Compact Microstrip-fed Square Loop Antenna for DTV Applications

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Abstract—A design method for a compact square loop antenna fed by a microstrip (MS) line for indoor digital television (DTV) applications is proposed. The proposed antenna consists of a square loop, circular sectors, and an MS line. The square loop combined with circular sectors is printed on one side of a substrate, and a 75 ohm MS line is printed on the other side. The circular sectors are used as a wideband balun or transition to connect the MS line and the square loop. The square loop is used instead of a circular loop in order to reduce the antenna size, and four edge slits are introduced at the corners where the square loop and the circular sectors contact each other to further reduce the antenna size. Performance of a circular loop antenna with circular sectors and performance of the proposed square loop antenna without the edge slits are compared with that of the proposed square loop antenna. A prototype of the proposed square loop antenna operating in the DTV band (470–806 MHz) is designed and fabricated on an FR4 substrate. Experiment results show that the proposed antenna has the desired impedance characteristics in a frequency band of 464–1,220 MHz (89.8%) for a voltage standing wave ratio (VSWR) < 2 covering the DTV band, and a broadside gain of 0.8–3.3 dBi in the DTV band.

Keywords—compact, square loop, microstrip-fed, circular sectors, indoor DTV

1. INTRODUCTION

Digital television (DTV) technology was developed to overcome analog TV’s disadvantages, such as low video quality and a low data rate. Since the switch from analog to digital transmission, terrestrial digital television broadcasting services have been widely used in many countries. A receiving antenna for terrestrial DTV needs to be designed to cover the frequency range of 470–806 MHz [1].
The applications for DTV-receiving antennas can be classified into two different categories: those for mobile devices, and those for indoor TV sets. The design requirements for mobile devices (such as mobile phones and laptop computers) are an omni-directional radiation pattern and a compact size to be integrated inside the devices. Various types of planar monopole and planar inverted-F–shaped antennas have been developed [2, 3].

For indoor DTV antennas in the home, size limitation is not critical, compared to antennas for mobile devices; either omni-directional or uni-directional radiation patterns are allowed. For them, dipole, log-periodic dipole array (LPDA), quasi-Yagi (QY), and loop antennas are widely used. A printed dipole antenna consisting of two asymmetric arms separated by a step-shaped feed gap was introduced [4]. A three-element LPDA antenna using fractal Koch dipole elements was designed [5]. A planar three-element QY antenna consisting of a dipole driver, a ground reflector, and a rectangular patch-type director was reported [6], and a planar tapered-loop antenna with a reflector was developed [7]. For the planar tapered-loop antenna, a PCB-type balun was used to transform the high input impedance of the loop, and this makes antenna fabrication more complicated. Therefore, a loop antenna with a simple integrated balun or transition needs to be investigated.

In this paper, a design method for a microstrip (MS)-fed compact square loop antenna with circular sectors for indoor DTV applications is presented. The circular sectors are used as a wideband balun or transition to connect a 75 ohm MS line and the square loop [8]. Note that a 75 ohm line is used instead of 50 ohms as a reference impedance for the feed, because 75 ohm coaxial cable is used for TV broadcast applications. The antenna size is reduced using the square loop instead of circular one and the slits introduced at four corners of the loop. A prototype of the proposed antenna was fabricated on an FR4 substrate, and its measured performance was compared with simulated results. The results in this work were obtained using a commercial electromagnetic simulator (CST Microwave Studio) and were validated by measurement of input voltage standing wave ratio (VSWR), gain, and radiation patterns tested in an anechoic chamber.

2. ANTENNA GEOMETRY AND DESIGN

The geometry of the proposed compact square loop antenna fed by an MS line is presented in Figure 1. It consists of a square loop with circular sectors and an MS feed line. A square loop combined with circular sectors is printed on one side of a substrate, and an MS line is printed on the other side. The end of the MS line is connected with the upper circular sector by using a via. Since the width of the 75 ohm MS line is very narrow and is similar to the diameter of the via, a circular patch with a diameter much larger than the MS line width is printed on the end of the MS line in order to connect the MS line and the via securely. The two circular sectors are used as a wideband transition to connect the 75 ohm MS line and the square loop.
To reduce the antenna size, the square loop is used instead of a circular loop, and four edge slits are appended at the corners where the square loop and the circular sectors contact each other to further reduce the antenna size. The length of the square loop is \( L \), and its thickness is \( w_1 \). The radius of the circular sectors is \( r_1 \), and the gap between the two sectors is \( g_1 \). The length and width of the four edge slits are \( l_s \) and \( w_s \), respectively. The distance between the center of the loop and the center of the via is \( d_1 \), and the radius of the via is \( r_{\text{via}} \). The width of the MS line is \( w_f \). The radius of the circular patch connecting the MS line and the via is \( r_p \). The length and width of the substrate are \( L \) and \( W \), respectively. The antenna is printed on an FR4 substrate having a dielectric constant of 4.4 (loss tangent = 0.025), and thickness \( d = 0.8 \) mm. The final design parameters to operate in a frequency range of 470–806 MHz are summarized in Table 1.

