Analysis and Design of Multi-Slab Dielectric Cover for Patch Antennas Directivity Enhancement

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Abstract: Using symmetrical multi-slab dielectric cover, a patch antenna having directivity of 30 dB is developed. The design and optimization of the multi-slab structure is achieved using a doubly recursive algorithm. A novel interpretation for the antenna radiation pattern is presented based on the calculated transmission coefficient of the cover. The antenna including the cover structure is simulated using the moment method-based software tool IE3D.

Key-Words: transmission spectrum, self-similar structures, antenna directivity, Computer-Aided Design (CAD), radiation pattern.

1 Introduction
The spectral transmission characteristics of self-similar stratified media exhibit sharp transmission peaks in high attenuation frequency bands [1]. This property gives rise to many potential applications such as the design of photonic bandgap devices, frequency selective surfaces and selective microwave filters [2-5].

In this letter, self-similar stratified slab structures are used above a patch antenna to increase its directivity. A simple design procedure is proposed: to have a good physical insight, a simple two-dielectric slabs structure is first studied, then for an improved performance - with more design parameters - another structure is studied by adding more symmetrical dielectric slabs. Based on a doubly recursive algorithm [2], the transmission coefficient of the symmetrical multi-slab dielectric cover is calculated for different angles of incidences and their corresponding polarizations. Used as a cover for a patch antenna, the calculated transmission coefficient is then used – for the first time to the authors’ knowledge - to explain the radiation pattern of the overall antenna structure. An analogous structure to the studied one has been presented in [6] and experimental results have been reported. However it does not interpret the radiation characteristics nor can it lead to a synthesis procedure. It has been also demonstrated that the separation between slabs is a critical design parameter. Such multi-slab symmetrical structures with variable separations may be regarded as pre-fractals with variable lacunarities; thus by varying the fractal generator, stage of growth and especially the fractal lacunarity, the required transmission spectra could be achieved.

2 Spectral and Spatial Transmission Characteristics of Symmetrical Multi-Slab Dielectric Structures:

![Diagram](image)

Fig.1. Symmetrical dielectric cover structure:
(a) Two-dielectric slabs. (b) Four-dielectric slabs structure.

The symmetrical dielectric cover structures of Fig. 1 are regarded as a fractal superlattice of total length h that is composed of alternating layers of refractive indices \(n_1\) (\(n_1\) being the dielectric substrate refractive index) and \(n_0\), embedded in a medium with index \(n_o\) (for
By comparing the calculated results shown in Fig. 3, we note that the 3-dB beamwidth has been significantly narrowed from 20° (cover (1)) to about 6° (cover (2)). This narrow beam-width is consequently expected to achieve an increased directivity if the dielectric structure is illuminated by a broadside antenna which will be verified in the next section.

3 Design and Results:

Fig. 4. The overall physical structure of the simulated antennas: (a) Antenna (1), (b) Antenna (2).

Fig. 5 Simulated total field maximum and broadside directivities for antennas (1) and (2) compared to that of the simple patch antenna without cover.

In this section, the previously designed symmetrical multi-slab dielectric structures are applied as a cover for a patch antenna. A computer-aided design (CAD) is carried out by an optimization program applying the calculated transmission coefficient for the cover. This optimization program varies the cover parameters ($\varepsilon_r$, $t$, $h$ and the air-gap width(s)) until the desired transmission characteristics for a given bandwidth and direction are obtained.

The antenna, including the optimized cover structure, is then simulated using the full-wave, MoM based IE3D simulator [7]. Experimental validation results for similar structures have been previously reported [6]. Both of the previously discussed cover structures have been used in the simulation. The
dielectric loss (\(\tan \delta = 0.00013\)) and the conductor losses have been taken into account in the simulation. The whole simulated antenna structure is composed of the patch antenna and the upper half of the cover structure (placed at a distance \(h_1/2\)) [6], as presented in Fig. 4 (a) and (b), the antenna applying cover (1) is referred to by antenna (1) and that applying cover (2) is referred to by antenna (2). Both antennas are probe-fed and have a 2.7 mm thick air substrate and designed to operate at 2.4 GHz.

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Fig. 5 shows the simulated total field directivity versus frequency in the broadside direction as well as the maximum total field directivity for both antennas (1) and (2) in addition to the simple un-covered patch antenna. For the antenna (1), there is a great agreement between the electromagnetic simulation results and the calculated transmission coefficient of cover (1), as the maximum broadside directivity is at 2.4 GHz. It can be seen that the antenna total broadside directivity has been doubled at the desired design frequency. The same agreement applies for the simulated results for the antenna (2) and the calculated transmission characteristics of the corresponding cover of Fig. 2 (b). The parameters of the cover (2) structure used are those of Fig. 2 (b) with \(h_2 = 12.1\) mm to have a broadside transmission peak at 2.4 GHz. From Fig. 5, for antenna (2) it can be seen that the antenna total broadside directivity has been doubled over the frequency range from 2.3 GHz to 2.45 GHz achieving a 6.25% broadside directivity bandwidth defined by 20 dBi with its maximum at 2.4 GHz, where the directivity value has been almost tripled (about 31 dBi) compared to that of the simple un-covered probe-fed patch antenna (9.7 dBi).

Fig. 6 (a) and (b) show the radiation patterns of both antennas (1) and (2), compared to the reference uncovered one in both E and H planes at 2.4 GHz. The simulated covered antenna radiation efficiency is almost 100 % at 2.4 GHz. By comparing Fig. 3 with the radiation patterns of Fig. 6, great agreement between the calculated transmission characteristics and the simulated radiation patterns is clearly verified. The simulated 3-dB beamwidths for both antennas (1) and (2) agrees with the previously discussed calculated ones of the corresponding covers in Fig. 3 which explains the increased directivity of antenna (2) compared to antenna (1).

This agreement between calculated and simulated results allows us to interpret the spatial power distribution within the radiation pattern for the multi-slab dielectric covered antenna structures. The power radiation is normally forbidden in the spatial transmission gaps and then is re-distributed according to the directions of the transmission maxima and their relative bandwidths to each other; this latter parameter governs the relative directivities at each radiation lobe at the corresponding transmission maximum for the same frequency.

In other words, the new radiation pattern of the covered antenna is mapped to its spatial transmission maxima and has relative directivities related to the relative bandwidths of these maxima. Consequently, for a given frequency, if the spatial transmission coefficient has a very narrow transmission peak as compared to the other one, no radiation in the direction corresponding to that peak will occur.

4 Conclusion

The direct correlation between the radiation pattern of dielectric, symmetrical superlattice covered patch antennas and the calculated spectral and spatial transmission spectra for the superlattice cover structure allows an optimized, accurate, computer-based synthesis for highly directive patch antennas. The cover structure is first studied analytically and optimized using CAD program then the whole antenna structure is simulated for validation.

References: