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Chebyshev Antenna Array Miniturization with Aperture Feeding based on Effective Neutralizing Line Design for Mutual Coupling Reduction

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Abstract

A compact eight-element linear aperture-fed microstrip antenna array is investigated for fifth-generation (5G) millimeter-wave applications. The work combines a Chebyshev-based element distribution with neutralization lines intended to suppress mutual coupling after reducing interelement spacing. First, a uniform aperture-coupled array is developed and modified to obtain a sidelobe level of approximately −20 dB. The spacing is then reduced from 2 mm to 1 mm, and additional conductive paths are introduced between adjacent elements to counteract induced coupling currents. The design uses a Rogers 5880 dielectric substrate and is evaluated through full-wave electromagnetic simulation. The proposed line dimensions are selected using circuit-based decoupling considerations and parametric simulations. Results reported for the final array include a maximum gain of 8.92 dB, a reported operating bandwidth of 3.09 GHz within approximately 25.84–28.95 GHz, and a minimum adjacent-element coupling level of −32.84 dB across that band. Comparisons between HFSS and CST scattering-parameter predictions support the consistency of the simulated response. These results suggest that neutralization lines can help preserve isolation while reducing the footprint of closely spaced Chebyshev antenna arrays.

Keywords:

Aperture-fed microstrip array; Chebyshev distribution; Mutual coupling; Neutralization lines; Millimeter-wave antennas; 5G; Antenna miniaturization.

1. Introduction

Fifth-generation wireless systems require antenna architectures that can be integrated into comparatively small platforms while maintaining usable bandwidth, gain, and radiation-pattern control. Microstrip antennas are attractive because they are low profile and compatible with printed-circuit fabrication. Nevertheless, reducing the separation between adjacent radiators increases the interaction of their near fields and surface currents. As a result, impedance matching, radiation patterns, and isolation may be degraded, particularly in arrays with multiple excited elements.

A variety of structural and circuit-based approaches have been investigated to address this problem. Conductive walls and shorting pins, for example, can interrupt selected coupling paths [1], whereas matching and decoupling networks can alter the effective port interaction [2]. Neutralization lines offer an alternative: an additional controlled coupling path may be dimensioned so that its induced signal counteracts the original coupling contribution [3]. The suppression mechanism, however, must be considered jointly with the element arrangement and the desired radiation characteristics.

The present study addresses this interaction in a linear eight-element aperture-fed patch array. Its central contribution is the combined use of a Chebyshev-oriented element distribution, reduced interelement spacing, and explicitly designed neutralization lines. Rather than relying on spacing alone to achieve isolation, the proposed arrangement introduces opposing current paths between neighbors. The design is assessed through scattering parameters, radiation patterns, current distributions, and cross-software simulation comparisons.

2. Methodology

The initial structure consists of eight rectangular microstrip patches arranged in a single linear row. It uses three functional layers: a lower feeding strip, an intermediate ground plane containing coupling apertures, and an upper radiating patch layer. The apertures and patches are oriented at approximately 45° relative to one another. The dielectric

material specified in the original design is Rogers 5880, with relative permittivity of 2.2 and a substrate thickness of 0.7884 mm. A nominal design frequency of 28 GHz is adopted. The baseline feed and patch dimensions are established through parametric simulations in HFSS.

In the first design step, a uniformly configured array is examined to establish the initial radiation response and mutual-coupling behavior. A Chebyshev-based weighting is then incorporated to target a sidelobe level of −20 dB. The study calculates normalized element coefficients for the symmetrical eight-element configuration as 0.55, 0.80, 0.92, 1.00, 1.00, 0.92, 0.80, and 0.55. These coefficients are represented in the design by corresponding patch widths of 2.41, 3.50, 4.03, 4.38, 4.38, 4.03, 3.50, and 2.41 mm. The resulting array is simulated again to examine the radiation pattern and its scattering parameters [4,5].

The subsequent miniaturization step reduces the spacing between adjacent elements from 2 mm to 1 mm. This increases the electromagnetic interaction between patches, so compactness is not treated as sufficient evidence of an improved design. The coupled response is described using scattering, impedance, and admittance matrices. For a two-port representation, the impedance matrix can be obtained from the scattering matrix as $Z = Z_0(I + S)(I - S)^{-1}$. Coupling is associated with off-diagonal terms, and ideal decoupling corresponds to cancellation of the effective transfer contribution.

