e-ISSN: 2147-8228

INTERNATIONAL JOURNAL OF APPLIED MATHEMATICS ELECTRONICS AND COMPUTERS

www.dergipark.org.tr/ijamec

International Open Access

Volume 08
Issue 04

December, 2020

Research Article

Hexagonal ring microstrip patch antennas for PCS and S-band radar applications

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ARTICLE INFO

Article history:
Received 17 September 2020
Accepted 9 October 2020

Keywords:
Antenna parameters
Hexagonal ring
Microstrip patch antenna
Personal communication service
S-band radar

ABSTRACT

In this study, two hexagonal ring microstrip patch antennas for Personal Communication Service (PCS/1850-1990 MHz) and S-band (2000-4000 MHz) radar applications are proposed and simulation results for antenna performance parameters are presented. The antennas consist of a hexagonal ring patch, a ground plane and a dielectric substrate in between. Edge length of each square antenna is 25 mm. Substrate height is 4.3 mm. Relative permittivity and loss tangent of the substrate material are 15.5 and 0.0001, respectively. Distance from center of the antennas to inner and outer hexagon corners are 4 mm and 10.19 mm, respectively. The antennas are fed by a 50-ohm coaxial probe. Depending on the feed location, resonant frequency and therefore application choice is achieved. Center of the antennas is denoted as (0, 0) mm. For the feed location of (-1.50, -4.19) mm, the antenna for PCS application resonates between 1830-2035 MHz with a bandwidth of 205 MHz. Voltage Standing Wave Ratio (VSWR) value at 1900 MHz is 1.1097. Unidirectional radiation patterns are obtained for both $Ø=0^{o}$ and $Ø=90^{o}$ planes. Maximum radiations occur at boresight with radiation levels of 12.09 dB and 12.10 dB for $Ø=0^{o}$ and $Ø=90^{o}$ planes, respectively. Maximum gain is 3.26 dBi for $Ø=0^{o}$ plane and 3.09 dBi for $Ø=90^{o}$ plane. For the feed location of (-7.36, 0.95) mm, the antenna for S-band application resonates between 3280-4015 MHz covering S-band with a bandwidth of 735 MHz. The frequency range and bandwidth are suitable for the radar application. VSWR value at the resonant frequency of 3650 MHz is 1.0164. Again, unidirectional radiation patterns are obtained for both $Ø=0^{o}$ and $Ø=90^{o}$ planes. Maximum radiations occur at boresight with radiation levels of 5.82 dB and 5.75 dB for $Ø=0^{o}$ and $Ø=90^{o}$ planes, respectively. Maximum gain is 4.14 dBi for $Ø=0^{o}$ plane and 4.03 dBi for $Ø=90^{o}$ plane.

1. Introduction

Microstrip patch antennas are widely utilized in many applications such as wireless communication systems, radar, telemetry and radio frequency identification. These antennas are advantageous to use in the mentioned applications as they are small, easy to fabricate, and low cost [1]. There is ample research that investigates different geometries and antenna performance parameters in literature: Feng et. al. [2] design a microstrip patch antenna that consists of two hybrid shape radiation patches and a pair of capacitances loaded loop (CLL) resonators. The structure operates between 5930-9230 MHz with a broadside gain varying from 4 to 6 dBi. Babakhani et. al. [3] propose a microstrip patch antenna topology with a central circular patch, a shorted annular ring around it, and another shorted annular ring encompassing the other two radiators. In one study [4], a rectangular microstrip patch antenna with two rectangular patches that operates between 2700-3030 MHz is investigated. The antenna has a wide beamwidth and reduced cross-polarization. In another research [5], a super wideband circular fractal microstrip patch antenna used with a rectifier circuit is examined. Maurya et. al. [6] present a circularly polarized hexagonal ring microstrip patch antenna with asymmetrical feed. The structure is suitable for S, C, and

