Parallel symmetrical notches loaded patch antenna for wireless applications

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Abstract

The theoretical analysis of parallel symmetrical notches loaded patch antenna for wireless applications is presented. The geometric analysis of the antenna is done to get the optimum results for wireless body area network. An antenna characteristic has been discussed for symmetrical notches length and width and distance between notches those optimum results. It is found that proposed antenna resonate at 2.37 GHz having the bandwidth of 14 MHz. The results of parallel notches loaded patch antenna is compared with reported, theoretical, and measured results.

Keywords Notches · Symmetrical · Split ring resonator (SRR) · Wireless body area network (WBAN)

1 Introduction

With extensive increase in various wireless electronic gadgets for wireless application, especially in patient care monitoring through wireless gadgets has been used in our present day life. These wireless electronic gadgets are wearable and strong, light weight, cost effective, bio-compatible, and mechanically robust and low power device with satisfactory outputs. Therefore, WBAN are more suitable in medical field for wireless electronic equipment because such type of devices uses special type of antenna to communicate with nearby device or to transmit the information. In particular, WBAN are equipped with various types of patch antenna such as slot antenna, circular ring, inverted F-shaped antenna, grid array antenna, and filters etc. [1–9]

The patch antennas reported for WBAN applications such as shorting pin loaded circular patch antenna operating at 2.45 GHz, antenna designed with Y-shaped microstrip acting as ground plane, 6.8 dBi gain switchable mode antenna, T-shaped design on FR4 with metal back ground,

slot loaded rectangular patch with ground plane, dipole antenna with slots on ground plane, inverted F-shaped patch antenna with tapered feed to increased bandwidth, rectangular ring shaped as radiating top and H-shaped slot on ground plane [1–4, 10–17]. All above discussed research papers of MSA are for WBAN but these papers has limitations such as complicated geometry, limited antenna gain and efficiency, parametric analysis is not provided and comparison with similar structure of antennas are not presented.

In this view, an antenna is proposed for wireless applications which have parallel symmetrical notches. The antenna performance has been studied theoretical and simulated results, further results are compared with similar radiating structures. All the antenna characteristics have been analyzed for wireless communication. The details of antenna design structures, radiation gain and efficiency are discussed in next section.

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2 Antenna design and circuit analysis

The antenna consist four notches that are so placed on the patch that represents like U-shaped from both side of the length of the patch. The patch is surrounded with rectangular path as shown in Fig. 1. Antenna design structure comprise of two parallel slots on bottom and top length. The proposed antenna is excited via SMA connector at point (6.85, 0) for both antennas with and without SRR. The radiating structure is designed over polyimide film (PF) have height $h = 0.15$ mm and dielectric constant ϵ_r , 2.7. Figure 2 shows that current density on the proposed antenna, near the notches density of current is more and surround ring resonator it is less. This happens because of

electromagnetic coupling between feed patch and square resonator.

Width of the rectangular patch is given as, $W_1 = \frac{c}{2f\sqrt{\epsilon_r+1}}$ mm,

Length of the rectangular patch is given as, $L_1 = \frac{c}{2f\sqrt{\epsilon_e}}$ mm,

$f = 2.37$ GHz is the resonating frequency for proposed antenna; c is the velocity of light in mm/s.

ϵ_e = effective dielectric constant.

The designed radiating structure can be represented into circuit system as shown in Fig. 3. A radiating structure

Fig. 1 Radiating geometry of designed antenna. Dimension in mm $L = 36$, $d = 18.55$, $d_1 = 12.15$, $L_3 = 1.05$, $L_p = 33.6$, $L_n = 0.5$, $W = 21$, $W_n = 2.7$, $W_1 = 8.1$, $W_2 = 13.3$, $W_{p1} = 1.2$, $W_p = 18.6$, $h = 0.15$ mm, and permittivity = 2.7

Fig. 2 Current distribution of electromagnetic coupled patch antenna

Fig. 3 Equivalent circuit of proposed antenna

consists of SRR which is represented as parallel combination of inductance L_c and capacitance C_c [18],

$$\text{where } L_L = 0.002L \left(2.303 \log_{10} \left(\frac{4L}{W} \right) - \gamma \right), \mu\text{H}$$

$\gamma = 2.853$, constant of microstrip square loop,

$$L = 8\Delta L - g, \text{ mm}$$

ΔL = extension in length, g = gap between two arms,

$$C_c = \frac{\epsilon_0 W W_{p1}}{L_3}, \text{ pF}$$

The resonating frequency f_{SRR} of square microstrip loop is given as,

$$f_{SRR} = \frac{1}{2\pi} \sqrt{\frac{1}{L_L C_c}}, \text{ GHz}$$

The input impedance of rectangular patch is represented as Z_p [19, 20], which is the parallel combination inductance, capacitance, and inductance are given as,

$$C_{p1} = \frac{L_1 W_1 \epsilon_0 \epsilon_e}{2h} \cos^2(\pi Y_0/L), \text{ pF}$$

$$R_{p1} = Q/\omega_r^2 C_{p1}, \text{ ohms}$$

$$L_{p1} = 1/\omega_r^2 C_{p1}, \text{ nH},$$

Resonating frequency of the rectangular patch is given as,

$$f_r = \frac{c}{2\pi \cdot L_{p1} \sqrt{\epsilon_e}}, \text{ GHz}$$

The four notches have been represented as Z_n with mutual inductance L_m and capacitance C_m [19], where L_m and C_m are given as,

$$L_m = \frac{k_c^2(L_{p1} + L_2) + [k_c^4(L_{p1} + L_2)^2 + 4k_c^4(1 - k_c^2)L_{p1}L_2]^{1/2}}{2(1 - k_c^2)},$$

$$C_m = \frac{-(C_2 + C_{p1}) + [(C_2 + C_{p1})^2 + (1 - 1/k_c^2)C_{p1}C_2]^{1/2}}{2},$$

C_2 = series combination of capacitances

L_2 = series combination of inductance.

