Comparative Study of the Radiation Pattern of Circular Patch Antenna by Using the Model of the Resonant Cavity Approach for Radio Frequency Identification (RFID)

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Abstract: - The main objective of this work is to make a comparative study of the radiation pattern of circular patch antenna excited in transverses magnetics modes. This Study is based on the model of the resonant cavity approach and intended for RFID application around a resonance frequency of 2.45 GHz. The simulation results show that the far field components E_θ and $E_\emptyset$ for dominant mode TM_{11} present the better results in terms of amplitude and half power beamwidth at -3 dB compared to higher order modes TM_{21}, TM_{31}, TM_{41}, TM_{51} and TM_{61}.

Key-Words: Cavity model, circular patch antenna, modes TM_{11}, TM_{21}, TM_{31}, TM_{41}, TM_{51} and TM_{61}, RFID, radiation pattern.

1 Introduction

In recent years, microstrip antennas have been one of the most innovative topics in antenna theory and design. The basic idea of microstrip antenna came from using printed circuit technology not only for the circuit component and transmission lines but also for the radiating elements of an electronic system. They are used in a wide range of modern microwave applications because of their simplicity and compatibility with printed circuit technology [1].

Radio frequency identification is an automatic identification technology that uses radio waves to transfer data between a reader and a tag attached to an object for objective of identification and tracking [2]. The radiated wave energizes the IC chip to allow proper communication of data transfer between the RFID reader and the tag. Reader antenna is required to be low in profile yet provides wideband characteristics of complex worldwide regulatory environment. The most common frequencies of RFID technology used are low (125 KHz), high (13.56 MHz), ultra-high (858 − 930 MHz) and microwave (2.4 GHz) [3]. The UHF and microwave bands are widely used due to their advantages of long read range and high data rate, it is favourable to design a single antenna, which operates on both frequency bands.

In this paper, we propose to make a comparative study of the radiation pattern of circular patch antenna excited in transverses magnetics modes. This Study is based on the model of the resonant cavity approach and intended for RFID application around a resonance frequency of 2.45 GHz.

2 Methods of Analysis

There are many methods of analysis for microstrip antennas. The most popular models are the transmission-line [4-5], cavity [6-10] and full wave [11-14].The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling [15]. Compared to the transmission-line model, the cavity model is more accurate but at the same time more complex. However, it also gives good physical insight and is rather difficult to model coupling, although it has been used successfully [16-18]. In general, when applied properly, the full-wave models are very accurate, very versatile, and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However, they are the most complex models and usually give less physical insight.

3 Cavity model

In the cavity model, the region between the patch and the ground plane is treated as a cavity that is surrounded by magnetic walls around the periphery and by electric walls from the top and bottom sides. Since thin substrates are used, the field inside the cavity is uniform along the thickness of the substrate [19-20]. The fields underneath the patch for regular shapes such as rectangular, circular, triangular and sectoral shapes can be expressed as a summation of the various resonant modes of the two-dimensional resonator.

The fringing fields around the periphery are taken care of by extending the patch boundary outward so that the effective dimensions are larger than the physical dimensions of the patch. The effect of the radiation from the antenna and the conductor loss are accounted for by adding these losses to the loss tangent of the dielectric substrate. The far field and radiated power are computed from the equivalent magnetic current around the periphery.

An alternate way of incorporating the radiation effect in the cavity model is by introducing an impedance boundary condition at the walls of the cavity. The fringing fields and the radiated power are not included inside the cavity but are localized at the edges of the cavity. However, the solution for the far field, with admittance walls is difficult to evaluate [21].

4 Radiation Pattern

The microstrip radiating element consists of a radiating structure spaced a small fraction of a wavelength above a ground plane, allowing radiation only into the upper half space. A circular element supported by a dielectric sheet is shown in figure 1.

