Coupling Effects on Polarization-Agile Patch Antenna Arrays

Hsinju Chen and Shih-Yuan Chen
Graduate Institute of Communication Engineering
National Taiwan University
Taipei, Taiwan
r06942011@ntu.edu.tw; shihyuan@ntu.edu.tw

Jennifer T. Bernhard
Electromagnetics Laboratory
University of Illinois at Urbana-Champaign
Champaign, IL, USA
jbernhar@illinois.edu

***Abstract*—This paper presents two configurations of four-element polarization-agile patch antenna array: corner-to-corner and side-to-side arrangement of simple stub-loaded elements. By feeding sequentially with 0.4λ element spacing at 1.575 GHz for GNSS applications on 1.6-mm FR4 substrate, both structures are smaller than the common half-wavelength spacing arrays, and have very low axial ratio of sub-0.1 dB, coupling coefficients of less than –22 dB, and realized gain of 5.68 dBic for RHCP and 6.18 dBic for LHCP of corner-to-corner configuration, as well as a CP gain of 6.81 dBic for side-to-side configuration to explore the effects of coupling on array performance.**

***Keywords*—polarization-agile antenna arrays, sequential feed, patch antennas, antenna coupling.**

I. Introduction

The coupling between elements in antenna arrays has always been a critical matter of antenna array design [1], especially when aiming for smaller element spacing than the common half-wavelength. While we want to achieve higher gain by putting more elements into a compact design, the study of coupling is necessary before aiming for a larger array.

Utilizing our previous antenna element [2] (Fig. 1), we propose two configurations (Fig. 2) of polarization-switchable, sequentially fed patch antenna array of 4 elements, one with the square patches aligning corner-to-corner, and the other side-to-side.

II. Proposed Polarization-Agile Antenna Array

A. Single Element Design [2]

The patch antenna elements in the array are individually reconfigurable in terms of circular polarization (CP). With proximity-coupled feed, DC block is inherent, and adding an inductance $\mathscr{L}$ of 45.6 nH on the corner furthest away from the feed for the least impact on the surface current, the design does not require bias tees. By changing the applied voltage between $\pm$0.8 V on the patch to control the PIN diodes connecting the two grounded stubs, we can switch between right- and left-handed circular polarizations (RHCP and LHCP) respectively.

Designed on 1.6-mm FR4 dielectric slabs ($\varepsilon_r = 4.3$, $\tan\delta = 0.011$) and centered at 1.575 GHz for GNSS applications, the simulated realized CP gain of a single element while considering the loss from PIN diodes (Skyworks SMP1322-040LF) is 1.83 dBic. Other results are shown in Fig. 3 as well as the diode model in Fig. 4.

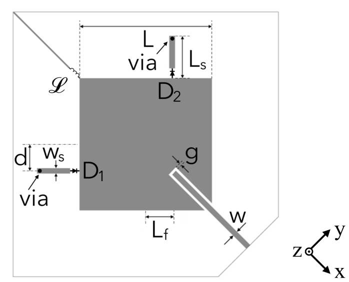
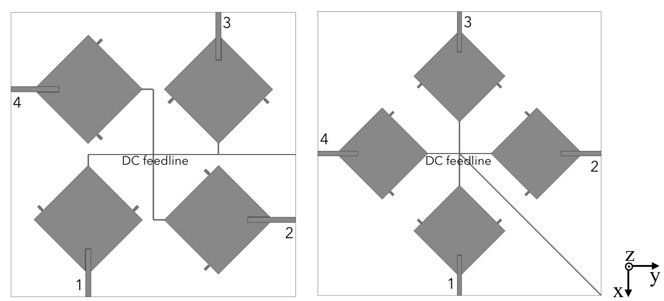
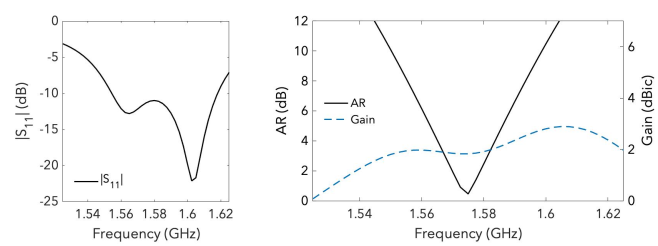


Fig. 1. Schematic of patch element. ($L = 44.9$ mm, $L_f = 12$ mm, $L_s = 3$ mm, $d = 15$ mm, $w_s = 1.5$ mm, $w = 3.07$ mm, $g = 0.1$ mm)



(a) (b)

Fig. 2. Two configurations of polarization-agile antenna arrays. (a) Corner-to-corner and (b) side-to-side configurations.



(a) (b)

Fig. 3. Simulated results of a single element. (a) $|S_{11}|$ and (b) AR and antenna efficiency.

B. Corner-to-Corner Configuration

The feeding method used in both configurations is sequential feeding, which is having a 90°-phase difference between adjacent feed lines: –90° in clockwise direction for LHCP and +90° for RHCP.

