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Comparative analysis of feeding techniques for cylindrical surrounding patch antenna

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ABSTRACT

In this research work, a cylindrical surrounding patch antenna (CSPA) with improved performance parameters based on inset feed method compared to other feed techniques has been proposed for 1.8 GHz applications. The designed and simulated CSPA is a rotary version of an initially designed rectangular planar patch antenna (RPPA). The RPPA is mounted on a cylindrical surface with radius (r) 10 mm which is an increased curvature for better -10 dB S-parameter (S_{11}), impedance band width (BW), voltage standing wave ratio (VSWR), radiation pattern, and gain. The copper radiating patch has been conformed on the surface of the grounded flexible polyimide substrate with relative permittivity (ε_r) 3.5 and thickness (h) 1.6 mm at normalized input impedance of 50 Ω. Results for the RPPA and the proposed CSPA have been compared with existing designs in terms of antenna size, resonant frequency (f_r), return loss (S_{11}), and gain while taking cognizance of the feeding techniques. The S_{11}, BW, VSWR, and gain are-12.784 dB, 28 MHz, 1.8, and 4.81 dBi respectively for the rectangular planar patch antenna and -35.571 dB, 66 MHz, 1.5, and 3.74 dBi, respectively for the cylindrical surrounding patch antenna.

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1. INTRODUCTION

High performance flexible conformal patch antenna is the main focus of research and applications for point-to-point communications, radar, medical industries, and aerospace [1, 2]. This is because it possesses better performance parameters like high gain, low return loss, higher bandwidth etc. compared to its planar counterpart. Planar patch antennas are known for their versatility in non-planar geometries and are thus applicable in different situations, construction, and suitability for integration with microwave circuits.

The radiating patch (element) is of various structures (configuration) with the most common been rectangular or circular in shape [3-5]. However, the planar and conformal patch antennas have some similar characteristics such as low profile, simplicity, lightweight, ease of integration with microwave-integrated systems. Cylindrical surrounding patch antennas (CSPA) is preferred because of its additional advantages. This include reduction of aerodynamic drag, mechanical robustness on host surfaces, reduced radar cross-section, wider angular coverage and ease of concealing within host surface making it an integral part of the host [1, 6, 7]. Reported research based on conformal patch antennas have demonstrated that the performance parameters of antennas are affected by feeding technique/method [8-12]

This present research work has analyzed the design and simulation of inset feed cylindrical surrounding patch antenna obtained from a conformal rectangule shaped planar-patch antenna at 1.8 GHz frequency band for mobile communication and automotive applications where antennas have to be integrated on curved surfaces. The approach takes into account the effect of curvature radius (r) on return loss ($S_{1,1}$), impedance Band Width (BW), Voltage Standing Wave Ratio, and the E- and H- plane radiation patterns of the antennas [11-15]. This research work has resolved the limitations of coaxial, probe and proximity feeding techniques and has justified that microstrip inset-feed technique can mitigate the shortcomings of other feeding methods.

This paper has been organized as follows: Section 2 deals with the design and modelling of the CSPA detailing the physical dimensions of the RPPA and the model of the proposed inset feed CSPA. Section 3 deals with results and discussions and its comparison with other existing model has been performed in section 4. Finally, section 5 presents the conclusion of the work and recommends future aspect.

2. PROPOSED MODEL OF THE CYLINDRICAL SURROUNDING PATCH ANTENNA

The designing of the cylindrical surrounding patch antenna has been first derived from a fundamental design of a rectangular patch and further optimized and conformed on the cylindrical surface. Subsequent subsections present the ordered design details.

2.1. Physical dimensions of rectangular planar patch antenna

The optimized physical dimension details of the designed rectangular planar patch antenna as shown in Figure 1 has been calculated by transmission line method by the use of (1) to (5). Table 1 depicts the complete details of the physical dimensions of the rectangular planar patch antenna [14-16].
The width of the patch (w_p) is:

$$w_p = \frac{c}{2 f_r \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1}$$

where c, f_r and ε_r are the velocity of light, resonant frequency, and permittivity of the substrate respectively. The width of the ground plane (w_g) which is the same as that of the substrate (w_s) is given as:

$$w_g = w_s = 6h + w_p \tag{2}$$

Also, the length of the ground plane (l_g) which is the same as that of the substrate (l_s) is obtained from:

