

# Reconfigurable Miniature Multi-Element Antenna for Wireless Networking

By **Bedri A. Cetiner, Luis Jofre and Franco De Flaviis**  
University of California at Irvine

**T**his article discusses a new reconfigurable broadband miniature antenna architecture able to change its working frequency, polarization or radiation pattern to achieve single broadband or dualband behavior for a single widebeam or multibeam diversity configuration. Two antenna geometries are considered, and 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 and to ensure that the impedance behavior and radiation characteristics were accurately predicted.

Motivated by the dime antenna, another novel miniature antenna geometry — qdime — was studied in detail. A mutual coupling analysis of qdime antenna pairs with respect to orientation was performed to determine the optimum multi-element antenna configuration for reduced mutual coupling and smaller size.

Short circuit striplines, having typical dimensions of radio frequency (RF) microelectromechanical systems (MEMS) switches, were appropriately located within the antenna structure to change its operating frequency and radiation pattern. Complete results are presented and discussed.

## Introduction

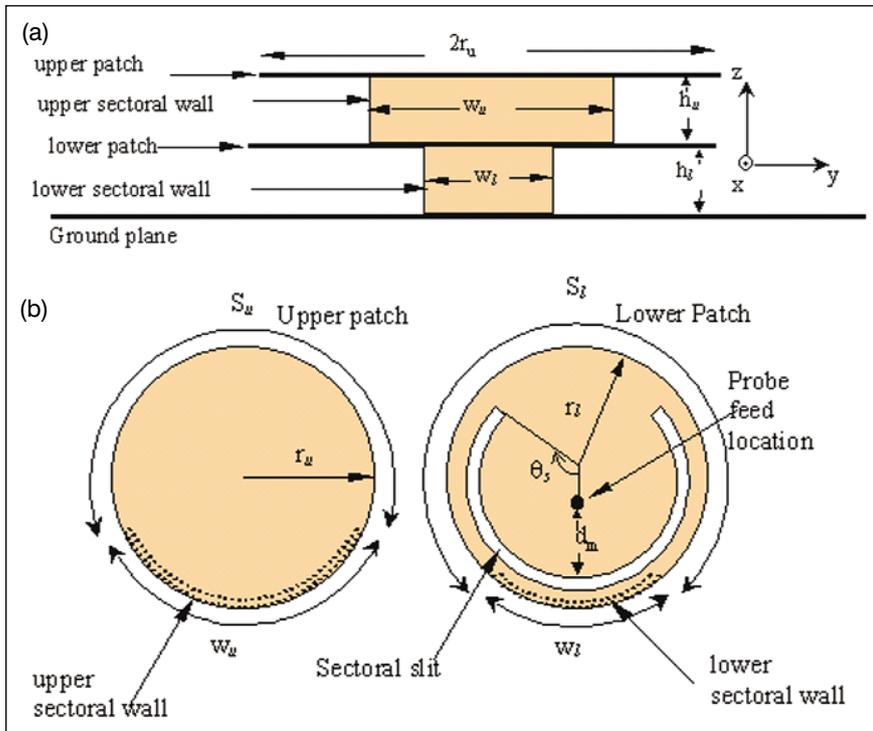
Deployment of fourth-generation cellular networks requires systems with broadband capabilities in high-mobility environments [1]. Further, data rates of more than 100 megabits per second (Mbps), high spectral efficiency and stronger fading mitigation have to be achieved. Technologies must be obtained, including multibeam antenna systems, wide-

band transceivers and robust and efficient space-time coding.

