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Correlation Coefficient Control For A Frequency Reconfigurable Dual-Band Compact MIMO Antenna Destined For LTE

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***Abstract*—In this contribution, we are proposing a compact design for an implementation of a two element MIMO antenna destined for LTE smart phones. The antennas are collocated at one end of the PCB to minimize antenna volume. Each element is dual-band and frequency reconfigurable using tunable capacitors. The MIMO performance is investigated in two different channel models through efficiency, branch power imbalance and envelope correlation. The proposed antennas have acceptable levels of isolation between them, even in the low-bands, while having a good efficiency. Furthermore, the correlation coefficient is controlled by manipulating the ground currents between the antennas using a tunable capacitor. Nonetheless, using this mechanism to control the coupling between the antennas, the total efficiency is affected.**

***Index Terms*—MIMO, correlation coefficient, low-band, antenna, handset.**

I. Introduction

THE advent of Multiple Input - Multiple Output (MIMO) in current and future wireless communications standards has drawn considerable attention from the research community in the past years [1]–[14]. Long Term Evolution (LTE) is one of the most widespread standards using this technology [15]. Receiver diversity and small antenna array design has been the subject of numerous research articles. However, due to practical constraints such as antenna isolation, current consumption and RF front-end design, the implementation of MIMO in commercial phones has been restricted to 2x2 downlink only systems.

The capacity increase of MIMO antenna systems is owed to the multi path richness of the wireless propagation channel [16]–[18]. Nonetheless, the performance increases is capped by the number of antennas, the power imbalance between the multiple links or their correlation [1], [2]. Unless an isolation enhancement technique is implemented, using traditional antennas, MIMO terminals have bad performance in the lower frequency bands of the spectrum allocated in the standards [3], [4]. Recently, carrier aggregation has been introduced in the 3GPP standardization efforts [15]. This means that the MIMO antenna has to satisfy a more complex set of constraints on top of the already existing ones due to the increased bandwidth requirements.

From the vast amount of available literature on the subject of antenna isolation, a couple of the most common methods are briefly described. The parasitic element method [7], [8] and the neutralization line [5], [6], [19], [20] introduce an additional coupling current that cancels the already existing electromagnetically induced one at the cost of near field sensitivity and loss in bandwidth. In a similar matter the decoupling networks achieve isolation by providing the cancelation at the feeding of the antenna port [9]–[12]. Ground plane current flow leads to significant antenna volume [13], [14].

The focus of this contribution is to investigate the MIMO performance of a compact collocated antenna for the newer, bigger body, smart phones without trying to implement a decoupling technique. Considering that the PCB ground plane is much larger that in the candy-bar type phones, there is a strong incentive to find the limits of MIMO antennas without dedicated isolation mechanism. Part of this work has been approached in [4], [21]. Still, the area of small high Q antennas is not as well debated. However, in this investigation only the case where the antennas are collocated at one end of the PCB is considered . The content of this paper is starting with the antenna description, continuing with the results and in the last part concluding on the work.

II. Proposed antenna design

The antenna element used here is a printed folded monopole, as illustrated in Fig. 1. Compactness is the only advantage of having the MIMO array in this configuration, collocated at one of the edges of the phone. The investigation has been carried out using the finite difference time domain method implemented in CST Microwave Studio. The folding and printing on FR4 improves significantly the antenna volume. Each element occupies an area of only 25x10 mm. However, this comes at the cost of sacrificing antenna bandwidth and increasing the ohmic losses. The bandwidth

