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A NEW DUAL-POLARIZED GAP-FED PATCH ANTENNA

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Abstract—In this paper, a new compact dual-polarized microstrip patch antenna is proposed. The patch is of rectangular shape and fed by a gap between the patch edge and a microstrip open end. Gap feeding at the edge of a rectangular patch antenna is proposed for the first time in this paper. This method of feeding occupies a negligible space compared to other feeding methods such as a quarter-wave transformer feeder, an inset feeder, a proximity coupler, and an aperture-coupled feeder. Dual-polarized radiation is realized by feeding a rectangular patch with two orthogonal gaps. First, a single-polarized patch is designed. The impedance matching property of the gap is analyzed using an equivalent circuit. Next, starting from dimensions of the single-polarized patch, a dual-polarized patch antenna is designed by optimizing the patch length and gap width. The designed antenna is fabricated and tested. The fabricated antenna has reflection coefficient less than −10 dB, port isolation greater than 30 dB, over 14.5–15.2 GHz, and a gain of 6.2 dBi at 14.9 GHz.

1. INTRODUCTION

Microstrip antennas find diverse applications due to compactness, light weight and ease of fabrication [1–3]. Recently, dual-polarized microstrip patch antennas (DPMPA) are getting more attention for

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various applications. DPMPA's are usually realized by exciting a microstrip patch with two orthogonally-placed feed lines [4–9]. Among methods of feeding a microstrip patch antenna (MPA) are direct feeding with a quarter-wave transformer, direct proximity coupling, proximity coupling via an aperture in the ground plane, and feeding by a coaxial probe.

Feeding patch antennas may also be achieved by a narrow gap between a microstrip open end and the patch edge. This gap feeding method enables one to realize a dual-polarized patch antenna in a minimum space. There have been a few studies in the gap feeding method. In Yu's work [10], a ring resonator is coupled to a microstrip line via a gap. In Jung's work [11], the coupling gap is used in the inset-fed patch antenna. The method of feeding a rectangular patch and a DPMPA by a gap between a microstrip open end and the patch edge, however, has not been published to the best of authors' knowledge.

In this paper, we propose a new compact dual-polarized microstrip patch antenna fed by gap. First, we present a single rectangular patch antenna fed by a gap. Next, based on the single patch design, we describe the structure and design of a dual-polarized patch antenna fed by gap. The idea of a dual-polarized gap-fed patch antenna presented in this paper is new and authors' own contribution. The proposed antenna is analyzed and optimized using the widely-used electromagnetic simulation software Microwave Studio$^{\text{TM}}$ (MWS) by CST. The designed antenna is fabricated and its performance is measured and compared with the simulation.

2. ANTENNA DESIGN

2.1. Gap-fed Rectangular Patch Antenna

A rectangular patch of width w_p and length l_p shown in Fig. 1 is printed on a substrate and fed by the gap between the open end of a microstrip line and the patch edge. The impedance matching is achieved by a gap which transforms the impedance seen at one of two radiating edges of the patch into the characteristic impedance of the feed line, usually $50\,\Omega$.

The structure in Fig. 1 can be represented by an equivalent circuit shown in Fig. 2 [12]. The patch impedance Z_p is transformed into the input impedance Z_{in} by equivalent capacitances of the gap C_g, C_{pm} and C_{pp}. Equivalent capacitances of an asymmetric microstrip gap can be evaluated using closed-form formulas by Kirschning and co-workers [13].

The design of the antenna shown in Fig. 1 starts with the initial value of the patch size. The patch width determines the level of the

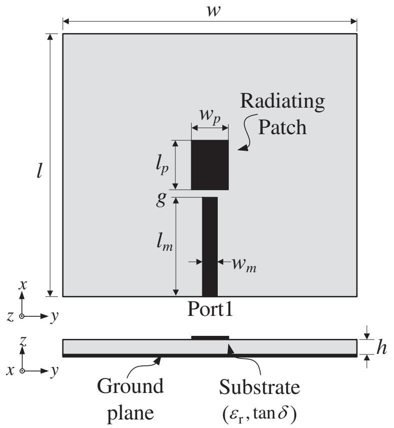


Figure 1. Structure of a rectangular patch fed by a single gap.

