Decreasing Mutual Coupling in a Phased Array Using a Mutual Coupling Based Element

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Abstract— Generally, mutual coupling substantially affects performance of arrays in both transmit and receive states. This paper is to address this challenge. In this paper, a densely packed S-band circularly polarized (CP) microstrip phased array antenna is designed. The point about the proposed array is the very low mutual coupling between its elements, despite the closely placed elements. This goal was achieved using a very high performance antenna element. The compact, wideband and high-gain circularly polarized antenna element was realized thanks to the instructive effect of the mutual coupling. To prove the concept, a linear five-element uniform array is considered. A mutual coupling of less than -25 dB has been achieved.

Keywords—array antenna, circularly polarized antenna, mutual coupling.

I. INTRODUCTION

Phased array antennas consist of multiple stationary antenna elements, which are fed coherently and use variable phase or time-delay control at each element to scan a beam to given angles in space. They are considered of great importance in wireless systems, due to their capability of providing a shaped pattern directive beam that can be scanned electronically [1]. In a practical situation, mutual coupling between elements degrades array's performance in terms of directivity, direction angle and shape of its beam. As phased arrays can be used in both transmit and receive systems, high mutual coupling substantially affects gain of system, interference rejection ability and accuracy of direction-of-arrival (DoA) estimation. In addition, high mutual coupling changes active impedance of antenna elements and makes them as direction-varying loads for driving power amplifiers and front ends. This matching degradation at the output of a PA causes an unexpected reflection that can cause performance degradation by producing nonlinear distortions, reducing output power, and efficiency or by causing instability [2].

Some researchers have proposed methods to accurately characterizing the array response in order to compensate the mutual coupling effects [3], which mostly are calibration-based methods [4-5]. In additions, many works have been reported to decrease elements' mutual coupling with adding defected ground planes [6] or electromagnetic band gap structures (EBGs) [7-8] in between of elements. Furthermore, one useful approach is to decrease the mutual coupling by increasing the

Fig. 1. The CP antenna, a) Side view, b) Top substrate holds patches and stacked strips, c) Bottom substrate contains FN

Fig. 2. Prototype of the CP antenna.

distance between elements. It has been reported in the literature by some unconventional array configurations, i.e. sparse [9] and thinned arrays [10].

This work is to address the high mutual coupling challenge in arrays. The goal of this work was to design a low mutual coupling and high aperture efficiency linear uniform array. This goal is realized by using a compact and highly directive antenna element.

Fig. 3. Simulated and measured gain and simulated losses and total efficiency for the integrated structure.

Fig. 4. The proposed five-element linear array

II. ELEMENT TOPOLOGY

In general, a microstrip sequentially rotated CP antenna can be composed of four identical patches driven by a sequentially quadrature-lagged phase shifting FN [11]. In contrast to the conventional designs which are made by four isolated patches, we proposed a CP antenna based on four highly coupled patches in [12].

The proposed structure is an integration of a radiating part and a FN, each on an individual substrate, see Fig. 1. The air gap between the substrates is realized by plastic spacers. The patches are driven by the metallic pins that connect the patches to the FN in the second substrate. The very small distance between the patches makes them highly coupled. This strong mutual coupling plays a fully constructive role here helping to reduce the size significantly. The antenna design is described in details in [12]. Fig. 2 shows a prototype of this design. And Fig. 3 summarizes its performance in terms of efficiency, gain and return loss.

III. THE ARRAY ANALYSIS

In order to investigate the mutual coupling in arrays, a linear densely packed array using the aforementioned antenna element has been shaped. The array consists five elements with center to center distance of 70mm, as shown in Fig. 4. The antenna elements are very close to each other, because the element lateral size is $68 \times 68 \text{ mm}^2$, which is $0.52\lambda_0 \times 0.52\lambda_0$ where λ_0 is the midband wavelength ($f_0 = 2.3 \text{ GHz}$). Despite the very small spacing between the elements, their mutual coupling is small. The array's performance was evaluated using commercial full-wave software CST Microwave Studio. The five elements were fed individually and S-Parameters matrix was calculated. Fig. 5 plots the mutual coupling coefficients, which are represented by non-diagonal elements of the S-parameters matrix. They all are smaller than -25dB all over the

Fig. 5. The mutual coupling between elements

Fig. 6. The reflection coefficient of elements

desired frequency band, which is considered a very low-level mutual coupling in the literature. The active reflection coefficients for the same array are depicted in Fig. 6. As it is expected, because of the very low mutual couplings, the reflection coefficient of elements has not been affected. Therefore, it is identical, not being related to each element's arrangement in the array, neither related to the array's main beam direction. It is a huge advantage for phased arrays, avoiding performance degradation of PAs' in terms of nonlinear distortions, instability, reducing output power, and efficiency.

