MODAL ANALYSIS OF PLANAR SYMMETRICAL FOLDED DIPOLE FOR MOBILE TERMINALS

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INTRODUCTION

The Theory of Characteristic Modes (TCM), first developed by Garbacz [1] and later refined by Harrington and Mautz in the seventies [2], can be used to obtain the radiating modes of any arbitrarily-shaped metallic structure. These radiating modes, known as characteristic modes, not only present really attractive orthogonality properties, but also bring physical insight into the radiating phenomena taking place on the antenna.

Because of these advantages, the TCM is extremely useful for systematic analysis and design of antenna. Recently, the TCM has been used for the design of diverse wire and planar antennas, obtaining excellent results [3]. In this paper the TCM is going to be used to provide a clear explanation of the operating principle of the planar symmetrical folded dipole antenna.

The characteristic modes ($\boldsymbol{J_n}$) can be defined as a set of orthogonal real surface currents associated to any conducting object, which depend on its shape and size, and are independent of any excitation source. The resonance frequency of the current modes can be determined by using the information provided by its associated characteristic angles (α_n). Characteristic angles can be defined as

$$\alpha_n = 180° - \tan^{-1}(\lambda_n) \tag{1}$$

where λ_n are the eigenvalues associated to each characteristic mode [2]. From physical point of view, the characteristic angle models the phase angle between a characteristic current $\boldsymbol{J_n}$ and the associated characteristic field $\boldsymbol{E_n}$. Hence, a mode is at resonance when its characteristic angle α_n is 180º. The closer the characteristic angle is to 180º, the better radiating behavior the mode presents.

As it will be shown, the variation of the eigenvalues as a function of frequency gives information about the resonances and radiating bandwidth of the different current modes. In general, eigenvalues range from -∞ to +∞. Considering a mode is at the resonance when its associated eigenvalue is zero, it is inferred that the smaller the magnitude of the eigenvalue is, the more efficiently the mode radiates when excited. Additionally, the sign of the eigenvalue determines whether the mode contributes to store magnetic energy ($\lambda_n > 0$) or electric energy ($\lambda_n < 0$).

Finally, associated to the characteristic currents, a set of characteristic fields can be computed. Therefore, the field radiated by the antenna can be expressed as a superposition of these characteristic fields or modal fields.

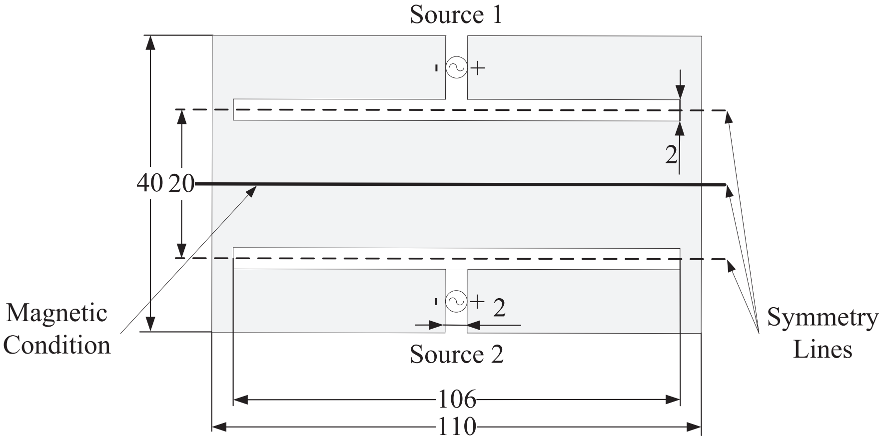

Figure 1: Studied antenna structure with symmetrical slots based on symmetry lines. White area is air when gray is marked as conducting material. (Units: mm)

MODAL ANALYSIS OF SYMMETRICAL FOLDED DIPOLE

In this section the modal study of the symmetrical folded dipole (Fig. 1) is presented. The antenna structure consists of 110 mm x 40 mm radiating ground plane. Two symmetrical slots (106 mm x2 mm) divides the ground plane in three separate parts or dipoles based on symmetry lines. It will be shown how, by using two equally fed sources to excite the folded dipoles, an artificial magnetic condition can be created in the symmetry axes between antennas.

Fig. 2 shows the normalized current distribution at resonance for the first nine characteristic modes ($\boldsymbol{J_n}$) of the symmetrical folded dipole. The structure is complicated and therefore, a higher number of modes should be considered to better understand the antenna behavior. The modes can be classified in antenna or transmission line modes depending on coupling experimented by the three dipoles that conforms the structure.

Antenna modes $\boldsymbol{J_1}$, $\boldsymbol{J_3}$ and $\boldsymbol{J_7}$ exhibit a magnetic condition at the symmetry axis of the radiating ground plane, so all currents are in phase in the three dipoles in which the structure is divided. On the contrary, transmission line modes $\boldsymbol{J_0}$, $\boldsymbol{J_2}$, $\boldsymbol{J_4}$, $\boldsymbol{J_5}$, $\boldsymbol{J_6}$ and $\boldsymbol{J_8}$ present currents flowing in opposite phase in the three dipoles that compose the structure.

Fig. 3 depicts the characteristic angles curves for the first nine characteristic modes of the symmetrical folded dipole. One can notice there is a special non resonant mode $\boldsymbol{J_0}$ whose currents form a close loop around the structure. Antenna modes $\boldsymbol{J_1}$, $\boldsymbol{J_3}$ and $\boldsymbol{J_7}$ present the softest slope at 180º, and hence, the widest radiation bandwidth. It should be remarked that mode $\boldsymbol{J_8}$, in spite of being a transmission line mode, exhibits quite good radiating behavior. This happens because in the mode $\boldsymbol{J_8}$, currents in the upper and lower dipoles are in phase, and hence, they reinforce each other providing good radiation performance.

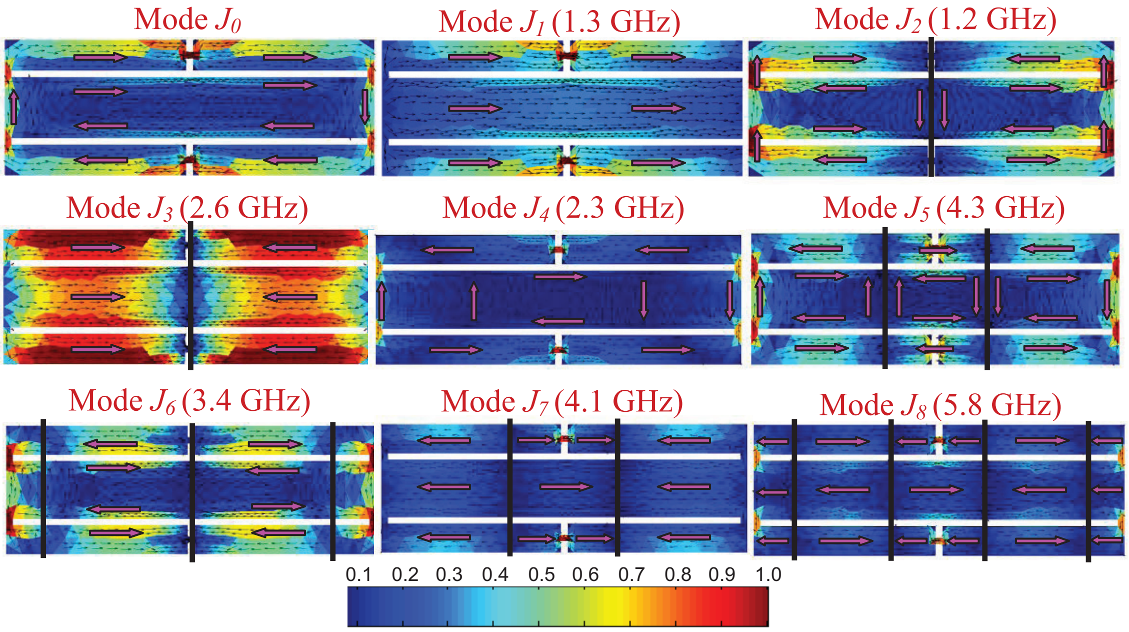

Figure 2: Normalized current distribution at resonance for the first nine characteristic modes of the symmetrical folded dipole.

Fig. 4 studies the contribution of each mode to the total power radiated by the antenna, when it is fed simultaneously at the centre of the upper and lower dipoles. The symmetry of the feeding favors the excitation of antenna modes and avoids the appearance of transmission line modes.

