Flexible and Conformal Printed Monopoles Antennas

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Abstract—This paper presents the development and design of flexible and conformal printed monopoles antennas. The main objective is to control the level of radiation in broadside antenna from zero to a maximum by changing the curvature of printed board. Two printed antennas types are considered: thin wire and disk monopole. Furthermore, with the curving radius R increasing, the classical null on the broadside radiation pattern disappears gradually for both wire and disk. Increasing the curvature radius of conformal flexible antenna while keeping all other parameters same, wire monopole antenna becomes mismatched while the disk monopole antenna which remains matched for all radius of curvatures. The simulated results of various monopoles are compared successfully with measurements.

1. INTRODUCTION

The demand for wireless communication systems is rapidly growing especially flexible and conformal antennas that have become widely researched for different fields of applications. Future wireless systems will provide various services such as broadband multimedia and high speed access. The related literatures to the conformal flexible antenna have been reported by several authors. Reference [1] presents a curved strip dipole antenna combined to EBG reflector; References [2–7] present a curved micro strip antenna with the goal to miniaturize the structure. Furthermore, flexible wireless technologies requires the integration of flexible, light weight, compact, and low profile antennas, Authors in [9–14] developed antennas for various technologies with all this characteristics. In [15–17], authors present flexible antennas that are particularly suitable for use in wearable applications. It is noted that in all the cases authors report the mismatch effect due to the curvature.

In this paper, conformal flexible monopoles antennas are presented and expected to work around $f = 2$ GHz using different radii of curvature and its ability to remain matched for many curvature radius. All structures use flexible, low dielectric permittivity substrate with $\varepsilon_r = 2.2$, $T_s = 0.254$ mm as thickness, with $T_m = 18$ μm as copper metal thickness mounted over a metallic ground plane and excited by a $50\,\Omega$ coaxial line.

2. CONFORMAL WIRE MONOPOLE ANTENNA

2.1. Description and Design Geometry

Figure 1(a) shows a wire monopole antenna, it is a quarter wavelength line at 2.2 GHz ($L_m = 34$ mm) printed on a substrate with dielectric constant $\varepsilon_r = 2.2$ and thickness $T_s = 0.254$ mm. The antenna can be bent on a cylindrical surface with R as a curvature radius (Figure 1(b)). The width (W_m) of the line is chosen such that it avoids the effect of coupling from the reflector plane.
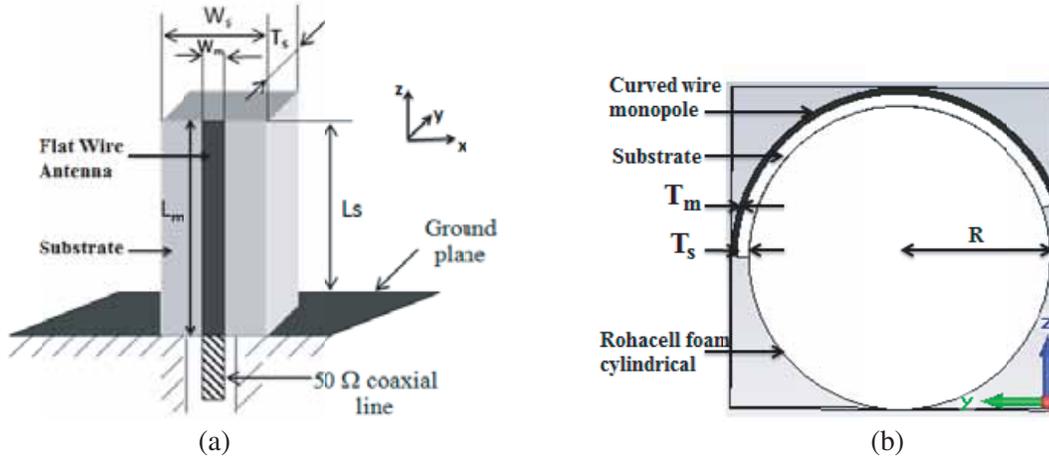
Figure 1. Structure of wire monopole antenna $W_m = 0.4\,\text{mm}$, $L_m = 34\,\text{mm}$, $W_s = 11\,\text{mm}$, $L_s = 35\,\text{mm}$, $T_s = 0.254\,\text{mm}$. (a) Flat antenna. (b) Curved antenna on cylindrical Rohacell foam.