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DOI: 10.18100/ijamec.796287

X band applications. Wang et. al. [7] design a microstrip patch antenna with a long rectangular patch shorted to a ground plane. The antenna operates in TM_{03} and TM_{11} modes, and has a wide bandwidth along with a high gain. In another article [8], a square microstrip patch antenna with an L-shaped slot in the patch is explored. The antenna operates at 1900 MHz and is circularly polarized. It is manufactured through 3D printing technology. Feng et. al. [9] design a single layer, wideband, differential-fed microstrip patch antenna with complementary split ring resonators and a set of coplanarly loaded rectangular parasitic elements. Bandwidth of the antenna ranges from 5350 MHz to 7000 MHz. Wen et. al. [10] analyze a bandwidth-enhanced, single-layer, differential-fed microstrip patch antenna under the operation of dual radiative TM_{30} and TM_{50} modes. In the topology, a pair of long slots are symmetrically etched on specific positions of the microstrip patch antenna. The structure operates between 5400-5740 MHz. Ntawangaheza et. al. [11] propose a U-slotted artificial magnetic conductor loaded microstrip patch antenna. The antenna is suitable for satellite communications, WLAN, and 5G applications between 3000-6000 MHz.

Microstrip patch antennas with ring patches have been of interest in various reports: Dhara and Mitra [12] investigate a triple band circularly polarized ring patch antenna, loaded with a single annular ring patch with eight symmetrical slots along its periphery and a series of octagonal closed ring resonators on the opposite side of the substrate. The structure resonates at 7500 MHz, 10200 MHz and 12200 MHz. Size of the antenna is larger compared to that of the designed antenna in this study although authors' design operates at higher frequencies. Rezazadeh and Shafai [13] propose a microstrip patch antenna with two concentric annular rings, where the inner ring is excited at the dominant TM_{11} mode and the outer ring is excited at TM_{21} mode. The antenna is aimed for L1 band GPS operation, and is capable of suppressing up to three radio frequency interferers. The structure is harder to fabricate/operate as it is fed by 4 coaxial probes and includes nylon screws. Its substrate is also thicker compared to the presented design in this research. In comparison with these available designs in the literature, proposed designs are relatively small, easy to fabricate, compact, and low cost while they are suitable for two wireless operations. They can also be further improved in terms of geometry and design parameters in order to optimize the operation frequency and bandwidth so that it would be possible to use the antennas in different wireless operations. Moreover, impact of roundness on antenna performance parameters could be investigated by analyzing annular ring microstrip patch antennas and the proposed designs.

In this study, two hexagonal ring microstrip patch antennas for Personal Communication Service (PCS) and S-band radar applications are suggested. Simulation results for antenna performance parameters in terms of bandwidth, Voltage Standing Wave Ratio (VSWR), radiation pattern, and maximum gain are presented and evaluated. Antenna structures are simulated and optimizations are performed by ANSYS HFSS.

Organization of this article is as follows: In Section 2, technical descriptions of the proposed antennas are provided. Next, simulation results are presented and discussed in Section 3. Finally, Section 4 concludes the study.

2. Antennas

Designed antennas consist of a hexagonal ring patch, a ground plane and a dielectric substrate in between. Edge length of each square antenna is denoted by *E*. Distance from the center of each antenna to inner and outer hexagon corners are represented by H_{in} and H_{out}, respectively. There are no slots or stubs in the ground planes. Substrate height for both structures is given by S_h. Antenna dimensions are depicted in Table 1. Relative permittivity and loss tangent of the substrate material are 15.5 and 0.0001, respectively. The antennas are fed by a 50-ohm coaxial probe.

Table 1 Antenna dimensions in mm

E	H_{in}	H_{out}	S_h
25	4	10.19	4.3

Proposed antennas are shown in Figure 1 and Figure 2. Both topologies have the same features in terms of dimension and material property. The difference between the two structures is the feed location, which provides a choice of resonant frequency and therefore application of interest.

Center of the antennas is denoted as (0, 0) mm. For the feed location of (-1.50, -4.19) mm, the antenna in Figure 1 resonates between 1830-2035 MHz with a -10 dB impedance bandwidth of 205 MHz including the frequency band of PCS application. For the feed location of (-7.36, 0.95) mm, the antenna in Figure 2 resonates between 3280-4015 MHz covering S-band with a -10 dB impedance bandwidth of 735 MHz. The frequency range and bandwidth are suitable for the radar application. Both feed locations are determined by carrying out optimizations.

After the microstrip patch antennas are designed, they are both simulated in order to obtain antenna performance parameters such as return loss, VSWR, radiation pattern and maximum gain. In the next section, simulation results are presented and evaluated to better understand the impact of feed location on the antenna performance parameters.