If the stubs on the inner area of the array are active, the

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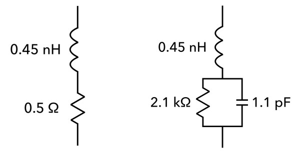


(a) (b)

Fig. 4. Diode model. (a) ON and (b) OFF state.

array is RHCP. Since RHCP mode creates greater coupling between elements due to a smaller distance between active stubs, we look closer into its performance.

Throughout the simulated frequency band of 1.525 to 1.625 GHz, the AR is excellent, being under 0.1 dB, except for when the spacing is 0.35λ, which happens to be the nearest possible spacing without overlapping elements. While the reflection coefficients are below –6 dB over 1.54 GHz, we are more interested in the coupling coefficients. Since the structure is point symmetric apart from DC bias feed, we look into S_{21} for all coupling between adjacent elements and S_{31} for coupling between elements across from each other.

To illustrate the performance, we compare three cases of different element spacings as shown in Fig. 5: 0.35λ, 0.4λ, and 0.5λ. Except for when the spacing is 0.35λ, all other coupling coefficients are lower than –20 dB, giving us a good isolation. Though using a spacing of 0.35λ is the most compact possible, we would sacrifice much of the gain. If we look further into the coefficients, we can see that the larger the spacing, the better the isolation as one would expect. For LHCP mode, the coupling coefficients do not differ much between different spacings due to a larger distance between active stubs, and results of AR and reflection coefficients are similar to those of RHCP mode.

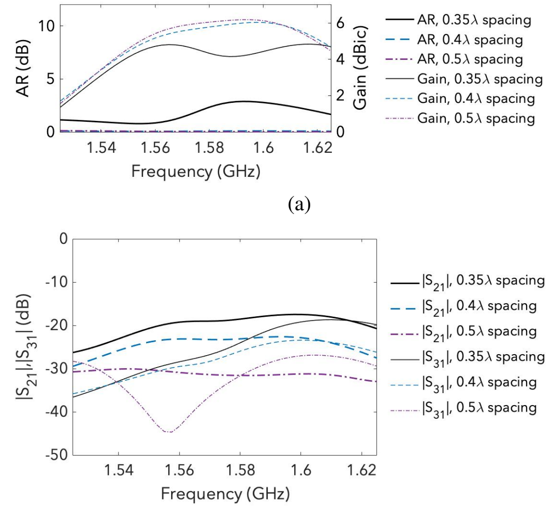
For a compact design with good performance, we choose 0.4λ for element spacing, and have a realized RHCP gain of 5.68 dBic in RHCP mode, and a realized LHCP gain of 6.18 dBic in LHCP mode.

C. Side-to-Side Configuration

For side-to-side configuration, the structure is more symmetric, and we can consider RHCP and LHCP modes to be the same. Also having a very low AR throughout the band, this configuration has $|S_{11}|$ lower than –6 dB over 1.56 GHz.

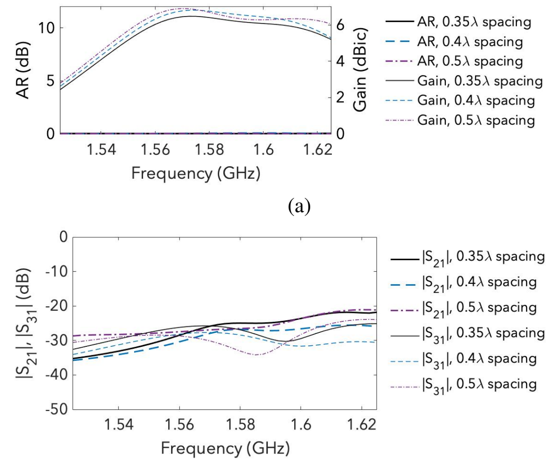
Though side-to-side means more parallel coupling at the patch edges, the arrangement in fact results in a larger distance between the edges and corners of the elements under the same antenna spacing. Comparing the same three different element spacings in Fig. 6, we see that the coupling coefficients do not differ much as the actual shortest distance between elements is larger, and the overall realized CP gains are also slightly larger than those of corner-to-corner configuration.

Specifically with 0.4λ spacing, the coupling coefficients are slightly lower than corner-to-corner ones, having –25 dB throughout the simulated band, and the realized CP gain is also higher, giving us 6.81 dBic. While both configurations are comparable in every aspect, the side-to-side configuration is more compact in size with higher gain while corner-to-corner has a slightly larger band due to the $|S_{11}|$ level.



(b)

Fig. 5. Simulated results of corner-to-corner antenna array in RHCP mode. (a) AR and realized RHCP gain and (b) coupling coefficients.



(b)

Fig. 6. Simulated results of side-to-side antenna array in RHCP mode. (a) AR and realized CP gain and (b) coupling coefficients.

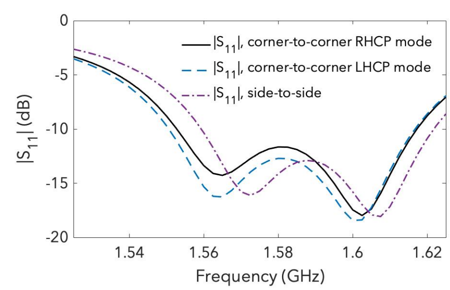


Fig. 7. Comparison of simulated $|S_{11}|$ with element spacing 0.4λ.

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