Design and Fabrication of Axially Symmetrical Quasi-Self-Complementary Antenna on Liquid Crystal Polymer Film

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Abstract

In this paper, a novel dual-band axially symmetrical quasi-self-complementary (AS-QSC) antenna is designed and fabricated on Liquid Crystal Polymer (LCP) film. Compared to the conventional AS-QSC structure, two transmission bands are created by integrating both H–shaped monopole and L-shaped notch together. The bandwidth of 10–dB return loss for each of two separate impedance bands is 430 MHz (centered at 3.95 GHz) and 520 MHz (centered at 5.5 GHz), respectively. The simulated radiating pattern and gain performance of the proposed antenna are shown and further investigated. The processes to reduce the overall size and improve the radiating patterns are demonstrated. The simulation results agree well with measured results.

***Keywords* -- Axially symmetrical quasi-self-complementary (AS-QSC) antenna, dual-band antenna, liquid crystal polymer (LCP), millimeter-wave, monopole and notch.**

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I. INTRODUCTION

There exists an increasing demand in high data rates and reduced latency for broadband wireless networks used in the upcoming fifth-generation (5G) communication system. During the early stage, sub-6 GHz (3.7~4.2 GHz) system which can use the existing communication system hardware without many changes and provide a broad operation band of 400 MHz has been acquired a great attention.

To provide the key features of 5G networks, a broadband antenna is required. The self-complementary (SC) antenna which was firstly demonstrated by Yasuto Mushiake [1]-[2] is commonly used for providing the wide operation bandwidth. In [3], additional resonances are excited and the bandwidth is increased up to 130% by embedding a pair of variable L-shaped slots and truncating in the ground plane. However, the size of such a wideband antenna is large. The application of combining both folded and self-complementary structures in [4] is proven to be very effective method for bandwidth improvement by more than 100%. A dongle-sized quasi-self-complementary UWB antenna [5] is proposed to radiate at both ultra-wide band and Bluetooth band and provide additional band-notch characteristics at WLAN frequency band. An L-shaped antenna having self-complementary structure on a finite-sized flat ground plane is investigated in [6]. The characteristics including the radiation efficiency and VSWR are further discussed with respect to the antenna dimensions. A monopole and a slot as its complementary element in [7] act as an antenna to achieve fairly wideband characteristics. A quasi-self-complementary antenna fed by a 50Ω coplanar waveguide is proposed for ultra-wide bandwidth applications [8]. It can offer an ultra-wide impedance bandwidth and feature a compact size without using a matching circuit.

The axially symmetrical self-complementary (AS–SC) has been an interesting research topic because of its constant input impedance and extremely wide bandwidth. The conventional wideband AS–QSC can be converted into a dual-band antenna with suitable modification. In this paper, a novel dual-band axially symmetrical quasi-self-complementary (AS-QSC) antenna centered at 3.95 and 5.5 GHz is designed and fabricated on Liquid Crystal Polymer (LCP) film. The Liquid Crystal Polymer (LCP) film becomes a very appealing substrate because of its low loss (tan δ= 0.002-0.005) up to 110 GHz [9] and near hermetic nature (water absorption < 0.04%). Also, it has additional advantages of inherent flexibility, stable relative dielectric constant and low melting temperatures. The LCP is considered to be highly promising material for sub-6G and mm-wave applications.

The paper is organized as follows. Section II presents the design and principle of LHL–shape antenna with AS–QSC structure. In Section III, both simulations and measurements results of the proposed antenna are further discussed. Finally, conclusions are given in Section IV.

II. QUASI-SELF-COMPLEMENTARY ANTENNA DESIGN

Fig.1 shows the geometry of the proposed AS–QSC antenna. Two L–shaped strips are integrated with the H-shaped strip to provide dual operation bands. The AS–QSC antenna is fabricated on a flexible substrate with dielectric constant $\varepsilon_r = 3$ and thickness of 0.1 mm, and. The microstrip feeding line with step impedance at the back side of the substrate is designed to match 50Ω. To implement the antenna in package technology, the extra via from the back side to the front side is required to connect with other RF modules. The simulations are conducted using the ANSYS HFSS software.