![Figure 1. Geometry of the proposed microstrip-fed square loop antenna: (a) the whole view and (b) the feed.](image-url)
Table 1. Final design parameters of the proposed compact MS-fed square loop antenna.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value [mm]</th>
<th>Parameter</th>
<th>Value [mm]</th>
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<tbody>
<tr>
<td>L</td>
<td>206</td>
<td>w_f</td>
<td>0.795</td>
</tr>
<tr>
<td>W</td>
<td>206</td>
<td>g_1</td>
<td>3</td>
</tr>
<tr>
<td>r_1</td>
<td>103</td>
<td>d_1</td>
<td>3.5</td>
</tr>
<tr>
<td>w_1</td>
<td>1</td>
<td>r_p</td>
<td>2</td>
</tr>
<tr>
<td>l_s</td>
<td>17.7</td>
<td>r_via</td>
<td>0.3</td>
</tr>
<tr>
<td>w_s</td>
<td>1</td>
<td>d</td>
<td>0.8</td>
</tr>
</tbody>
</table>

For the performance comparison, three different antenna structures are considered. The first structure is an MS-fed circular loop antenna with circular sectors, as shown in Figure 2(a). The circular loop is used instead of a square loop, and the diameter of the circular loop is the same as the length of the square loop. For the second structure, an MS-fed square loop antenna with circular sectors is considered. The last structure is the proposed MS-fed square loop with circular sectors and four edge slits.

Figure 2. Three antenna structures considered for performance comparison: (a) an MS-fed circular loop antenna with circular sectors, (b) an MS-fed square loop antenna with circular sectors, and (c) the proposed MS-fed square loop with circular sectors and four edge slits.

Figure 3 shows the simulated input impedance, reflection coefficient, and broadside gain characteristics of the three structures in Figure 2. For the MS-fed circular loop with circular sectors in Figure 3(a), the frequency band for a VSWR < 2 is 515.4–2,011.0 MHz, but it cannot cover the low frequency region of the DTV band. The input resistance varies rapidly in the range of 49–165 ohms, whereas input reactance in the band varies in the range of –48 to 48 ohms. Broadside gain (+z direction) in the DTV band is in the range of –0.6 to 3.1 dBi.

When the circular loop is replaced by the square loop, Figure 3(b)
shows that the frequency band for a VSWR < 2 shifts toward the lower frequencies at 469.0–1,368.5 MHz, and the DTV band is fully covered. The input resistance varies rapidly in the range of 51–129 ohms, whereas input reactance in the band varies in the range of –46 to 43 ohms. In this case, broadside gain in the DTV band is increased to 1.1–3.6 dBi.

To further decrease the lower limit of the frequency band, four edge slits are appended at the corners where the square loop and the circular sectors contact each other, as shown in Figure 2(c). Figure 3(c) shows the frequency band for a VSWR < 2 moves further toward the low frequencies at 459.3–1,241.5 MHz. The input resistance varies rapidly in the range of 70–127 ohms, whereas input reactance in the band varies in the range of –47 to 51 ohms. Broadside gain in the DTV band is slightly decreased to 0.8–3.3 dBi due to the size reduction.

For the proposed compact MS-fed square loop antenna, the most important design parameter for antenna performance is the gap between the two circular sectors \( g_1 \). Figure 4 shows the effects of varying \( g_1 \) on the input reflection coefficient and broadside gain characteristics of the proposed antenna. Other design parameters are the same as those in Table 1. As \( g_1 \) increases from 1 mm to 5 mm, the frequency band for a VSWR < 2 shifts toward the low frequency;
impedance matching in the frequency range of 600–700 MHz deteriorates. The broadside gain below 650 MHz increases, whereas that in the remaining high-frequency region of the DTV band decreases, as shown in Figure 4(b).

![Figure 4](image.png)

Figure 4. Effects of varying $g_1$ on the performance of the proposed antenna: (a) input reflection coefficient and (b) broadside gain.

3. EXPERIMENT RESULTS AND DISCUSSION

A prototype of the proposed compact MS-fed square loop antenna was fabricated on an FR4 substrate. Figure 5 shows photographs of the fabricated antenna.

![Figure 5](image.png)

Figure 5. Photographs of the fabricated antenna: (a) front view and (b) back view.

Figure 6 compares the simulated and measured input reflection coefficient characteristics of the fabricated antenna. The simulated and measured frequency bands of the proposed antenna for a VSWR < 2 are
459.3–1,241.5 MHz and 464–1,220 MHz, respectively. The frequency band of the measured input reflection coefficient is slightly reduced, compared to the simulated result. The simulated broadside gain is 0.8–3.3 dBi in the DTV band, whereas the measured gain ranges between 0.9 dBi and 3.0 dBi.

Figure 6. Measured performance: (a) input reflection coefficient and (b) broadside gain.

The radiation patterns of the proposed antenna in the y-z and z-x planes at 500 MHz, 700 MHz, and 800 MHz are plotted in Figure 7. The simulated and measured patterns agree quite well.
Figure 7. Measured radiation patterns in the y-z and z-x planes at (a) 500 MHz, (b) 700 MHz, and (c) 800 MHz.

4. CONCLUSION

A method for designing a compact square loop antenna with circular sectors fed by an MS line for indoor DTV applications was presented in this paper. The circular sectors are used as a wideband transition to connect a 75 ohm MS line and the square loop. The antenna size is reduced by using the square loop and four edge slits appended at the corners where the square loop and the circular sectors are in contact.

A prototype of the proposed square loop antenna operating in the DTV band (470–806 MHz) was designed and fabricated on an FR4 substrate. The length of the proposed antenna is about 0.32λ, where λ is the free space wavelength at 470 MHz. The proposed antenna has the desired impedance characteristics, with a frequency band of 464–1,220 MHz for a VSWR < 2, and a broadside gain of 0.8–3.3 dBi in the DTV band.

The proposed antenna can be useful as a receiving antenna for indoor DTV applications.
References


