Reconfigurable Miniature Multielement Antenna for Wireless Networking

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Abstract

We present a new reconfigurable broadband miniature antenna architecture that is able to change its working frequency, polarization, or radiation pattern to get single broadband or dualband behavior for a single widebeam or multibeam diversity configuration. Two antenna geometries are considered. A single element antenna, the so-called dime antenna, is introduced. A prototype dime antenna operating at 5.2 GHz was fabricated and measured to validate the accuracy of the simulation tool in terms of accurately predicting its impedance behavior and radiation characteristics. Motivated by the dime antenna another novel miniature antenna geometry, called qdime, was studied in detail. Mutual coupling analysis between qdime antenna pairs with respect to orientation is investigated to determine optimum multi-element antenna configuration (less mutual coupling and less space occupation) for use in diversity systems that require sufficiently decorrelated received signals at each antenna element. Short circuit striplines, having typical dimensions of RF MEMS switches, are appropriately located within the antenna structure to change its operating frequency and radiation pattern. Results are presented and discussed.

I. Introduction

Deployment of Fourth-generation cellular networks will require systems with broadband capabilities in high-mobility environments [1]. Data rates greater than 100 Mbits/s, high spectral efficiency, and stronger fading mitigation have to be achieved. Technologies needed to obtain such specifications include multibeam antenna systems, wideband transceivers, and robust and efficient space-time coding.

Current trends in communication systems integrate different radio modules into one piece of equipment and miniaturize every possible component. This requires small and robust multi-band antennas. In addition, the need to employ antenna diversity on the communication system to improve receiver performance, by overcoming multipath propagation effects, is another factor that drives multielement antenna system consisting of small antennas appropriate for diversity combining (decorrelated received signal at each antenna element $\Leftrightarrow$ small mutual coupling between antenna elements)[2].

In this paper we present a new antenna architecture, based on a miniature multi-layered broadband antenna, the dime antenna [3], as an individual radiating element (radius $< 0.2\lambda$ and thickness $< 0.05\lambda$), consisting of four such antenna elements. We then combine switches (either PIN or MEMS depending on the application) [4] located at the following: into the resonant aperture to change working frequency, or into the feeding line to select active radiation beams.

The dime antenna is presented in section IIA. We then aim at modifying its structure such that the new geometry, the qdime antenna, achieves better mutual coupling and occupies less area when multiple antennas are used. In section IIB, firstly a computational study on a single qdime antenna element performance is studied. Having studied single antenna element, short circuit strip lines representing MEMS switches are strategically located in the antenna structure. Successively switching on a specific number of these elements allows the operation of frequency to be tuned. Then mutual coupling analysis for antenna pairs with respect to orientation is investigated. Upon identifying the effects of different design parameters on antenna performance a four-element architecture of the qdime with overall dimensions of $\lambda/2 \times \lambda/2 \times \lambda/20$ is presented.

II. Antenna Geometries and Characterization

A. The Dime Antenna

The dime antenna architecture is shown in Fig.1. It consists of two stacked circular patches, upper and lower patches, with a perimeter close to $\lambda/2$ over a ground plane. We propose to use a volumetric geometry different from that of printed antennas to exploit the range of physical limits [4]. A sectoral slit with a slit angle of $\theta_s$
was etched into the lower patch to reduce its size and control the impedance matching level. This structure forms two planar radial transmission lines between three planes (upper and lower patches, and ground plane), ended by the upper and lower cylindrical slots with lengths $S_u$ and $S_l$ and limited by upper and lower connecting sectoral walls (or shorting walls) with lengths of $w_u$ and $w_l$ (Fig.1). Upper and lower layers are of the thicknesses $h_u$ and $h_l$, respectively. A coaxial probe simultaneously feeds the two cylindrical antenna slots. The sectoral slit etched into the lower patch forces current to travel from the feed point along the circular slit, then down to ground level through the lower shorting wall. The placement of the inner conductor of coaxial, which is determined by the distance $d_m$, and the length of the sectoral slit determined by $\theta_s$ are key parameters in achieving good input matching. Slot lengths $S_u$ and $S_l$ and the length of the feed point ground path determine resonant frequencies. There has been detailed discussion on how these parameters play a role on antenna performance and radiation characteristics [3]. An antenna operating at 5.2GHz was fabricated and its return loss was measured. The agreement between measured and calculated return loss, as shown in Fig.2, validates the accuracy of the simulation technique (HFSS7) used in terms of accurately predicting antenna's impedance behavior.