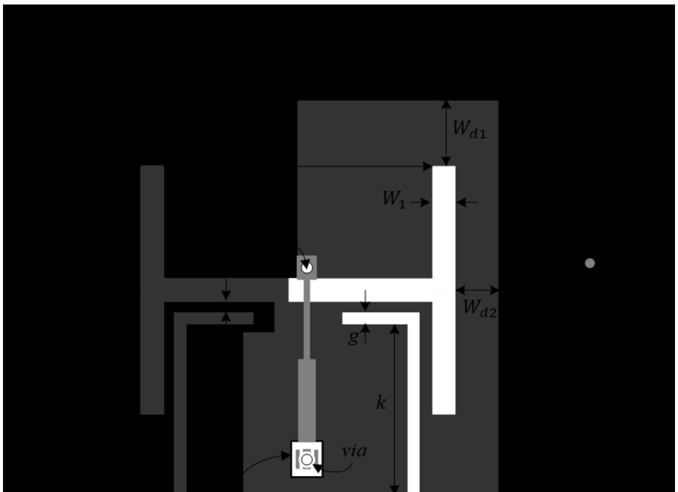


Fig. 1 Proposed of the axially symmetrical quasi-self-complementary antenna.

A. The H-shaped QSC Antenna Design

Base on [4], the basic transmission line model is employed to analyze the proposed H-shaped antenna shown in Fig. 2. The width W_1 of radiating slot is firstly chosen to provide the required characteristic impedance at the center frequency of 5.5 GHz. The half wavelength l of the radiating slot section at the corresponding operation frequency can be calculated. The series slot-lines reactance of X_t terminated on both ends need to be considered, as given by

$$X_t = Z_{os} tan\left[\frac{2\pi}{\lambda_{os}} \times \left(\frac{l}{2} - W_1 \times 2\right)\right] \quad (1)$$

where Z_{os} and λ_{os} are the characteristic impedance and the guided wavelength of the slot-line, respectively. Once the terminated reactance of X_t is obtained, the length l'' of series slot-line can be determined using the following expression

$$l'' = tan^{-1}\left(\frac{X_t/2}{Z_{os}'}\right) \times \frac{\lambda_{os}'}{2\pi} \quad (2)$$

where Z_{os}' and λ_{os}' are the characteristic impedance and the guided wavelength of the terminating slot-line. The values for l and l'' are found to be l = 14 mm and l'' = 8.5 mm, respectively. Fig.3 shows the return loss and bandwidth of the proposed H-shaped antenna.

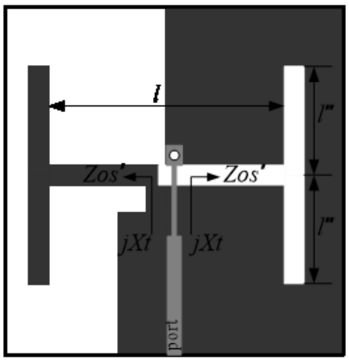


Fig. 2 The wideband axially symmetrical quasi-self-complementary antenna.

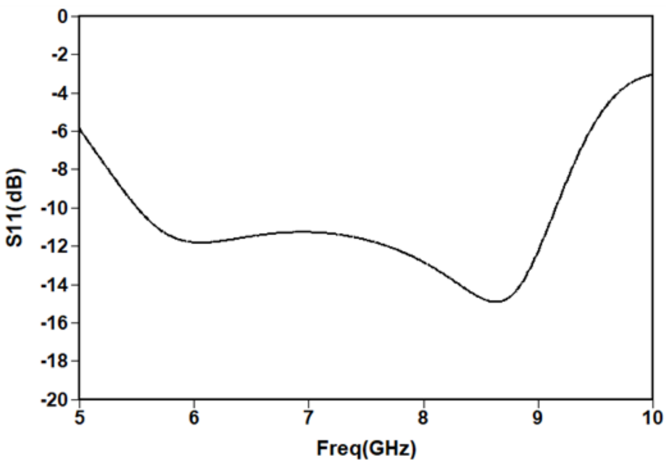


Fig. 3 Simulated return loss versus frequency for wideband axially symmetrical quasi-self-complementary antenna.

B. The L-shaped Strip-line Design

To provide another operation band, the L-shaped strip is added. The configuration of the L-shaped strip is shown in Fig. 4.

