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Characteristic Mode Based Pattern Reconfigurable Antenna for Mobile Handset

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***Abstract*—Pattern reconfigurability is a desirable feature of mobile handset antennas, as it enables the antennas to adapt to non-stationary propagation environments. However, it is difficult to vary the radiation pattern of a handset antenna at frequencies below 1 GHz because the entire chassis commonly acts as the main radiator. Hence, designing pattern reconfigurability based on the antenna element (secondary radiator) alone can severely limit the achievable pattern diversity. In this work, a dual-band (0.85-0.90 GHz and 1.93-2.11 GHz) handset antenna with pattern reconfigurability at the low band is designed by loading the periphery of the chassis with a metal bezel. The bezel loading adds a new resonant characteristic mode to the chassis, on top of the fundamental resonant mode. These two modes are selectively excited for pattern reconfigurability using a suitable feed and two PIN diodes, which yield an envelope correlation of below 0.2 in the low band (0.07 at 0.87 GHz). Moreover, since the proposed antenna is fully integrated into the bezel structure, it does not occupy any extra space on the chassis, which also allows more antennas to be implemented, e.g., for MIMO applications.**

***Index Terms*—mobile antennas, characteristic modes, pattern reconfigurable antennas**

I. INTRODUCTION

Pattern reconfigurable antennas have been gaining interest in wireless communications due to their ability to adapt their patterns to variations in the propagation environments. For example, it can be used to increase the signal-to-interference-and-noise ratio (SINR) by directing the nulls of their radiation patterns to the interferers [1]. The nulling of the interferers leads to a more reliable link, a higher data rate or a larger coverage area.

Recently, several pattern reconfigurable antennas have been proposed for mobile handsets [2]-[4], which rely on PIN diodes to switch between different antenna configurations in terms of the parasitic loads [2], the antenna geometry [3], [4] and the feeding network [4]. However, to our knowledge, existing pattern reconfigurable handset antennas operate at frequencies above 1.8 GHz. This is likely because lower cellular bands are below 1 GHz, where the antenna elements are electrically compact and commonly rely on the electrically larger chassis to be the dominant radiator [5]. Moreover, typical handset chassis dimensions offer only one resonant characteristic mode (CM) below 1 GHz, which gives a dipole radiation pattern [6]. Thus, reconfiguring the antenna element (e.g., by switching the antenna geometry) has only limited impact on the total radiation pattern, which is dominated by the radiation from the single-mode chassis.

Fortunately, some recent results [7], [8] show that two or more resonant CMs can be obtained from the handset chassis at frequencies below 1 GHz by making opportunistic use of popular handset design features such as a metal bezel [9].

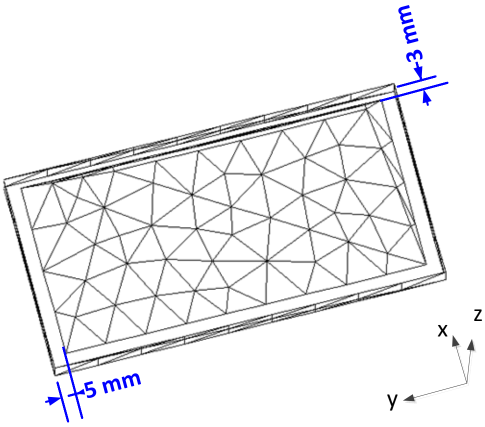
In this work, we utilize the multiple CMs of a bezel-loaded chassis to design a dual-band antenna with pattern reconfigurability, focusing mainly on the low band. Using two PIN diodes to turn an inverted-F antenna (IFA) into a part of the bezel structure, the antenna pattern can be switched between a new resonant mode and the fundamental dipole mode. The correlation of the antenna patterns between the two reconfigurable states is below 0.2 in the low band. The proposed antenna design is fully integrated into the bezel structure. Therefore, it frees up more space within the handset for implementing additional antennas, such as adding one or more co-band antennas for MIMO operation.