$$l_g = 6h + l_p \tag{3}$$

However, the resonant frequency (f_r) is:

$$f_r = \frac{c}{2 l_{eff} \sqrt{\varepsilon_r}} \tag{4}$$

and finally, the effective length of the patch (l_{eff}) is given by:

$$l_{eff} = l_p + 2\Delta l_p \tag{5}$$

where the extended length (Δl) due to fringing effect is:

$$\frac{\Delta l_p}{h} = 0.412 \left(\frac{(\varepsilon_{reff} + 0.3)(w_p / h + 0.264)}{(\varepsilon_{reff} - 0.258)(w_p / h + 0.8)} \right)$$

Moreover, the effective dielectric constant (ε_{reff}) due to dielectric constant of the substrate (ε_r) and that of air (ε_o) which is responsible for fringing field (effect) is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \left(\frac{12h}{w_p} \right) \right)^{-1/2}$$

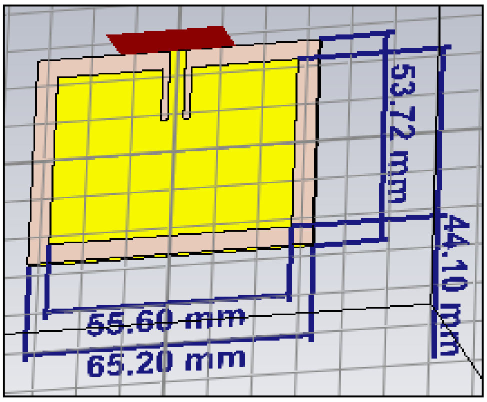


Figure 1. Dimension details of the designed rectangular planar patch antenna

Table 1. Physical parameters of the rectangular planar patch antenna

Description	Design Parameter	Value
	Length of Patch (l_p)	44.100 mm
Patch	Width of Patch (w_p)	55.600 mm
	Patch thickness (t)	0.035 mm
Substrate/Ground plane	Length of Substrate/Ground plane ($l_s = l_g$)	53.720 mm
	Width of Substrate/Ground plane ($w_s = w_g$)	65.200 mm
	Inset feed length (l_f)	18.225 mm
Microstrip feed	Inset feed length (f_l)	13.425 mm
	Inset feed Width (w_f)	3.644 mm
Substrate	Height (h)	1.600 mm
Ground plane	Thickness (t)	0.035 mm
Patch/Microstrip feed	Gap between Patch and feed (g_{pf})	1.000 mm

2.2. Model of the proposed inset feed cylindrical surrounding patch antenna

The proposed CSPA shown in Figure 2 is a rotary version of the RPPA obtained by transformation of the optimized RPPA on a grounded flexible polyimide substrate of curvature radius (*r*) computed based on the assumption that the perimeter of the cylindrical substrate is equal to the width of the RPPA as:

$$p = w_p = \frac{2\pi r\theta^0}{360^0} = r\phi \tag{6}$$

where p is the perimeter of the cylinder formed by the substrate and *r* is the curvature radius while θ and ϕ are angles in degrees and radian formed by the radius of the patch at the center of the cylinder.