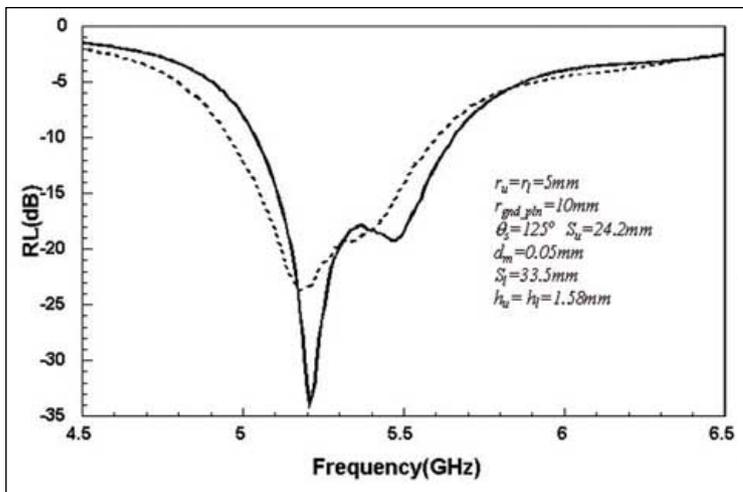
A current trend in communication systems is to integrate different radio modules into one piece of equipment and miniaturize every possible component. This approach requires small and robust multiband antennas. In addition, the need to employ antenna diversity to improve receiver performance by overcoming multipath propagation effects is another factor that drives multi-element antenna systems consisting of small antennas with decorrelated received signals at each element with small mutual coupling between antenna elements [2].

In this article, we describe a new antenna architecture based on a miniature multilayered broadband antenna, the dime antenna [3], as an individual radiating element (radius less than  $0.2\lambda$  and thickness less than  $0.05\lambda$ ), consisting of four such antenna elements. This architecture combines switches (either PIN or MEMS [4]), located at the resonant aperture to change working frequency, or into the feeding line to select active radiation beams.

We first discuss the dime antenna and we then modify its structure to a new geometry — the qdime antenna — that achieves better mutual coupling and occupies less area when multiple antennas are used. In the next section, a computational study on a single qdime antenna element is presented. Short circuit strip lines representing MEMS switches are strategically located in the antenna structure. If a specific number of these elements are switched on successively, the frequency of operation can be tuned. This is followed by a mutual coupling analysis for antenna pairs with respect to orientation. Upon identifying the effects of different



▲ **Figure 1. The structure of the dime antenna: (a) side view, (b) top views of the patches.**



▲ **Figure 2. Comparison of calculated and measured return loss for the fabricated dime antenna.**

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.

## Antenna geometries and characterizations

### The dime antenna

The dime antenna architecture is shown in Figure 1. It consists of two stacked upper and lower circular patches, with a perimeter close to  $\lambda/2$  over a ground

plane. We propose a volumetric geometry different from that of printed antennas to make full use of the range of physical limits [5]. 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. 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  $w_l$  (see Figure 1). Upper and lower layers are of the thicknesses  $h_u$  and  $h_l$ , respectively.

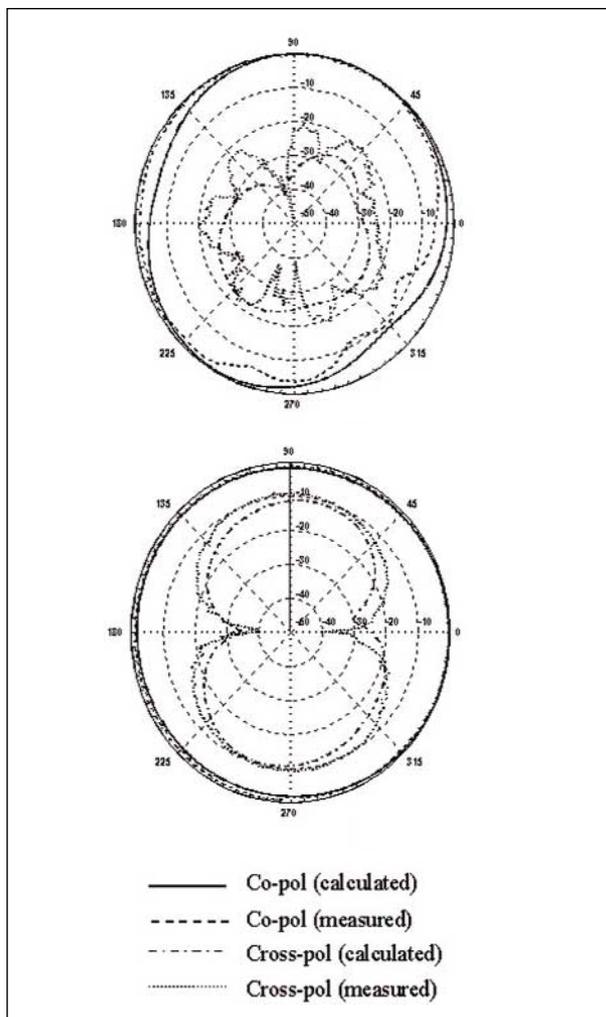
A coaxial probe simultaneously feeds the two cylindrical antenna slots. The sectoral slit etched into the lower patch forces current to travel from the feed point along the circular slit, then down to ground level through the lower shorting wall. The placement of the inner coaxial conductor is determined by the distance  $d_m$ , and the length of the sectoral slit determined by  $\theta_s$  are key parameters in achieving good input match-