II. CHARACTERISTIC MODE ANALYSIS

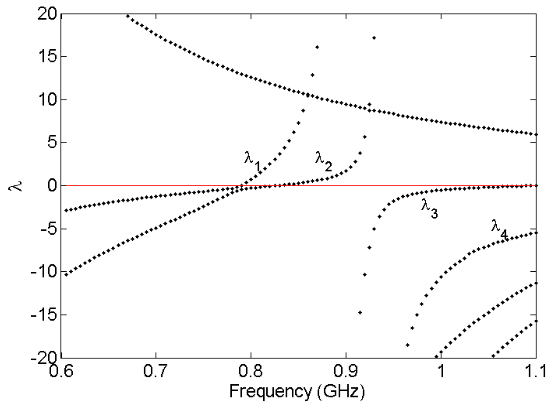
Based on the Theory of Characteristic Modes [10], a bezel-loaded chassis [7] as shown in Fig. 1(a) was analyzed. The handset chassis has the overall dimensions of 130 mm × 66 mm × 8 mm. The flat conductive ground plane is encircled by the bezel. The gap between ground plane and the bezel is 5 mm on three sides and 3 mm on the fourth side, as illustrated in Fig. 1(a). The smaller gap was to allow for more convenient implementation of the capacitively-coupled feed, which was later added to the design. The characteristic eigenvalues of the whole structure were calculated and presented in Fig. 1(b). It can be observed that besides the *fundamental chassis mode*, which is denoted by λ_2 in the figure, there exists a second resonant mode (λ_1) below 1 GHz, which resonates at around 0.8 GHz. By analyzing the characteristic current distribution and far-field pattern, the second mode was defined as the *bezel mode*.

The normalized characteristic electric far-field patterns of the two modes are presented in Fig. 2. On the *xy* plane, the magnitudes of the patterns are perfectly complementary to each other. On the *xz* and *yz* planes, there are some overlaps at around $\theta = \pm 90°$. However, phase differences enable the two modes to remain uncorrelated. Therefore, it is possible to reconfigure the radiation pattern of the antenna by switching between the bezel mode and the chassis mode.

Normally, the chassis mode is relatively easy to excite due to its existence over a larger bandwidth, regardless of how the chassis is loaded. For this reason, effort was first made to excite the bezel mode.

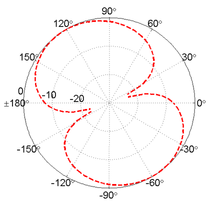


(a)

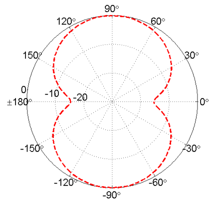


(b)

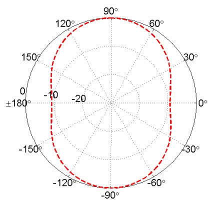
Fig. 1. (a) Structure of the bezel-loaded chassis, shown with the meshing used to obtain the impedance matrix; (b) Characteristic eigenvalues of the bezel-loaded chassis.



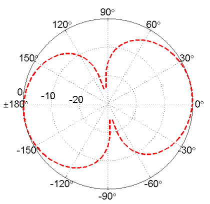
(a) BM, *xy* plane



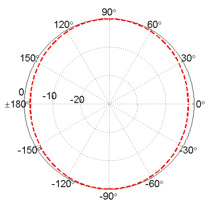
(b) BM, *xz* plane



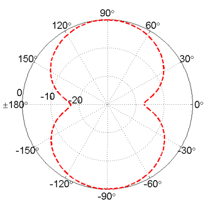
(c) BM, *yz* plane



(d) FCM, *xy* plane



(e) FCM, *xz* plane



(f) FCM, *yz* plane

Fig. 2. Characteristic far-field patterns of the bezel mode (BM) (a)-(c) and the fundamental chassis mode (FCM) (c)-(f) at 0.8 GHz.