2.2. Wire Monopole Antenna Results

The antennas were curved on cylindrical Rohacell foam with dielectric permittivity $\varepsilon_r = 1$ and radius equal to: 12.5 mm, 17.5 mm, 45 mm and 60 mm. Antennas were simulated by CST [18], and the simulated results were compared to measurements.

Figure 2 shows the simulated (Figure 2(a)) and measured (Figure 2(b)) return losses of curved wire monopole antennas in the frequency range 1 to 3 GHz. A good agreement is obtained.
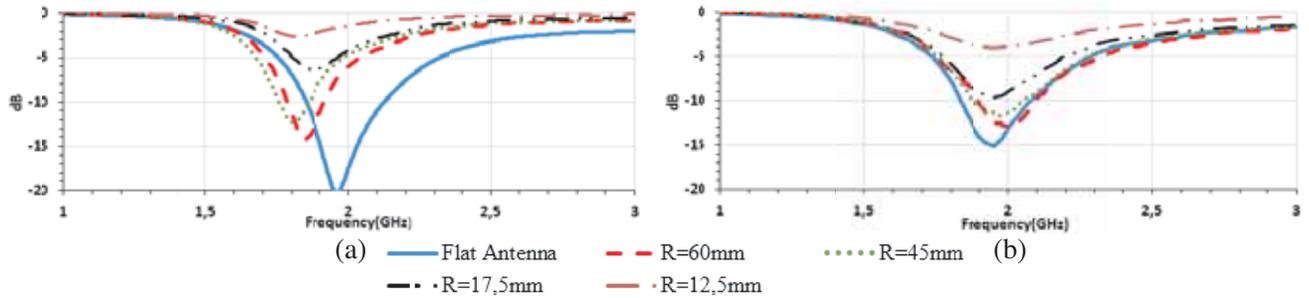

Figure 2. Return loss of wire monopole antenna versus R. (a) Simulated results. (b) Measured results.

2.3. Radiation Pattern of Wire Monopole Antenna

Figure 3 shows the effect of the curvature on the radiation pattern and especially in the broadside direction. It is noted that for small radius of curvature, the null disappears when curving radius R decreases from ∞ (flat) to 12.5 mm, and the broadside level varies from $-40\,\text{dB}$ to $-2.64\,\text{dB}$. These results are confirmed by measurements given in Figure 3(b). The measured cross polarization is lower than $-25\,\text{dB}$ compared to the simulation value $-50\,\text{dB}$.

Figure 4 shows the H plane in the flat case and curved cases. For the flat case, the E plane has a null in the broadside, which is why we consider the E_θ as the co-polarization component at $\theta = 90°$, and it is plotted versus φ (around the monopole). The level is very stable as expected (Figure 4).