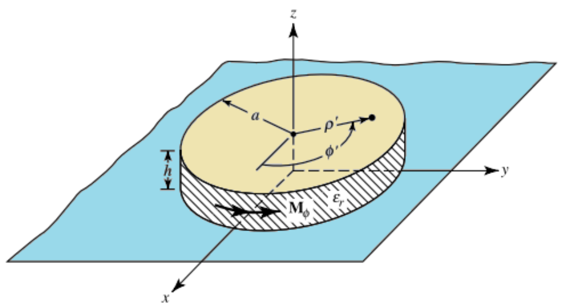

Fig.1: Geometry of circular patch antenna

The disk is excited by a microstrip transmission line connected to the edge, or by a coaxial line from the back at the plane $\emptyset' = 0$. The fields between the disk and the ground plane are similar to those obtained by considering the antenna to be a narrow cavity with a magnetic wall along the perimeter. Among the various modes that may be excited in such disk resonators are the TM_{mn0}, modes with respect to the z axis. That structure has been analyzed [22] and the fields inside the cavity are given as

$$E_\rho = E_\emptyset = H_z = 0 \tag{1}$$

$$E_z = E_0\, J_m(k\rho')\cos m\emptyset' \tag{2}$$

$$H_\rho = -j\,\frac{m\omega\varepsilon}{\rho k^2} E_0\, J_m(k\rho')\sin m\emptyset' \tag{3}$$

$$H_\emptyset = -j\,\frac{\omega\varepsilon}{k} E_0\, J'_m(k\rho')\cos m\emptyset' \tag{4}$$

where k is the propagation constant in the dielectric which has a dielectric constant $\varepsilon = \varepsilon_0\varepsilon_r$, J_m is the Bessel function of the first kind and order m, and the prime indicates differentiation with respect to the argument, ω is the angular frequency ($\omega = 2\pi f$). The open circuited edge condition requires that $J'_m(k.a_e) = 0$, where a_e is the effective radius of the disk. Thus for each mode structure a particular radius can be found associated with the zeros of the derivative of the Bessel functions. E_0 is the value of the electric field at the edge of the patch across the gap.

The radiation from the disk is derived from the E field across the aperture between the disk and the ground plane at $\rho' = a_e$.

Based on (2) evaluated at the electrical equivalent edge of the disk $\rho' = a_e$, the magnetic current density can be written as [23].

$$M_S = -2\hat{n}\, x\, E_{z|\rho'=a_e} = \hat{a}_\emptyset\, 2E_0\, J_m(ka_e)\cos m\emptyset' \tag{5}$$

Since the height of the substrate is very small and the current density of (5) is uniform along the z direction, we can approximate (5) by a filamentary magnetic current of:

$$I_M = hM_S = \hat{a}_\emptyset 2hE_0\, J_m(ka_e)\cos m\emptyset' = \hat{a}_\emptyset 2V_0\cos m\emptyset' \tag{6}$$

where, $V_0 = hE_0\, J_m(ka_e)$ at $\emptyset' = 0$.

V_0 : the edge voltage.

The far fields in standard spherical coordinates may be found from a potential function or from the dual solutions of circular loop antennas [21] :

$$E_\theta = -j^m \frac{k_0 a_e V_0}{2r} e^{-jrk_0} B_M(k_0 a_e \sin\theta)\cos m\emptyset \quad (7)$$

$$E_\emptyset = j^m \frac{k_0 a_e V_0}{2r} e^{-jrk_0} B_P(k_0 a_e \sin\theta)\cos\theta \sin m\emptyset \quad (8)$$

where: $$\begin{cases} B_M(X) = J_{m-1}(X) + J_{m+1}(X) \\ B_P(X) = J_{m-1}(X) - J_{m+1}(X) \end{cases} \quad (9)$$

5 Resonant Frequencies

The resonant frequencies of TM_{mn0} modes in the circular antenna are given as [24]

$$(f_r)_{mn0} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\left(\frac{U_{mn}}{a}\right) = \frac{CU_{mn}}{2\pi a\sqrt{\varepsilon_r}} \quad (10)$$

The first six values of U_{mn} are shown in table 1.

Table 1: Order mode of U_{mn} values

TM_{mn}	U_{mn}
TM_{11}	1.8412
TM_{21}	3.0542
TM_{31}	4.2012
TM_{41}	5.3175
TM_{51}	6.4156
TM_{61}	7.5013

The parameter U_{mn} determines the frequency ratio of various modes of resonant frequency.

An effective radius a_e slightly larger than the physical one has been introduced [25] to account for stray fields along the edge of the resonator :

$$a_e = a\left\{1 + \frac{2h}{\pi a\varepsilon_r}\left[ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad (11)$$

$$a = \frac{F}{\left[1+\frac{2.h}{\pi F\varepsilon_r}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right]^{\frac{1}{2}}} \quad (12)$$

where: $$F = \frac{8.791.10^9}{f_r\sqrt{\varepsilon_r}} \quad (13)$$

6 Results and Discussion

The circular antenna excited for six different modes $TM_{11}, TM_{21}, TM_{31}, TM_{41}, TM_{51}$ and TM_{61} are designed at resonance frequency 2.45 GHz, with a dielectric constant of the substrate $\varepsilon_r = 2.2$ (Rogers RT/duroid–5880).

The far field components E_θ (E–plane) and $E_\emptyset$ (H–plane) for these modes are simulated by using the equations (7) and (8) respectively. The simulation results of these components are represented in figures 2 and 3.

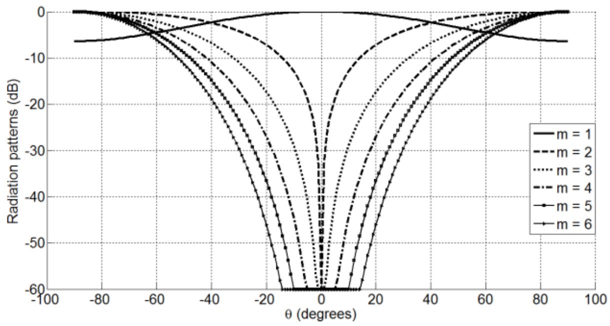

Fig. 2 : Radiation patterns E_θ (E − plane) of circular patch antenna excited in TM_{m1} at $f_r = 2.45\ GHz$, $h = 3.2\ mm$ and $\varepsilon_r = 2.2$

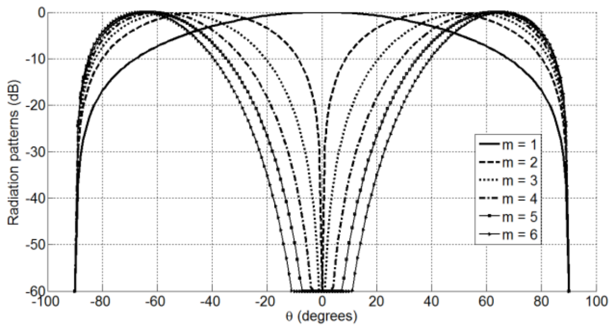

Fig. 3. Radiation patterns $E_\emptyset$ (H − plane) of circular patch antenna excited in TM_{m1} at $f_r = 2.45\ GHz$, $h = 3.2\ mm$ and $\varepsilon_r = 2.2$

From the figures 2 and 3, the far field components E_θ and $E_\emptyset$ for the dominant mode TM_{11} reach a maximum value in term of amplitude at $\theta = 0\ degrees$.

We also find that when we excite our circular patch antenna by higher order transverses magnetics modes TM_{21}, TM_{31}, TM_{41}, TM_{51} and TM_{61}, the amplitudes of the far field components E_θ and $E_\emptyset$ cancel each at $\theta = 0\ degrees$.

Indeed, the far field components E_θ and $E_\emptyset$ for the dominant mode TM_{11} present the better results in terms of amplitude at $\theta = 0\ degrees$ and half power beamwidth at -3 dB compared to the higher order modes.

7 Conclusion

In this work, we have presented the comparative study of the radiation pattern of circular patch antenna at resonant frequency 2.45 GHz for RFID application.

The simulation results show that the far field components E_θ and $E_\emptyset$ for the dominant mode

TM_{11} present the better results in term of amplitude compared to the higher order transverses magnetics modes.

The study conducted throughout this work will serve as a reference to the designer for the design and realization of the circular patch antennas for a notebook of predefined load.

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