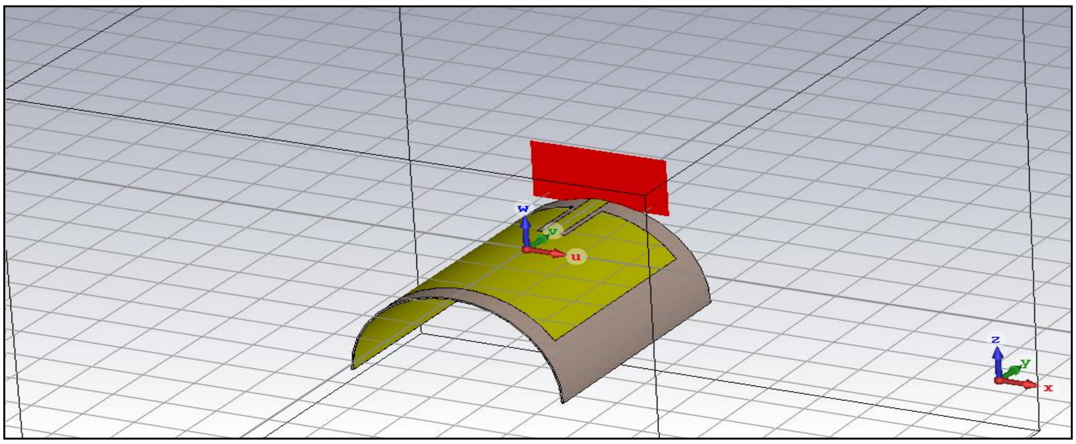


Figure 2. Designed proposed cylindrical surrounding patch antenna

The RPPA is bent along the patch width (*H-plane*) since it affects the impedance bandwidth significantly. The other physical dimensional details such as the length of the patch (l_p) and length of the substrate/ground plane (l_s/l_g) are taken as the height of the cylindrical structure. Since RPPA is intended to be conformally mounted on a cylindrical surface, the choice of a flexible substrate is essential to solve the effect of substrate cracking caused by bending effect and curvature radius. Bending and curvature radius are key determinants of the performance of cylindrical antennas as reported in literatures [17-19]. To reduce the effect of the substrate on the antenna performance, a flexible and almost non-cracking substrate polyimide with a permittivity (ε_r) 3.5, permeability (μ_r) 1 and loss tangent (tan δ) 0.0027 was chosen for the design of the antenna [20]. The cylindrical bending process was achieved by keeping the radius (r) of the cylinder constant at an optimized radius of 10 mm because decreasing the radius (i.e. increasing the curvature) from higher values to the optimized value increases the bandwidth of the antenna which is a desirable parameter for antenna performance [21, 22].

3. PARAMETRIC ANALYSIS OF THE PROPOSED CYLINDRICAL SURROUNDING PATCH ANTENNA

In this work, polyimide material with a thickness of 1.6 mm has been used as substrate because of its flexibility to conform on cylindrical surface. Various results from the design is presented as follows.

3.1. Return loss (S-parameter, S_{11})

Figures 3 and 4 shows the return loss (S-parameter, S_{11}) in dB for the rectangular planar patch antenna and the cylindrical surrounding patch antenna at resonant frequency (f_r) 1.8 GHz. The rectangular planar patch antenna achieved a return loss of -12.784 dB, while the cylindrical surrounding patch antennas with a curvature radius (*r*) of 10 mm achieved a return loss of -35.571 dB.