Fig. 7 shows 3D radiation pattern of the array at midband frequency which is 2.3 GHz and for several steering angles. This figure is to demonstrate the array's ability in beam-steering without dramatically affecting the overall directivity, thanks to the very low-level mutual couplings.

To evaluate directivity of the array and compare it with the single element, Fig. 8 is presented. Directivity in the array is 5.3 dB more than single element's gain at midband frequency ($f_0 = 2.3 \text{ GHz}$).

IV. CONCLUSION

In this paper, a densely packed S-band circularly polarized (CP) microstrip phased array antenna is presented. In contrast to the very closely placed elements, mutual coupling between the proposed array's elements is less than -25dB in all the desired

Fig. 7. 3D radiation patterns of the array show beam scanning at 2.3GHz (Phi = 0, -12, -25, -35 degree)

frequency band. The low mutual couplings provide constant active impedances for the elements, which is essential to keep the performance of driving PAs high. In addition, in receive systems, DoA algorithms work on their best performance.

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REFERENCES

1. Mailloux RJ. Phased array antenna handbook. Artech house; 2017 Nov 30.
2. S.K. Dhar, A. Abdelhafiz, M. Aziz, M. Helaoui and F.M. Ghannouchi, "A Reflection-Aware Unified Modeling and Linearization Approach for Power Amplifier Under Mismatch and Mutual Coupling," IEEE Transactions on Microwave Theory and Techniques, vol. 66, No. 9, pp.4147-4157, 2018.
3. S. Henault, and Y. Antar, "Unifying the Theory of Mutual Coupling Compensation in Antenna Arrays," IEEE Antennas and Propagation Magazine, vol. 57, No. 2, pp.104-122, 2015.
4. M. Wang, X. Ma, S. Yan and C. Hao, "An Autocalibration Algorithm for Uniform Circular Array with Unknown Mutual Coupling," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp.12-15, 2015.
5. H. Liu, L. Zhao, Y. Li, X. Jing and T.K. Truong, "A Sparse-Based Approach for DOA Estimation and Array Calibration in Uniform Linear Array," IEEE sensors journal, vol. 16, No. 15, pp.6018-6027, 2016.
6. K. Wei, J. Li, L. Wang, Z. Xing and R. Xu, "S-Shaped Periodic Defected Ground Structures to Reduce Microstrip Antenna Array Mutual Coupling," Electronics Letters, vol. 52, No. 15, pp.1288-1290, 2016.
7. F. Yang and Y. Rahmat-Samii, "Microstrip Antennas Integrated with Electromagnetic Band-Gap (EBG) Structures: a Low Mutual Coupling Design for Array Applications," IEEE transactions on antennas and propagation, vol 51, No. 10, pp.2936-2946, 2003.
8. M. SalarRahimi, J. Rashed-Mohassel and M. Edalatipour, "Radiation Properties Enhancement of a GSM/WLAN Microstrip Antenna Using a Dual Band Circularly Symmetric EBG Substrate," IEEE Transactions on Antennas and Propagation, vol. 60, No. 11, pp. 5491-5494, 2012.

Fig. 8. Gain versus frequency for single element and the 5-element linear array

9. C.L. Liu and P.P. Vaidyanathan, "Super Nested Arrays: Linear Sparse Arrays with Reduced Mutual Coupling—Part I: Fundamentals," IEEE Transactions on Signal Processing, vol. 64, No. 15, pp.3997-4012, 2016.
10. A.R. Raza, W. Liu and Q. Shen, "Thinned Coprime Array for Second-Order Difference Co-Array Generation with Reduced Mutual Coupling," IEEE Transactions on Signal Processing, vol. 67, No. 8, pp.2052-2065, 2019.
11. J. Huang, "a Technique for an Array to Generate Circular Polarization with Linearly Polarized Elements," IEEE Trans. Antennas Propag., vol. 34, no. 9, pp. 1113-1124, 1986.
12. M. SalarRahimi, V. Volski and G.A. Vandenbosch, "Mutual Coupling Based Compact Wideband Circularly Polarized Antenna," IEEE Transactions on Antennas and Propagation, vol. 67, No. 7, pp.4872-4877, 2019.