Compact Planar Dielectric Disk Antennas for X- and KU- Bands

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Abstract. The influence of edge effects on the characteristics of the dielectric disk antenna is investigated. The regularity in beamforming is determined depending on the geometrical and electrical parameters of antenna. Two modes of antenna operation are analyzed. It is shown that the antenna can produce both the multi-beam and mono-beam radiation pattern. The number of antenna prototypes overlapping X- and KU bands are manufactured and tested.

1. Introduction

The major disadvantage of microstrip circular disk antennas is their narrow bandwidth. One of the approaches to overcome this problem is replacing the metal patch with a dielectric disk of low-loss, high-dielectric material [1]. It has already been shown that thin-disk dielectric patch antennas may possess radiation characteristics substantially different from those of conventional metal patches [2, 3]. Here, in the strict problem formulation the radiation pattern of such the antenna with an infinite ground plane under resonance conditions is omni-directional in the horizontal plane while in the vertical plane antenna produces no field along zenith direction. However, the experimental investigations point out that in practice the finite ground plane availability is a reason of visible transformations in the radiation pattern shape which became multi-beam one [4]. Nowadays, there is a need and practical interest in designing high efficiency and low cost planar antennas with mono-beam radiation pattern for various RF wireless communication applications at higher frequencies. In this paper, we establish the regularity in correlation of geometrical and electrical parameters of the dielectric disk antenna (DDA) with radiation characteristics to create the compact planar DDA for X- and K_U-bands.

2. Antenna Design

DDA under studying consists of the dielectric disk (0.5mm of thickness) having the relative permittivity ε_d=90 and radius a. The disk of the radius a is located above the grounded substrate with different relative permittivity ε_s and radius R (Fig. 1).

In experiments the axial-symmetrical excitation is realized by a 50-Ohm coaxial feed placed strongly at the antenna center. In accordance with [1, 2] the geometrical and electrical parameters of DDA are chosen to excite the necessary TM mode in the structure. The measurements were carried out on the experimental stands allowing the recording of the near-fields in the inductive region of antenna, as well as radiation patterns and return loss data [5].

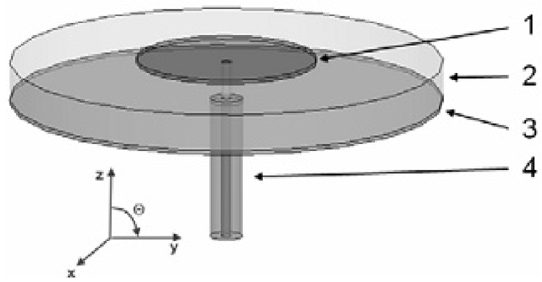


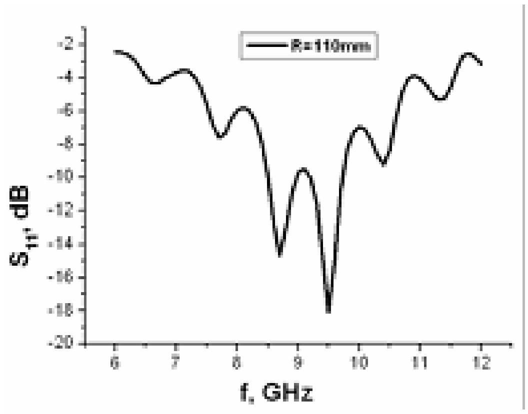
Fig. 1. Schematic view of the DDA: 1 – dielectric disk; 2 – substrate; 3 – ground plane; 4 - coaxial feed.

