Matching Layer Design Procedure for a Novel Broadband Dielectric Lens Antenna

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ABSTRACT

Dielectric lens antennas fabricated with a dense dielectric material allows good power transfer efficiency through the lens and improves the front to back radiation ratio of the antenna. On the other hand, using dense dielectric material in fabrication of a dielectric lens antenna causes deterioration in the radiation properties of the antenna. These undesirable effects due to the internal reflections can be reduced using matching layers (ML) at the top of the antenna. In this work, a quarter wavelength ML design procedure for a novel ultra wide band (UWB) dielectric lens antenna is proposed. It is exhibited that the lateral wave antenna concept promises impedance matching over factor one to three bandwidth, very high efficiency, and high directivity in one plane thanks to the appropriate MLs coated to the top of the antenna. The radiation patterns of the antenna are simulated using the software computer simulation technology (CST). The simulation results verify that MLs designed by quarter-wavelength matching technique improves the radiation characteristics of an UWB antenna significantly.

KEYWORDS

Dielectric lens antennas, UWB antennas, matching layer, high directivity, quarter-wavelength matching.

1 PAPER PREPARATION

In the last decades there has been increasing interest in dielectric lens antennas [1-3]. More recently [4] has shown innovative planar implementations of dielectric lens antennas could be used, even if over relatively narrow frequency ranges. In dielectric lens antenna applications, the relative permittivity of the lens material should be chosen carefully, since the materials having low dielectric contrast and high dielectric contrast with free space have distinctive influences on the radiation characteristics of the antenna. Dielectric lens antennas fabricated with a dense dielectric material allows good power transfer efficiency through the lens and improves the front to back radiation ratio of the antenna. On the other hand, using dense dielectric material in fabrication of a dielectric lens antenna causes deterioration in the radiation properties of the antenna.

Typically, when the relative permittivity of the selected lens material is higher than three, considerable amount of internal reflections occur at the dielectric-air interface [5]. The amount of internal reflections due to the dielectric contrast with free space, increase dramatically with the increment of dielectric contrast. In Figure 1, the transmitted power amount of four different materials from dielectric-air interface is demonstrated with the purpose of emphasizing the influence of selected lens material on forming strong internal reflections. Here, the lens materials are selected as Teflon $(\varepsilon_r = 2.25)$, Macor $(\varepsilon_r = 6)$, Alumina $(\varepsilon_r = 8.5)$ and Silicon $(\varepsilon_r = 11)$.

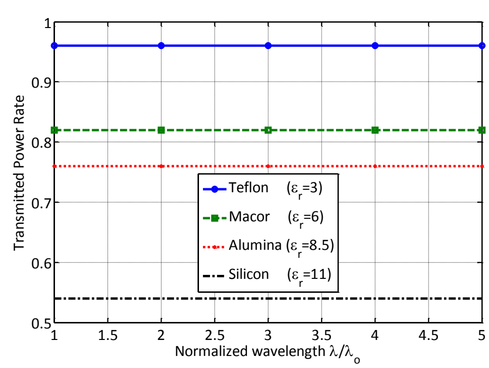
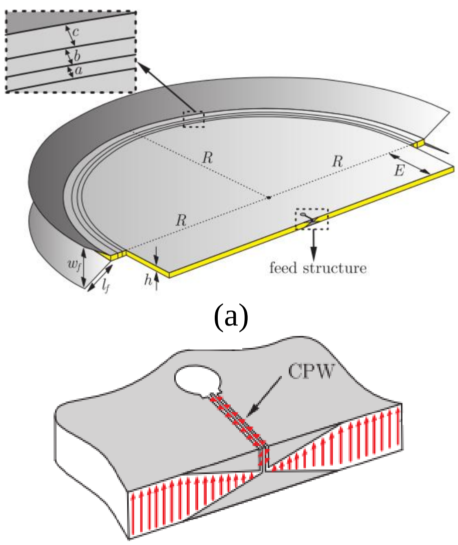


Figure 1. Transmitted power rate as a function of normalized wavelength λ / λ_0 for four different dielectric materials.

Fig. 1 shows the transmitted power amounts from dielectric-air interface which are 0.96, 0.82, 0.76 and 0.54 for the materials Teflon, Macor, Alumina and Silicon, respectively. According to these transmitted values, it is clear that when Silicon is used as the lens material, 46% of the incident power will be reflected from the interface and consequently, strong internal reflections of order two or more will occur.