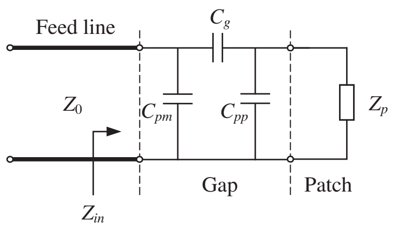


Figure 2. Equivalent circuit of a rectangular patch fed by a single gap.

radiation resistance of the patch. The patch length determines the resonant frequency. For this work, we designed the antenna for use at 14.9 GHz with a bandwidth of 400 MHz for terrestrial microwave communication applications. The proposed antenna, however, can be realized at any frequency as far as it can be fabricated within a specified tolerance. With patch initial dimensions w_p and l_p calculated using design equations in [14] for $f_r = 14.9$ GHz, $\varepsilon_r = 2.5$ and $h = 0.787$ mm, we adjust patch width w_p, patch length l_p and gap width g for good impedance matching. The final dimensions of the patch antenna are $w_p = 4$ mm, $l_p = 5.24$ mm, $g = 0.40$ mm, $w_m = 2.26$ mm, and $l_m = 16.95$ mm. The impedance seen at one edge of the patch Z_p is found to be $320 - j55\,\Omega$ from the simulation by Microwave Stuio$^{\text{TM}}$, which is then transformed into the input impedance $Z_{in} = 50 - j0.02\,\Omega$ by capacitances $C_{pm} = 0.051$ pF, $C_{pp} = 0.162$ pF, and $C_g = 0.035$ pF. Values of capacitances C_{pm}, C_{pp}, and C_g are calculated using formulas in [13].

The width 2.26 mm of a 50-ohm microstrip line on a 0.787-mm thick substrate is not small compared with the width of the patch. To verify that the line operates in its fundamental quasi-TEM mode, we have calculated the frequency $f_{HE,1}$ for the onset of the HE_1 mode [15] and the frequency f_{CT} for the lowest-order transverse microstrip resonance using formulas in [16] and obtained $f_{HE,1} = 25.4$ GHz and $f_{CT} = 36.8$ GHz, which are much larger than the operating frequency 14.9 GHz of the antenna. Therefore the 50-

ohm microstrip should perform satisfactorily in its quasi-TEM mode. It is well known that the radiation from a uniform microstrip line operating in its fundamental quasi-TEM mode is very small. Some radiation may occur at discontinuities in the microstrip line. In the case of the proposed antenna, the only discontinuity is the microstrip open end, which in our case is part of the radiating aperture.

Figures 3 and 4 show the simulated reflection coefficient and the gain pattern, respectively, of the patch antenna of Fig. 1. The antenna has a very low reflection coefficient of -45 dB at the resonant frequency 14.9 GHz. The impedance bandwidth (-10 dB reflection) is 4.15% (620 MHz), the antenna gain is 6.8 dBi, and 3-dB beamwidths are 89° and 77° in vertical and horizontal planes, respectively.

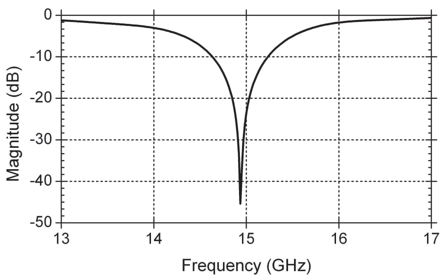


Figure 3. Reflection coefficient of a rectangular patch fed by a single gap.