3. Results and Discussion

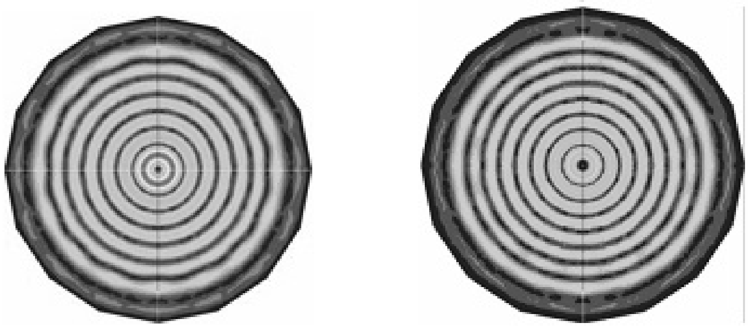
In accordance with theoretical calculations [1, 2] the ratio between the dielectric disk radius and substrate height of DDA for the infinite polystyrene substrate (ε_s=2.04) was selected to excite necessary TM modes in the structure. On the basis of experimental results the antenna with substrate radius R=110 mm operates in the multi-frequency mode (Fig. 2a). In particular, the analysis of near-fields in the inductive region of DDA pointed out the two possible modes of antenna operation, namely: (i) the "disk resonator mode" (Fig. 2b) and (ii) the "spatial diffraction lattice mode" (Fig. 2c). As one sees from these pictures, one has the visible field concentration close to the disk surface for the first mode of operation (Fig. 2b). Note that just such complete near-field distributions determine the multi-beam radiation in the far-zone [4].

We have also determined that the substrate size reduction gives rise to reducing the number of lobes, resonance frequencies, and interference circus in the near field. Moreover, the decreasing of power loss in this case leads to the antenna efficiency increasing. At the same time, the antenna bandwidth decreases due to increasing of the working mode Q-factor. The subsequent investigations pointed out the existence of the thresholds in the grounded substrate dimensions corresponding to the transition from the multi-beam radiation pattern to the mono-beam one. For example, the aforementioned transition for antenna under study is observed for the ratio of dielectric disk and grounded substrate radii more than 3.6. The DDA characteristics for R=15mm is shown in Fig. 3.

With the aim to improve the antenna performance, the substrate with low permittivity (ε_s=1.07) has been employed. It has been not a surprise because for such the antenna design the power losses associated with the dielectric substrate modes excitation are minimized. Just the near-field distributions in the inductive region of antennas illustrate the aforementioned statement. The near-field distributions of DDA with a foam substrate are shown in Fig. 4 for different substrate dimensions.

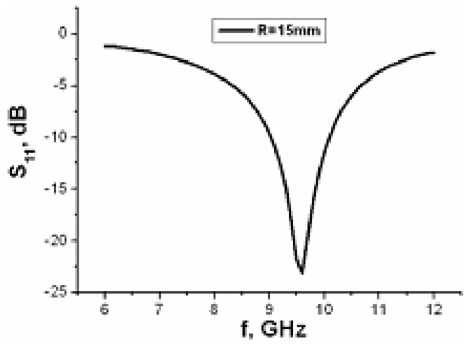


a)



b) c)

Fig. 2. Input return loss (a) and near-fields of DDA with the grounded polystyrene substrate of radius R=110mm and disk radius a=12.5mm at f=8.7GHz (b) and f=9.5GHz (c), respectively.



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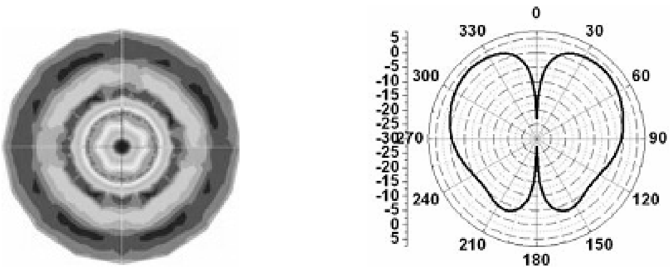
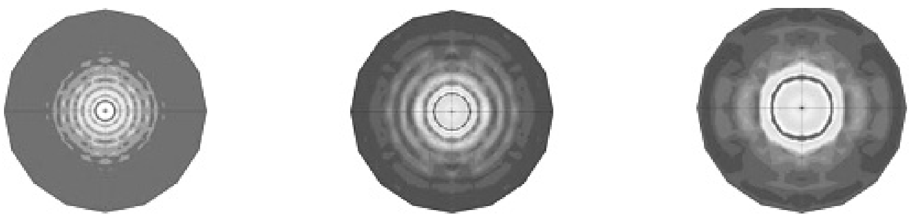


Fig. 3. Input return loss (a), near-field (b), and radiation pattern (c) of the DDA with the grounded polystyrene substrate of radius R=15mm and disk radius a=12.5mm at f=9.6GHz.



a) b) c)

Fig. 4. Near-field distributions of the DDA with a foam substrate: R=110mm r_d=12.5mm, h=1mm, f=14GHz (a); R=45mm, r_d=12.5mm, h=1.25mm, f=14.5GHz (b); R=15mm, r_d =12.5mm, h=1.25mm, f=14.4GHz (c).