For the curved case, the E plane has no null in the broadside, and the radiation pattern is like a patch antenna case, which is why we consider the E_φ as the co-polarization component at $\varphi = 0°$, and it is plotted versus θ. The radiation pattern in this case is much directive (like a patch) (Figure 4). It indicates that the cross polarization is quite high ($-10\,\text{dB}$).
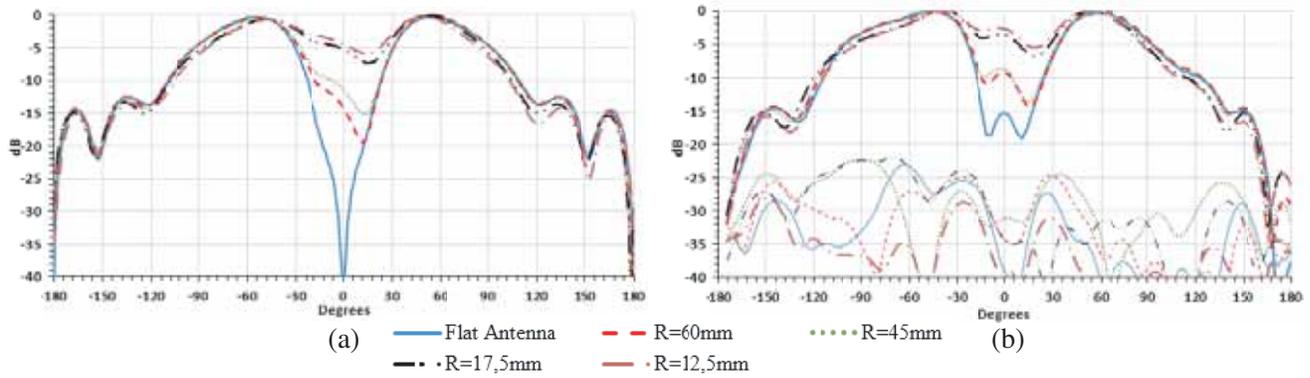
(a)

(b)

Flat Antenna — — R=60mm ••••• R=45mm
— • R=17,5mm —— • R=12,5mm

Figure 3. E-plane radiation pattern at 2 GHz for wire monopole antenna versus radius of curvature: Co-polarization E_θ and cross polarization E_φ for $\varphi = 90°$ versus θ. (a) Simulation. (b) Measurement.

(a)

(b)

Flat Antenna — — R=60mm ••••• R=45mm
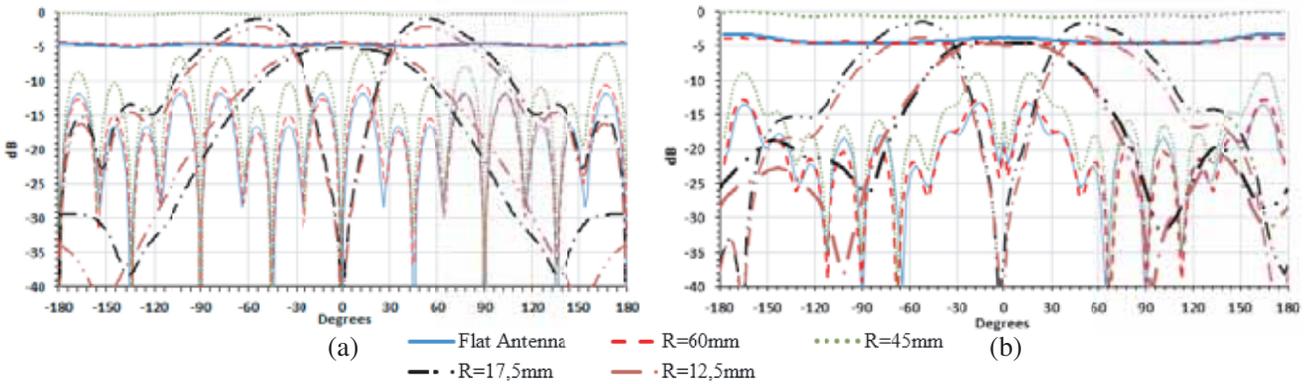— • R=17,5mm —— • R=12,5mm

Figure 4. H-plane radiation pattern at 2 GHz for wire monopole antenna versus radius of curvature. (a) Simulation. (b) Measurement. For flat wire monopole ($R = \infty$) and curved wire with $R = 60$ mm & $R = 45$ mm, Co-polarization E_θ and cross polarization E_φ for $\theta = 90°$ versus φ. For curved wire monopole with $R = 12.5$ mm & $R = 17.5$ mm, Co-polarization E_φ and cross polarization E_θ for $\varphi = 0°$ versus θ.