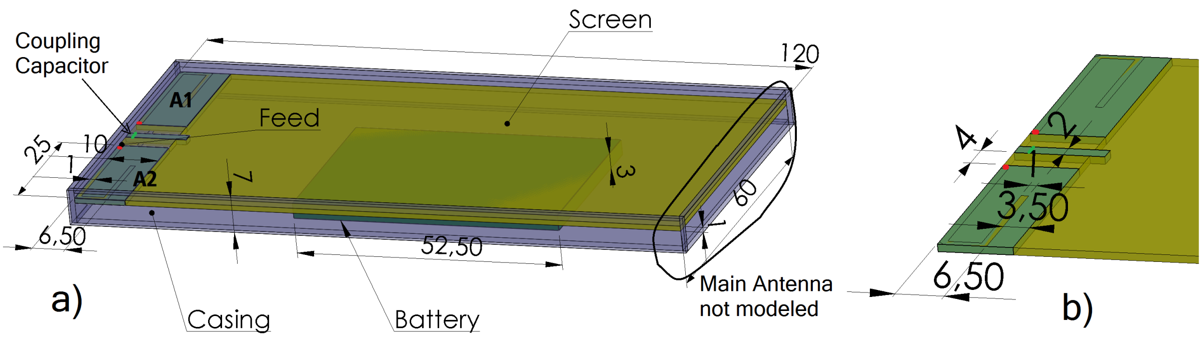

Fig. 1. The dimensions for the investigated MIMO 2x2 antenna and a close up of antenna elements. The classical bottom antenna design is not modeled.

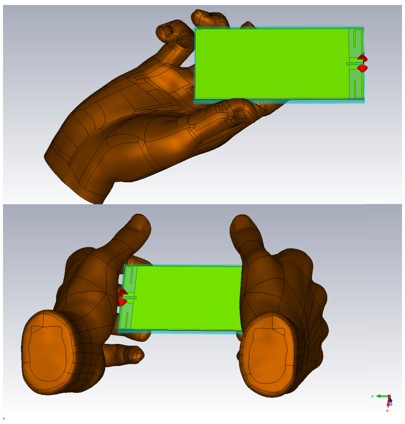

Fig. 2. The two hand phantoms used in the investigations(top figure Hand, bottom 2Hands).

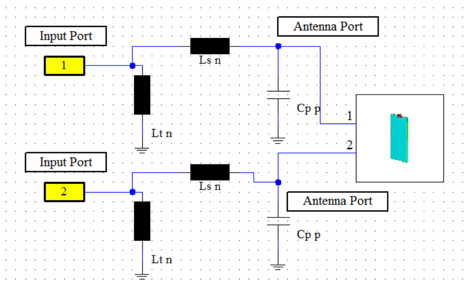

Fig. 3. The feeding networks topology used to tune the antennas, losses included in the simulations but not illustrated.

shrinkage can be overcome by adopting a tunable mechanism for the resonance frequency of the antenna nonetheless, the instantaneous bandwidth of the antenna does not cover a whole band, Tx and Rx bands including duplex spacing. Nevertheless, the antenna system can be used as a secondary antenna for MIMO/Diversity or for a MIMO system that supports carrier aggregation by setting different resonance frequencies for the two antennas. For the sake of brevity, the third antenna(main antenna, that covers both Tx and Rx Bands) is not modeled.

Recent advances in tunable capacitors technology suggest that these components are ready to make the transition from research projects to mass production [22]. Utilizing MEMS technology, the design used for this contribution includes a tunable matching network which consists of a pi network with two inductors and one tunable capacitor, as illustrated in Fig. 3. The first inductor, of 2.5 nH, is used to match the antennas impedance to 50 Ohm and the second inductor, a 5 nH air wound coil, controls the initial resonance frequency of the radiating element which is tuned down by increasing the value of the parallel capacitance. The losses in the matching network have been included in order to have a complete assessment. Furthermore, the components used for the matching network are off the shelf components in order to analyze what is technically possible using the state of the art. The element presented here has a dual band operation mode. As highlighted by Fig. 4, the two resonances are not independent nonetheless, the frequency offset can be controlled by modifying the distance between the tip of the antenna and the rest of the elements body.

Each antenna design has been evaluated in three different sets of simulation results, in free space and with two different hand phantoms. The free space investigation (Ant+Cassing) probes into the challenges of a practical phone design by including the losses in the feeding network, conductive and dielectric antenna losses(Copper and FR4), phone casing(Rexolyte) and the battery(Nickel). A tunable capacitor is introduced in between the monopoles to control antenna correlation(Coup Cap). The user's influence is investigated by introducing the two user data grips, as shown in Fig. 2 according to the guidelines from [23]. The performance of the antenna has been investigated tuned to six frequency, three in the low bands(728,860 and 960Mhz) and three at the high bands(1.8,2 and 2.2 GHz), to illustrate the tuning range.