Neutralization lines are therefore introduced between neighboring radiators. The design objective is to make the added coupling contribution approximately opposite to the original contribution in both phase and suitable amplitude. In the paper's simplified representation, the target is $Z_{21} + ZN \approx 0$. The reported final geometric parameters are a line width Wd of 0.4 mm, lengths Ld1 and Ld2 of 6.4 and 4.0 mm, respectively, and an angle α of 6.38°. These dimensions are determined by circuit-based reasoning combined with HFSS parametric evaluation. The final configuration is compared with its compact counterpart before adding the lines.

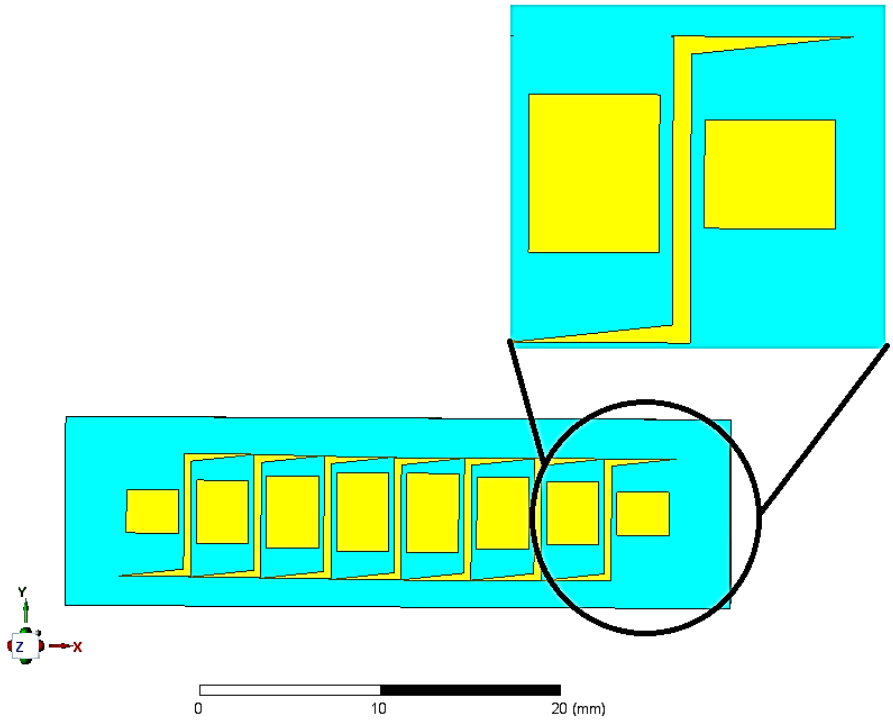


Figure 1. Final compact Chebyshev array with the proposed neutralization lines used for mutual-coupling reduction.

3. Results and Discussion

Simulations of the initial uniformly configured array show an undesired sidelobe pattern and appreciable coupling between neighboring elements. Chebyshev-based redistribution improves sidelobe behavior, although it does not by itself resolve the array-isolation problem. After the spacing is halved to 1 mm, strong interaction between neighboring elements produces a less favorable pattern and deteriorates the scattering response. The original paper reports that the compact structure without neutralization lines exhibits a substantially narrower matching bandwidth of approximately 507 MHz, with an operating-frequency shift toward 27.6 GHz. These observations motivate the added neutralization paths.

For the final array incorporating the neutralization lines, the original study reports an adjacent-element coupling value of −29.76 dB and a minimum coupling level of −32.84 dB within the stated operating band. These values are

reported for different characterizations of the response and should not be interpreted as a single identical measurement. The reported bandwidth is 3.09 GHz, with band edges stated as 25.84 and 28.95 GHz. The maximum simulated gain is 8.92 dB, and the targeted sidelobe level is −20 dB. Taken together, the results indicate that the array can retain satisfactory radiation characteristics while operating with 1 mm element separation.

The simulated surface-current distributions help explain the physical operation. Without the additional connections, energizing one port gives rise to appreciable induced current on neighboring patches. With the neutralization lines installed, the reported current maps show a stronger concentration of current around the driven element and weaker induced currents on adjacent elements. This interpretation is consistent with the decoupling model: a deliberately introduced interaction path can oppose the uncontrolled interaction that arises from element proximity.

An independent numerical comparison is performed with CST and HFSS. The paper compares the S11 and S21 responses obtained using both solvers and reports closely aligned trends. Such agreement provides useful cross-validation of the numerical predictions, although the original article does not present a fabricated prototype or experimental measurement. Accordingly, the present extended abstract describes the demonstrated outcomes as simulation-based rather than experimentally confirmed.

