Broadbeam microstrip patch antenna using higher order modes

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***Abstract*—The aim of this contribution is to assess the potential of using various microstrip radiating elements excited with different modes to achieve wide pattern beamwidths. The proposed antenna is made in classic microstrip technology and consists of a circular disk and a ring. The two radiating elements are excited for the TM10 and TM31 modes, respectively. Only the disk is fed, and the ring is connected to the disk through a microstrip line.**

The proposed antenna is matched at the 2.4GHz industrial, scientific and medical band (ISM) and exhibits a bandwidth of 120MHz. The combination of the two radiating elements achieves a 3dB beamwidth of 160 degrees. The maximum gain is 5.7dBi.

***Index Terms*— Microstrip antenna, higher order mode, wide beam antenna**

I. Introduction

Wide beam antennas are suitable for on-body or satellite applications and have been broadly studied in the literature [1]–[4]. For scenarios where the antenna is expected to radiate only in one hemisphere of the space, widebeam antennas can provide higher gains than a monopole or a dipole with omnidirectional patterns. This is useful for scenarios where the communication is established in one hemisphere, like antennas placed on walls, for instance.

Patch antennas are widely used due to their fabrication simplicity, versatility, and cheap manufacturing costs. The radiation pattern of these antennas exhibit its maximum gain in the direction perpendicular to their surface. Their intrinsic beamwidth when operating at their fundamental mode ranges between $70 - 90°$ [5], providing a medium gain. However, one can find in the literature several antennas which take advantage of exciting higher order modes on microstrip antennas to get broadside monopole-like radiation patterns [6]–[8].

Additionally, there are studies conducted on extending the beamwidth of microstrip antennas. For example, in [9] a 3D ground structure is used to modify the behavior of the fringing fields. However, these solutions are not convenient when a low profile is crucial.

In this contribution, we explore the potential of using various modes in a single radiating element to widen the beamwidth of microstrip antennas. We propose a single layer microstrip antenna, which consists of a circular disk and a ring. The principle of this antenna is to excite mode TM10 in the disk and mode TM31 in the ring. The combination of the different radiation patterns of these two modes leads to a 3dB beamwidth of 160 degrees. The impedance match bandwidth covers the 2.4GHz ISM band, with a reflection coefficient lower than -10dB over the entire band.

II. Antenna design

The antenna consists of a microstrip antenna made of a disk surrounded by a ring placed on a square dielectric slab over a circular ground plane. The shape of the dielectric has been selected in order to simplify the manufacture process, while circular ground plane and antenna will ensure that the fringing fields between the antenna and the ground are symmetric. The substrate used has a relative permittivity of 2.2 and a loss angle of 0.0009 and a thickness of 6.35mm.

The antenna is fed by a coaxial probe connected to the disk. A short line connects the ring to the disk. The geometry is depicted in Figure 1.

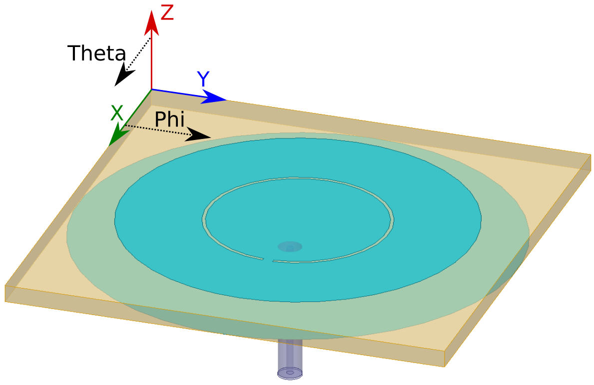


Fig. 1: Antenna 3D geometry.

The key parameters of the antenna geometry are the width of the ring, $ring_w$, the diameter of the disk, $disk_{diam}$, the width of the slot separating between them, gap_w, and the width of the line which connects the disk and the ring, $strip_w$. All these dimensions are depicted in the Figure 2.

To efficiently combine the radiation pattern of the disk and the ring, they should have dimensions such that the desired modes (TM10 for the disk and TM31 for the ring) should occur in the center of our frequency band of interest. The parameters used to tune the resonances of each, are $disk_{diam}$, $ring_w$ and $strip_w$. These are set to 52mm, 24.5mm and 3mm, respectively. The parameter $strip_w$ is crucial for the tuning of the resonances, since it controls the coupling between the

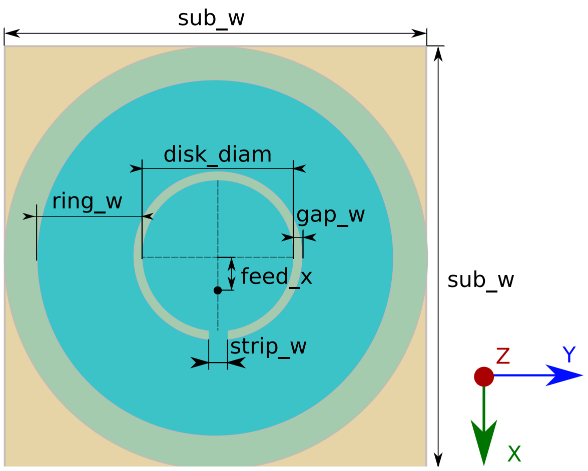


Fig. 2: Top view of antenna geometry.

disk and the patch. Another parameter to account for during the design is gap_w, which value is set to 1mm. A large value of gap_w leads to a small value of $ring_w$, which in turn would need to be increased in order to maintain the resonance at the same frequency. This would increase the overall size of the antenna. The parameter sub_w defines the size of the substrate and is set to 130mm.