In [5], a ML design procedure based on quarter-wavelength matching is described for narrow band lens antennas. The MLs are coated to the top of the antenna and the authors observed that applying MLs improves not only the return loss but also the radiation characteristics of a narrow band lens antenna.

A novel dielectric lens antenna capable of radiating with phase centers that is stable over a wide frequency range is presented in [6]. The planar UWB dielectric lens antenna concept promises impedance matching over factor a one to three bandwidth, very high efficiency, and high directivity in one plane. The antenna is composed by a slab of dense dielectric bounded by a parallel plate waveguide as given in Figure 1.



(a)

(b)

Figure 2. Geometry of the (a) antenna and (b) feeding.

In this work, the appropriate ML design for the planar dielectric lens antenna [6] is introduced. The design procedure is based on quarter-wavelength matching method and the necessity of using MLs at the top of the lens is explained in details. The radiation patterns of the lens antenna for without ML, with one ML, two MLs and three MLs cases are represented in order to demonstrate the role of MLs on the radiation characteristics of the antenna. The radiation patterns of the antenna are simulated using the software CST [7].

2 THE LATERAL WAVE ANTENNA CONCEPT

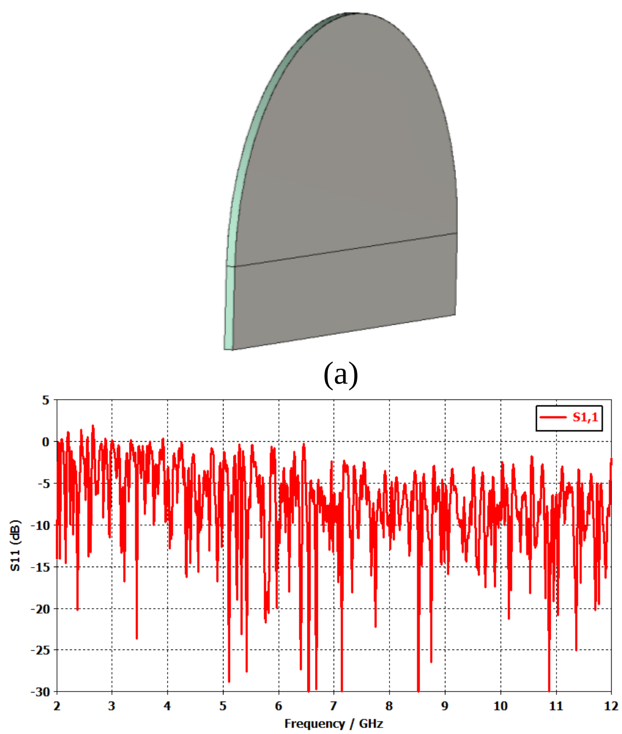
The geometry under investigation, presented in Figure 1(a) and (b) consist of two perfectly conducting planar waveguides in the *z*-direction that sandwich a homogeneous dielectric of permittivity ε_{r2}(z>0). The permittivity of the medium under the waveguides is ε_{r1} (z<0) and without loss of generality, we assume that $\varepsilon_{r2} > \varepsilon_{r1}$. The separation between the perfectly conducting planar waveguides is indicated as w_s which is uniform in *x*. The antenna is excited by a *y*-oriented electric dipole also of length w_s, placed at the origin of the reference system. The eccentricity *e* of the ellipse that focuses in broadside part of the rays emerging from the lower focus is defined by the dielectric constant of the lens, $e = 1/\sqrt{\varepsilon_r}$.

The dielectric constant of the lens was chosen as $\varepsilon_r = 9.8$. The elliptical shape of the lens was synthesized as the union of a hemi cylinder of diameter *D* = 25*cm*, and a rectangular dielectric slab base of height $b = D/2\sqrt{\varepsilon_r}$,in the present case *b*=*4.375cm* and width $w_s = 5\,mm$. For the UWB matching of the antenna, a flaring having length of *l* = 20*mm* and height of *h* = 17.5*mm* is added to the termination of the matching layers which can be in Figure 2(a). Three matching layers are used to diminish the reflections from the dielectric-air interface. The design procedure of the matching layers and the influences of the number of MLs on the return loss and the radiation characteristics of the antenna are given in the application examples section.