III. Antenna Configuration

Following the field analysis in [7], to excite the full wavelength bezel mode, a capacitively coupled feed can be placed along the bezel length, as shown in Fig. 3. The small narrow plate with the dimensions of 16 mm × 5 mm was attached to the bezel and displaced by 5 mm from the center of the bezel length. The plate was fed by a vertical strip with the width of 1 mm. A microstrip feed line was added to the antenna to enable practical antenna measurement. To match the antenna for wideband operation, an *L*-matching network, including a 2.7 pF series capacitor and a 6.8 nH parallel inductor, was added to the port. It is noted that the matching network slightly modified the resonant frequency as compared to that obtained from the modal analysis.

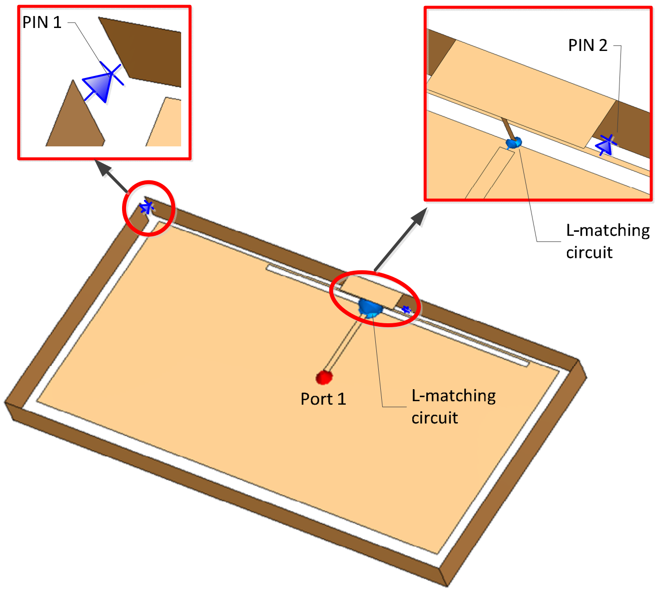
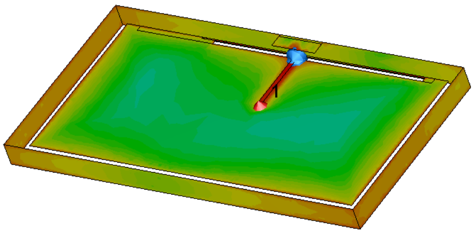


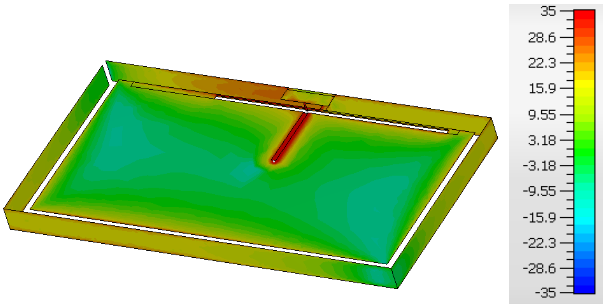
Fig. 3. Geometries of the pattern reconfigurable handset antenna.

In order to excite two different modes with the same feeding location and matching network, a change in the antenna structure was required. Implementing an IFA along the length of the chassis was a good choice due to the IFA's ability to excite the fundamental chassis mode as well as its compactness and convenient integration with the bezel structure. To create an IFA structure, a strip connecting the main chassis and the bezel was added as a "shorting pin", which is located 4 mm from the feed (along the chassis length). At the same time, the bezel is disconnected at one end to satisfy the length requirement of the IFA to resonate at the same frequency.

The connecting strip and the disconnection of the bezel can be realized using PIN diodes in practice (e.g., BAP1321-02 from NXP), as depicted in the subfigures of Fig. 3. When PIN diode 1 is on and PIN diode 2 is off, the bezel mode is excited. On the other hand, when PIN diode 1 is off and PIN diode 2 is on, the antenna becomes an IFA, such that the fundamental dipole mode of the chassis is excited. The current distributions at the two modes are presented in Fig. 4.



(a) bezel mode



(b) fundamental chassis mode

Fig. 4. Magnitudes of current distributions (in dB) for the reconfigurable antenna at 0.87 GHz.