The minimum circumference of the ring is limited by $disk_{diam}$, and therefore the minimum order of the mode that we can excite in the ring for the selected geometry is the TM31. The current distributions of the modes TM10 and TM31 are depicted in Figure 3.

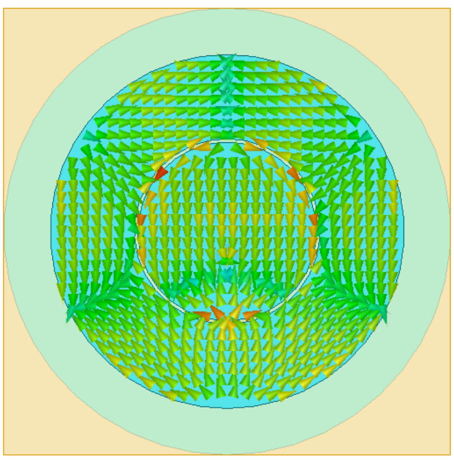


Fig. 3: Current distribution of antenna at 2.45GHz.

III. Results

A. Simulation of proposed antenna

The designed antenna is matched from 2.39 GHz to 2.51 GHz, having a bandwidth of 120 MHz. One can see in Figure 4 that the resonances of the disk and the ring collapse to a single one since they occur at very close frequencies. A larger separation between resonances becomes would lead to different radiation patterns at the lowest and highest frequency of the band. This is due to the unbalance between the contribution of the two radiating elements at these extreme frequencies.

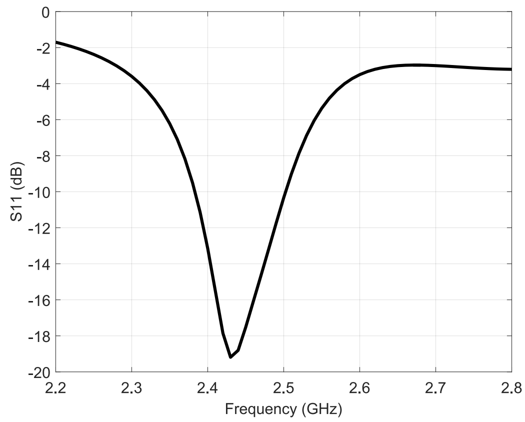


Fig. 4: Reflection coefficient

The radiation pattern of the disk patch antenna has its peak gain on the Z axis. On the other hand, the ring generates a monopole-like radiation pattern which has its peak gain in the XY plane and is zero along the Z axis. These two patterns combined, result in a substantial increase of the beamwidth when compared to a single patch antenna, as can be seen in Figure 5. The 3dB beamwidth and peak gains for different frequencies are gathered in the Table I.

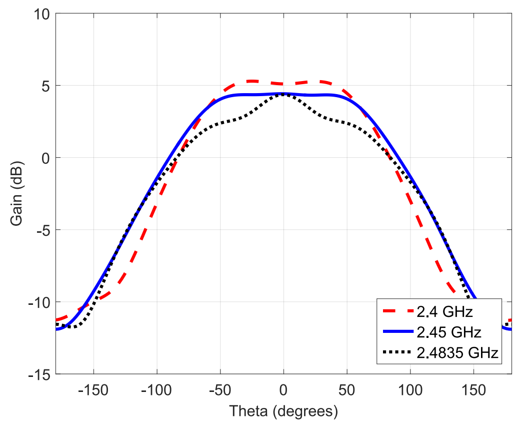


Fig. 5: Radiation pattern YZ cuts for the lowest, center, and highest frequency of the 2.4GHz ISM band.

Due to the circular symmetry of the antenna geometry, the beamwidth not only increases in the plane YZ but also in the XZ plane, as shown in Figure 8. The 3dB beamwidth and peak gains for the XZ pattern cut are gathered and in the Table I.

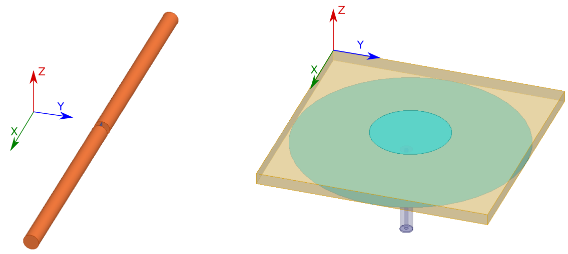
B. Comparison with canonical and state-of-the-art antennas

In order to better understand the advantages of the proposed antenna in terms of beamwidth and gain, we compare it with a resonant dipole and a single disk patch antenna.