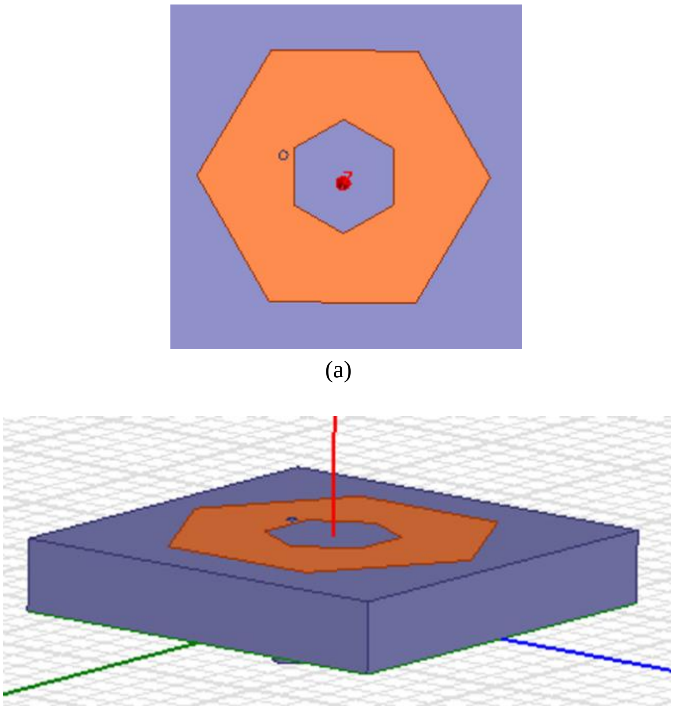

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Figure 1. Designed antenna for PCS application: a) top view, b) side view. Circle on the patch corresponds to the coaxial feed

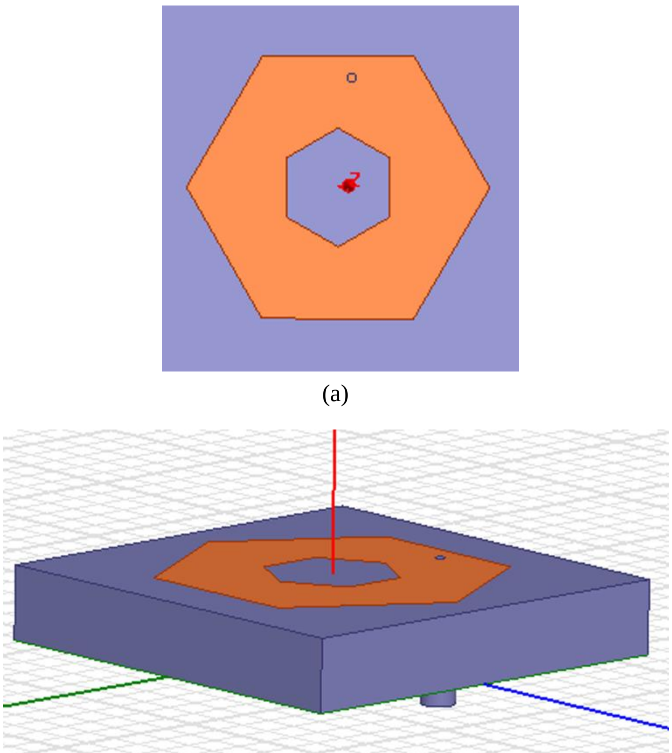

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Figure 2. Designed antenna for S-band radar application: a) top view, b) side view. Circle on the patch corresponds to the coaxial feed