3 MATCHING LAYER DESIGN

In order to reduce internal reflections significantly and consequently, enlarge the operating frequency band and also improve the radiation characteristics appropriate MLs has to be designed for antennas having dense dielectric material. One of the ML design method is the using quarter-wavelength matching structure. This method for ML design is verified for narrow band antenna applications in [5]. Here, a similar ML design procedure will be followed, but this time for an UWB application.

A dense dielectric material, $\varepsilon_{c1} = 9.8$ is chosen as lens material of the lateral wave antenna [6]. As mentioned before, more than 25% of the power will be reflected from the dielectric-air interface if the permittivity of the material is higher than 9 ($\varepsilon_c \geq 9$). The aim was to design a high gain UWB dielectric lens antenna operating between 4-12 GHz frequencies. As the first step, the antenna structure in Figure 3(a) is designed; the return loss variation of the structure is given in Figure 3(b). It is clear from s_{11} variation that due to the strong internal reflections, the antenna cannot be used in the desired frequency band.

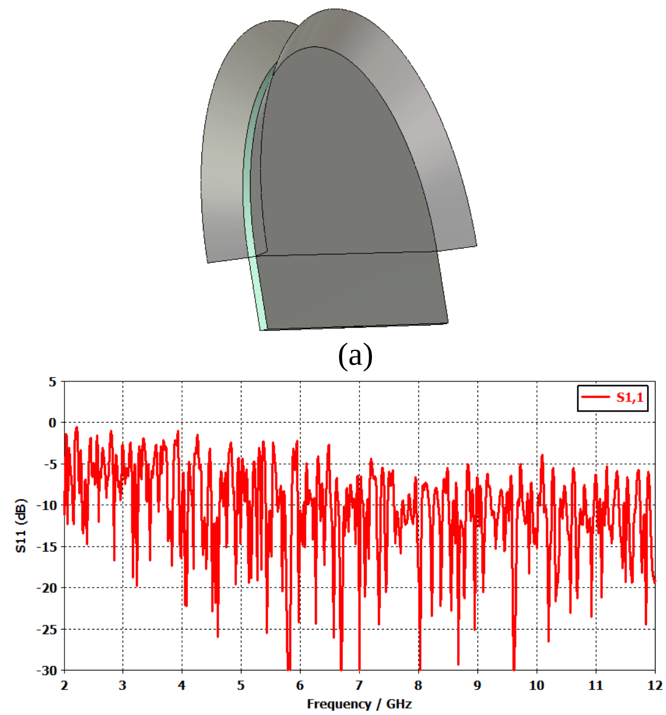


(a)

(b)

Figure 3. The antenna without ML and flaring part (a) geometry, (b) return loss.

As the second step, in order to facilitate the radiation into free space, a short metallic flaring is added to the antenna. The structure with the flaring is given in Figure 4(a) and the return loss variation of the antenna is given in 4(b), respectively. According to Figure 4(b), adding a flaring part at the top of the antenna didn't improve return loss amount alone.



(a)

(b)

Figure 4. The antenna with flaring without MLs (a) geometry, (b) return loss.

Thus, three different cases are investigated: one ML case, two MLs case and three MLs case. These MLs are designed with quarter-wavelength matching technique using equations (1.a) and (1.b).

$$h_{ML} = \lambda_c / 4 \qquad (1.a)$$

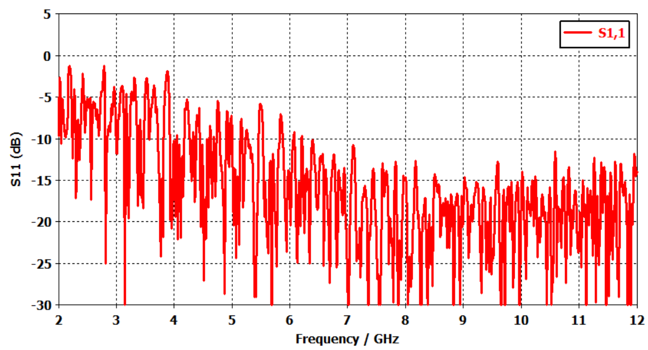
$$\varepsilon_{r2} = \sqrt{\varepsilon_{r1} . \varepsilon_{r3}} \qquad (1.b)$$

where, h_{ML} is the thickness of the ML and λ_c is the wavelength inside the dielectric material. Relative permittivity values of the materials can be calculated using (1.b). Using the above given equations, thickness and relative permittivity values for all three cases are calculated, and listed in Table 1.

