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Multiband Diversity Antenna Performance Study for Mobile Phones

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ABSTRACT: Spatial diversity is a popular multiple antenna system technique, due to simplicity in implementation. However, its application has thus far been limited to systems where the electrical separation between adjacent antennas typically exceeds half a wavelength. This is because a more compact design induces higher antenna correlation and impedance mismatch, which results in lower diversity gains. In this paper, the performance of a compact multiband diversity antenna is investigated in both simulations and measurements. The dual-antenna structure is designed for the future WCDMA bands of WCDMA850, WCDMA1800 and 3G EU (UMTS), where the antenna separation at the WCDMA850 band is 0.24*wavelength. The measured results indicate that an average effective diversity gain of 7.3 dB at the 1% probability level can be achieved for the three bands

INTRODUCTION

Advancement in the mobile industry [1] and a need for a higher data transfer demand a rapid adoption of new technologies. Diversity is a well known technique to improve error performance and thus system capacity when transmitting over fading radio channels [2], [3]. Although receive diversity has found widespread application in second generation (2G) mobile communication systems, and transmit diversity has also been standardized for 3G systems, their implementations have thus far been limited to the base-stations. One challenging problem with implementing spatial diversity in a mobile phone is the close proximity among the antennas and the resulting high signal correlation and antenna coupling loss [4].

The implementation of compact multiband diversity (or MIMO) antennas is the subject of [5] and [6]. However, instead of mobile communication bands, both studies focus on the wireless-LAN frequency bands of 2.4 and 5.2 GHz. In [5], the antenna separation of the dual double-T monopoles is greater than half-a-wavelength (0.5λ), even at the lower band. Therefore, good diversity gain is obtained for both bands. On the other hand, the separation between oppositely oriented dual-PIFA antennas in [6] is only 0.25λ. Nonetheless, only the mean MIMO capacity performance is examined in [6]. Furthermore, both [5] and [6] employ identical antennas for the dual-antenna configuration.

In this paper the spatial diversity performance is investigated for two multi-band antennas on a single ground plane with dimensions 100×40×8 mm, or $0.3\times0.12\times0.024\ \lambda$ (length×width×height) for the lowest frequency band. The diversity antenna is designed for the future WCDMA bands of WCDMA850, WCDMA1800 and 3G EU (UMTS). A number of different candidate single multiband antennas satisfying the bandwidth requirement have been adapted and evaluated for dual-antenna diversity operation. The final prototype, as presented in this paper, consists of two non-identical multiband antennas. In particular, the main antenna is a monopole based antenna and covers the frequency bands 805-1150, 1780-2170 MHz at a measured 5 dB impedance bandwidth. The second (or diversity) antenna is a PIFA-based antenna which covers the bands 830-950, 1770-1950, 2070-2170 MHz at a measured 5 dB impedance bandwidth.

The paper is divided into the following sections: In the theoretical part, three relevant metrics for diversity performance are described. The compact diversity antenna used in this study is then presented. For performance evaluations, the simulation methodology and the experimental setup are first described. This is followed by the results and a discussion of the diversity performance for the proposed antenna structure. Finally a summary concludes the paper.

THEORY

Three performance metrics are used to evaluate the diversity performance in this paper: *envelope correlation coefficient*, ρ_e (calculated from either scattering parameters [7] or radiation patterns [8]), *diversity gain* and *effective diversity gain* [9]. Calculating the envelope correlation coefficient from the scattering parameters is more convenient since it is much easier to obtain the scattering parameters than the radiation patterns. From [7], the envelope correlations coefficient for uniform incident waves can be calculated from the scattering parameters as

$$\rho_e = \frac{\left|S_{11}^* S_{12} + S_{21}^* S_{22}\right|^2}{\left(1-\left|S_{11}\right|^2-\left|S_{21}\right|^2\right)\left(1-\left|S_{22}\right|^2-\left|S_{12}\right|^2\right)}, \tag{1}$$

where S_{ij} is the s-parameter reflection coefficient for the input signal reflecting from port j into port i.
The envelope correlation coefficient as calculated from the radiation patterns in spherical coordinates $\Omega=(\theta,\phi)$ [8] is

$$\rho_e = \frac{\left|\oint\left(XPR\cdot E_{\theta X}(\Omega)E_{\theta Y}^*(\Omega)P_\theta(\Omega)+E_{\phi X}(\Omega)E_{\phi Y}^*(\Omega)P_\phi(\Omega)\right)d\Omega\right|^2}{\oint\left(XPR\cdot G_{\theta X}(\Omega)P_\theta(\Omega)+G_{\phi X}(\Omega)P_\phi(\Omega)\right)d\Omega\cdot\oint\left(XPR\cdot G_{\theta Y}(\Omega)P_\theta(\Omega)+G_{\phi Y}(\Omega)P_\phi(\Omega)\right)d\Omega}, \tag{2}$$

where $G_\theta = E_\theta(\Omega)E_\theta^*(\Omega)$ and $E_{\theta X}(\Omega), E_{\theta Y}(\Omega), E_{\phi X}(\Omega)$ and $E_{\phi X}(\Omega)$ are the vertical (θ) and horizontal (ϕ) polarized complex radiation patterns of antennas X and Y in the diversity system, $P_{\theta,\phi}(\Omega)$ is the incident power spectrum for the different polarizations, and XPR (cross polar discrimination) is the time averaged vertical-to-horizontal power ratio.