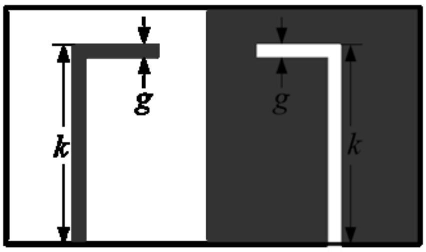


Fig. 4 The L-shaped strip configuration.

The length of the L-shaped strip is given by [10]

$$k = \frac{3 \times 10^8}{4 f_0 \sqrt{\varepsilon_r}} - \Delta k \qquad (3)$$

where f_0 is the operation frequency of the designed antenna and ε_r is the LCP dielectric constant. The parameters k and g, the length of the L-shaped strip and the gap width, can determine the resonant frequency of the L–shaped strip. The modification term Δk is an effective length resulting from the effect of the gap g. The analysis model for L–shaped strip can be constructed through manipulations of a pair of coupled lines and termination conditions. This L–shaped strip and its complementary are integrated with the H shaped QSC structure to excite another passband. Besides, the impedance matching in the higher band becomes worse when gap s between L–shaped strip and H–shaped strip gets closer. This is demonstrated in Fig. 5 and Fig. 6.

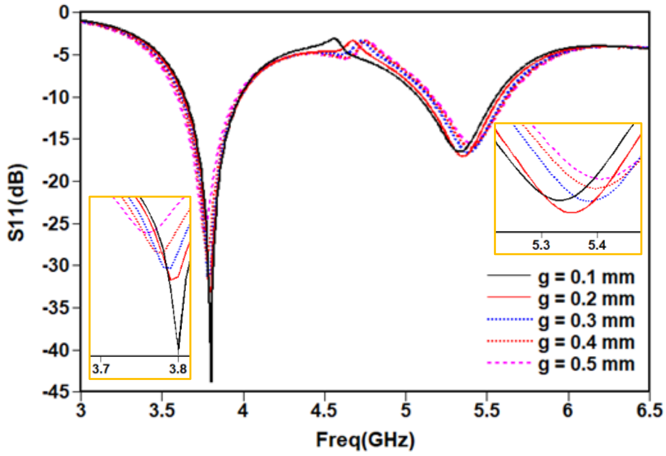


Fig. 5 Simulated return loss versus frequency for various g.

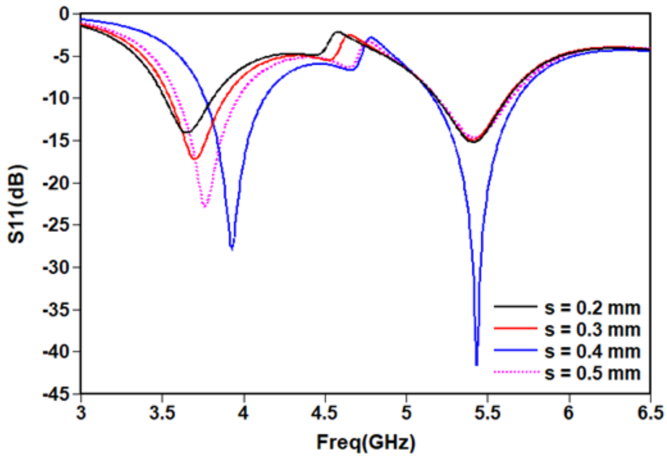


Fig. 6 Simulated return loss versus frequency for various *s* between L–shaped strip and H–shaped strip.

