation axis. The frequency response of these two configurations exhibits sharp transmission peaks inside high attenuation frequency bands. This property has been exploited with success for the design of selective microwave filters.

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