3. Results and Discussions

Figure 3 illustrates the return loss versus frequency for the hexagonal microstrip patch antenna designed for PCS application. The antenna operates between 1830-2035 MHz with a resonant frequency of 1915 MHz. The -10 dB impedance bandwidth is hence 205 MHz. Figure 4 shows VSWR variation against frequency. VSWR value at 1900 MHz, which is the center frequency for PCS application, is 1.1097. Radiation patterns at 1900 MHz for Ø=0^{O} and Ø=90^{O} planes are given in Figure 5. For both planes, unidirectional radiation patterns are obtained, and maximum radiations occur at boresight direction. Maximum radiation levels are 12.09 dB and 12.10 dB in Ø=0^{O} and Ø=90^{O} planes, respectively. Maximum gain value is 3.26 dBi for Ø=0^{O} plane and 3.09 dBi for Ø=90^{O} plane. Figure 6 shows the return loss against frequency for the hexagonal microstrip patch antenna aimed for S-band radar application. The antenna operates between 3280-4015 MHz with a -10 dB impedance bandwidth of 735 MHz. Resonant frequency value is 3650 MHz. Figure 7 depicts VSWR variation against frequency. VSWR value at the resonant frequency is 1.0164. Radiation patterns at 3650 MHz are presented in Figure 8. Again, unidirectional radiation patterns with maximums at boresight direction are observed in Ø=0^{O} and Ø=90^{O} planes. Maximum radiation levels are 5.82 dB and 5.75 dB in Ø=0^{O} and Ø=90^{O} planes, respectively. Maximum gain value is 4.14 dBi for Ø=0^{O} plane and 4.03 dBi for Ø=90^{O} plane. It is evident from the return loss results that the antenna designed for S-band radar application has a wider bandwidth than the antenna aimed for PCS application. VSWR values for the two antennas are close to each other. However, VSWR value for the antenna for PCS application is higher than that of the antenna for S-band radar application. In terms of radiation patterns, the antenna aimed for PCS application has higher radiation levels than the antenna designed for S-band antenna. Both antennas have unidirectional radiation patterns in Ø=0^{O} and Ø=90^{O} planes with maximum values at boresight direction. The antenna for S-band radar application has higher maximum gain values in Ø=0^{O} and Ø=90^{O} planes than the antenna for PCS application.

In microstrip patch antennas, resonance occurs when total path length of surface current equals to half wavelength. When the antenna is fed at one location, a surface current distribution is formed on the patch. For the PCS application, the antenna is fed at (-1.50, -4.19) mm, which yields a certain path length of surface current resulting in a resonant frequency of 1915 MHz. Likewise, another surface current distribution is formed when the antenna is fed at (-7.36, 0.95) mm for the S-band radar application yielding a resonant frequency of 3650 MHz. Detailed analysis of resonant frequency calculation by using path length of surface current can be found in [14].

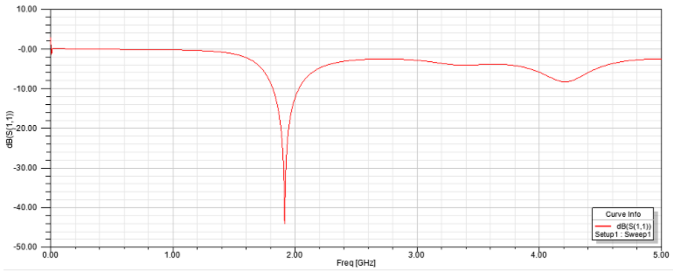


Figure 3. Return loss versus frequency for the antenna designed for PCS application

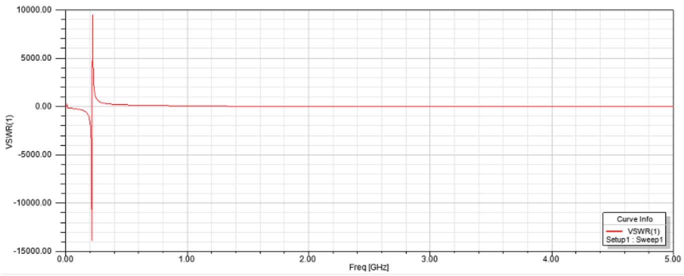
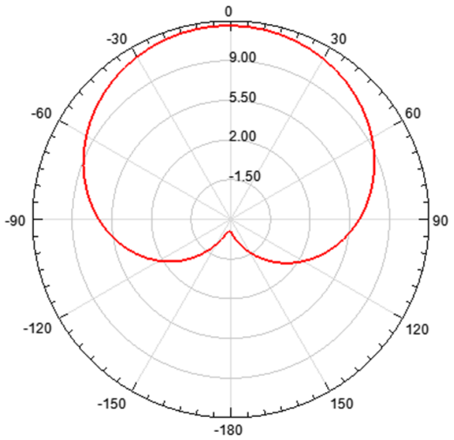


Figure 4. VSWR versus frequency for the antenna designed for PCS application



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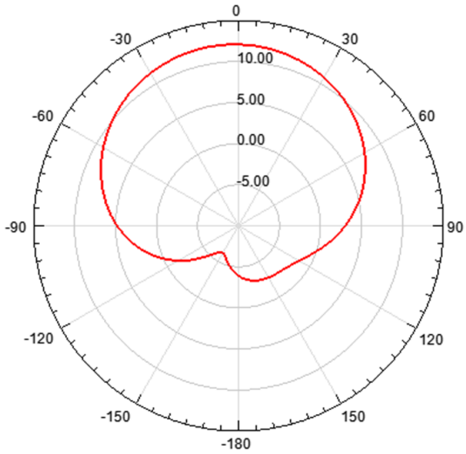

