Journal of information and
communication convergence engineering
http://jicce.org

J. Inf. Commun. Converg. Eng. 14(4): 222-226, Dec. 2016 Regular paper

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-Ω 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. A prototype of the proposed square loop antenna operating in the DTV band (470–806 MHz) is designed and fabricated on an FR4 substrate. Experimental results show that the proposed antenna has the desired impedance characteristics in the frequency band of 464–1,220 MHz (89.8%) for a voltage standing wave ratio (VSWR) of <2 covering the DTV band, and a broadside gain of 0.8–3.3 dBi in the DTV band.

Index Terms: Circular sectors, Compact, Indoor DTV, Microstrip-fed, Square loop

I. 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. Therefore, 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: applications 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 for integration into the devices. Thus far, various types of planar monopole and planar inverted-F–shaped antennas have been developed [2, 3].

For indoor DTV antennas at home, the size limitation is not critical, as 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. Previously, 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

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Received 07 September 2016, **Revised** 07 September 2016, **Accepted** 18 October 2016
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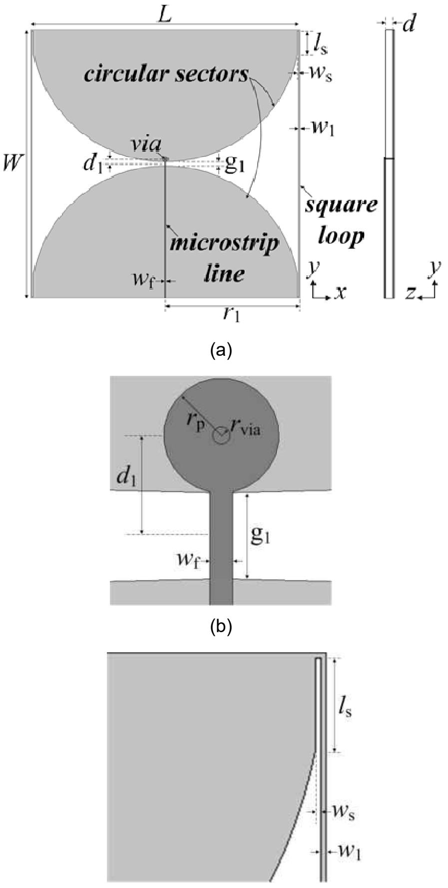
Open Access http://doi.org/10.6109/jicce.2016.14.4.222 print ISSN: 2234-8255 online ISSN: 2234-8883

developed [7]. For the planar tapered-loop antenna, a PCB-type balun was used for transforming the high input impedance of the loop, making antenna fabrication more complicated. Therefore, a loop antenna with a simple integrated balun or transition needs to be developed.

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-Ω MS line and the square loop [8]. Note that a 75-Ω line is used instead of 50 Ω as the reference impedance for the feed, because a 75-Ω coaxial cable is used for TV broadcast applications. The antenna size is reduced using a square loop instead of a circular one and the slits introduced at the four corners of the loop. A prototype of the proposed antenna was fabricated on an FR4 substrate, and its measured performance was compared with the simulation results. The results in this work were obtained using a CST Microwave Studio and were validated by a measurement of the input voltage standing wave ratio (VSWR), gain, and the radiation patterns tested in an anechoic chamber.



(a)

(b)

(c)

Fig. 1. Geometry of the proposed microstrip-fed square loop antenna: (a) the whole view, (b) the feed, and (c) the edge slit.

II. ANTENNA GEOMETRY AND DESIGN

The geometry of the proposed compact square loop antenna fed by an MS line is presented in Fig. 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 to the upper circular sector by using a via. Since the width of the 75-Ω 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-Ω 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 come into contact with each other in order to further reduce the antenna size. The length of the square loop is L, and its thickness is w_l. The radius of the circular sectors is r_l, and the gap between the two sectors is g_1. The length and the 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_l, and the radius of the via is r_{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 the 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 the frequency range of 470–806 MHz are summarized in Table 1.

For the performance comparison, three different antenna structures are considered, as shown in Fig. 2. The first structure is an MS-fed circular loop antenna with circular sectors. 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.

Table 1. Final design parameters of the proposed compact MS-fed square loop antenna

Parameter	Value (mm)	Parameter	Value (mm)
L	206	w_f	0.795
W	206	g_1	3
r_1	103	d_1	3.5
w_1	1	r_p	2
l_s	17.7	r_{via}	0.3
w_s	1	d	0.8

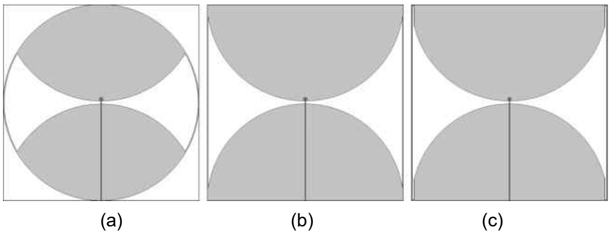


Fig. 2. Three antenna structures considered for performance comparison: (a) an MS-fed circular loop antenna with circular sectors, (b) an MS-fed square loop antenna with circular sectors, and (c) the proposed MS-fed square loop with circular sectors and four edge slits.