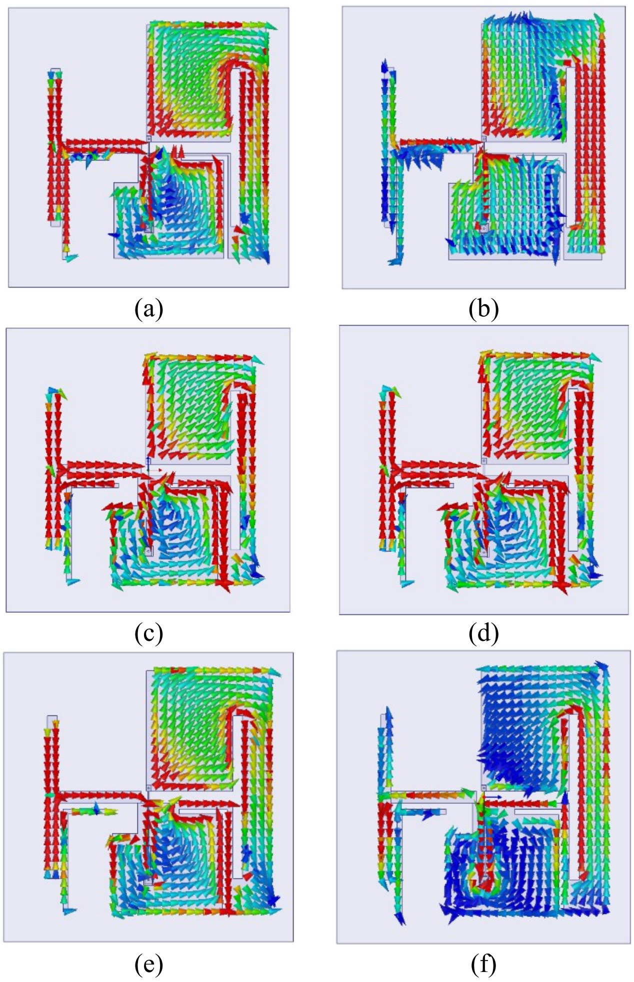
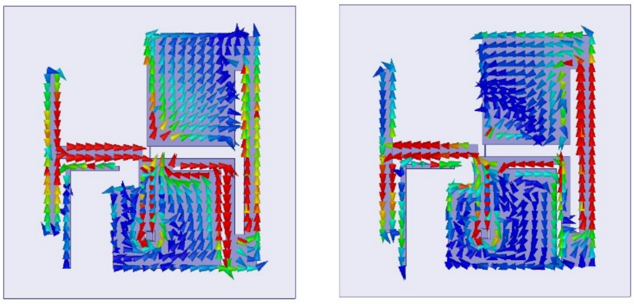


Fig. 7 Simulated surface current distributions at (a) 3.95 GHz and (b) 5.5 GHz with s = 0.2 mm, (c) 3.95 GHz and (d) 5.5 GHz with s = 0.4 mm (e) 3.95 GHz and (f) 5.5 GHz with s = 0.5 mm.



(a) (b)

Fig. 8 Simulated surface current distributions at (a) 3.95 GHz and (b) 5.5 GHz of the proposed antenna.

The surface current distributions simulated at 3.95 and 5.5 GHz are shown in Fig. 7 and Fig. 8.

C. Finite Ground Plane Considerations

Fig. 9 displays the comparison of simulated return loss of the proposed AS–QSC antenna for W_{d1} varying from 2.00 to 2.75 mm. It is shown that the upper band can be independently controlled and shift to the lower frequency as W_{d1} becomes longer, meanwhile, the lower operation band remained unchange.

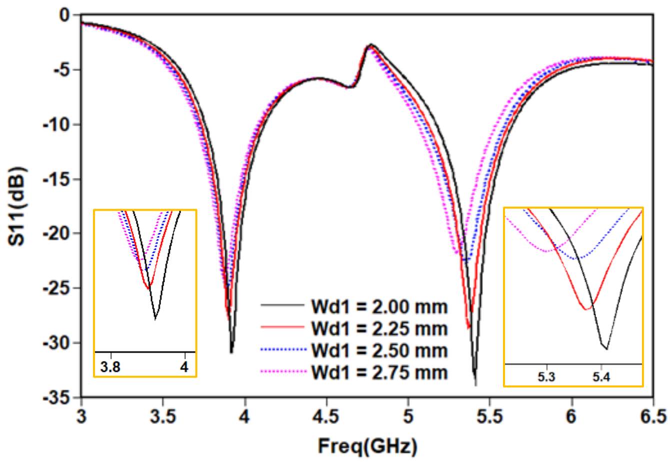


Fig. 9 Simulated return loss versus frequency for various W_{d1} values.