ing. Slot lengths  $S_u$  and  $S_l$  and the length of the feed point to ground path determine resonant frequencies. A detailed discussion on how these parameters play a role on antenna performance and radiation characteristics can be found in [3]. An antenna operating at 5.2 GHz was fabricated and its return loss and radiation pattern were measured. The agreement between measured and calculated data, as shown in Figure 2 and Figure 3, validates the accuracy of the HFSS7 [6] simulation predicting the antenna's impedance behavior and radiation characteristics.

### The qdime antenna

The geometry of the qdime antenna is obtained by modifying the geometry of the dime antenna (see Figure 4 and 5). The upper patch in Figure 4 is shown as wireframe for the sake of illustration. This architecture has the advantage of having less mutual coupling over the dime antenna for use in multi-element antenna systems with separate channels for diversity combining.

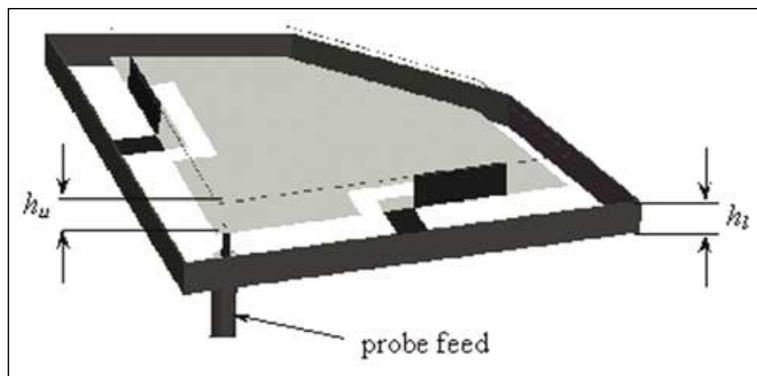
Like the dime antenna, its structure includes two planar transmission lines between three planes (upper quarter patch, lower quarter patch and ground plane). Unlike the dime antenna, however, the lower slot is horizontal in terms of electric field distribution. This was done to reduce mutual coupling between individual antenna elements when they are adjacent in multi-ele-



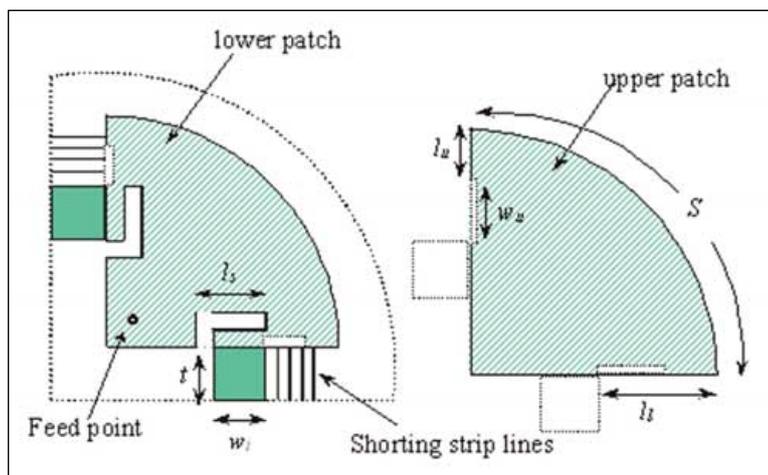
▲ **Figure 3.** Comparison of calculated and measured radiation patterns for the fabricated dime antenna: (a) E-plane, (b) H-plane.

ment antenna configuration. Two vertical walls with length of  $w_u$  and height of  $h_u$ , connecting the lower to upper patch, determine the upper slot length ( $S_u = S + 2l_u$ ) and the height of the upper layer  $h_u$  (see Figure 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 the lower patch level with height  $h_l$ . This wall forms a horizontal lower slot to confine the horizontal component of the electric field. 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 the resonant frequency, allowing for a small antenna.