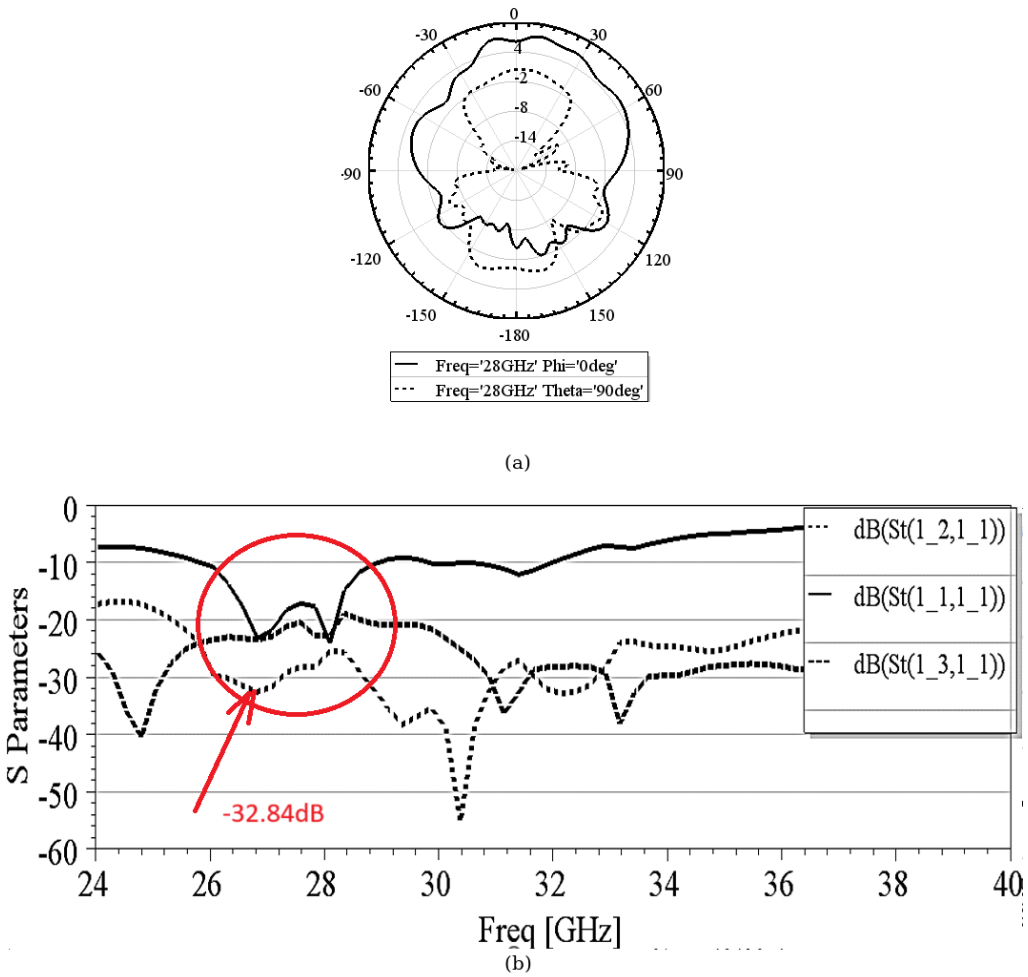


Figure 2. Final-array results: (a) radiation pattern and (b) S-parameter response after applying the neutralization lines.

4. Conclusions

This study develops a compact 1 × 8 Chebyshev aperture-fed printed antenna array and investigates the effect of adding neutralization lines after reducing the separation between radiating patches. The simulations indicate that the additional conductive paths mitigate the mutual-coupling penalty associated with closely spaced elements. The final reported performance includes a minimum coupling of −32.84 dB in the designated band, an 8.92 dB maximum gain, and a sidelobe-level target of −20 dB. The qualitative agreement between HFSS and CST predictions strengthens confidence in the numerical outcome.

The principal practical implication is that compact array layouts need not rely solely on increased element separation to limit coupling; engineered alternative current paths may provide additional design freedom. However, the conclusions remain limited to the modeled geometry and the reported electromagnetic simulations.

Fabrication tolerances, experimentally measured isolation, and integration with a complete feeding and packaging system warrant further study. The approach could also be examined for other array tapering schemes, subject to independent optimization and verification.

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