2.4. Gain of Curved Wire Antennas

Table 1 shows that with increasing radius of the curvature, the gain decreases from 4.42 dB of flat wire antenna to -0.88 dB of curved wire antenna $R = 12.5$ mm.

Table 1. Comparison of simulated and measured gain of curved wires monopoles antennas.

R (mm)	∞ (Flat)	60	45	17.5	12.5
Simulated Gain (dBi)	4.42	3.32	2.68	2.7	−0.88
Measured Gain (dBi)	3.94	3.1	2.6	1.6	−0.1

The lower value of -0.88 dB explains that the antenna approaches the reflector plane due to the short circuit.

The gain was measured in IETR SATIMO multi-probe near-field measurement system and also by classical calibration and comparison with a known horn antenna.

In order to have this interesting behavior of radiation pattern versus antenna curvature, it is proposed to design a more broadband antenna to keep it matched for all curvature.

3. CONFORMAL MONOPOLE DISK ANTENNA

In this section, a disk monopole antenna is chosen mainly because of its attraction and also for its being a popular antenna due to its larger bandwidth [8].

3.1. Antenna Description and Design Geometry

Figure 5 shows a quarter wavelength (at 1 GHz) printed disk monopole antenna with diameter $D = 73$ mm, which can be bent on a cylindrical surface with R as curvature radius as presented in Figure 1(b). In order to be flexible, a Rogers RT-5880 substrate $(W_d \times L_d)$ with $\varepsilon_r = 2.2$, thickness $T_s = 254$ µm, $W_d = 75$ mm and $L_d = 75$ mm has been used.
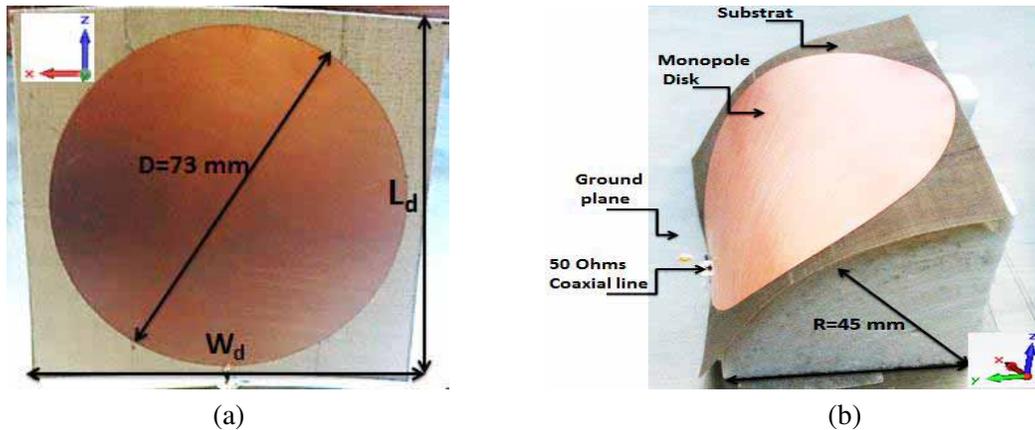

(a)   (b)

Figure 5. Photograph of the fabricated disk monopole antenna. (a) Flat disk. (b) Curved disk on cylindrical Rohacell foam.

3.2. Monopole Disk Antenna Results

Figure 6 shows the simulated and measured return losses of curved disk monopole antennas.

