Miniature Multielement Antennas for Diversity Wireless Communications

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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. First the basic so-called “dime” geometry is introduced. Numerical and experimental results for a prototype at 5.2 GHz are presented. Based on the dime antenna, a multielement architecture for use in diversity systems is presented. 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. Simulated results for a 4-element prototype with a frequency band operation from 5 to 6 GHz are presented. Circuitual and radiation characteristics are discussed in terms of reconfigurability and diversity capabilities.

I. INTRODUCTION

Deployment of next-generation wireless networks requires systems with broadband capabilities in high-mobility environments [1]. Applications range from personal communications to home, car and office networking. High data rates (100 Mbits/s and above), high spectral efficiencies, and stronger fading mitigation have to be achieved. Technologies needed to obtain these specifications, include diversity systems, wideband transceivers, and robust and efficient space-time coding. The need to employ antenna diversity on the communication system to improve receiver performance, by overcoming multipath propagation effects, drives multielement antenna system consisting of small antennas appropriate for diversity combining (decorrelated received signal at each antenna element ⇔ small mutual coupling between antenna elements)[2]. Accordingly, small, low cost and reliable multipurpose antenna geometries (broadband, dual band, reconfigurable, etc) need to be developed.

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 < 0.2λ and thickness < 0.06λ), consisting of four such antenna elements. We then combine switches (either PIN or MEMS depending on the application) [4] located at the following places: 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, has a convenient surface to place the MEMS switches 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, mutual coupling analysis for antenna pairs with respect to orientation is investigated. Then 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. Upon identifying the effects of different design parameters on antenna performance a four-element architecture of the qdime with overall dimensions of 0.8λ x 0.8λ x 0.06λ 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 λ/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 [5]. A sectoral slit with a slit angle of θ_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 have thicknesses h_u and h_l, respectively. A coaxial probe simultaneously feeds the two cylindrical antenna slots. The λ/2 dimension of the slot lengths S_u and S_l, and the λ/4 length of the feed point to ground path determine resonant frequencies. There has been detailed discussion on how these parameters play a role on antenna performance and radiation characteristics [3]. To validate the simulation, a test antenna at 5.2 GHz (next generation Bluetooth frequency band) was fabricated and its circuital and radiation parameters were measured. Very good agreement between simulated and measured results for the return loss of the antenna are represented in Fig.2. For a 1:2 VSWR, a 12% bandwidth is achieved and preliminary dual band behavior is observed. In order to characterize antenna coverage its radiation pattern was numerically simulated and experimentally measured. Fig.3, shows comparative results for the E-plane (x-z plane) and H-plane (x-y plane), with very good agreement for both co-polar (θ) and cross-polar (φ) components. In accordance with its geometry and size, the antenna exhibits a very uniform radiation pattern close to elemental dipole behavior, which makes it suitable for broad coverage applications. Finally we performed a gain measurement using two different reference antennas, a λ/2 dipole and a λ/4 monopole, which consistently gave a maximum gain of 2 dBi±0.2dB.

B. The multielement geometry

Although the dime antenna described above is already small in size, we have changed its geometry slightly to optimize it for a diversity system. This new geometry, called quarter-dime antenna (qdime), is obtained by square-shaping the back of the antenna to better fit the 4-element geometry and is shown in Fig.4 and 5 (the upper patch, in Fig.4, is shown as wireframe for the sake of illustration). It has the advantage of

![Fig.1 The structure of the dime antenna: (a) Side view, (b) Top views of the patches](image)

- upper patch
- upper sectoral wall
- lower patch
- lower sectoral wall
- Ground plane

![Fig.2 Comparison of calculated and measured return loss for the fabricated dime antenna](image)

- measured
- calculated
- r_u=r_l=5mm
- r_c=10mm
- θ_s=125°
- S_u=24.2mm
- d_m=0.05mm
- S_l=33.5mm
- h_u=h_l=1.58mm

![Fig.3. Comparison of calculated and measured radiation pattern for the fabricated dime antenna. a) E-plane b) H-plane](image)
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 adjacent to each other in multi-element antenna configuration. Two vertical walls with the length of $w_l$ and height of $h_u$, connecting lower patch to upper patch determine the upper slot length $S_u=S+2l_u$, and the height of the upper layer $h_u$

Fig.4 Architecture of the qdime antenna.

Fig.5 Top views of the lower and upper patches (please refer to Fig.5). 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 $h_l$. The length of the horizontal lower slot is $S_l=S+2l_l$ and is determined by the horizontal wall length $w_l$. 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.

Similarly to the dime antenna, an appropriate choice of $l_s$, $S_l$ and $S_u$ effectively tunes the antenna for dual band or single broadband operation. 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 $S_l$) 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.

As a next step towards multielement geometry, the interaction between two close identical qdime elements as a function of orientation angle $\alpha$ has been studied. In Fig.7 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 $\alpha=90^\circ$, where an optimum electrical separation and field orthogonality is reached. 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, having minimum space requirements and compatible with a mutual coupling figure under –15dB. Fig. 8 shows the actual dimensions of the antenna for 5 to 6 GHz broadband operation, with an overall dimension of $45\times45\times3.2\text{mm}^3$ ($0.8\lambda \times 0.8\lambda \times 0.06\lambda$ at 5.5GHz). To add frequency or pattern reconfigurability to the multielement antenna, we placed shorting strip lines (60$\mu$m x 200$\mu$m in size) representing MEMS switches in different locations of the antenna structure. These striplines were first 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. 8 shows of successive actuation of a number switch tunes the operation frequency. As a second step, switches were 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. Fig. 10 shows the co-polar x-z plane pattern radiated by the antenna element number 1 and 2. The results for the different radiation patterns show different degrees of pattern orthogonality, suitable for antenna radiation pattern diversity system.

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.

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