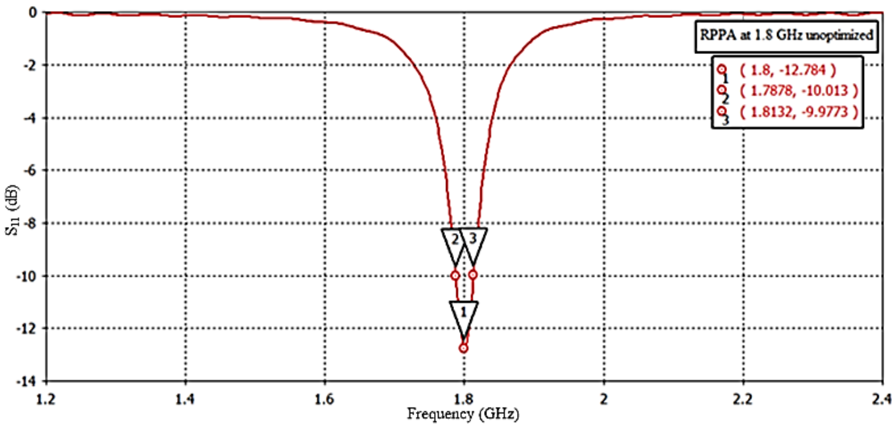


Figure 3. Return loss for rectangular planar patch antenna at 1.8 GHz

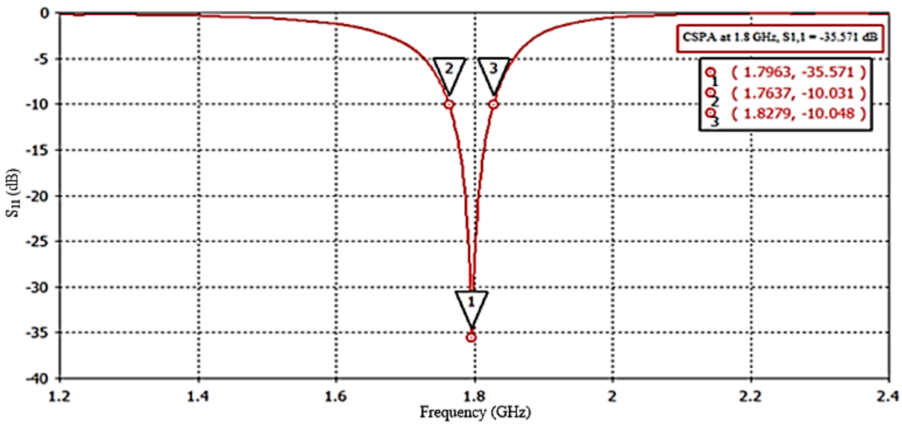


Figure 4. Return loss for cylindrical surrounding patch antenna at 1.8 GHz

3.2. Impedance bandwidth

The impedance bandwidth for the rectangular planar patch antenna and the cylindrical surrounding patch antenna at resonant frequency (f_r) 1.8 GHz can be obtained from Figure 3 and Figure 4. The rectangular planar patch antenna achieved an impedance bandwidth of 28 MHz at a frequency range of 1.7856-1.8142 GHz while the cylindrical surrounding patch antennas with a curvature radius (r) of 10 mm achieved a -10dB impedance bandwidth of 66 MHz at a frequency range of 1.7623-1.8281 GHz.

3.3. Voltage standing wave ratio (VSWR)

The voltage standing wave ratio (VSWR) shown in Figure 5 and Figure 6 are for the rectangular planar patch antenna and the cylindrical surrounding patch antennas respectively. VSWR indicates the level of matching/mismatch between the signal feed line and the antenna with a typical value of 1:2. The VSWR from the figures are 1.8 and 1.5 respectively. This shows that the two antennas are well matched at the resonant frequency of 1.8 GHz.

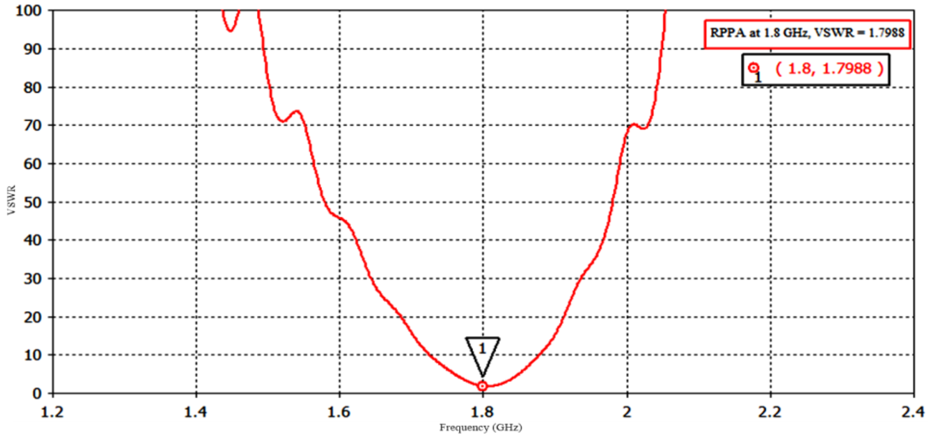


Figure 5. Voltage standing wave ratio for rectangular planar patch antenna at 1.8 GHz

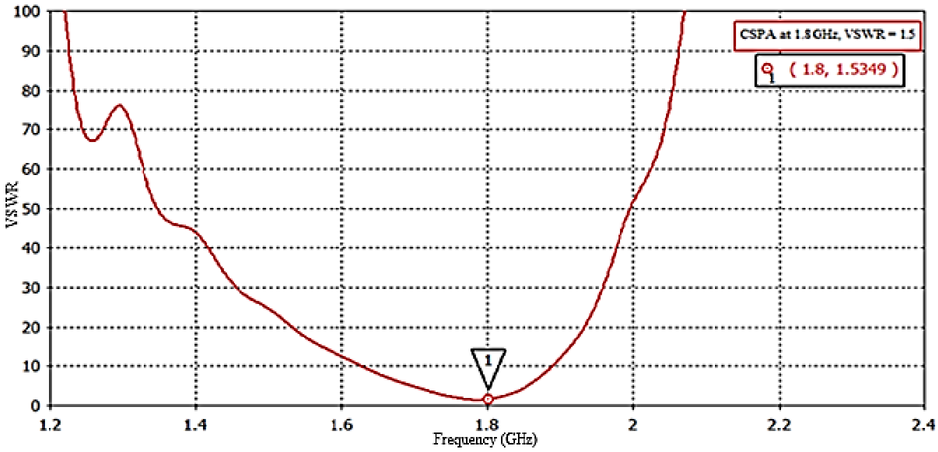
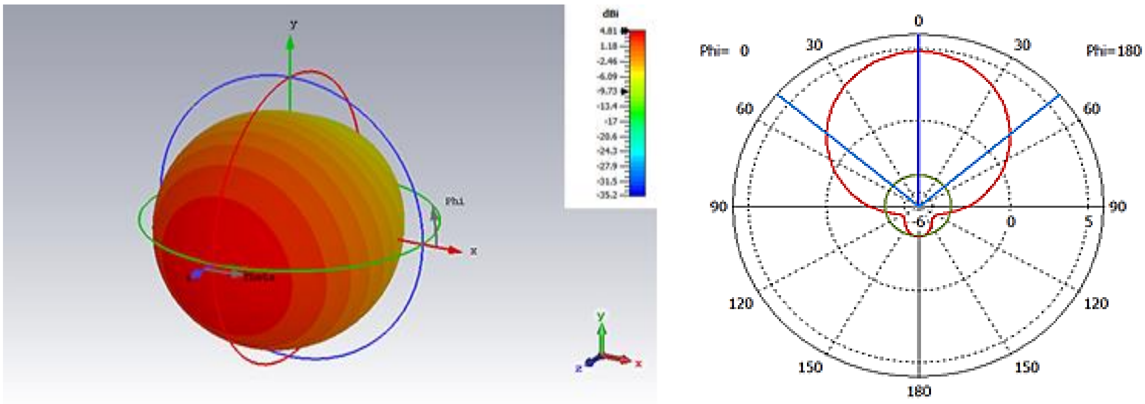


Figure 6. Voltage standing wave ratio for cylindrical surrounding patch antenna at 1.8 GHz