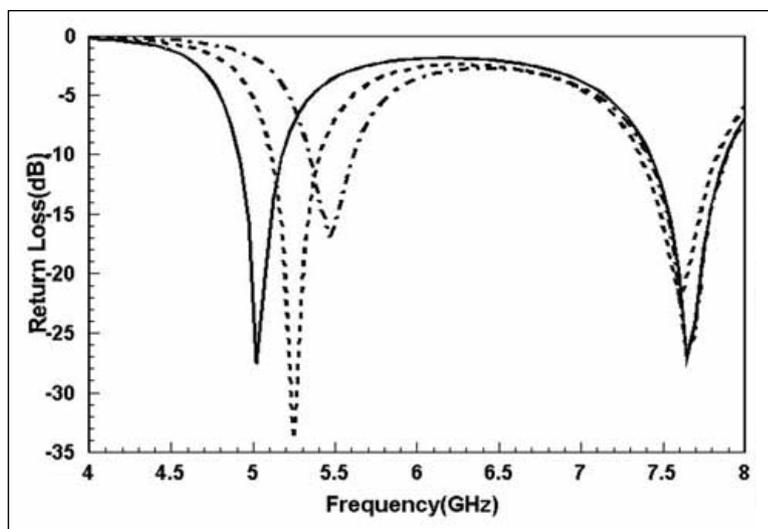
The key design parameters (i.e., lower slot length ( $S_u$



▲ **Figure 4.** Architecture of the qdime antenna.

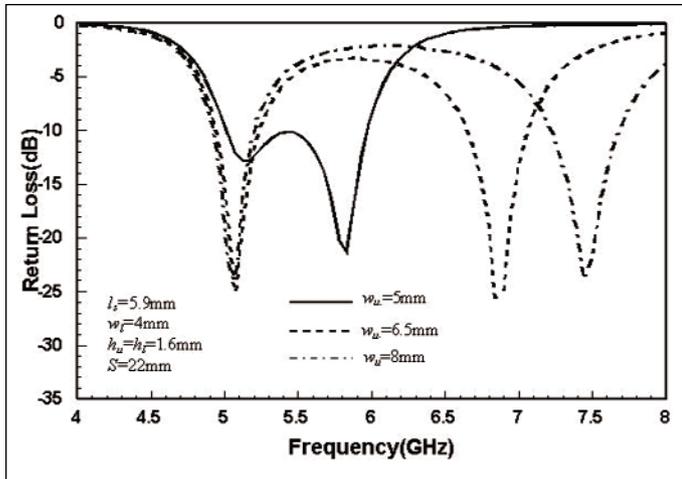


▲ **Figure 5.** Top views of the lower and upper patches.

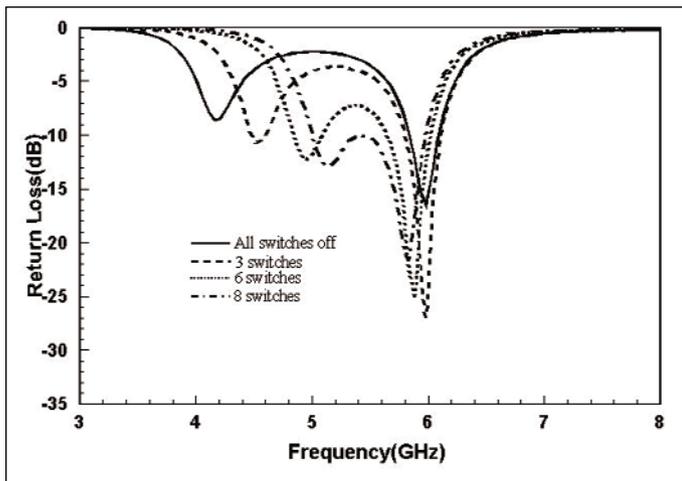


▲ **Figure 6.** Return loss of the qdime antenna as a function of  $w_l$ .