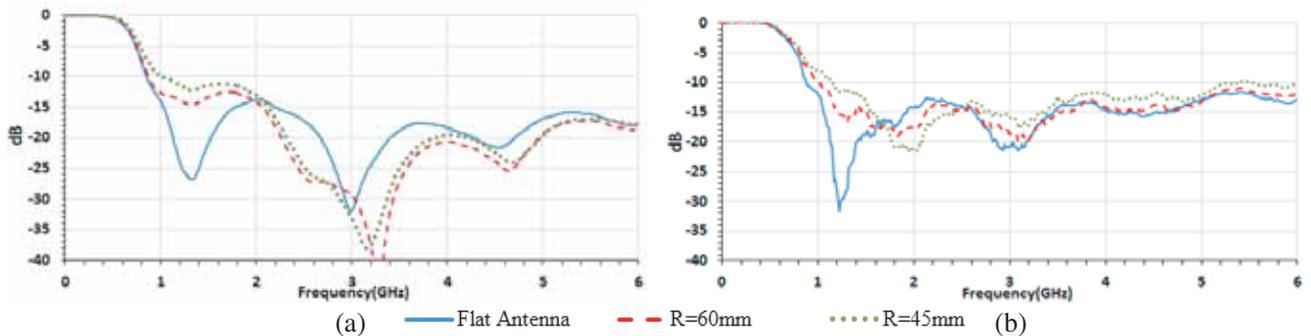(a)   —— Flat Antenna   – – R=60mm   ·····R=45mm   (b)

Figure 6. Return loss of monopole disk for various curvatures. (a) Simulation. (b) Measurement.

One advantage of the disk antenna is its capability to remain matching even if it is curved. The measured results are in good agreement with simulated ones for low frequencies till up to 1.4 GHz, and for high frequencies, a shift between simulations and measurement can be observed, due to the realized prototype.

It is worth to note that from 2 GHz (theoretically and experimentally), the antenna's good matching is ensured (Figure 6). That is why it is preferred to give the results at this frequency for all curvature.

3.3. *E*-Plane and *H*-Plane Radiation Patterns

Figure 7 shows the effect of the curvature on the radiation pattern.

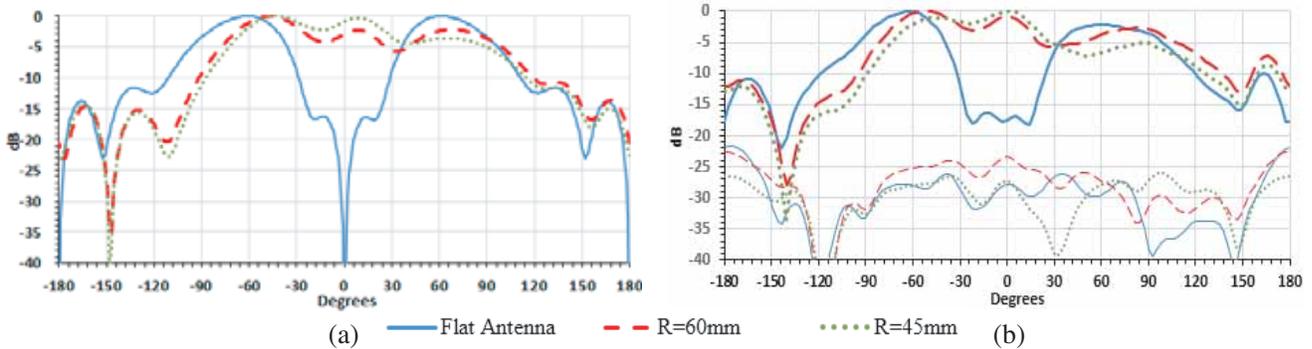(a)   Flat Antenna   — — R=60mm   ····R=45mm   (b)

Figure 7. *E*-plane radiation pattern at 2 GHz for monopole disk antenna versus radius of curvature. (a) Simulation. (b) Measurement. Co-polarization E_θ and cross polarization E_φ or $\varphi = 90°$ versus θ.

It has the same remarks as those concerning the wire monopole antenna. The null disappears in the broadside direction when the disk monopole antenna is curved. The difference is that this effect appears for big radiuses of curvature ($R = 45$ mm and $R = 60$ mm). The simulated cross polarization is lower than -50 dB, but the measured one is about -25 dB. The simulated (Figure 7(a)) results are in good agreement with the measurements (Figure 7(b)).