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Figure 5. Radiation patterns at 1900 MHz for antenna designed for PCS application: a) Ø=0^{O} plane, b) Ø=90^{O} plane

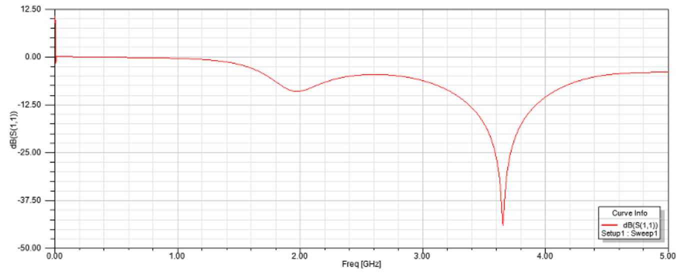


Figure 6. Return loss versus frequency for the antenna designed for S-band radar application

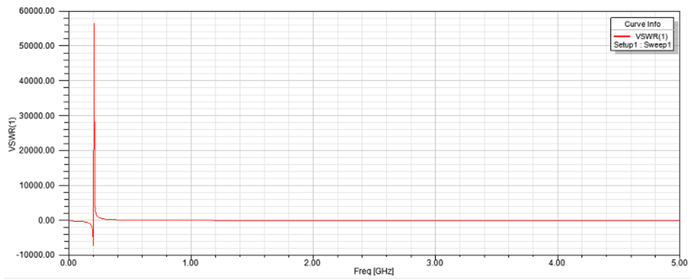
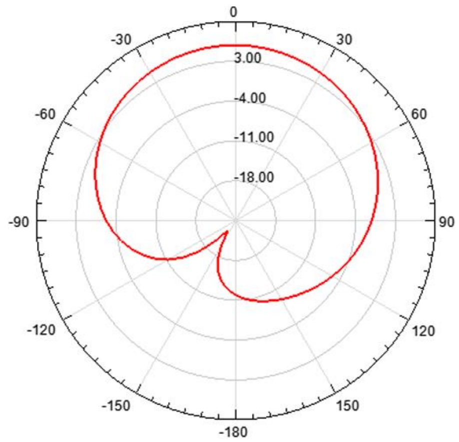


Figure 7. VSWR versus frequency for the antenna designed for S-band radar application



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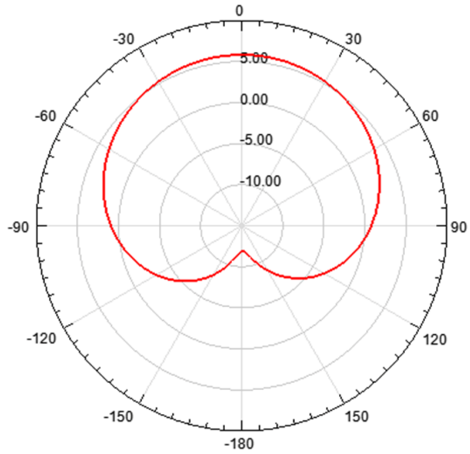

(b)

Figure 8. Radiation patterns at 3650 MHz for antenna designed for PCS application: a) Ø=0^{O} plane, b) Ø=90^{O} plane

4. Conclusions

Two hexagonal ring microstrip patch antennas for Personal Communication Service (PCS) and S-band radar applications are designed. Two different resonant frequencies are formed by mounting the 50-ohm coaxial feed in two different locations on the antennas. Simulation results representing the antenna performance parameters such as return loss, VSWR, radiation pattern and maximum gain are presented and evaluated. Simulations and optimizations are carried oon aut by ANSYS HFSS. In the future, patches with different number of edges could be designed in order to investigate the impact of roundness. As the number of edges increases, the patch shape resembles an annular ring, which has a theoretical basis in terms of various mode excitations for microstrip patch antennas [15].

Author's Note

Abstract version of this paper was presented at 9th International Conference on Advanced Technologies (ICAT'20), 10-12 August 2020, Istanbul, Turkey with the title of "Hexagonal Ring Microstrip Patch Antennas For PCS And S Band Radar Applications".

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