

A Hybrid-Mode Microstrip Patch Antenna Array with Intrinsic Mutual Coupling Reduction

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Abstract—This paper proposes a novel method for mutual coupling reduction in a two-element array of microstrip patch elements with close edge-to-edge spacing. The orthogonality of the transverse magnetic (TM) and transverse electric (TE) modes is exploited in a two-element hybrid-mode array composed of one TM-mode patch and one TE-mode patch with inherent element isolation. It is shown that for an extreme case of 0.02λ edge-to-edge spacing, a mutual coupling level of approximately -18.4 dB can be achieved along with stable gain and about 10% impedance bandwidth, indicating that this method electromagnetically isolates two patch elements successfully.

I. INTRODUCTION

Antenna arrays composed of microstrip patch antenna elements have become commonplace among numerous commercial and defense applications, especially those pertaining to radar. Microstrip patch elements are relatively easy and inexpensive to fabricate, are lightweight and low-profile, have low radar cross-sections, and have high conformability [1]; these advantages come at the expense of narrowband operation and the potential to excite surface waves, each of which has been remedied in the literature. Combining multiple elements into an antenna array drastically improves antenna performance far beyond that of a single constituent element; namely, antenna arrays offer higher gain, electronic beam steering capability, and pattern reconfigurability.

Mutual coupling, the electromagnetic interactions between neighboring antenna elements, is of utmost priority in antenna array design. High mutual coupling can cause scan blindness, degradation in radiation performance, gain loss, asymmetric radiation pattern shape, impedance mismatch, increased back-lobe radiation, and a multitude of other issues [1]. As array elements become more tightly packed, the coupling between them becomes stronger. Mutual coupling reduction methods aim to electromagnetically isolate each array element while maintaining a small distance ($<0.5\lambda$) between them.

Mutual coupling predominantly originates from the unintended excitation of surface waves across and within the overall antenna structure. Mutual coupling reduction techniques have been heavily studied in the literature and include but are not limited to: metasurface superstrates [2], single-negative (SNG) and double-negative (DNG) metamaterials [3], electromagnetic bandgap (EBG) structures [4], defected ground structures [5], parasitic structures [6], and the excitation of orthogonal radiation modes [7]. This paper proposes utilizing the orthogonality of the dominant transverse magnetic (TM) and transverse electric (TE) modes to create a two-element microstrip patch array with inherent mutual coupling capability. The TE-excited rectangular patch antenna was reported in

[8-10]. However, to the authors' knowledge, this is the first time TM- and TE-mode patch elements in the same array are proposed as a mutual coupling reduction technique. The array has been full-wave analyzed using the finite-element based electromagnetic solver HFSS.

II. MUTUAL COUPLING BETWEEN TWO TM-MODE MICROSTRIP PATCH ELEMENTS

A microstrip patch element that excites the dominant TM_{10} mode via an L-probe incorporated into the patch as a coplanar L-strip was reported in [11]. When two of these patches are placed in an array with 0.02λ edge-to-edge separation and only one patch is excited, surface waves readily propagate from the driven patch to the passive patch resulting in strong induced surface currents and a mutual coupling as high as -4.93 dB. The surface current densities induced on the passive patch will reradiate and cause additional induced current densities on the driven patch, resulting in impedance mismatch and a shift in resonant frequency. Due to space constraints, the figure depicting these details is omitted.

The technique proposed in this paper replaces one TM-mode element with an element that excites the dominant TE_{10} mode adopted from [8], thus utilizing the intrinsic orthogonality of pure TM and TE modes to reduce mutual coupling without the use of external structures. Mathematically, assuming that two fields exist in free space with different modes A and B

$$\mathbf{E}_A = \mathbf{e}_A \exp(-j\beta_A z), \quad \mathbf{H}_A = \mathbf{h}_A \exp(-j\beta_A z) \quad (1)$$

$$\mathbf{E}_B = \mathbf{e}_B \exp(-j\beta_B z), \quad \mathbf{H}_B = \mathbf{h}_B \exp(-j\beta_B z) \quad (2)$$

the orthogonality relation is derived using Lorentz reciprocity. That is, the orthogonality relationship between the field with mode A and the field with mode B is shown to be

$$\iint_S [\mathbf{e}_A \times \mathbf{h}_B^* + \mathbf{e}_B^* \times \mathbf{h}_A] \cdot \hat{\mathbf{z}} dx dy = 0 \quad (3)$$

indicating that modes A and B are electromagnetically isolated. Herein, the modes A and B are the TM_{10} and TE_{10} modes, respectively.