Figure 8 shows the H plane in the flat case and curved cases. For the flat case, the E plane has a null in the broadside as the wire case, that is why we consider the E_θ as the co-polarization component at $\theta = 90°$, and it is plotted versus φ (around the monopole). The level presents some small ripple as expected (Figure 8).

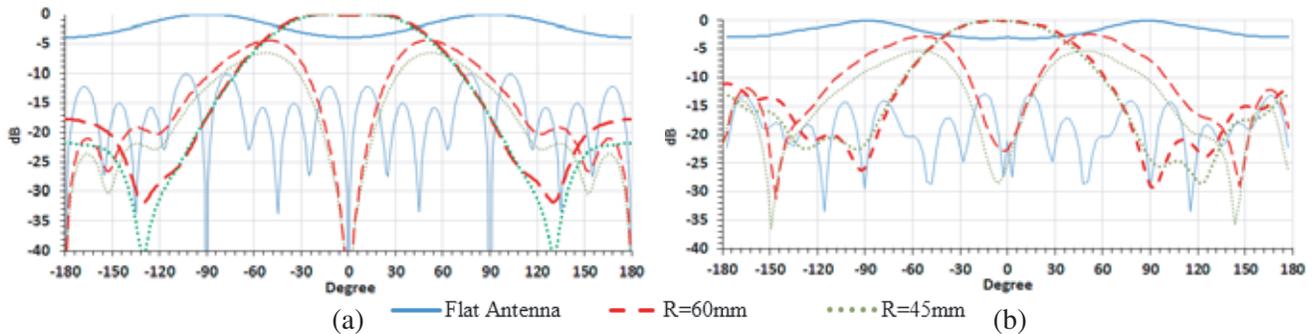(a)   Flat Antenna   — — R=60mm   ····R=45mm   (b)

Figure 8. *H*-plane radiation patterns at 2 GHz of disk monopoles antennas. (a) Simulation. (b) Measurement. For flat disk monopole ($R = \infty$), Co-polarization E_θ and cross polarization E_φ or $\theta = 90°$ versus φ. For curved disk monopole ($R = 60$ mm & $R = 45$ mm) Co-polarization E_φ and cross polarization E_θ or $\varphi = 0°$ versus θ.

For the curved case, the E plane has no null in the broadside direction, and the radiation pattern is like a patch antenna case, which is why we consider the E_φ as the co-polarization component at $\varphi = 0°$, and it is plotted versus θ. The radiation pattern in this case is much directive (like a patch) (Figure 8). It is noted that the cross polarization is quite high especially beyond $\pm 30°$. Measured results in (Figure 8(b)) show a good agreement with the simulated ones (Figure 8(a)).

3.4. Realized Gain of Disk Antennas

As indicated in Table 2, the disk monopole antenna maintains an interesting realized gain for both flat and curved wire monopole antennas.

Table 2. Comparison of simulated and measured gain of curved disk monopole antenna.

R (mm)	∞ (Flat)	60	45
Simulated Gain (dBi)	5.29	4.9	5.16
Measured Gain (dBi)	4.8	4.4	5.0

As expected, the curvature allows the monopole antenna to radiate in the broadside. It can be easily imagined that this kind of flexible antenna is associated with mechanical actuator and can easily be reconfigured.

4. CONCLUSIONS

This paper proposes the effects of the curvature on the return loss and radiation pattern for both flexible printed wire and disk monopole antennas. The choice of $T_s = 0.254$ mm is good and gives the antennas more flexibility. Curvature affects the radiation in the beam axis and is more beneficial for the disk monopole antenna than a wire monopole antenna. The simulated result shows a good agreement with experimental measurements for the various conformal curved monopole antennas.

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