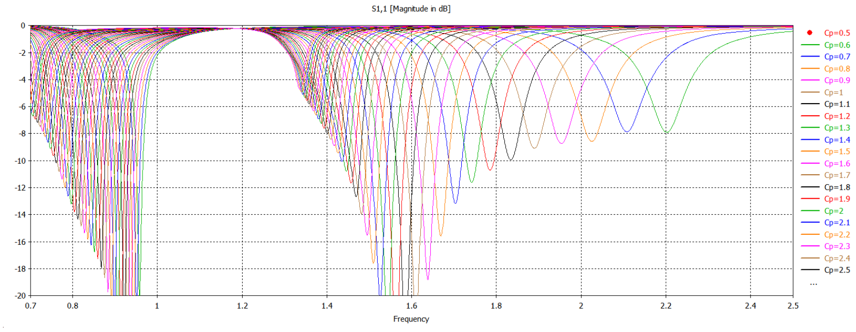

Fig. 4. Input reflection coefficient for the antenna shown in Fig. 1 for the different values of the tunning capacitor from the feeding network.

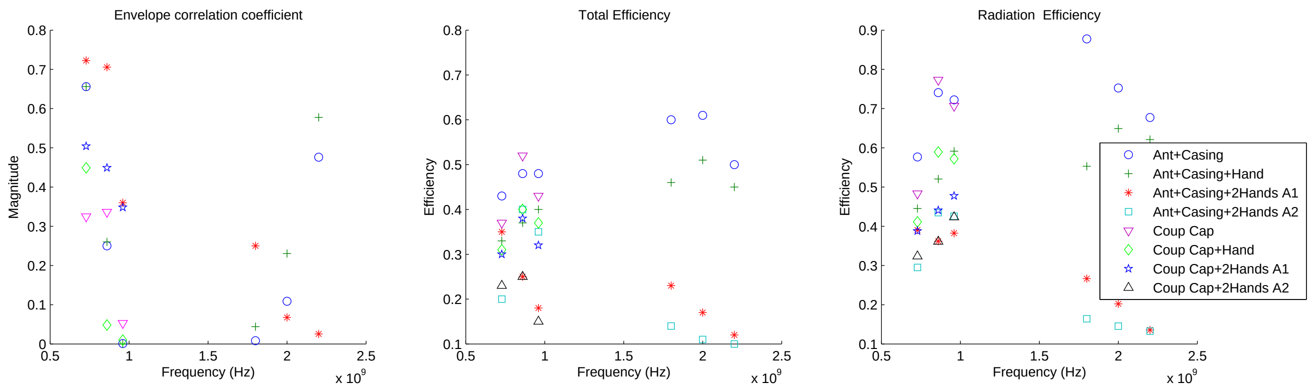

Fig. 5. Simulated results for the isotropic environment.

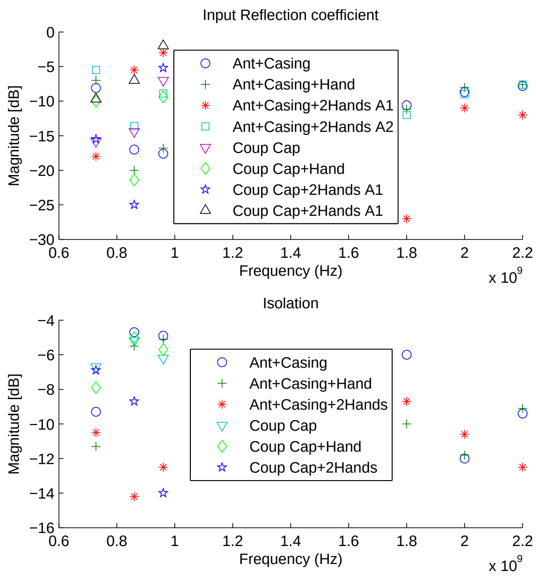

Fig. 6. Simulated S parameters for all of the investigated cases.

TABLE I
MEAN VALUES AND STANDARD DEVIATION(STD) OF MIMO METRICS IN A DIRECTIVE CHANNEL FOR THE ANTENNA IN FREE SPACE AND DATA MODE FOR THE 72 AZIMUTH ROTATIONS.