In this paper the combining technique used to combine the diversity signals is selection combining [3]. The effective diversity gain [9] at a given probability level (e.g., 1% or 50%) is given by

$$DG_{eff} = DG\cdot e_{ref} = \left(P_{div}/P_{ref}\right)\cdot e_{ref}, \tag{3}$$

where DG is the diversity gain, e_{ref} is the total radiation efficiency (including both ohmic and impedance mismatch losses) of the reference antenna, P_{div} is the power level after diversity combining, and P_{ref} is the power level at the reference antenna. P_{div} and P_{ref} are taken at the given probability level and P_{ref} is the antenna with the higher power).

COMPACT ANTENNA PROTOTYPE

The two antennas used in this study are based on previous antennas presented in [10] and [11]. The left antenna (port 1) in Fig. 1 is a PIFA-based antenna [10]. The big patch excites the most power for the lower (WCDMA850 band) while the upper branch controls the WCDMA1800 band. A shorted parasitic patch creates the resonance for the UMTS band. The right monopole-based antenna (port 2) [11] in Fig. 1 has a dense meandering patch on the right side which controls the WCDMA850 band. The bigger branch on the upper side facilitates the resonance for the WCDMA1800 band while the smaller, shorted parasitic element creates a capacitive load and tunes the resonance for the UMTS band. The dimensions for the PIFA (antenna 1) are 40×18×7 mm (xyz) (se Fig.1 for coordinates) and 40×16×7 mm (xyz) for the monopole. (antenna 2). The spacing between the feed points of the two antennas is 84 mm or 0.24λ (for WCDMA850) The length of the whole multiple antenna structure is 100 mm but since there is no conductor under the monopole, the length of the ground plane is only 84 mm.

PERFORMANCE EVALUATIONS

Simulation and Experimental Setups

The amplitude and phase of E_θ and E_ϕ and efficiencies of the prototype diversity antenna are simulated in the method-of-moments software IE3D [12]. The results are exported to a Matlab® program where the diversity performance metrics of envelope correlation and effective diversity gain are calculated. The prototype antenna is also manufactured and measured to verify the simulated results (see Fig. 1). The amplitude and phase of E_θ and E_ϕ and total efficiencies of the antennas are measured in a Satimo anechoic chamber [13].

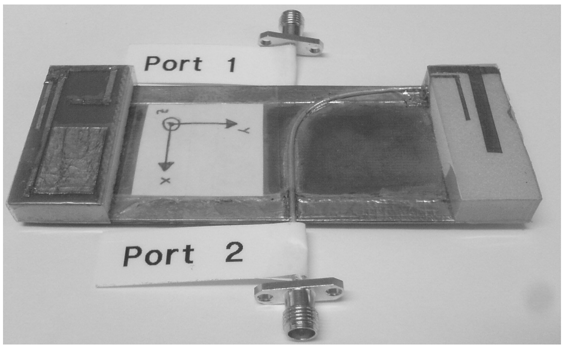

Fig. 1 Manufactured antenna

The measured results from Satimo are then evaluated in the aforementioned Matlab® program for diversity performance. In [14], it was concluded that a three-dimensional uniformly distributed case could be used when calculating the envelope correlation coefficients and diversity gains. For this reason, a uniform distribution of the incident waves is assumed when calculating the results (for IE3D and Satimo) in Fig. 3a and Tab. 1.

Results and Discussions

The s-parameters simulated in IE3D and those measured in a network analyzer are given in Fig. 2. The agreement between the simulation and measurement is quite good. However it can be seen in Fig. 2b that the maximum value for the S_{12}-parameter for the lowest WCDMA850 band is about -4 dB in simulations, while it is about -9 dB in the measurements. Since there is a 5 dB difference in the coupling, the correlations coefficient calculated from the measurement results is expected to be lower and thus the diversity gain higher for the lowest band. Moreover, it is also observed in Figs. 2d and 2f that the measured S_{11} and S_{22}-parameters are shifted in phase with respect to the simulated parameters in the vicinity of the lowest band. In contrast, good agreement is obtained between simulated and measured phase of S_{12} (see Fig. 2e). Therefore, the phase behavior is also expected to contribute to discrepancies between the envelope correlations obtained from the simulated and measured results using (1).

The above observations are confirmed in Fig. 3 where it can be seen that the envelope correlation coefficient is indeed much lower for the lowest band in measurements than in simulations.