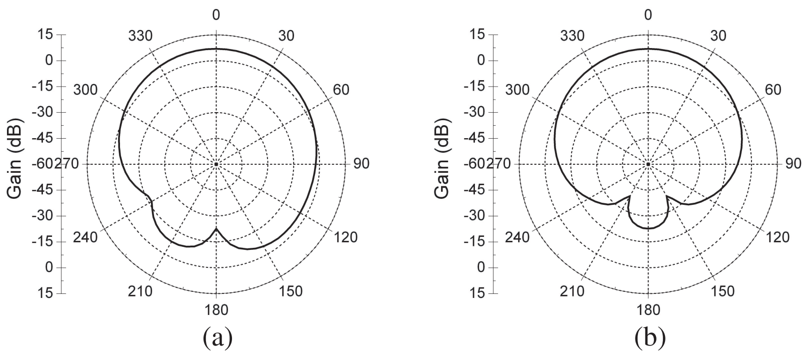


Figure 4. Gain patterns of a rectangular patch fed by a single gap. (a) Vertical and (b) horizontal planes.

2.2. Dual Polarized Gap-fed Patch Antenna

The proposed antenna shown in Fig. 5 is fed by two orthogonal gaps. First, dimensions of a rectangular patch fed by a single gap are used as the initial dimensions of the dual-polarized patch. With initial dimensions un-modified, the dual-polarized antenna has poor performance as can be seen in Fig. 6, where the reflection and isolation performances of the un-optimized patch are shown. The patch impedance Z_p is not well matched to the characteristic impedance Z_0 of the feed line.

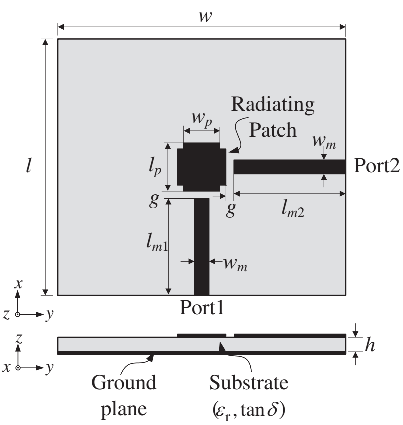


Figure 5. Structure of the proposed antenna.

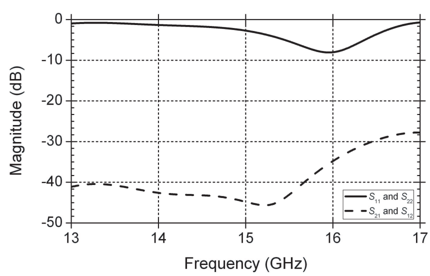


Figure 6. Reflection and isolation coefficients of the un-optimized dual-polarized patch.

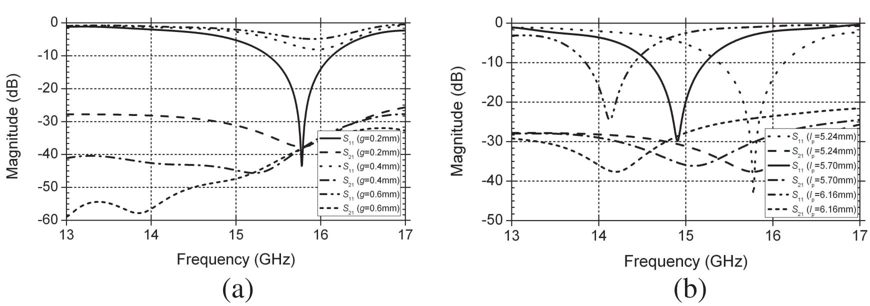


Figure 7. Parametric analysis of the dual-polarized patch by changing. (a) Gap width and (b) patch length.

The parametric studies are carried out to find the effect of the patch length and the gap width as shown in Fig. 7, from which we derive a method of antenna optimization. First, the antenna impedance matching is achieved by adjusting the gap width, and then we adjust the patch length to obtain a resonance at the desired frequency. Final dimensions of the proposed antenna are summarized in Table 1.

Table 1. Dimensions of the proposed antenna.

