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Feed Design Synthesis using Shorting Pins Illustrated by Characteristic Mode Analysis to Achieve Dual Resonances

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***Abstract*—This paper discusses altering characteristic modes using shorting pins to achieve dual resonance. The two shorting pins were introduced in the structure such that one shorting pin is used to alter the horizontal current mode, and the other changes the vertical current modes. The systematic adjustment of shorting pins helped control the antenna's impedance matching and dual frequency resonance. It is also shown that variation in Xpin parallel to horizontal currents and away from the origin increased the lower order frequency. Then, the variation in Ypin parallel to the vertical currents but towards the origin lowere the higher-order resonant frequency such that the dual resonanc was achieved.**

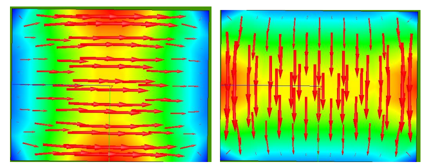
I. Introduction

As 6G communication applications call for modern solu tions, Microstrip Patch Antennas (MPA) have shown promis ing results for being miniature, inexpensive, and obtainin large bandwidths [1], [2]. However, the design process of patch antenna consists of complex parameters that could b more convenient to manage. The insightful and systematic de sign procedures are needed to reduce the overall computational cost of antenna design procedures [3].

The shorting pin is a popular reactive loading technique to optimize antenna performance [4]- [9]. The shorting pins were employed in patch antennas to suppress harmonics and miniaturize the antenna [4], to introduce coupling null [5] or decouple polarization [6], to enhance the bandwidth [7], [8], and to design pattern reconfigurable antenna [9]. Characteristic Mode Analysis (CMA) models the scattering complexity of the current distribution to a set of real eigenvalues that can tell the physical properties of the conducting body. In [5]- [7], CMA was employed such that the modal weighting coefficient, surface current distribution, or modal significance guided the optimal design process, but most of them present a complex analysis of multiple shorting pins and higher order modes. This paper uses CMA to illustrate the systematic design process of achieving dual resonance in a rectangular patch using two shorting pins. The lower-order modes, highlighted by our modal analysis, are fundamental sets that are more malleable than higher orders. The associated eigen-currents illustrate how scattering can be directed for desired results.

II. Antenna Design and Characteristic Modes

The rectangular patch antenna was simulated using Altair FEKO on a single-layer FR4 substrate with a dielectric constant($\epsilon_r = 4.3$), and the thickness is 1.6mm. The surface currents of characteristic antenna modes before feed excitation



(a) J2 (b) J3

without feed

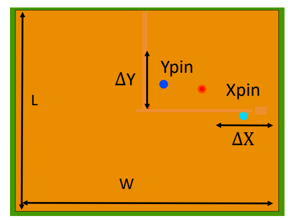


Fig. 2. Antenna Configuration with shorting pins with feed position at (8.255mm, 3.255mm) L=301.6mm, W=39.5211mm

are shown in Fig.1. It can be seen that J2 is horizontal current mode resonating at 1.9 GHz, and J3 is vertical current mode resonating at 2.4 GHz. After excitation, the antenna showed a narrow bandwidth behavior at 2.4 GHz. The input admittance at resonant frequency can be expressed as [3]

$$Y_{in} = \sum_n Y_n = \sum \alpha_n V_n^i \tag{1}$$

where the input admittance Y_{in} is the sum of the modal admittances Y_n . In the above equation, α_n (modal weighting coefficient) determines how strongly the n^{th} characteristic mode contributes to the total surface current. $V_n{}^i$ is the modal excitation coefficient, which accounts for how feed affects each mode's contribution to the total current.

Two shorting pins were placed around the feed pin to adjust the reactive loading and control the dual resonance of the antenna (See Fig.2). It can be seen in the Smith chart plot in Fig.3(c) that the antenna's matching was poor and inductive, with a potential for dual resonance. The input admittance after shorting pins can be expressed as

$$Y_{in} = Y_{feed} + Y_{Xpin} + Y_{Ypin} \tag{2}$$

In the first step, Ypin was fixed at (3.25mm, 5.25mm), and Xpin moved away from the center (Δx, -0.745mm) but in parallel to the direction of horizontal currents. The change

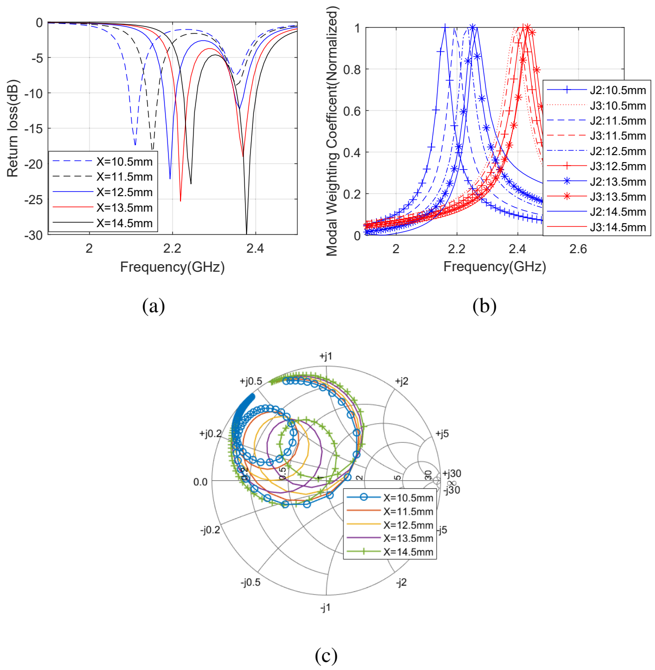


Fig. 3. (a) Return Loss (b) Modal Weighting Coefficient (c) Smith Chart for Xpin Variation

in the Xpin position introduces capacitance to counter the inductive reactance which affects the lower resonant frequency and closes the gap between J2 and J3 (See Fig.3). The effect of Xpin can be expressed as

$$\Delta X \approx \Delta \alpha_2 \tag{3}$$

which shows that the change in Xpin distance is proportional to the change in modal behavior J2 with negligible change in J3. It also improved the impedance matching, but more was needed to achieve dual resonance.

In the next step, Xpin's position was fixed at the (14.5mm,-0.745mm), but Ypin was varied from its last position (3.25mm, Δy), in parallel to vertical currents. The movement of Ypin towards the center introduced a more capacitive effect. It changed the J3 or higher order frequency such that dual resonance was achieved at the cost of reduced higher resonant frequency as shown in Fig.4. The effect of Ypin can be shown as

$$\Delta Y \approx \Delta \alpha_3 \tag{4}$$

It can also be observed that the adjustment of both pins induces capacitive reactance, yet Xpin moved away from the center, and Ypin moved towards the center.

III. Conclusion

This paper presents a systematic procedure for controlling the resonance of a probe-fed microstrip patch via reactive loading. The two fundamental characteristic modes were exploited to realize dual resonance using two shorting pins. The shorting pins were systematically adjusted in the direction of fundamental characteristic modes. This adjustment brought the two modes closer by inducing capacitive reactance that counters the mismatch due to inductive reactance.

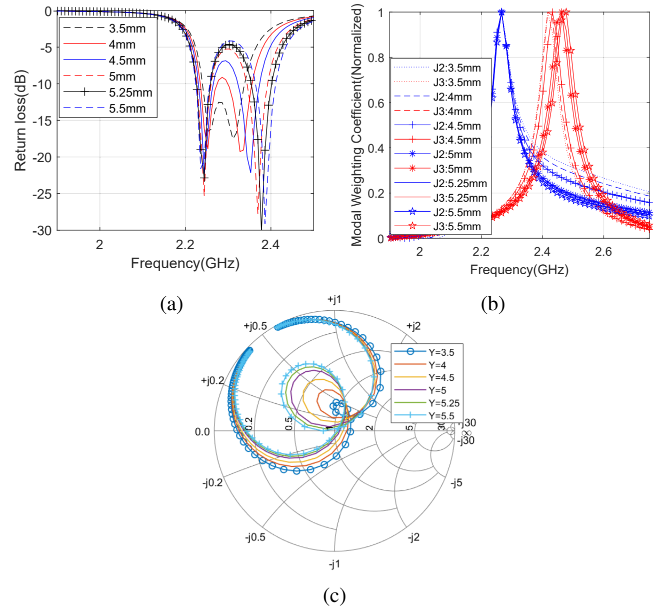


Fig. 4. (a) Return Loss (b) Modal Weighting Coefficient (c) Smith Chart for Ypin variation

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