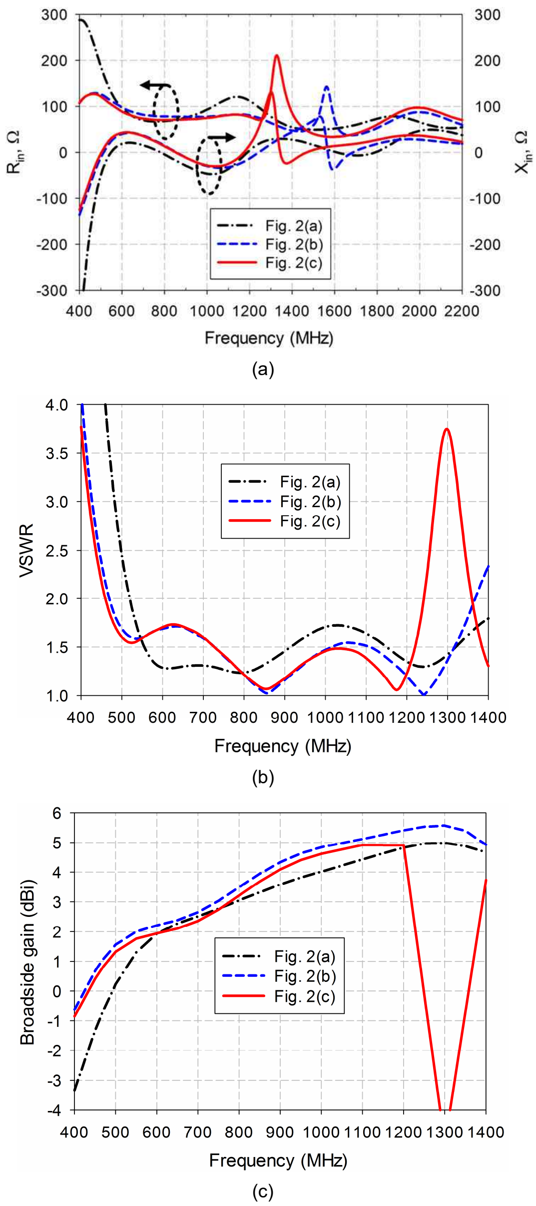


Fig. 3. Performance comparison of the three antenna structures shown in Fig. 2: (a) input impedance, (b) reflection coefficient, and (c) broadside gain.

Fig. 3 shows the simulated input impedance Z_{in} (=R_{in} + X_{in}) reflection coefficient, and broadside gain characteristics of the three structures shown in Fig. 2. For the MS-fed circular loop with circular sectors shown in Fig. 2(a), the frequency band for VSWR < 2 is 515.4–2,011.0 MHz, but it cannot cover the low-frequency region of the DTV band. The input resistance R_{in} varies rapidly in the range of 49–165 Ω, whereas the input reactance X_{in} in the band varies in the range of –48 to 48 Ω. The 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, Fig. 3(b) shows that the frequency band for 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 Ω, whereas the input reactance in the band varies in the range of –46 to 43 Ω. In this case, the 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 come into contact with each other, as shown in Fig. 2(c). Fig. 3(b) shows that the frequency band for VSWR < 2 moves further towards the low frequencies at 459.3–1,241.5 MHz. The input resistance varies rapidly in the range of 70–127 Ω, whereas the input reactance in the band varies in the range of –47 to 51 Ω. The broadside gain in the DTV band is slightly decreased to 0.8–3.3 dBi because of the size reduction.

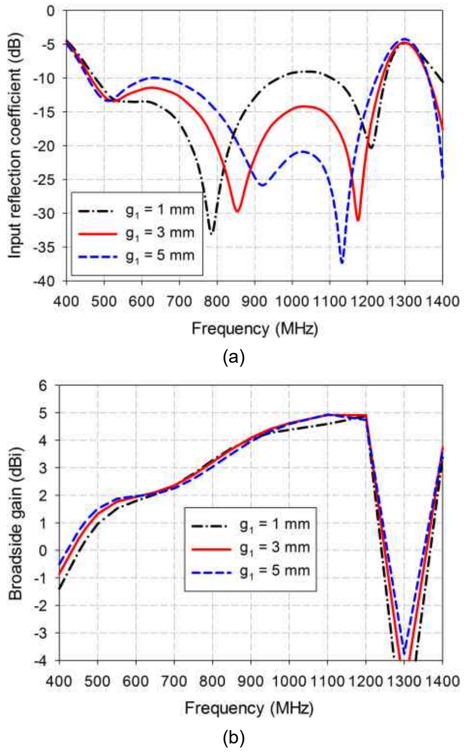


Fig. 4. Effects of varying g_1 on the performance of the proposed antenna: (a) input reflection coefficient and (b) broadside gain.