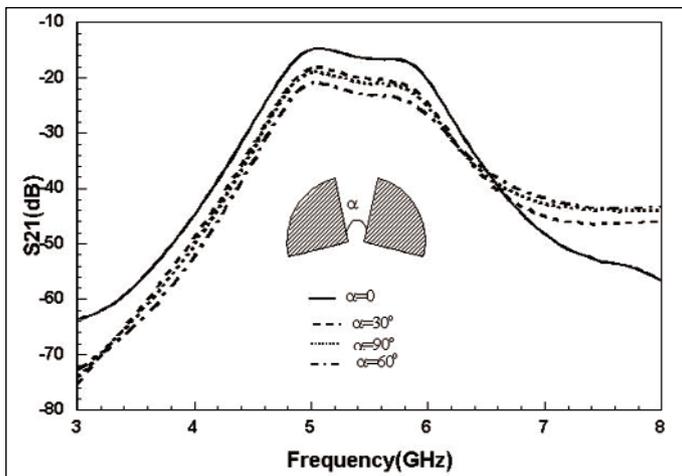
$\Leftrightarrow w_u$ ), upper slot length ( $S_l \Leftrightarrow w_l$ ) and, slit length  $l_s$ ) affect antenna performance. Appropriate choices of these dimensions allow either dual-band or single-



▲ Figure 7. Return loss of the qdime antenna as a function of  $w_u$ .



▲ Figure 8. Return loss for the MEMS switch-tunable qdime antenna. Shorting strip lines have 0.2 mm width, 1.6 mm length and are separated by 0.15 mm.



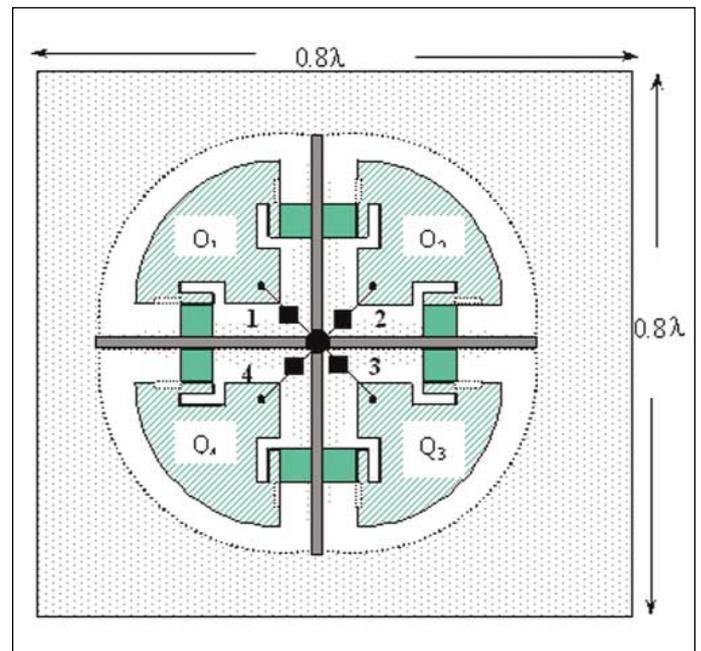
▲ Figure 9. Comparison of mutual coupling as a function of orientation angle  $\alpha$  between two qdime antennas.

broadband operation. Return loss as a function of frequency for different horizontal wall lengths,  $w_l$ , is plotted in Figure 6. For the dimensions in this figure, 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  $S_l$  is decreased), the resonant frequency shifts higher as predicted, while the higher resonant frequency and its matching remain unaffected.

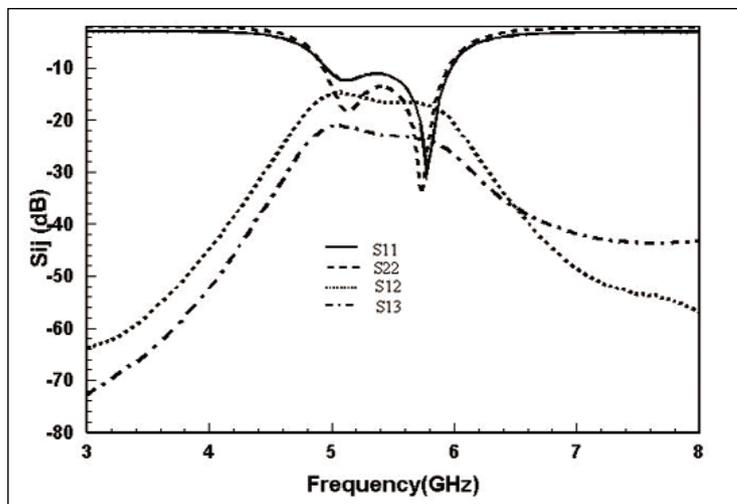
Similar results are obtained by varying  $w_u$  while leaving other parameters unchanged. Figure 7 shows that  $w_u$  controls the higher resonant frequency and if it is chosen close to  $w_l$  (upper slot length  $S_u$  is close to lower slot length  $S_l$ ), the antenna has single broadband behavior. A bandwidth close to 20 percent is achievable for the 5 to 6 GHz frequency band for this miniature antenna. The effect of different slit lengths,  $l_s$ , on input impedance was also investigated. The results indicate that slit length effects both the resonant frequencies and matching. As  $l_s$  is increased, resonant frequencies become closer and single broadband operation is obtained.

These discoveries allow development of strategies for the design of 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 the antenna structure to change its resonant frequency by changing corresponding element dimensions with the switch on and off. These striplines were placed at the lower patch, spanning from it to the vertical wall, so the lower slot length could be changed with a change in  $w_l$ . When applied bias actuates the MEMS



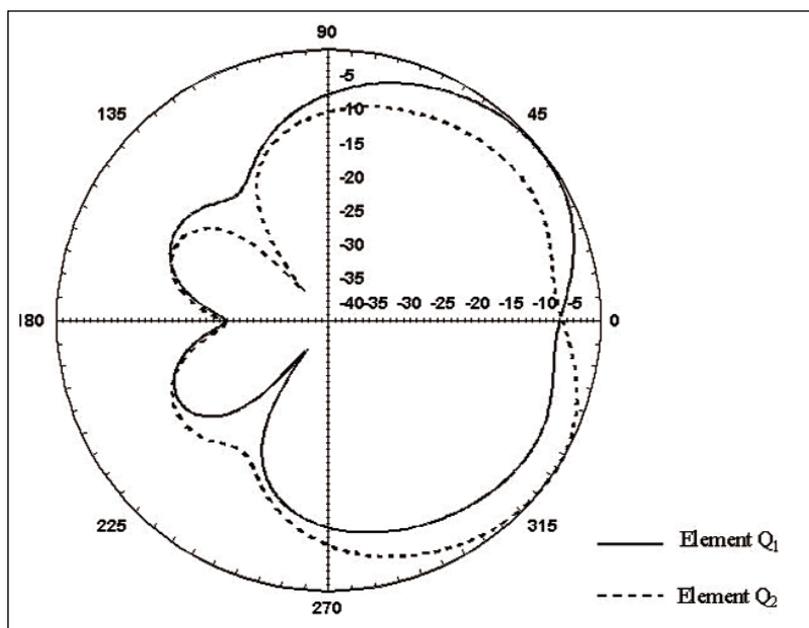
▲ Figure 10. Top view of the lower patch plane of the MEMS switch-tunable four-element qdime antenna. MEMS switches (1 through 4) are indicated.



▲ **Figure 11.** Return loss and mutual coupling for the four-element antenna system.

switch, its buckled mechanical membrane would provide physical contact between lower patch and vertical wall. Figure 7 shows successive actuation of a number switch to tune the operation frequency.

Finally, we studied the interaction between two antenna elements by looking at mutual coupling as a function of the orientation angle  $\alpha$ . Figure 9 compares the mutual coupling of antenna pairs for different orientation angles. Mutual coupling is lowest when the antennas are oriented with  $\alpha = 90^\circ$ . After we identified the effects of different antenna parameters on a single antenna and investigated mutual coupling, we designed a multi-element configuration of four qdime antennas



▲ **Figure 12.** Co-polar x-z plane patterns corresponding to the qdime elements  $Q_1$  and  $Q_2$ .