l = 14 mm	l'' = 8.5 mm	W_1 = 0.8 mm	k = 10 mm
g = 0.4 mm	s = 0.4 mm	W_{d1} = 2.25 mm	W_{d2} =0.2 mm
L = 17 mm	W = 19 mm		

III. RESULTS AND DISCUSSION

For the E-plane pattern, $E_\theta(\theta)$ was measured in the $\varphi = 0^\circ$ plane. The measurement of $E_\varphi(\theta)$ in the $\varphi = 90^\circ$ plane provides the H-plane pattern of the antenna. Fig. 10 exhibits polarizations and radiation patterns the proposed dual band AS-QSC antenna. Fig. 11 shows the pattern of Fig. 10 in three-dimensional, spherical displays. In Fig. 11 (a), it is observed that that the radiation coverage is well in x–y plane at 3.95GHz, and the antenna operation in H-plane is omni–directional, and in E-plane is figure–eight directional. In Fig. 11 (b), it is noticed that the radiation pattern at 5.5 GHz have nulls in both radiation plane because of the finite dimensions of the ground plane and discontinuities.

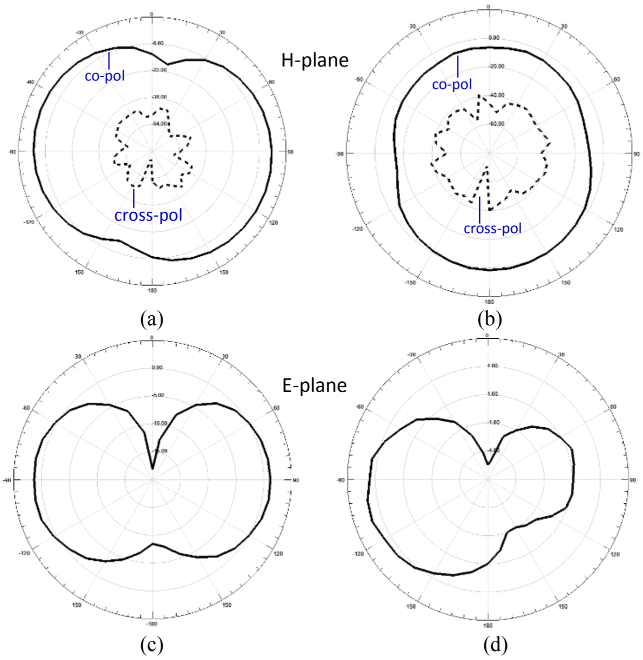


Fig. 10 2—D radiation patterns of the proposed antenna with co-pol and cross-pol at (a) 3.95 GHz and (b) 5.5 GHz and $\varphi = 0^{\circ}$ E-plane at (c) 3.95 GHz and (d) 5.5 GHz.

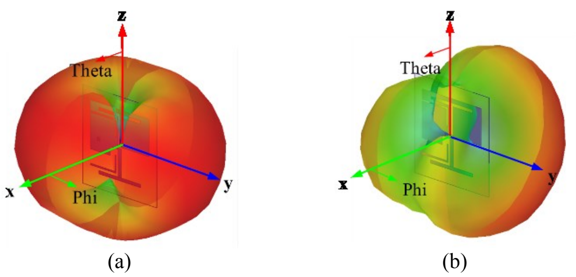
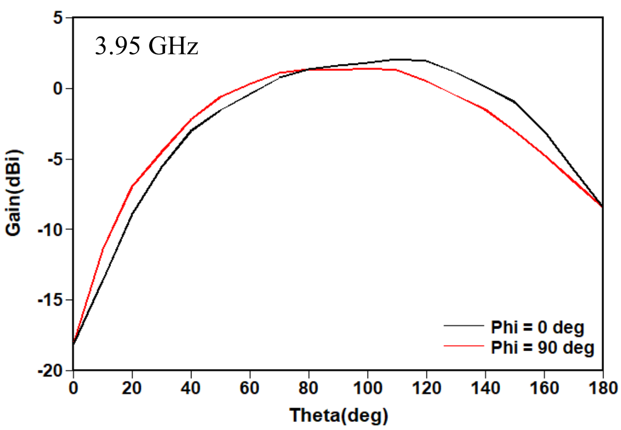
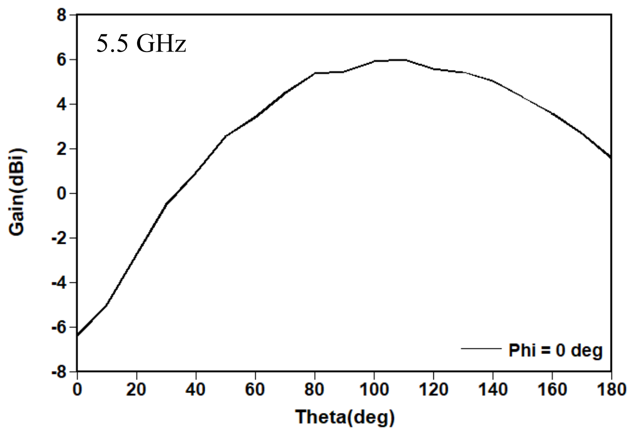