As observed in Fig. 4, when the symmetrical feeding is used only modes $\boldsymbol{J_1}$, $\boldsymbol{J_7}$ and $\boldsymbol{J_8}$ are excited and hence contribute to radiation. As confirmed by Fig. 3, these three modes are precisely the ones that present widest radiating bandwidth (together with mode $\boldsymbol{J_3}$, that is not excited as it presents zero current at the feeding points).

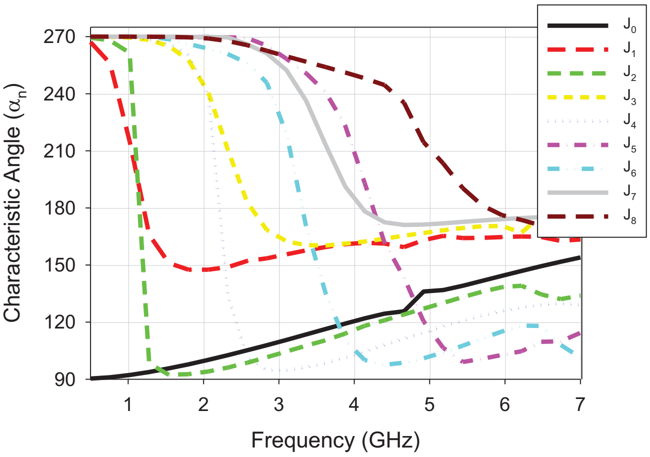

Figure 3: Contribution of each mode to the total radiated power of the double folded dipole when it is fed simultaneously at the centre of the upper and lower dipoles.

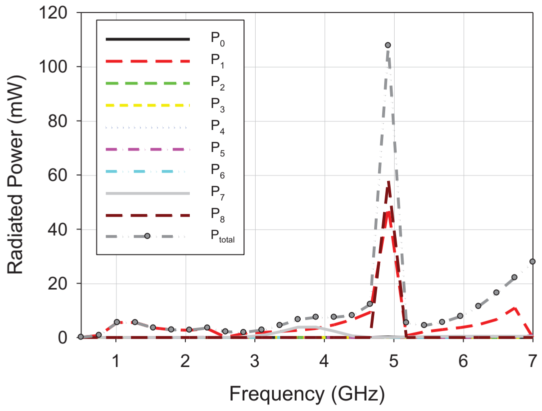

Figure 4: Contribution of each mode to the total radiated power of the symmetrical folded dipole when it is fed simultaneously at the centre of the upper and lower dipoles.

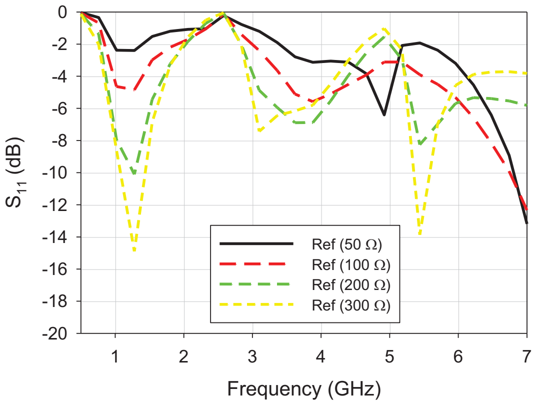

Figure 5: S_{11} parameter of the symmetrical folded dipole with symmetrical feeding calculated for different reference impedances.

Finally in Fig. 5 the S_{11} parameter is computed for different reference impedances when the symmetrical folded dipole is excited symmetrically. Due to the large radiation resistance of the excited antenna modes, the better matching is obtained for the highest reference impedance.

Once more, mode $\boldsymbol{J_1}$ plays an essential role in the structure, as it dominates at the lowest frequencies; it keeps contribution to the total radiated power long after the resonance, combining modes $\boldsymbol{J_7}$ and $\boldsymbol{J_8}$ by creating the second and third radiation peaks, respectively.

CONCLUSIONS

The modal analysis has demonstrated that in the symmetrical folded dipole, there are antenna modes that in case of being excited yield very wideband radiating behaviour. This behaviour is associated to the creation of a magnetic condition at the symmetry axis, which generates currents flowing in phase along the structure that reinforce to increase radiation. Using symmetrical feeding, it is possible to excite only antenna modes, avoiding at the appearance of transmission line modes whose excitation would ruin the matching bandwidth.

REFERENCES

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