III. TE- AND TM-MODE MICROSTRIP PATCH ELEMENTS: HYBRID-MODE ARRAY

The original TE-mode patch was developed in [9] and modified in [10] to simplify the excitation method by incorporating the L-probe as an L-strip coplanar with the patch. The TE patch and TM patch were slightly tuned to account for any shifting in resonant frequency as the spacing between the patches decreased. The orthogonality of the TE and TM modes requires that the boundary conditions of those modes

be satisfied; thus, the TE-mode microstrip patch cavity model, whose side walls mimic the property of a perfect electric conductor, was utilized to increase the purity of each mode.

The two-element hybrid-mode array is created with one TE-mode element adopted in [8] and one TM-mode element that are spaced 0.02λ edge-to-edge. Each array element was individually excited, and the induced surface current density on the opposing element was observed. The corresponding full-wave results are depicted in Fig. 1 in which only the TE-mode element is excited in Fig. 1 (a) and only the TM-mode element is excited in Fig. 1 (b). As observed, the induced surface current densities are significantly weakened compared to those in the conventional TM-mode patch array discussed in Sec. II, verifying the expected orthogonality between the TE and TM modes.

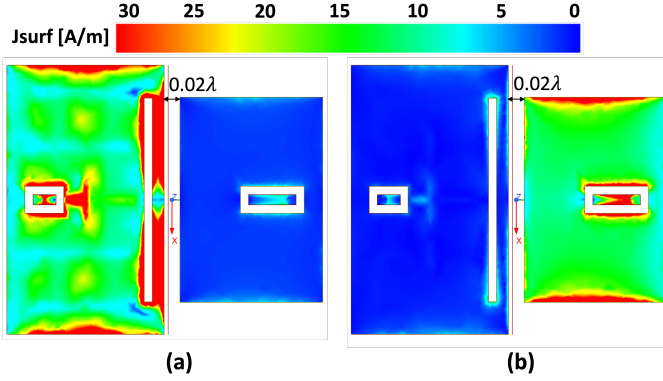


Fig. 1. Hybrid-Mode array surface current distributions for 0.02λ edge-to-edge spacing when (a) only the TE-mode patch is excited and (b) only the TM-mode patch is excited.

The scattering parameters of the array, depicted in Fig. 2, indicate that both elements resonate at the desired frequency f_0 near 4 GHz, have at least 10% impedance bandwidth, have a mutual coupling less than -15 dB over the entirety of the impedance bandwidth, and have a mutual coupling of -18.36 dB at the resonant frequency f_0 . Additionally, at f_0 , the mutual coupling level in the hybrid-mode array is -13.43 dB lower than the two-element TM-mode patch array.

The gain versus frequency results for each element at boresight, plotted in Fig. 3, indicate stable gain patterns with a maximum gain of 7.01 dBi and show that approximately 29% of the frequency bandwidth occurs between the 3 dB gain variation points.

IV. CONCLUSION

A new mutual coupling reduction method is proposed that utilizes the orthogonality of TM and TE modes to create a novel hybrid-mode microstrip patch array with intrinsic element isolation. At 0.02λ edge-to-edge spacing, the results indicate that the hybrid-mode array decreases mutual coupling by an additional -13.43 dB when compared to a two-element array of the discussed TM-mode elements, a total of -18.36

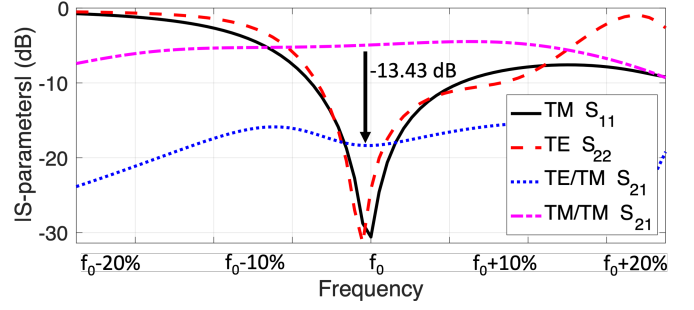


Fig. 2. S-parameters for the hybrid-mode array and highlighting the difference between the mutual coupling S-parameter of the two-element TM-mode array and the hybrid-mode array given that f_0 is near 4 GHz.

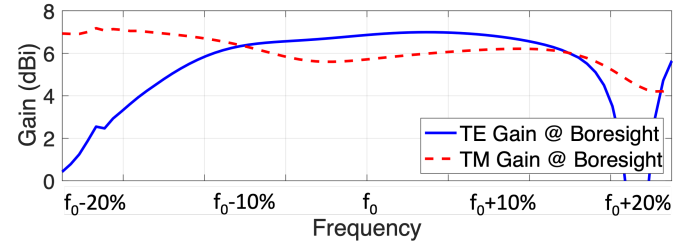


Fig. 3. Gain versus frequency for each of the hybrid-mode array elements at boresight given that f_0 is near 4 GHz.

dB overall. Further results and array details will be presented and discussed at the conference.

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