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Design of Miniaturized Microstrip Patch Antennas Using Non-Foster Circuits for Compact Controlled Reception Pattern Antenna Array

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Abstract

The global positioning system (GPS) is a useful system in civilian and military applications. However, because of the weak signal, GPS receivers are vulnerable to interference caused by unwanted signals or intentional jammers. To alleviate this issue, a controlled reception pattern antenna (CRPA) array can be employed to adaptively place radiation pattern nulls toward the direction of the signal interference. The performance of the CRPA array improves as the number of antenna elements increases. Therefore, antenna miniaturization is highly desirable for CRPA applications. We designed a compact CRPA array based on seven electrically miniaturized microstrip patch antennas (MPAs) on a 5-inch ground platform. We used a non-Foster matching circuit to match efficiently miniaturized MPAs on an FR-4 substrate. Experimental results show that the non-Foster matching circuit significantly improves such elements of antenna performance as return loss and antenna gain. In addition, we confirmed that the mutual coupling of the proposed CRPA array is less than -45 dB.

Key Words: CRPA Array, GPS Antenna, Non-Foster Circuit.

I. INTRODUCTION

The global positioning system (GPS) is a useful system that provides location and time information about moving objects in civilian and military applications [1]. However, this system is vulnerable to interference caused by unwanted signals or intentional jammers. A controlled reception pattern antenna (CRPA) array can be an effective way to protect GPS receivers against jamming [2]. The array consists of an antenna array and a processing unit that performs a phase-destructive sum of the incoming interference signals. In other words, the function of the array is equivalent to making nulls toward interference in the array radiation pattern. The performance of the CRPA array is proportional to the number of antenna elements, and thus, antenna miniaturization is highly desirable. High-dielectric substrates are used to miniaturize microstrip patch antennas (MPAs)—e.g., the dielectric constant of 14 [3]. This approach, however, results in high mutual coupling among the antenna elements, and thus, pattern distortions and gain degradation may occur [4].

In this work, we design extremely miniaturized MPAs on a substrate with a low dielectric constant for a compact CRPA array. To match the impedance of the electrically miniaturized MPAs, we employ a non-Foster matching circuit (NFMC) between the feeder and the antenna body, and the resulting antenna performances are verified with measurements.

II. ANTENNA SYSTEM DESIGN

MPAs were fabricated on an FR-4 substrate with a dielectric

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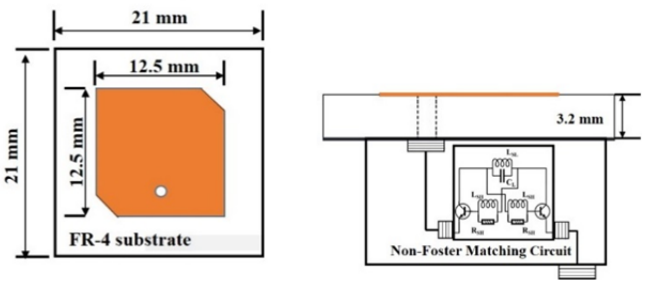
constant of 4.4, a loss tangent of 0.002, and a thickness of 3.2 mm. This low-dielectric substrate was adopted to achieve low mutual coupling among the antenna elements. The physical dimensions of the substrate were 21 mm × 21 mm, and those of the MPAs were 12.5 mm × 12.5 mm. As the MPAs were electrically miniaturized, the center frequency of the antenna was approximately 4.8 GHz, which is much higher than the target L_1 band (1.57542 GHz). At the targeted L_1 band, the electrical size (ka) of the MPAs was equal to 0.2916, where k is the free-space wavenumber and a is the radius of the smallest sphere enclosing the patch. Due to the electrically small antenna size, the MPAs exhibited a high input reactance at the frequency of interest, resulting in a large return loss for impedance matching. Fig. 1 shows the schematic of the miniaturized MPAs with an NFMC, and Fig. 2 shows the fabricated compact CRPA array. The array consisted of seven individual antennas mounted on a 5-inch circular ground platform.

An NFMC was then employed to cancel out the high input reactance at the frequency of interest. Fig. 3(a) shows the schematic of the proposed NFMC, and it consists of two crossed-coupled NPN bipolar junction transistors (BJTs), NE68133. Note that the supply voltage (V_{DC}) is 5 V, and commercial inductors from TDK are employed in the simulation. A positive load capacitor C_L = 20 pF is connected between the emitters of two BJTs, and consequently, the impedance is converted to that of a negative capacitor. Fig. 3(b) shows the fabricated NFMC on a 4-layer FR-4 substrate with a physical size of 20 mm × 20 mm. The advantage of this multi-layer configuration is that the parasitic effects can be miniaturized by reducing the feedback path length, and thus, it enhances the stability. The basic characteristics of the NFMC are observed in Fig. 3(c); the reflection coefficient on the Smith chart changes in the counterclockwise direction as the frequency increases [5].