The total input impedance of the proposed antenna is given as

$$Z_{in} = \frac{1}{Z_p} + \frac{1}{Z_m} + Z_n + \frac{1}{Z_c},$$

$$\text{where } Z_m = j\omega L_m + \frac{1}{j\omega C_m} \text{ and } Z_{srr} = \frac{1}{j\omega L_c} + j\omega C_c.$$

2.1 On body model without and with tumor

The designed antenna is also simulated by considering the human body with and without tumor. Antenna is kept above the human body spacing between skin and antenna in 1 mm and an antenna is excited. Figure 4 the block diagram of on body human model with proposed antenna.

Fig. 4 Design of prototyped model of body considering **a** without and **b** with tumor/stone/swelling in muscles/fractured bone

Fig. 5 Comparison of S_{11} (dB) with frequency for the described antenna and without SRRs

Fig. 7 The frequency versus S_{11} (dB) on varying the dielectric of the antenna

Fig. 6 The frequency versus S_{11} (dB) for heights of substrate (h)

Fig. 8 The frequency versus S_{11} (dB) for distance between the notches d_1

3 Results and discussion

The proposed antennas radiating structure are compared with plot shown in Fig. 5. It is observed that antenna resonates between 2.36 and 2.39 GHz frequency which can be utilized for wireless application for WBAN and WMAN.

The height of proposed antenna ($h = 0.15$ mm for polyimide film) is varied as shown in Fig. 6. Firstly, it has been increased from 0.15 mm to 0.4 mm and changes are observed in resonating frequencies. It is found that at $h = 0.4$ mm antenna S_{11} is near -2 dB means antenna is not radiating. At $h = 0.1$ mm, the resonating frequency shift towards lower side with decrease in bandwidth and S_{11} is observed at -11 dB.

The permittivities of proposed antenna are varied and remaining other parameters is kept constant to examine the behavior of the permittivity on the antenna reflection coefficients as shown in Fig. 7. On decreasing permittivity of proposed antenna from 2.7 (PF) to 2.32 (RT Duroid) resonating frequency shifts from 2.37 to 2.52 GHz whereas for the permittivity of PDMS it is noted that antenna resonates at 2.2 GHz and for FR4 it is resonating at 1.9 GHz. This change in characteristics of the antenna is because of dielectric behavior of the material used.

Distance between the notches d_1 has been changed and noted the changes in reflection coefficient S_{11} (dB) as shown in Fig. 8. It is observed that distance between the notches d_1 has been changed from $d_1 = 8.2$ mm to 6.2 mm

then frequency band shifts from 2.37 to 2.47 GHz, whereas when d_1 is changed from 8.2 to 10.2 mm shifting in resonating frequency are observed from 2.37 to 1.99 GHz and change in bandwidth is observed too.

Distance between the notches d as per Fig. 1 and noted the changes in reflection coefficient S_{11} (dB) as shown in Fig. 9. It is observed that on varying distance between the notches d has been changed from $d = 12.56$ to 18.56 mm then frequency band shift towards lower frequency side with decrease in bandwidth. It is found that at $d = 17.56$ mm and 18.56 mm resonating frequency has gone above -10 dB. The change in resonating frequency is observed because the change in electric current on the radiating surface.

The comparison plot is shown in Fig. 10 for the proposed radiating structure with and without cancer cells on human body. It is found that resonating frequency shifts as antenna is exposed to any opaque material depending upon the dielectric properties of the material. Similarly, when the proposed antenna is excited above the human body it has been observed that resonating frequency shifts from -19 to -16 dB with decrease in bandwidth. Further, on considering the cancer cells the bandwidth decreases and it is observed that antenna is resonating at 2.37 GHz near -13.98 dB. The proposed antenna is compared without SRRs also and it is found that resonating frequency is shifted from 2.37 to 2.41 GHz.

It is observed from the plot shown in Fig. 11 that simulated parallel notches loaded antenna structure has given similar results as in reported [21], simulated and theoretical results. It is found that there is no change in bandwidth of simulated and measured results but there change in the resonating length of frequency.

Fig. 9 The frequency versus S_{11} (dB) for distance between the notches d

Fig. 10 The frequency versus S_{11} (dB) for proposed radiating structure on human body model, with cancer cells, and splitted resonator rings

It is observed from the Fig. 12 that proposed antenna E-plane pattern has linear polarization in broadside direction with two beams like structure. This type of pattern is suitable for sensing the reflected signal from tumor, swelling, stones, fracture bones etc. Further, H-plane pattern has 84.5° 3-dB beam width in broadside direction. The maximum gain of antenna is found to be 1.23 dBi and 1.51 dBi for simulation and theoretical examination.

Fig. 11 The frequency versus S_{11} (dB) for the reported [21], theoretical and proposed antenna

Fig. 12 Radiation pattern of proposed antenna for E- and H-plane at 2.37 GHz resonance

4 Conclusion

The designed radiating structure has given efficient performance at the desired frequency. It is found that proposed antenna can be used for detecting cancer cells, swelling and tumor on the human body. Antenna parametric analysis has been performed and it was observed that designed antenna characteristic depends on the notches etched over the radiating surface. Further, results comparison has been done for simulated antenna design on IE3D with circuit theory concept results simulated on MatLab. The reflection coefficient result is approximately matches with simulated, theoretical and reported findings. The designed radiating structure can be used for wireless applications for WBAN and WMAN.

Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests regarding the publication of this paper.

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