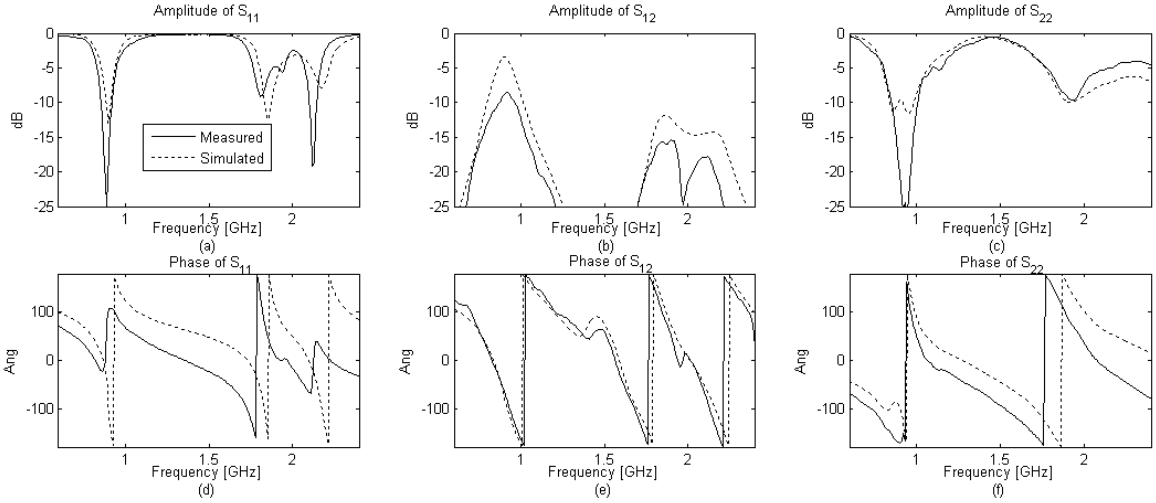

Fig. 2 Simulated and measured scattering parameters.

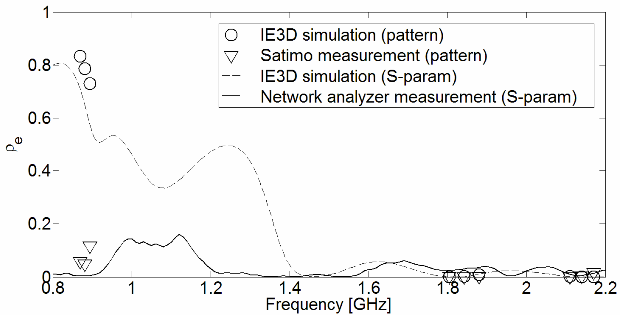

Fig. 3 Envelope correlation coefficients calculated from radiation patterns and scattering parameters

Tab. 1 Diversity gain and effective diversity gain at 1% probability [dB] from simulations and measurements

Frequency [MHz]	869	881.5	894	1805	1842.5	1880	2110	2140	2170
	Diversity gain								
IE3D (simulated)	6.53	7.02	7.48	10.15	10.17	10.16	10.13	10.11	10.09
Satimo (measured)	10.08	10.10	9.95	10.20	10.20	10.20	10.20	10.20	10.17
	Effective diversity gain								
IE3D (simulated)	3.84	3.77	3.76	8.69	9.03	9.25	9.03	8.95	8.88
Satimo (measured)	6.77	7.15	5.94	7.65	7.47	7.06	8.48	7.45	7.96

Because of the lower measured envelope correlation coefficient for the lowest band, both the measured diversity gains and the measured effective diversity gains are approximately 3 dB higher than their simulated counterparts for the lowest band (see Tab. 1). On the other hand, the agreement between simulated and measured diversity gains is very good for the two higher bands. However, since the efficiencies for the two higher bands are lower in the measurements than in the simulations, the measured effective diversity gains are lower than the simulated gains.

One possible reason for the aforementioned higher measured coupling for the lowest band (see Fig. 2b) is that the simulated diversity antenna is not exactly identical to the manufactured antenna of Fig. 1. In particular, the simulated version does not include the metallic feeding cables (soldered onto the ground plane at several points) and the SMA connectors, which extends beyond the ground plane at right angles. The practical feeding arrangement can influence the current flow on the ground plane and reduce the coupling predicted by simulation. Due to space constraint, a more comprehensive description and analysis of the present work, including the radiation patterns of the prototype diversity antenna, are relegated to [15].

CONCLUSIONS

The diversity performance of a compact prototype antenna structure, consisting of two triband antennas, has been examined for the WCDMA850, WCDMA1800 and UMTS bands. It is shown that significant diversity gains can be obtained, even at the lowest band where the antenna separation is merely 0.24λ. In particular, effective diversity gains of up to 7 dB (at 1% probability level) can be achieved for the WCDMA850 band, while at the higher frequency bands of WCDMA1800 and UMTS the gains are as high as 8-9 dB.

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