Annular Ring Patch Antenna for Wearable Applications

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Abstract - The concept of being connected anywhere and everywhere is the main driving force for developing and researching the potential Wireless Body Area Networks operated in WLAN and HiperLAN bands. This paper presents design, development and evaluation of a copper based annular ring microstrip antenna suitable for wearable applications in WLAN band. Both simulated and experimental results on the performance characteristics of this antenna are presented.

I. INTRODUCTION

For the Wireless Body Area network (WBAN) to be accepted by the majority of consumers, the radio system components, including the antenna, need to be somehow hidden and compact and low weight. This requires the possible integration of these systems within clothing [1-2]. In the recent times, research projects have been initiated, under the concept of smart clothing or electro-textiles, to integrate antennas and RF systems into clothes with regard to size reduction and cost effectiveness, so the wearer will not even notice that these sub-systems exist. The applications of compact small antennas have also been receiving an increasing attention in the past few years for the convenience of integrating them with any small handheld or body-worn communication devices.

Annular ring microstrip antenna [3] is an alternate to standard rectangular and circular microstrip antennas. The main advantage of annular ring geometry over other microstrip antenna geometries is that for operation at a given frequency in the fundamental mode, the annular ring antenna occupies the smallest physical area. This characteristic makes the annular ring very attractive as individual element for arrays. Another interesting feature of this geometry is that the separation of resonant modes can be controlled by the ratio of outer to inner radii. It is also possible to combine the circular ring with a concentric circular disk to form a compact dual-band antenna [4]. The microstrip ring structure has been used to measure the dielectric constant of the substrate material [5]. It has also been used as a radiator for medical applications [6].

This paper presents design, development and evaluation of a copper based annular ring microstrip antenna for wearable applications in WLAN band. The rest of the article has been organized as follows: Section II describes the design aspects of this type of antenna. This Section also explains the electromagnetic modelling and fabrication of antenna. Both simulated and experimental results on performance characteristics of the antenna developed are presented in Section III. Concluding remarks of this experimental study are offered in Section IV.

II. ANTENNA DESIGN AND DEVELOPMENT

The geometry of an annular ring microstrip antenna developed for body wearable applications with the coordinate system used is shown in fig. 1. It comprises a ring shaped conductor on one side of a dielectric substrate with a ground plane on the other side. Polyester fabric is used as the dielectric substrate whose dielectric constant is 1.44 as measured by employing a novel technique (based on resonance method) proposed in [7]. The design specifications of the antenna are given below:

- Resonant frequency: 2.4 GHz
- Substrate permittivity: 1.44
- Substrate thickness: 2.85 mm
- Loss tangent of the substrate: 0.01
- Material used for patch and ground plane: Copper
- Material used for dielectric substrate: Polyester fabric

The design procedure involves selection of outer and inner radii of the annular ring. The ratio of outer radius (b) to inner radius (a) is taken as 2 (b/a = 2). The basic equation relating the resonant frequency of the annular ring antenna to its dimensions is given by,

\[ f_{\text{nm}} = \frac{\chi_{\text{nm}} c}{2\pi \sqrt{\varepsilon_r}} \quad (1) \]

where \( f_{\text{nm}} \) is the resonant frequency of the microstrip ring corresponding to the mode \( \text{TM}_{\text{nm}} \) and \( c \) is the velocity of light.

Fig. 1 Geometry of annular ring microstrip antenna
in free space, $\varepsilon_r$ is the relative dielectric constant of the substrate used and $\omega_m$ is the root of characteristic equation describing the modes of propagation.

The modeling of the antenna is performed using Method of Moments (MoM) based IE3D simulator [8] from Zeland Software Inc., USA. An infinite ground plane is assumed in the simulation so as to (i) avoid back lobes in the radiation pattern of the antenna (ii) reduce the diffraction and scattering effects at the edges of the ground plane and to (iii) minimize the undesirable effects of surface waves. The dimensions of the ground plane in the fabricated antenna are taken as 200 mm X 200 mm. This antenna makes use of Copper for both top signal layer and the bottom ground plane and employs polyester fabric as its substrate material. The size of the insulating fabric material used is equal to that of ground plane. The insulating polyester fabric pieces are stacked and stitched properly to get the required thickness. While assembling the antenna elements, the conductive fabrics are just fixed on the dielectric fabric material using scotch tape and due care is taken such that there is no air gap between the insulating fabric material and the conducting parts of the antenna. While modeling the coaxial probe feed to patch, the inner and outer diameters of the probe are taken as 1.3 mm and 4.1 mm respectively. The feed position is optimized to get good matching characteristics (50 ohm impedance) at the center frequency and it is located at 42 mm from the centre of the ring along the radial direction.

III. RESULTS ON PERFORMANCE CHARACTERISTICS OF WEARABLE ANTENNAS

A. Return Loss Characteristics

A.1 Simulated and Measured Results

Simulations and measurements are carried out over the frequency range of 2.0 GHz to 3.0 GHz with a frequency step size of 20 MHz to determine the return loss characteristics of the antenna developed. Fig. 2 shows a snapshot of the experimental setup used for this purpose. Fig. 3 shows the simulated and measured $S_{11}$ plots of Copper based annular ring microstrip antenna. As depicted by the simulation results, this wearable antenna resonates at a frequency of 2.4 GHz and exhibits a -10 dB return loss bandwidth of 43.39 MHz. The measurements are done using a vector network analyzer (Model # 5071 B) from Agilent Technologies. Initially, the network analyzer is calibrated using the 2 port Ecal module [9], bearing model # 85092C for an operating frequency ranging from 2 GHz to 9 GHz, which provides excellent accuracy. The fabricated annular ring antenna structure is measured for a resonant frequency of 2.485 GHz having an impedance bandwidth of 45.2 MHz with a return loss of -15.84 dB at the resonant frequency as shown in Fig. 3.

A.2 Discussions

The measured results are tabulated in table 1 along with the corresponding theoretical predictions for the investigated antenna. The Copper based annular ring microstrip antenna shows good agreement between simulated and measured values of resonant frequency, the deviation being 3.5% only. The deviation of measured resonant frequency from simulated frequency may be due to inaccuracies in the fabrication process. As far as the impedance bandwidth is concerned, there is a very good match between simulated and measured data.

Fig. 2 Snapshot of experimental setup for $S_{11}$ measurement

Fig. 3 Return loss characteristics of the antenna

B. Far-Field Radiation Pattern Characteristics

B.1 Radiation patterns (Simulated and Measured)

The total far-field radiation patterns of the modelled antenna, in both principal planes of $\phi = 0^\circ$ and $\phi = 90^\circ$, are obtained at the corresponding simulated resonant frequencies. The fabricated antenna is subjected to far-field radiation pattern measurements at its measured resonant frequency in a rectangular shielded anechoic chamber. This indoor far-field measurement system has Agilent make network analyzer (Model # PNA E8362B) along with automated positioner controller with integrated PCU. The instrumentation system is housed in a control room adjacent to the chamber. The chamber is equipped with CCTV facility to visualize the activity inside during antenna pattern measurement.
Simulated and measured far-field patterns of this annular ring antenna are shown in figures 4 and 5 respectively.

**B.2 Gain, Directivity and Efficiency**

Simulations are done for a range of frequencies from 2.0 GHz to 3.0 GHz in order to find the antenna parameters like gain, directivity and radiating efficiency. The gain of the antenna in the same frequency range is measured using gain-comparison method [10]. Variations of simulated gain, measured gain and simulated directivity as functions of frequency for the investigated antenna are plotted in figure 6. The measured values of directivity of this antenna are computed from the corresponding measured radiation patterns using the standard formulae [10] and are tabulated in table 1.

**B.3 Discussions**

Referring to the radiation pattern of the antenna studied, it is understood that the antenna exhibits a nearly “rabbit ear” beam pattern. The discrimination between co-polar and cross polar components obtained with fabricated wearable antenna is reasonably good for practical applications. However, in the case of simulation process, the magnitude of cross polar components in both principal planes is extremely low and hence the discrimination between co and cross polar components in these planes is very high. The simulated and measured values of 3dB beam-width in the principal planes of the investigated antenna, as obtained from two lobes in each of the principal planes, are tabulated in table 1. It is seen that there exists a reasonable match between estimated and measured values of 3dB beam-width.

At the resonant frequency, the respective predicted values of gain and directivity of the antenna are 4.32 dBi, and 6.99 dBi. The measured values of gain and directivity of this antenna at its resonant frequency are 4.29 dBi and 8.71 dBi respectively. The performance characteristics of the investigated antenna are listed in Table 1. The characteristics exhibited by the developed antenna are very useful for practical considerations.
TABLE 1

PERFORMANCE CHARACTERISTICS OF ANNULAR RING ANTENNA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Simulated</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant freq (GHz)</td>
<td>2.4</td>
<td>2.485</td>
</tr>
<tr>
<td>Imp. Bandwidth (MHz)</td>
<td>43.39</td>
<td>45.2</td>
</tr>
<tr>
<td>Gain at resonance (dBi)</td>
<td>4.32</td>
<td>4.29</td>
</tr>
<tr>
<td>Directivity (dBi)</td>
<td>6.99</td>
<td>8.71</td>
</tr>
<tr>
<td>3 dB beam-width in azimuth plane (deg)</td>
<td>47.87, 73.08</td>
<td>47.87, 102.34</td>
</tr>
<tr>
<td>3 dB beam-width in elevation plane (deg)</td>
<td>51.64, 62.82</td>
<td>48.91, 103.14</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

The following conclusions may be drawn from this experimental work. Firstly, microstrip antenna is a suitable candidate for wearable applications, as it can be built using fabric substrate materials. In this paper, a copper based annular ring microstrip antenna has been designed, developed and tested in order to get its impedance and radiation characteristics. The antenna presented is very versatile and it is easy to make it operate at various frequency bands. In addition, the well known techniques [3] of improving bandwidth and obtaining different polarizations, adopted for conventional microstrip patch antennas are readily suitable for wearable antennas too. It may be concluded that these textile based microstrip patch antennas may eventually replace patch antennas on standard PCB substrates for various applications.

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REFERENCES