(a) (b)

Fig. 1. Schematic of miniaturized MPAs: (a) top view and (b) side view.

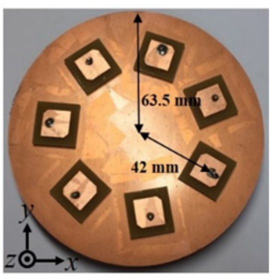


Fig. 2. Fabricated compact CRPA array.

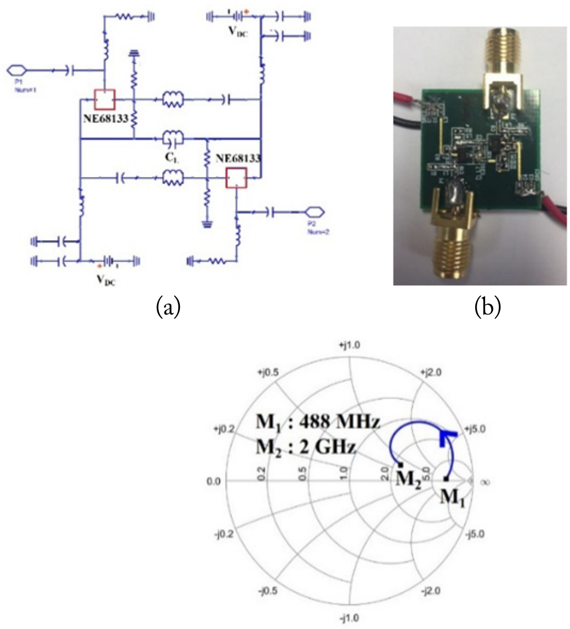


Fig. 3. (a) Schematic of NFMC, (b) fabricated NFMC, and (c) reflection coefficient of NFMC.

NFMCs are potentially unstable due to the inherent positive feedback [5]. Therefore, it is important to investigate the stability of the entire antenna system, including the MPAs and the NFMC. By using a time domain approach [6], we confirmed that the proposed antenna system is stable. Fig. 4 shows the measured reflection coefficients of the miniaturized MPAs for the compact CRPA array. The dashed line shows the reflection coefficient when only the CRPA array was measured, while the solid line represents the reflection coefficient of the proposed CRPA array with the NFMC added between the array and the feeder. As can be seen in the figure, the NFMC significantly improved the matching performance of the CRPA array near the target L_1 frequency band. Fig. 5 shows the plot of the measured far-field radiation patterns of the compact CRPA array

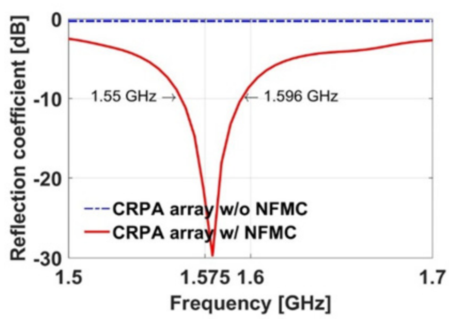
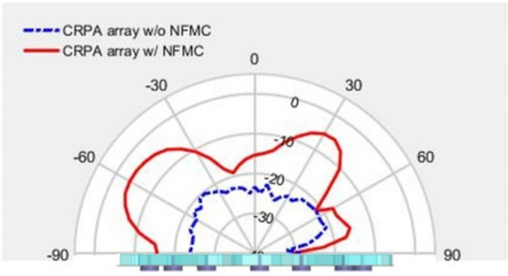
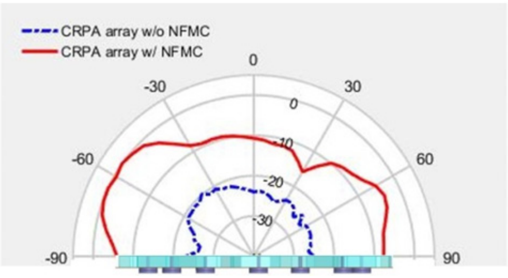


Fig. 4. Reflection coefficient.



(a)



(b)

Fig. 5. Far-field radiation pattern (dB scale): (a) zx-plane and (b) zy-plane.

with and without the NFMC at 1.5752 GHz. The adopted NFMC also dramatically improved the gain of the CRPA array. Finally, we measured the mutual coupling between the array elements, which is one of the most important parameters for the CRPA array. Toward this purpose, the NFMC was inserted in one antenna, and the other antennas were terminated at 50 Ω. The result confirmed that the worst mutual coupling was less than -45 dB in the L_1 band.

III. CONCLUSION

We proposed miniaturized MPAs on a FR-4 substrate for a compact CRPA array. A NFMC was designed to efficiently match the electrically miniaturized antennas in the CRPA array. Experimental results showed the reflection coefficient of -21 dB at the center frequency and the 10-dB bandwidth of over 45 MHz. The NFMC led to dramatic improvement in the antenna gain, while the mutual coupling of the proposed CRPA array remained less than -45 dB.

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