A Novel Herringbone Circularly Polarized Quasi Lumped Antenna Array

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***Abstract* ─** Herein, a series herringbone fed traveling wave quasi-lumped circularly polarized antenna array is presented. The proposed quasi-element antenna comprises a narrow strip inductor parallel to the interdigital capacitor. The inductor was placed at the center finger and shorted across the interdigital capacitor with pad capacitors connected at both ends of the structure. Circular polarization was achieved by feeding the quasi elements at the corners with a 90° phase difference along a travelling wave microstrip feed line. The proposed quasi-lumped element antenna has the potential to realize significant size reductions, and it will ultimately be lightweight, small volume, and inexpensive. The antenna characteristics of the array antenna, including return loss and radiation patterns, were characterized. The size of the antenna structure was 21 mm × 38 mm, allowing for potential use in wireless communication systems that use the 5 GHz ISM band.

***Index Terms* ─** Array, circularly polarization, gain, herring fed, quasi lumped, radiation pattern, return loss.

I. INTRODUCTION

In modern communication systems, circularly polarized (CP) antennas are favored over linearly polarized (LP) antennas owing to their flexibility in terms of steering angle between the transmitting and receiving antenna [1]. CP antennas are more suitable for several applications including mobile and fixed satellite systems, remote control, telemetry, wireless communication, and radar systems in which the multi-path fading, absorption, and reflectivity are major concerns [1–5].

Over the past two decades, researchers have developed several CP antennas designs that suffer from narrow axial ratio bandwidth for lower frequency ranges [1–6]. To enhance the CP radiation, different shapes of patches and slots were prepared, including L-shaped [3] and lightning-shaped slots [5], and the insertion of inverted and stepped L- or T-shaped strips was reported [6,7]. In [7–10], different phase feeding topologies featuring seven quarter-wave transformers in circular [3] and circular arc-shaped patterns [8]. An overall improvement of the CP array performance can be achieved using the sequential rotation phase feeding method. A sequential rotation feed network is typically designed using different power divider circuits. Furthermore, multi-band and single antenna topologies have been reported to enhance bandwidth [11–13].

To date, many feeding techniques have been reported for achieving improved CP properties in microstrip antenna arrays. For instance, series feed [14], parallel feed [15], and sequential rotation feed [16] techniques have been developed. Parallel and corporate feeds have advantages in terms of excitation networks for printed antenna arrays and exhibit design flexibility and facile formation of two-dimensional arrays [15]. However, these methods have some drawbacks during prototyping, including unbalanced pattern and mutual coupling effects between the elements and feed network. The series feed topology represents a more concise network because it requires shorter transmission lengths and less junctions, resulting in lower insertion loss. However, it experiences narrow bandwidth and inherent phase differences caused by the differences in feed line lengths [17].

The purpose of this article is to acquire a circular polarization and to reduce array size. The circular polarization produced will use the herringbone feeding technique and the quasi-lumped elements used to reduce array size.

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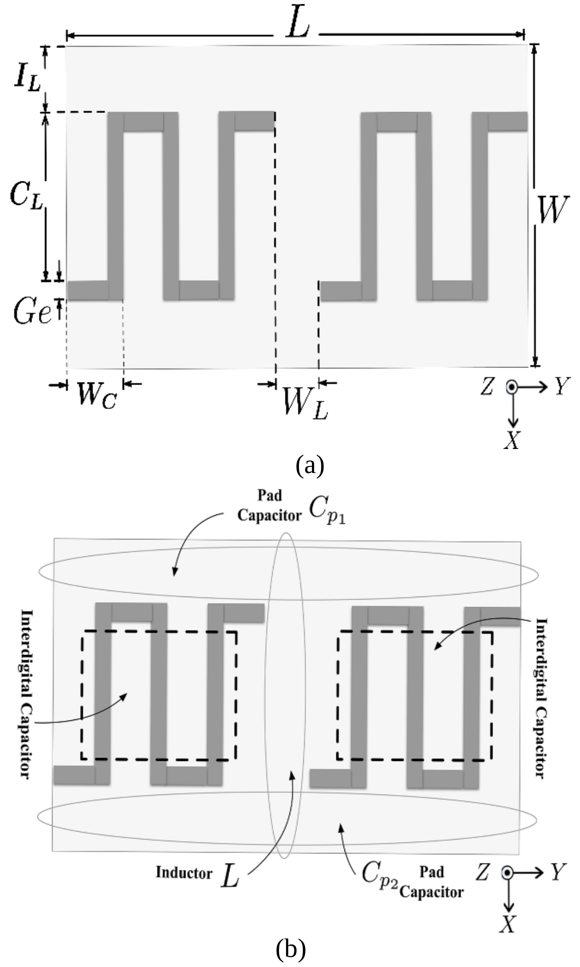
Section 2.1 shows the configuration of a single radiating element. The array used for the herringbone feeding technique is presented in Section 2.2. In Section 3, the S11 and radiation pattern results are presented.

II. SINGLE ELEMENT ANTENNA GEOMETRY

By definition, lumped elements are much smaller than their respective wavelengths. Thus, microstrip shorts and stubs with physical lengths of less than a quarter-wavelength at the operating frequency are required for approximate microwave operation of lumped elements in microstrip structures and are referred to as quasi-lumped. A schematic of the quasi-lumped element resonator is shown in Fig. 1. Whilst, the equivalent lumped circuit is shown in Fig. 2. The proposed resonator antenna consists of a narrow straight strip inductor in parallel with an interdigital capacitor [18].



(a)

(b)

Fig. 1. The proposed resonator antenna: (a) the allocation of equivalent lumped elements, and (b) the parameters used to calculate the equivalent lumped elements.

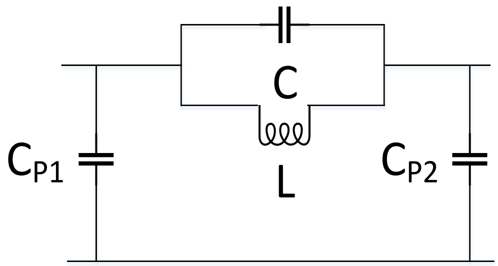


Fig. 2. Equivalent circuit of the proposed antenna.

The equation used to determine the resonant frequency of the proposed antenna has been previously reported [19,20,21]:

$$f=\frac{1}{2\pi\left[\sqrt{\left(L\left(C_{p1}C_{p2}/(C_{p1}+C_{p2})\right)+C\right)}\right]}. \quad (1)$$

From Equation (1), the resonance frequency is determined by the equivalent lumped elements L, C_{p_1}, C_{p_2} and C. These lumped elements were calculated by solving Equations (2) to (6) in an iterative manner using Matlab®.

The inductor L is a single, narrow and straight conductor positioned at the center. The inductance can be calculated by Equation (2):

$$L=200\times10^{-9}I_L\left[\ln\left(\frac{2I_L}{W_L+h}\right)+0.50049+\frac{W_L}{3I_L}\right]. \quad (2)$$

Where h is the substrate thickness.

The interdigital capacitor, C, is a multi-finger periodic structure and the capacitance arises across a narrow gap between the conductors. These gaps are very long and can be folded to reduce the area and form a lumped element. The equation used to determine the series capacitance of the interdigitated structure is Equation (3):

$$C=\varepsilon_0\left(\frac{\varepsilon_r+1}{2}\right)\left[(N\text{-}\Delta)C_L\right]. \quad (3)$$

Where,

N is the fingers number,

Δ is the correction factor $\Delta=0.5\left(w_{eff}\text{-}w\right)$,

$w_{eff}=1.5\times10^{-3}$, w is the finger width.

The length of interdigital finger C_L is calculated by Equation (4). Whilst, the width of the whole structure is calculated by Equation (5):

$$I_L=C_L+g_e, \quad (4)$$

$$w=2\times I_L^{/}+I_L. \quad (5)$$

The parasitic capacitors C_{p_1} and C_{p_2} connected at both ends of the structure, act as capacitors to ground. By adjusting the parasitic capacitors, the resonant frequency of the resonator can be tuned. Equation to determine pad capacitances is given in Equation (6):

$$C_P = \left[\frac{2.85\varepsilon_{eff}}{\ln\left[1+(1/2)(8h/\varepsilon_{eff})\left[(8h/\varepsilon_{eff})+\sqrt{(8h/\varepsilon_{eff})^2+\pi^2}\right]\right]} \right], \times \frac{1}{25.4\times10^{-3}} \tag{6}$$

where h is the substrate height.

The radiating element dimensions were obtained from Equations (2) – (6). Table 1 shows the dimensions of a single quasi lumped antenna at the targeted resonance. The parameters were determined using Equations (2) – (6) at a resonant frequency of 5.8 GHz, whereas the resonant frequency was calculated using Equation (1). Table 2 presents the equivalent lumped elements for single quasi lumped antenna.

Table 1: The proposed antenna quasi-lumped element parameters

Parameter	**Dimension [mm]**
W_C	0.35
I_L	3.35
C_L	3.05
N	8
$I_L^{/}$	1.23
g_e	0.3
W_L	1.2
L	5.4
W	5.8
h	0.813

Table 2: The proposed antenna design parameters

C	**C_{P1}**	**C_{P2}**	**L**
0.347 PF	0.17 PF	0.17 PF	1.74 nH

III. CONFIGURATION OF ARRAY FEED

The proposed herringbone antenna design comprises four identical resonating elements. These resonators consist of resonant quasi-lumped elements fed in a quadrature at a design center frequency of 5.8 GHz. The resonators were oriented at ±45° with respect to the feeding line. The quadrature feed yields in the excitations were 90° out of phase. Hence, the technique naturally exhibits circular polarization [22]. The resonators were allocated by to achieve a quadrature phase. In each resonator, the return phase of the reflection from the second element was 180° out of phase with the reflected wave from the initial element [23]. Thus, reflection enhancement is inherently achieved by the resonator design. The first resonator trigger along the feed line dictates the leading phase and the circular polarization orientation. The herringbone antenna has a shorter feeding line than that of a meandering antenna, resulting in array size reduction [24]. Figure 3 presents the prototyped antenna array in CST Microwave Studio.