Parameters	**Designation**	**Dimensions (mm)**
Substrate material	Glass-reinforced Teflon	$\varepsilon_r = 2.5$, $\tan\delta = 0.001$
Substrate size	$w \times l \times h$	$45.0 \times 40.00 \times 0.787$
Patch width	w_p	4.00
Patch length	l_p	5.70
Gap width	g	0.20
Microstrip line width	w_m	2.26
Microstrip line length	l_{m1}	16.95
	l_{m2}	19.45

3. MEASUREMENTS

The proposed antenna is fabricated and its performance is measured and compared with the simulation. The fabricated antenna is shown in Fig. 8, where the antenna circuit board is placed on a metal block and coaxial-to-microstrip adaptors are used to connect the antenna to test equipments. Such performance of the fabricated antenna as gain, reflection coefficient, port isolation and radiation patterns are measured using a network analyzer (HP 8720C) and far-field antenna test instruments in an anechoic chamber.

Figure 9 shows a comparison of the measured and simulated reflection coefficients and port isolations of the proposed antenna. Measured results agree well with the simulation. The reflection coefficient of the antenna is less than -10 dB and the port isolation is greater than 30 dB over 14.5–15.2 GHz. In [4] and [6], the port isolation in a dual-polarized patch is 28 dB and 20 dB respectively.

Figure 10 shows gain patterns at 14.9 GHz with the antenna excited at port 1 and the port 2 connected to a matched load. The proposed antenna's gain is 6.2 dBi, and its 3-dB beamwidths are 109° and 62° in vertical and horizontal planes, respectively. Measured gain patterns agree with the simulation in the upper hemisphere, where the maximum error in gain is 2.5 dB.

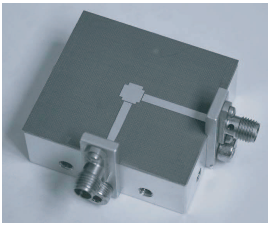


Figure 8. Fabricated antenna.

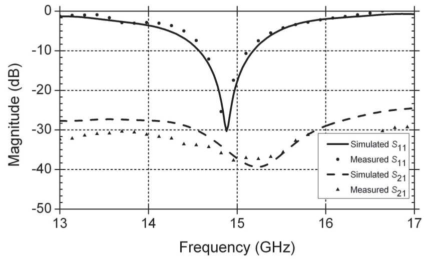
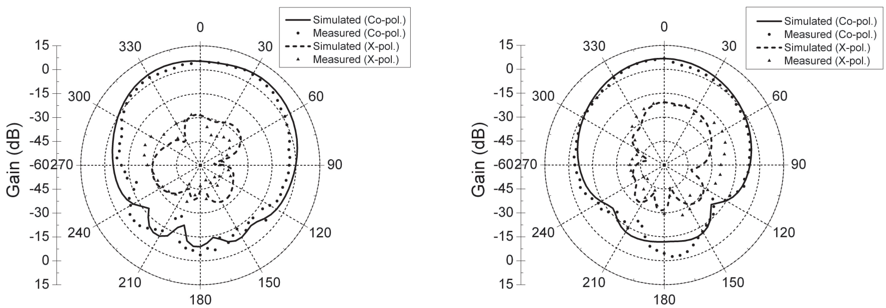


Figure 9. Reflection and isolation performances of the fabricated antenna.



(a) (b)

Figure 10. Gain patterns of the fabricated antenna at 14.9 GHz on (a) vertical and (b) horizontal planes.

4. CONCLUSION

In this paper, we proposed a new compact dual-polarized microstrip patch antenna. Dual-polarized radiation, good impedance matching, high port-isolation, and compactness of feeding are achieved by feeding a rectangular patch with two orthogonal gaps between the patch edge and a microstrip open end. The impedance matching property of the gap is analyzed using the equivalent circuit representation of the antenna. The patch length and gap width are adjusted to obtain the final optimized antenna. The designed antenna is fabricated and tested. Measurements of the fabricated antenna show that the proposed antenna has a gain of 6.2 dBi, 3-dB beamwidths of 109° and 62° in vertical and horizontal planes, respectively, at 14.9 GHz. The reflection coefficient is less than −10 dB and the port isolation is greater than 30 dB over 14.5–15.2 GHz. The dual-polarized patch antenna proposed in this paper can be utilized in such applications as dual-polarized reflector antenna feeds and dual-polarized patch arrays where the feed circuit of the radiating element needs to be realized in a minimum space.

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