Result	Ant+Cassing			Coupling Cap		
Frequency (MHz)	728	860	960	728	860	960
BPR(dB) FS Mean/STD	0.01/ 0.23	0 / 0.59	0.01/ 1.09	0.02/ 0.05	0.01/ 0.51	0.04/ 0.80
Env Corr FS Mean/STD	0.91/ 0.01	0.73/ 0.01	0.41/ 0.01	0.85/ 0.01	0.75/ 0.01	0.69/ 0.01
BPR(dB) Data Mode Mean/STD	2.18/ 0.30	1.11/ 0.91	0.30/ 0.34	3.90/ 0.40	2.29/ 1.35	0.30/ 0.34
Env Corr Data Mode Mean/STD	0.72/ 0.05	0.49/ 0.04	0.19/ 0.03	0.56/ 0.07	0.18/ 0.05	0.06/ 0.04

III. RESULTS

The efficiency results from Fig. 5 indicate that the antenna has decent performance even with the different grips. In the evaluation of the design against the user influence, we can observe that the one hand grip has a very symmetric effect on the two elements and because the index finger is relatively far from the radiating element, the influence is almost negligible. This is not the case for the two hand grip. In the low band, the ground plane is the main radiator and the antenna element has a high Q. As a consequence it will have concentrated near-fields around the element. In this two hand grip in the low bands, even though the left hand covers most of the radiating element, the ground plane is relatively free because the hands obstruct just the ends of the board so the low band is not so affected compared with the one hand grip. However, the radiation at higher frequencies is severely obstructed because most of the power is absorbed in the palm, as indicated by the low radiation efficiency plotted in Fig. 5.

Antenna correlation is computed from the gain patterns in isotropic channels and in a measurement derived channel model [24] with an XPR of 5.5 dB, as described in [25]. The directive channel model is rotated in azimuth in 5 degree steps and statistics of the BPR(Branch Power Ratio) and correlation for the two designs are collected in free space and in data mode which are defined as in [25]. The results from Fig. 5 indicate that the coupling capacitor helps decorrelate the antennas. The most dramatic improvement is seen in the simulation with the directive channel model and user hand phantom, as illustrated in table I. By modifying the coupling between the antennas, the capacitor changes the array factor and therefore the gain patterns of the individual antennas. Furthermore, the predominant polarization characteristics of the initial elements are kept and decorrelation is achieved by the change in gain pattern.

IV. CONCLUSIONS

In the paper, a compact tunable dual band antenna has been investigated. In addition, a preliminary analysis has been carried out to investigate the user's influence. State of the art component have been used for the matching network to investigate current practical possibilities for future implementation. It was found that even using a very simple and low cost antenna manufacturing technique (PCB etched in FR4) the components have a quality good enough to have acceptable performance. A simple tunable capacitor is proposed to address the issue of the high correlation in the low bands. It offers a degree of freedom for minimizing the user's effect on the MIMO performance.

REFERENCES

[1] A. Tulino, A. Lozano, and S. Verdu, "Impact of antenna correlation on the capacity of multiantenna channels," *Information Theory, IEEE Transactions on*, vol. 51, no. 7, pp. 2491–2509, 2005.

[2] A. Molisch, M. Steinbauer, M. Toeltsch, E. Bonek, and R. Thoma, "Capacity of mimo systems based on measured wireless channels," *Selected Areas in Communications, IEEE Journal on*, vol. 20, no. 3, pp. 561–569, 2002.

[3] D. Wu, S. Cheung, T. Yuk, and L. Liu, "Design of a printed multiband mimo antenna," in *Antennas and Propagation (EuCAP), 2013 7th European Conference on*, 2013, pp. 2020–2023.

[4] S. Zhang, K. Zhao, Z. Ying, and S. He, "Adaptive quad-element multi-wideband antenna array for user-effective lte mimo mobile terminals," *Antennas and Propagation, IEEE Transactions on*, vol. 61, no. 8, pp. 4275–4283, 2013.

[5] A. Chebihi, C. Luxey, A. Diallo, P. Le Thuc, and R. Staraj, "A novel isolation technique for closely spaced pifas for umts mobile phones," *Antennas and Wireless Propagation Letters, IEEE*, vol. 7, pp. 665–668, 2008.

[6] M. Han and J. Choi, "Dual-band mimo antenna using a symmetric slotted structure for 4g usb dongle application," in *Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on*, 2011, pp. 2223–2226.