As can be seen from these distributions the antenna operation corresponds to the “disk resonator mode”. By reducing the substrate radius, the number of interference circles decreases and for the DDA with R=15mm the interference picture vanishes virtually. The corresponding radiation patterns are shown in Fig. 5. We can observe the mono-beam radiation pattern in the broadside direction of the DDA and power radiation increasing in the backside direction.

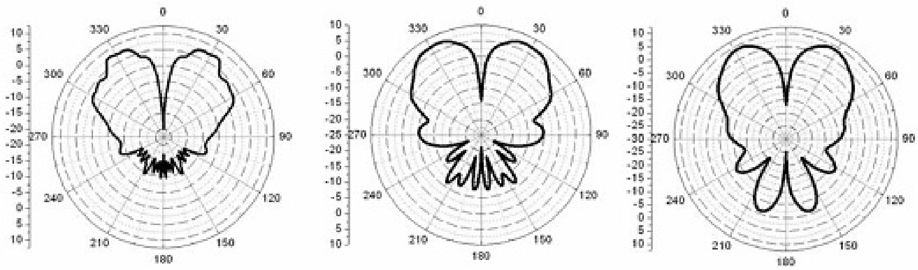


Fig. 5. Radiation patterns of the DDA: R=110mm rd=12.5mm, h=1mm, f=14GHz (a); R=45mm, r_d=12.5mm, h=1.25mm, f=14.5GHz (b); R=15mm, rd=12.5mm, h=1.25mm, f=14.4GHz (c).

As a result of the comprehensive investigations the effect of disk and substrate radii, as well as the substrate height on such antenna characteristics as the resonance frequency, radiation pattern, bandwidth and efficiency has been analyzed. For example, the resonance frequency of the DDA with the fixed grounded substrate size moves toward higher frequencies when reducing the dielectric disk radius (see Fig. 6). In this case, the impedance bandwidth and efficiency of the antenna increases.

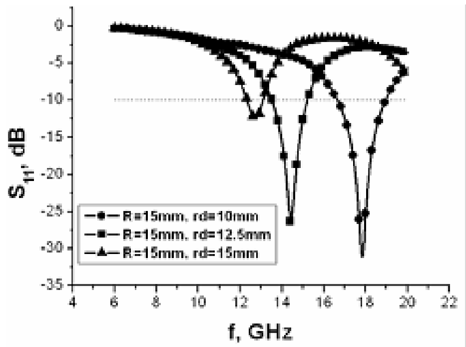


Fig. 6. Input return loss of the DDA versus the dielectric disk radius.

Fig. 7. Antenna prototype.

Based on the results noted above the number of compact antenna prototypes have been manufactured and tested. The measured antenna characteristics are in good agreement with simulations. These antennas demonstrate the mono-beam radiation pattern in the impedance bandwidth and overlap the frequency range 8 – 20GHz. The photo of antenna prototypes is shown in Fig. 7.

4. Conclusions

The finite grounded substrate of dielectric disk antennas with the ratio of dielectric disk and grounded substrate radii more than 3.6 and relative substrate permittivity more than 2 leads to the multi-frequency mode of operation and multi-beam radiation pattern. Based on the analysis of field distributions in the inductive region of antennas under study it has been shown that two types of operation modes with close frequencies called as “disk resonator mode” and “spatial diffraction lattice mode” can be realized. For both cases the spatial field distribution along the grounded substrate radius appears to be similar to the divergent interference circles, but for the “disk resonator mode” the field is concentrated close to the disk surface. The effect of geometrical and electrical parameters of antenna on its characteristics has been analyzed. The compact antenna prototypes producing the mono-beam radiation pattern in the impedance bandwidth no worse than 12% for the frequency range 8 – 20GHz have been manufactured and tested.

References

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