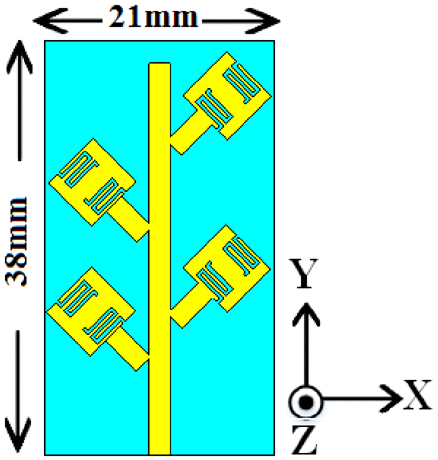


Fig. 3. The 5.8 GHz proposed herringbone array. [Microstrip length is 36 mm].

IV. RESULTS AND DISCUSSIONS

Figure 4 shows the fabricated antenna array on an RO4003C microwave substrate with a relative permittivity of 3.38 and a thickness of 0.813 mm.

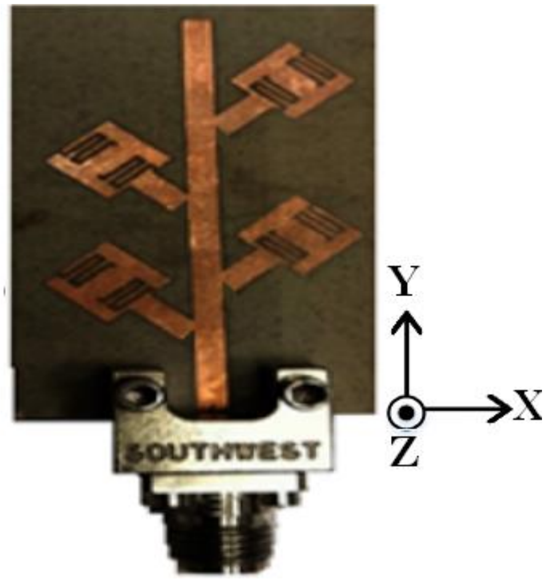


Fig. 4. The 5.8 GHz prototyped herringbone array.

The simulation and measurement results for the input return loss are shown in Fig. 5. The minimum simulated input return loss for a frequency fine-tuned to 5.788 GHz was –14.21 dB, whereas the minimum measured return loss was approximately –15.84 dB at 5.79 GHz. These results indicate the antenna was resonating at the designed frequency.

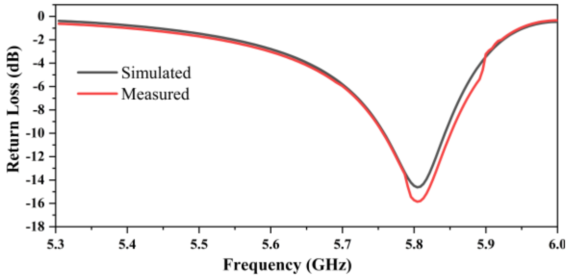


Fig. 5. The simulated and measured return loss results.

Figure 6 shows the simulated and measured co-polarization and cross-polarization patterns in the xz-plane at 5.788 GHz. Cross-polarization was higher than co-polarization by approximately 20 dB in the broadside direction, which is characteristic of left-hand circular polarized (LHCP) radiation. The gain of the array was improved to 5.28 dBi compared to that of a single element, which showed a gain of 1.33 dBi.

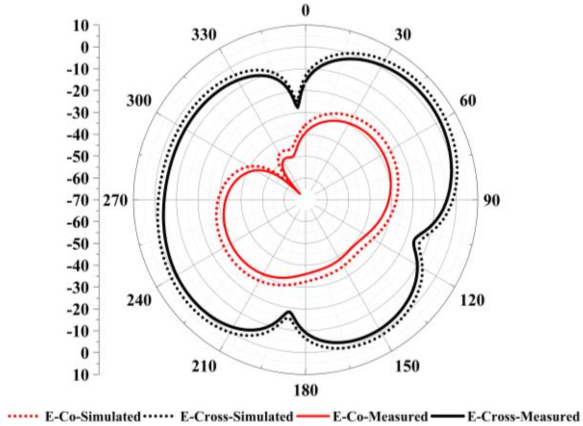


Fig. 6. The simulated and measured results for E-co. and E-cross. polarized.

V. CONCLUSION

Herein, a novel feeding technique for the preparation of a CP quasi lumped antenna was presented. The proposed array was fed by a herringbone microstrip orienting the elements ±45° from the feed line to achieve CP radiation. A noticeably reduced size of the array was achieved compared to that of conventional microstrip antennas. Table 3 shows a notable size reduction comparing the proposed array with various designs reported in literature.

Table 3: A size comparison between the proposed design and several designs reported in the literature

Reference	Array Size [mm]
[25]	85×110
[26]	70×70
[27]	70×70
[28]	70×70
[29]	60×60
Proposed work	21×38

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