[7] B. K. Lau and J. Andersen, "Simple and efficient decoupling of compact arrays with parasitic scatterers," *Antennas and Propagation, IEEE Transactions on*, vol. 60, no. 2, pp. 464–472, 2012.

[8] J. Andersen and H. Rasmussen, "Decoupling and descattering networks for antennas," *Antennas and Propagation, IEEE Transactions on*, vol. 24, no. 6, pp. 841–846, 1976.

[9] A. Tatomirescu, M. Pelosi, M. Knudsen, O. Franek, and G. Pedersen, "Port isolation method for mimo antenna in small terminals for next generation mobile networks," in *Vehicular Technology Conference (VTC Fall), 2011 IEEE*, 2011, pp. 1–5.

[10] R.-A. Bhatti, S. Yi, and S.-O. Park, "Compact antenna array with port decoupling for lte-standardized mobile phones," *Antennas and Wireless Propagation Letters, IEEE*, vol. 8, pp. 1430–1433, 2009.

[11] S.-C. Chen, Y.-S. Wang, and S.-J. Chung, "A decoupling technique for increasing the port isolation between two strongly coupled antennas," *Antennas and Propagation, IEEE Transactions on*, vol. 56, no. 12, pp. 3650–3658, 2008.

[12] C. Volmer, J. Weber, R. Stephan, K. Blau, and M. Hein, "An eigen-analysis of compact antenna arrays and its application to port decoupling," *Antennas and Propagation, IEEE Transactions on*, vol. 56, no. 2, pp. 360–370, 2008.

[13] K. Sato and T. Amano, "Improvements of impedance and radiation performances with a parasitic element for mobile phone," in *Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE*, 2008, pp. 1–4.

[14] H. Li, B. K. Lau, and Z. Ying, "Optimal multiple antenna design for compact mimo terminals with ground plane excitation," in *Antenna Technology (iWAT), 2011 International Workshop on*, 2011, pp. 218–221.

[15] 3GPP, "3gpp release 11," 3GPP, Tech. Rep., January 2013. [Online]. Available: http://www.3gpp.org

[16] R. Vaughan and J. Andersen, "Antenna diversity in mobile communications," *Vehicular Technology, IEEE Transactions on*, vol. 36, no. 4, pp. 149 – 172, nov. 1987.

[17] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Communications*, vol. 6, pp. 311–335, 1998.

[18] H. Holma, A. Toskala, K. Ranta-aho, and J. Pirskanen, "High-speed packet access evolution in 3gpp release 7 [topics in radio communications]," *Communications Magazine, IEEE*, vol. 45, no. 12, pp. 29–35, 2007.

[19] S.-W. Su, C.-T. Lee, and F.-S. Chang, "Printed mimo-antenna system using neutralization-line technique for wireless usb-dongle applications," *Antennas and Propagation, IEEE Transactions on*, vol. 60, no. 2, pp. 456–463, 2012.

[20] A. Diallo, C. Luxey, P. Le Thuc, R. Staraj, and G. Kossiavas, "Enhanced two-antenna structures for universal mobile telecommunications system diversity terminals," *Microwaves, Antennas Propagation, IET*, vol. 2, no. 1, pp. 93–101, 2008.

[21] Y.-J. Ren, "Ceramic based small lte mimo handset antenna," *Antennas and Propagation, IEEE Transactions on*, vol. 61, no. 2, pp. 934–938, 2013.

[22] A. Morris, "Integrated tuning technology for antennas and radio front ends," in *Adaptable and Tunable Antenna Technology for Handsets and Mobile Computing Products, 2009 IET Seminar on*, 2009, pp. 1–34.

[23] CTIA, "Ctia certification test plan for mobile station over the air performance. rev. 3.2. method of measurement for radiated rf power and receiver performance." Tech. Rep., November 2012.

[24] M. Knudsen and G. Pedersen, "Spherical outdoor to indoor power spectrum model at the mobile terminal," *Selected Areas in Communications, IEEE Journal on*, vol. 20, no. 6, pp. 1156 – 1169, Aug. 2002.

[25] B. Yanakiev, J. Nielsen, M. Christensen, and G. Pedersen, "Antennas in real environments," in *Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference on*, 2011, pp. 2766–2770.