(see Figure 10), with a minimum size and compatibility with a mutual coupling figure under  $-15$  dB. This planar set of four elements is well suited to employ MEMS switches in its structure. These switches would connect the central feeding line to each individual antenna feed point. This allows the selection of any active radiation beam for polarization diversity and reconfigure radiation patterns. Figure 12 shows the co-polar x-z plane radiation pattern when either only switch 1 or only switch 2 is in the on state, respectively.

## Conclusion

The qdime antenna, a novel miniature antenna with attractive impedance and radiation characteristics, has been introduced for communication applications where antenna space is limited. Its architecture includes an optimized 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  $l_s$  on antenna performance.

A mutual coupling analysis was performed to evaluate the interaction of antenna elements in a multi-element system. MEMS switches may be strategically placed within the antenna structure to employ reconfigurability in terms of frequency range and radiation pattern capabilities to implement diversity combining. ■

## Acknowledgments

The authors would like to thank Professor N. G. Alexopoulos for helpful discussions on basic antenna parameters. This research was supported in part by the Broadcom Company under MICRO grant 00-28 and DARPA grant MDA972-00-1-002.

## References

1. J.L. Pan, S.S. Rappaport and P.M. Djuric, "A Multibeam Medium Access Scheme for Multiple Services in Wireless Cellular Communications," *1999 IEEE International Conference on Communications*, Vol. 3, 1999.
2. J.S. Colburn, et al, "Evaluation of Personal Communications Dual-Antenna Handset Diversity Performance," *IEEE Trans. Antennas Prop.*, Vol. 47, 1998.
3. B.A. Cetiner, L. Jofre and F. De Flaviis, "A Miniature Broadband Antenna for Portable Communications Terminals," *IEEE AP-S International Symposium*, Boston, July 8-13, 2001.
4. B.A. Cetiner, et al, "Integrated MEM Antenna System for Wireless Communications," *IEEE MTT-S 2002*, Seattle, June 2-7, 2002.
5. R.F. Harrington, "Effect of Antenna Size

on Gain, Bandwidth and Efficiency,” *J. Res. Nat. Bureau Standards-D, Radio Propagation*, Vol. 64D, 1960. 6. Ansoft Corporation, HFSS 7.

## Author information

Dr. Bedri Cetiner received a Ph.D. in electronic and communication engineering from the Yildiz Technical University, Istanbul, Turkey, in 1999. He was formerly with the University of California, Los Angeles, as a visiting scholar. Since June 2000, he has been with the Electronics and Computer Engineering Department of the University of California, Irvine, as a research scientist with UCI. His research interest is focused on the analysis and design of microwave circuits, application of MEMS for development of microwave devices and small size reconfigurable anten-

nas for smart wireless communication systems. He may be reached via E-mail: bedri@uci.edu; Tel: 949-824-6181; or Fax: 949-824-3732.

Dr. Luis Jofre received a master of science degree and a Ph.D. in electrical engineering from the Universitat Politècnica de Catalunya (UPC), Barcelona, Spain, in 1978 and 1982, respectively, where currently he is a full professor and was formerly dean of the Telecommunications Engineering School and vice-president of the UPC. He is now a visiting professor at the University of California, Irvine. His research interests include antennas, scattering, electromagnetic imaging, wireless communications and miniaturization. He may be reached via E-mail: luis.jofre@upc.es; Tel: +34 93 401 6819; or Fax: +34 93 401 7232.

Dr. Franco De Flaviis received his

Ph.D. from the University of California at Los Angeles in 1997. He has been an assistant professor at the University of California at Irvine since June 1998. His research focuses on the integration of novel materials and technologies in electromagnetic circuits and antenna systems for the realization of “smart microwave systems.” His current research is the synthesis of novel low-loss ferroelectric material operating at microwave frequency that can be used as a phase shifters design to be employed in scan-beam antennas systems. He is also working on the implementation and design of novel MEMS switches to be used as analog tunable capacitors at microwave frequency for the realization of tunable filters, reconfigurable antennas and tunable phase shifters.