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# Analysis of an Annular Coupled Patch Using CMA and CMT

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The Annular Coupled Patch antenna (ACP) is a circular patch with an interior ring of vias (see Fig. 1). It offers low profile, omnidirectional (monopole-like) radiation pattern and broad bandwidth [1]. As in [2], this paper uses Characteristic Mode Analysis (CMA) to decompose the ACP geometry into two distinct but coupled resonators: a cylindrical resonator within the vias and an annular patch resonator outside the vias. This paper shows that Coupled Mode Theory (CMT) accurately models the CMA resonances of the full ACP structure.

CMA is a modal decomposition based on the method of moments (MoM) wherein a real, orthogonal basis $J_n$ results from $[X]\,J_n = \lambda_n\,[R]\,J_n$ where $[Z] = [R] + j[X]$ is the MoM impedance matrix and $\lambda_n$ is the eigenvalue. CMT describes the dynamics of a system of two coupled resonators as the superposition of two coupled modes, a lower-frequency in-phase mode and a higher-frequency anti-phase mode. The coupled mode frequencies $\omega_{\pm}$ are related to the uncoupled mode frequencies $\omega_{1,2}$ by:

$$\omega_{\pm} = \omega_0 \pm \sqrt{\left(\frac{\omega_2 - \omega_1}{2}\right)^2 + |K|^2} \tag{1}$$

where $\omega_0 = (\omega_2 + \omega_1)/2$ and $K$ is the coupling coefficient.

CMA of an ACP structure shows only two modes, modes 1 and 9, are significantly excited within the impedance bandwidth. The parallel combination of the two modal impedances accurately replicates the driven antenna impedance, which exhibits a loop in the Smith chart providing broad bandwidth. Fig. 1 shows the mode 1 and 9 charge distributions. These charge distributions exhibit in-phase and anti-phase relationships as explained in the Fig. 1 caption. While in-phase and anti-phase modes have been shown in [1], these modes have not, to the authors' knowledge, been linked to CMT before. This paper demonstrates that CMT accurately models the ACP resonances via equation (1). It shows the coupling of the resonators provides broad impedance bandwidth and that the stable radiation pattern is a result of only a single resonator radiating. This knowledge may be used to develop a first-principles design procedure for the ACP and to understand its relation to other multi-resonant antenna structures.

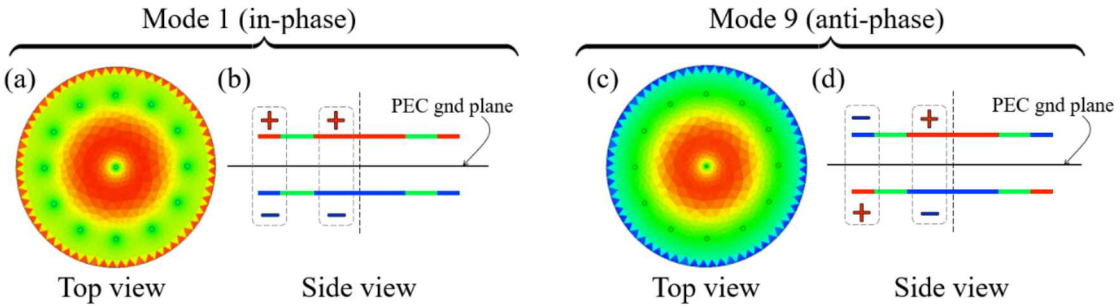


**Figure 1.** CMA mode 1 and 9 charge distributions near band center (5.5 GHz). The in-phase and anti-phase relationships are identified by considering the inner and outer charge rings as dipoles with respect to their ground plane images (the dipoles are grouped with a dashed rectangle in the side views).

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1. J. Liu, Q. Xue, H. Wong, H. W. Lai and Y. Long, "Design and Analysis of a Low-Profile and Broadband Microstrip Monopolar Patch Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 1, pp. 11-18, Jan. 2013.

2. J. J. Borchardt and T. C. Lapointe, "U-Slot Patch Antenna Principle and Design Methodology Using Characteristic Mode Analysis and Coupled Mode Theory," *IEEE Access,* vol. 7, pp. 109375-109385, 2019.