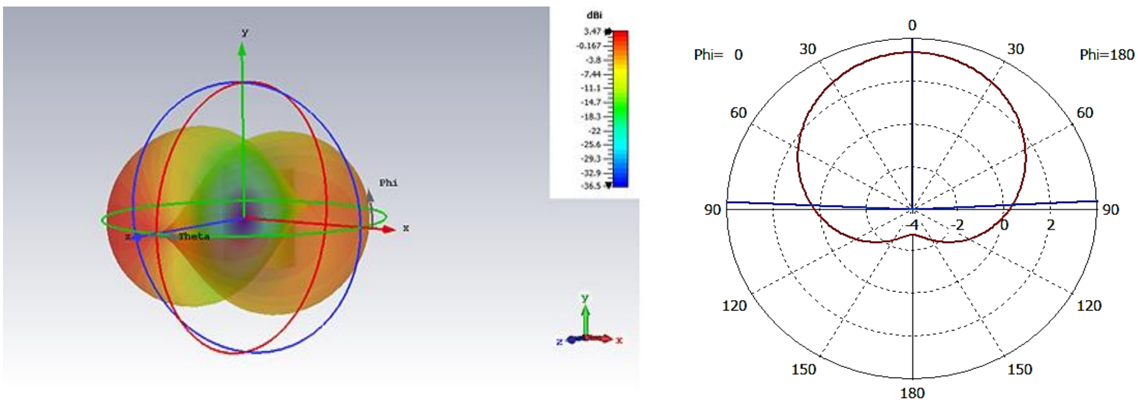
3.4. Farfield radiation pattern

The farfield radiation pattern is the plot of the farfield properties as a function of spatial co-ordinates specified by elevation angle (θ) and azimuth (ϕ) or can be defined as plot of power radiated per unit solid angle [11, 14, 15]. It could be in polar, Cartesian, 2D or 3D graph. It shows the antenna gain at different points in space as well as the antenna directivity. Figure 7(a) and Figure 7(b) depicts the 3D and polar plot radiation patterns for the rectangular planar patch antenna while Figure 8(a) and Figure 8(b) depicts the 3D and polar plot radiation patterns for the cylindrical surrounding patch antenna. The farfield plot and radiation pattern of the cylindrical surrounding patch antenna is different from the rectangular planar patch antenna because its surface is not parallel to the principal axes. The gains of the antennas are 4.81 dBi and 3.47 dBi for the RPPA and the CSPA respectively. From Figure 7(b), the main lobe magnitude, main lobe direction, 3 dB angular width, and side lobe level for the rectangular planar patch antenna are 4.78 dBi, 0.0 deg., 98.9 deg., and -8.6 dB at 1.8 GHz respectively. From Figure 8(b), the main lobe magnitude, main lobe direction, and 3 dB angular widths for the cylindrical surrounding patch antenna are 3.34 dBi, 0.0 deg., and 174.8 deg. at 1.8 GHz respectively.



(a) (b)

Figure 7. (a) Farfield 3D-radiation pattern for rectangular planar patch antenna and
(b) Farfield plot of radiation pattern for rectangular planar patch antenna



(a) (b)

Figure 8. (a) Farfield 3D-radiation pattern for cylindrical surrounding patch antenna and
(b) Farfield plot of radiation pattern for cylindrical surrounding patch antenna

4. COMPARISON OF THE PROPOSED CYLINDRICAL SURROUNDING PATCH ANTENNA WITH EXISTING DESIGNS

The selection of a feeding technique is a critical issue for patch antennas because it affects the patch size, return loss, VSWR, BW, and Smith chart [17, 23]. The authors chose inset feed technique because it simple to model, easy to fabricate, and easy to match in terms of impedance [23]. The performance of the proposed cylindrical surrounding patch antenna has been compared with existing designs in other to support its importance as a candidate antenna for curved surface applications as reported in literature. The comparison is shown in Table 2.

Table 2. Comparison of proposed antenna with existing designs

Reference	Substrate Type	Feed Type	Antenna size (mm^3)	Resonant frequency (GHz)	Return loss (dB)	Gain (dBi)
[24]	Polyamide	Microstrip/Inset	50×40×0.8	1.8/13.3	-16 to -43	5.53
[25]	Roger's RT Duriod 5880	Coaxial	200×200×6	1.8/2.4/3.5/5.8	-17 t0 -30	2.6/2.3/3/2
[26]	Plexiglass	Microstrip	56×44×0.8	1.575/2.45/3.5/5.2	-22 to -28	3.55/3.93/5.02/4.86
[27]	Roger's RT Duriod 5880	NA	51×35×1.57	1.2/1.5/2.4/3.3/5.8	NA	1.07/1.75/1.88/1.52/5.48
[28]	(NA)	NA	16×16.3×0.254	7.5/8.5/9.5	-10 to -40	2.0 -3.2 (dBic)
[29]	FR4	Microstrip	65×38.5×0.8	0.95/1.5/2.4	-22 to -34	1.2/1.2/1.3
[30]	FR4	Inset Microstrip	58×40×1.6	2.4/5/5.87	-12 to -27	5.2/4.8/5
Proposed antenna	Polyimide	Inset Microstrip	44×55.6×0.035	1.8	-35.571	3.47

5. CONCLUSIONS AND FUTURE ASPECTS

In this paper, we have proposed a cylindrical surrounding patch antenna for application in 1.8 GHz application for mobile communication where antennas have to be integrated on curved surfaces. Antenna performance parameters such as return loss, impedance bandwidth, *VSWR*, and radiation pattern for the rectangular planar patch antenna and the cylindrical surrounding patch antenna has been investigated with reference to its planar counterpart. It has been observed that using a cylindrical grounding structure could increase frequency bandwidth, better beamwidth, and good radiation characteristics of the patch. Also, it has been observed that the physical size of an antenna is usually inversely proportional to its resonant frequency. The proposed CSPA compared to existing designs as shown in Table 2 is suitable for vehicular application. The antenna performance parameter such as gain, bandwidth, greater beam width and better coverage (angular width) etc. can be improved by use of array antennas. This will further enhance ominidirectionality and portability.

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