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). Fig. 4 shows the effects of varying g_1 on the input reflection coefficient and the broadside gain characteristics of the proposed antenna. Other design parameters are the same as those listed in Table 1. As g_1 increases from 1 mm to 5 mm, the frequency band for 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 Fig. 4(b).

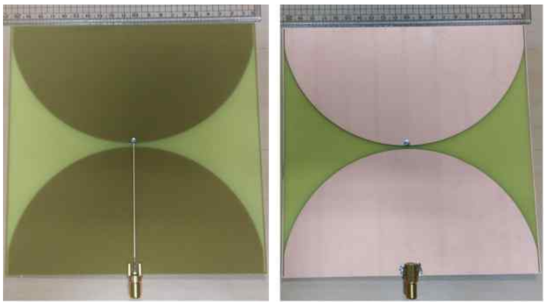
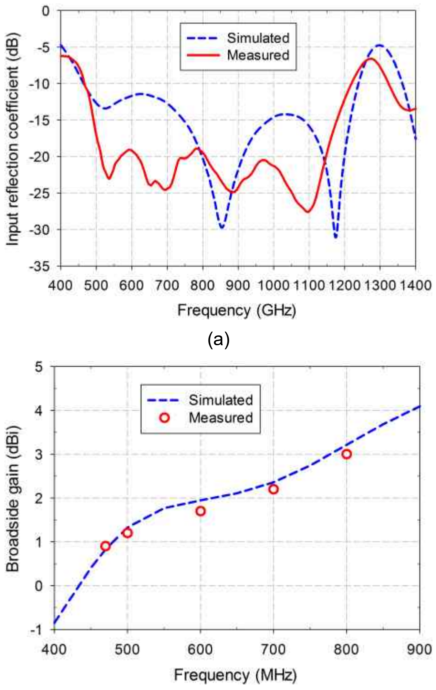
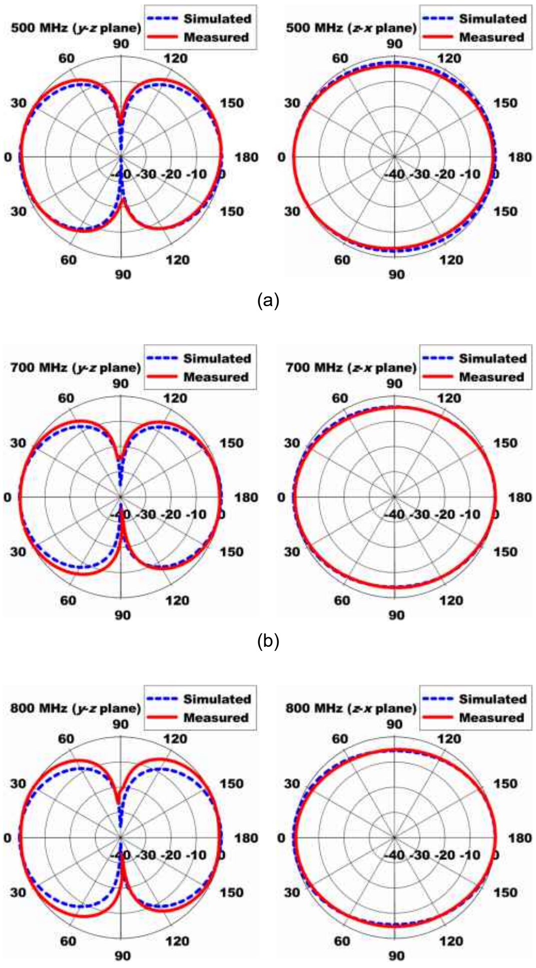

(a) (b)

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



(b)

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



(a)

(b)

(c)

Fig. 7. Measured radiation patterns in the y–z and z–x planes at (a) 500 MHz, (b) 700 MHz, and (c) 800 MHz.

III. RESULTS

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

Fig. 6 compares the simulated and the measured input reflection coefficient characteristics of the fabricated antenna. The simulated and the measured frequency bands of the proposed antenna for 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, as compared to the simulation 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.

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 Fig. 7. The simulated and the measured patterns agree quite well.

IV. 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-Ω 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 0.32 λ, where λ denotes 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 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.

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