For the bezel mode, the current follows a one-wavelength sinusoidal distribution along the bezel. For the fundamental chassis mode, the current is mainly on the shorting pin and the part between the shorting pin and the disconnection. In addition, strong current also appears along the length of the chassis, which matches well the fundamental chassis mode current distribution.

In order to support multiband operation at higher frequencies, a slot antenna, with a length of 78 mm and 1 mm away from the chassis edge, was etched in the chassis. The slot antenna is excited by the same capacitive feed.

IV. Simulation Results

The magnitudes of the reflection coefficient of the antenna in its two operating states (or modes) are presented in Fig. 5. For the low frequency band, the bezel mode covers the band 0.82-0.92 GHz, whereas the fundamental chassis mode covers 0.85-0.90 GHz. The bezel mode offers a relatively larger bandwidth since the matching network is specifically designed for it. For the high frequency band, both modes cover 1.93-2.11 GHz. In addition, the bezel mode also covers the band 1.61-1.67 GHz.

The simulated radiation patterns of the proposed antenna in its two states are shown in Fig. 6 for 0.87 GHz. It is observed that those patterns follow the characteristic patterns in Fig. 2 very well, meaning that the bezel and fundamental chassis modes are successfully excited by the two structures. Some differences can be seen in the fundamental chassis mode on the *yz* plane: the characteristic pattern is omnidirectional, whereas CST simulation gives a small null on one side. This is due to the finite influence of the bezel when the chassis is excited. As can be observed in Fig. 4(b), there is still some current along the other parts of bezel when the fundamental chassis mode is excited. A very low envelope correlation of 0.067 is obtained between the two states at 0.87 GHz, and the correlation is below 0.2 within the low band.

Since no explicit effort was made to optimize the high band performance, the patterns of the two reconfigurable states are highly correlated in the high band (i.e., up to 0.64). However, as mentioned earlier, the focus of this paper is to provide proof-of-concept for reconfigurable handset antennas below 1 GHz. The optimization of high band performance is left for future work. For example, the multiband design approach of [11] can be attempted to simultaneously achieve low inter-state pattern correlation for both low and high bands.

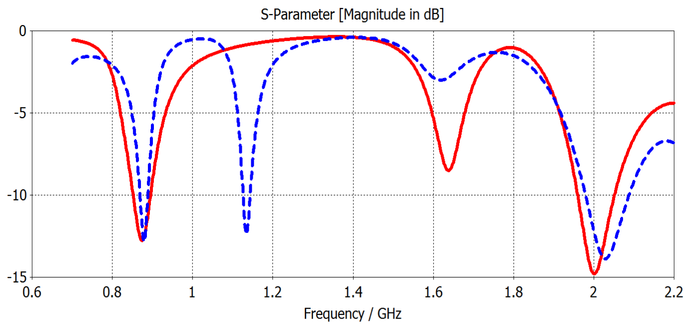
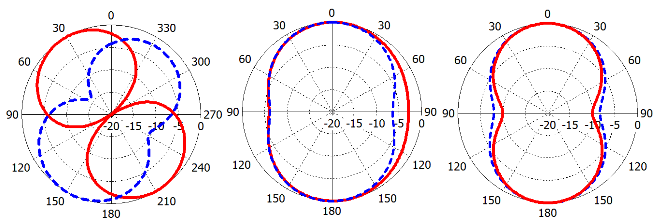


Fig. 5. Magnitudes of the reflection coefficient (in dB) of the proposed antenna in its two operating states: (—) bezel mode, (- -) fundamental chassis mode.



(a) *xy* plane (b) *xz* plane (c) *yz* plane

Fig. 6. Radiation patterns of the reconfigurable antennas at 0.87 GHz: (—) bezel mode, (- -) fundamental chassis mode.

V. Conclusions

A CM based pattern reconfigurable antenna is proposed and investigated in this work. Through loading the chassis with a bezel, two resonant CMs were created and utilized for pattern reconfigurability at 0.85-0.90 GHz. With two PIN diodes, the patterns can be switched between two different states, providing a low correlation of up to 0.2 in the low band. Possible future work includes experimental verification of the simulation results, optimization of pattern correlation at the high band and addition of more antenna elements for MIMO applications.

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