TABLE I: 3dB beamwidth and peak gain for YZ and XZ pattern cuts for various frequencies.

Freq (GHz)	3dB beamwidth (deg)		Peak gain (dBi)	
	YZ cut	XZ cut	YZ cut	XZ cut
2.4	138	102	5.3	5.7
2.45	159	115	4.4	5.2
2.4835	139	129	4.4	5.6

These antennas are broadly used and studied and serve as examples of omnidirectional and directional radiation patterns. We implement a $\lambda/2$ dipole and a disk patch which uses the same substrate and ground than the proposed antenna, as seen in Figure 6.



(a) (b)

Fig. 6: Canonical dipole (a) and patch (b).

In the Figure 7, we can see that the proposed antenna has lower gain and broader beamwidth than the patch antenna for the YZ pattern cut. The gain is higher and the beamwidth smaller if we compare with the dipole.

The comparison of XZ pattern cuts is depicted in Figure 8. In that case, the beamwidth of the dipole is close to that of the patch, while the proposed antenna has a broad beamwidth while maintaining an intermediate gain. All the 3dB beamwidths and peak gains for both pattern cuts are gathered in Table II.

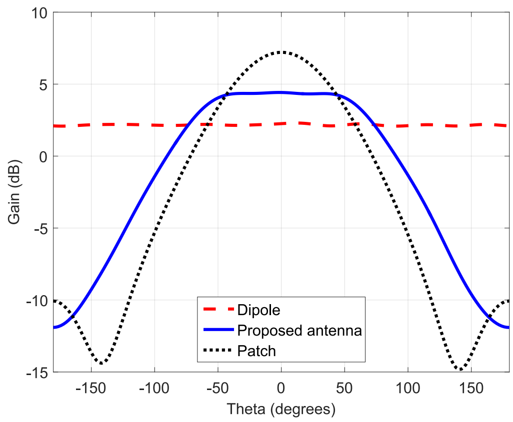


Fig. 7: Comparison of YZ pattern cut at 2.45GHz for the three antennas.

From the results, we can conclude that the proposed antenna exhibits higher gain than an omnidirectional dipole, and significantly broader beamwidth than a patch antenna. The proposed antenna provides a broad maximum beamwidth of 160º, which significantly improves the beamwidth of microstrip antennas using 3D ground structures for similar frequencies, while keeping low profile. For example, in [9] the authors report a maximum beamwidth of 110º using such structures. Antennas using conductive posts around a patch antenna to extend the beamwidth, provide equivalent beamwidth than our antenna at the expense of complicating the geometry. That is the case of the antenna reported in [2], which exhibits a maximum beamwidth of 160º. Therefore, the benefit of our antenna lays on its simple geometry and its potential to further increase its beamwidth.

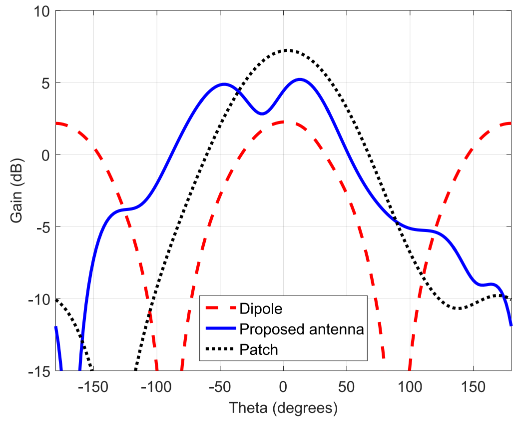


Fig. 8: Comparison of XZ pattern cut at 2.45GHz for the three antennas.

TABLE II: Comparison of 3dB beamwidths and peak gains for YZ and XZ pattern cuts at 2.45 GHz for various antennas.

Antenna	3dB beamwidth (deg)		Peak gain (dBi)	
	YZ cut	XZ cut	YZ cut	XZ cut
Dipole	360	76	2.3	2.7
Proposed antenna	159	115	4.4	5.2
Patch	70	68	8.5	8.5

IV. Conclusion and Future Work

In this contribution, we assess the potential of combining various modes in the same antenna structure to achieve a wider beamwidth. A simple antenna geometry was designed to illustrate this idea,resulting in a give a 3dB beamwidth of up to 160 degrees in the 2.4GHz ISM band.

We can conclude that the proposed antenna establishes a good compromise between high beamwidth and medium gain. The results also prove the potential of the presented technique to widen the beamwidth of microstrip antennas.

As future work, we envision using more complex feeding techniques and geometries in order to excite circular polarization and to miniaturize the size of the antenna.

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