Fig. 11 3—D radiation pattern of the proposed antenna at (a) 3.95 GHz and (b) 5.5 GHz.

For the simulated gain values shown in Fig. 12, the radiation pattern of the proposed antenna is about 2.08 dBi in Fig. 12(a), and is about 6.03 dBi in Fig. 12 (b). The finite ground plane leads to the nulls in the radiation pattern and limits the gain performanc.



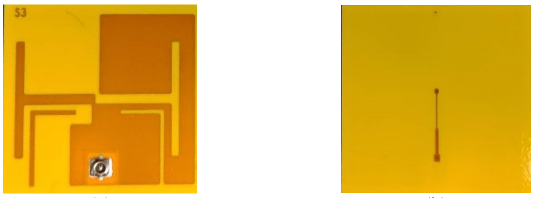
(a)



(b)

Fig. 12 Simulated radiation pattern of the proposed antenna at (a) 3.95GHz and (b) 5.5GHz.

The prototype of the proposed microstrip line fed QSC antenna is shown in Fig. 13. It is processed on the novel LCP substrate which is a thermosetting material.



(a) (b)

Fig. 13 The prototype of the proposed microstrip line fed quasi-self-complementary antenna, (a) front side and (b) back side.

Fig. 14 displays the measured return loss curves of the proposed antenna. The measured 10–dB return loss of two operation bands is from 3.80 to 4.15 GHz at the sub–6 G band and from 5.25 to 5.75 GHz at the WLAN band. Compared to the simulation results, the lower band is from 3.77 to 4.20 GHz and the upper band is from 5.17 to 5.69 GHz. The simulation results agree well with measured ones.

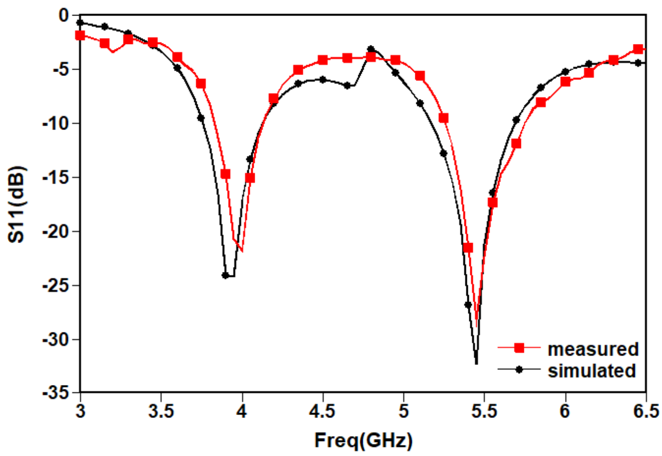


Fig. 14 Simulated and measured return loss curves of the proposed antenna.

IV. CONCLUSIONS

A novel quasi–self–complementary antenna is designed and investigated in this paper. It exhibits well electrical small dimensions,0.32 $\lambda_g \times 0.35\ \lambda_g$, and satisfactory impedance bandwidth for both sub–6 GHz band and WLAN band. Also, the results show that LCP materials is suitable for passive components design in radio frequency communication systems. The conventional wideband AS–QSC antenna can be converted to a dual-band antenna with suitably designing the length and gap of the HL–shaped structure. It has been shown that the flexible substrate LCP can offer both wide impedance bandwidth and well return loss bandwidth at the same time.

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