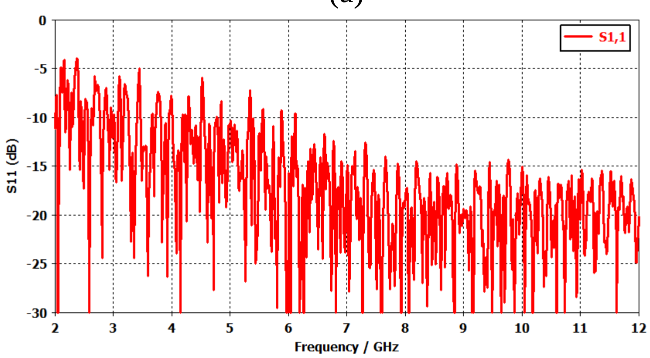
Table 1. Relative permittivity and thickness values of Optimized MLs.

Single ML	Double MLs	Triple MLs
$\varepsilon_1 = 3.13, h_1 = 5.29mm$	$\varepsilon_1 = 4.58, h_1 = 4.38mm$ $\varepsilon_2 = 2.14, h_2 = 6.4mm$	$\varepsilon_1 = 5.54, h_1 = 3.98mm$ $\varepsilon_2 = 3.13, h_2 = 5.29mm$ $\varepsilon_3 = 1.77, h_3 = 7.04mm$

Three antenna configurations are prepared according to Table 1. The first antenna has one ML, the second one has two MLs and the third one has three MLs; all antennas have the flaring part to facilitate the radiation into free space. The return loss variations of the antennas with frequency are exhibited in Figure 5.



(a)



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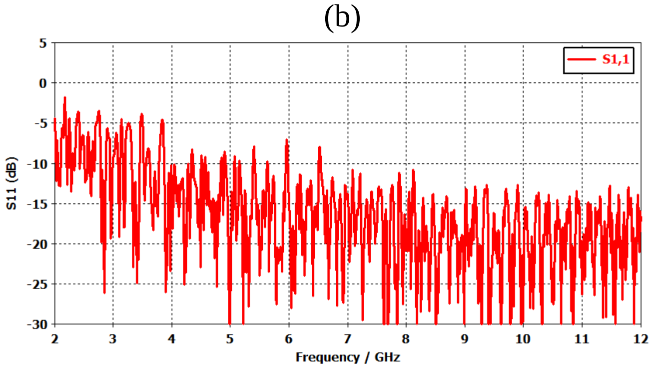


(c)

Figure 5. Return loss variation of the antennas having (a) 1 ML, (b) 2 MLs and (c) 3 MLs.

When Figure 5 is investigated, it can be concluded that the antenna having one ML can operate between 6-12 GHz frequencies effectively. For the two MLs case the operating frequency is extended to 5-12 GHz frequency band which is not wide enough to satisfy the design goal. According to Figure 5(c), the operation frequency band of the antenna having three MLs satisfies the aim of the design. Thus, this antenna structure, corresponds to Figure 2(a), is accepted as the best one. To exhibit also the influence of number of matching layers on the radiation characteristics of an antenna, the directivity values of each case is given as follows:

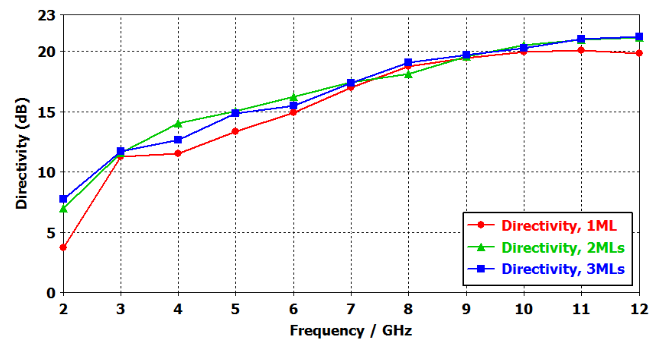
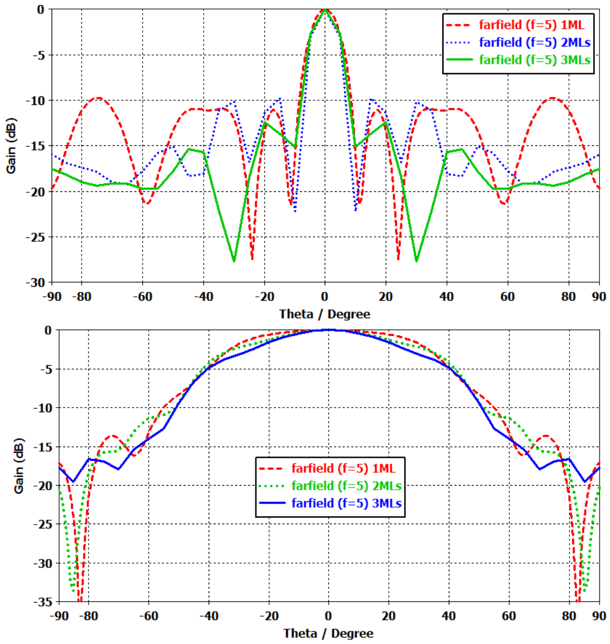


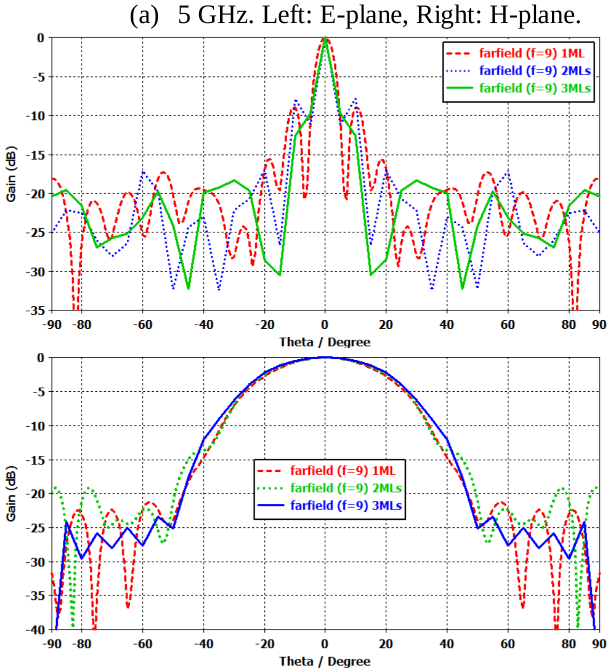
Figure 6. Directivity values of dielectric lens antenna having (a)1 ML, (b) 2 MLs, and (c) 3 MLs.

The directivity value of the antenna having one ML is a few lower than the other cases as given in Figure 6, especially at 4 and 5 GHz frequencies. For the other two cases, it can be concluded that the directivity values slightly differs from each other.

In Figure 7, the influence of the number of MLs upon the radiation characteristics of an UWB dielectric lens antenna are highlighted at 5 and 9 GHz frequencies in both principal planes. For all cases, side lobe levels (SLL) of the patterns are in a reasonable range. Neverheless, it can be concluded that the antenna structure having three MLs have superior radiation characteristics than the other cases, especially in terms of SLL.



(a) 5 GHz. Left: E-plane, Right: H-plane.



(b) 9 GHz. Left: E-plane, Right: H-plane.

Figure 7. Influence of the number of MLs upon the UWB dielectric lens antenna radiation patterns in E and H planes (a) 5 GHz; (b) 9 GHz.

4 CONCLUSIONS

In this work, a quarter wavelength ML design procedure for a novel ultra UWB dielectric lens antenna is proposed. It is exhibited that the lateral wave antenna concept promises impedance matching over factor one to three bandwidth, very high efficiency, and high directivity in one plane thanks to the appropriate MLs coated to the top of the antenna. Three different cases are considered; single ML, double ML and triple ML case. According to the return loss variation of the antennas an acceptable return loss value is achieved using three MLs at top of the antenna. The radiation pattern characteristics of all cases are also investigated. Although the directivity values and radiation pattern characteristics such as SLL and half-power beam with are quite good for all cases, triple ML case has superior radiation characteristics. Nevertheless, relative permittivity values of the materials evaluated using quarter-wavelength matching technique may not be realistic for practical applications. Because these materials having the calculated relative permittivities possibly will not be commercially exist.

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