**B. The qdime antenna**

The geometry of the qdime antenna is obtained by modifying the geometry of the dime antenna and is shown in Fig.3 and 4 (the upper patch, in Fig.3, is shown as wireframe for the sake of illustration). It has the advantage of having less mutual coupling over the dime antenna for use in multi-element antenna systems providing separate channels for diversity combining.

Like the dime antenna its structure includes two planar transmission lines between three planes (upper quarter patch, lower quarter patch and ground plane). Unlike the dime antenna, however, the lower slot is horizontal in terms of electric field distribution. It was constructed so to reduce mutual coupling between individual antenna elements when they are located adjacently in multi-element antenna configuration. Two vertical walls with the length of $w_u$ and height of $h_u$, connecting lower patch to upper patch determine the upper slot length $S_u=5+2h_u$, and the height of the upper layer $h_u$ (please refer to Fig.4). Two horizontal walls with the length of $w_l$ and width...
of \( t \), connect the lower patch layer to the ground plane through a vertical wall which surrounds the lower patch and stretches from ground level to lower patch level with height \( h_t \). This wall forms a horizontal lower slot where the horizontal component of electric field is confined. The length of the horizontal lower slot is \( S_t = S + 2l_t \) and is determined by the horizontal wall length \( w_t \). The slit structure with length \( l_s \) etched into the lower patch increases the effective electrical length of the antenna and decreases resonant frequency allowing miniaturization in antenna size.

First we investigate how key design parameters affect antenna performance: lower slot length \( (S_t \approx w_u) \), upper slot length \( (S_u \approx w_l) \) and, slit length \( l_s \). Appropriate choice of such element dimensions allows dual-band operation or single broadband operation. Return loss as a function of frequency for different horizontal wall lengths, \( w_l \), is plotted in Fig.5. For the chosen dimensions (see Fig.5) of antenna elements the antenna has dual band behavior. The curves show that \( w_l \) controls the location of the lower resonant frequency. As \( w_l \) is increased (lower slot length \( S_t \) is decreased) the resonant frequency shifts into higher values as expected, while the higher resonant frequency and its matching level remain unaffected. Similar results are obtained by varying \( w_u \) while keeping other parameters fixed. From Fig.6, it is seen that \( w_u \) controls the higher resonant frequency and if it is chosen close to \( w_l \) (upper slot length \( S_u \) is close to lower slot length \( S_t \)) the antenna has single broadband behavior. It is observed that a bandwidth close to 20% is achievable for the frequency band of interest (5-6GHz) from this miniature antenna. The effect of various slit lengths, \( l_s \), on input impedance was also investigated. The results indicate that slit length plays a role on both resonant frequencies and matching level. As \( l_s \) is increased resonant frequencies become closer so that single broadband operation is obtained.

These results allow development of methodologies to design antennas for operation at a defined frequency range either for dual-band or broadband single frequency operation.

We placed shorting strip lines representing MEMS switches in antenna structure to change its resonant frequency by changing corresponding dimensions of antenna elements with switch on and off. These striplines were placed at the level of lower patch spanning from the lower patch to the vertical wall such that they allow changing lower slot length with a change in \( w_l \). When applied bias actuates the MEMS switch its buckled mechanical membrane provides physical contact between lower patch and vertical wall. Fig. 7 shows of successive actuation of a number switch tunes the operation frequency.
Finally we intended to investigate the interaction between two antenna elements by studying mutual coupling as a function of orientation angle $\alpha$. In Fig.8 the mutual coupling of antenna pairs for different orientation angles is compared. It is observed that mutual coupling is lowest when the antennas are orientated with $\alpha=90^\circ$. Upon identifying the effects of different antenna parameters on a single antenna performance and studying mutual coupling we designed a multi-element configuration consisting of four qdime antennas, as shown in Fig.9, having minimum space requirements and compatible with a mutual coupling figure under $-15\text{dB}$. This planar set of four elements is very well suited to employ MEMS switches in its structure. Such switches are located so they connect the central feeding line to each individual antenna’s feed point. This allows selection of any active radiation beam making the system capable to implement polarization diversity and providing reconfigurability in terms of radiation pattern.

### III. Conclusions

The qdime antenna, a novel miniature antenna structure, having attractive impedance and radiation characteristics has been introduced for communication applications where space volume for the antenna is quite limited. Its architecture is obtained by optimizing that of the dime antenna for multi-element operation. The qdime antenna was studied in detail to determine the effects of design parameters $w_l$, $w_u$, and $l_t$ on antenna performance. Mutual coupling analysis was carried out to evaluate the interaction of antenna elements in a multi-element system. MEMS switches were strategically placed within the antenna structure to employ reconfigurability in terms of frequency range and radiation pattern capabilities in order to implement diversity combining.

### References:


