Effect of Human Interaction on Diversity Performance of Polarization Diversity PIFA on Portable Telephone

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1. Introduction

The multipath interference is one of the major problems emerged in mobile communication environment. There are many alternative schemes on antenna diversity technique to overcome deep fading caused from the multipath propagation. The space diversity needs large antenna separation to obtain small correlation coefficient. The alternative diversity scheme which is interesting is polarization diversity because two diversity antenna branches can be arrayed in the same position to save the space. The authors proposed a planar inverted-F antenna (PIFA) modified to apply for polarization diversity [1]. The structure of the antenna resembles the conventional PIFA, except that it has two additional semiconductor switches at the opposite positions to each other with respect to the feed position. By turning on either of the switches, the polarization of the antenna can be changed. However, the radiation patterns and diversity performance of this polarization diversity on portable telephone in vicinity of the human body including head, hand, and shoulder have never been studied. This paper investigates the electromanetic interaction between the antenna on portable telephone and the operator body under the mobile multipath environment. The results are revealed in terms of the mean effective gain, the radiation pattern correlation, the diversity gain, and the diversity antenna gain quantitatively.

2. Configuration and Modeling

The polarization diversity PIFA consists of a square metallic patch with the length of 26mm, to operate at the frequency of 1.8 GHz, located on a portable telephone of dimension 25x45x130mm as shown in fig. 1(a). On the top-left corner of the patch is shorted to the telephone via a permanent shorted-pin. There are two RF-switches on the top-right (A) and the bottom-left (B) corners. To take into account the interaction of human body, the cylindrical

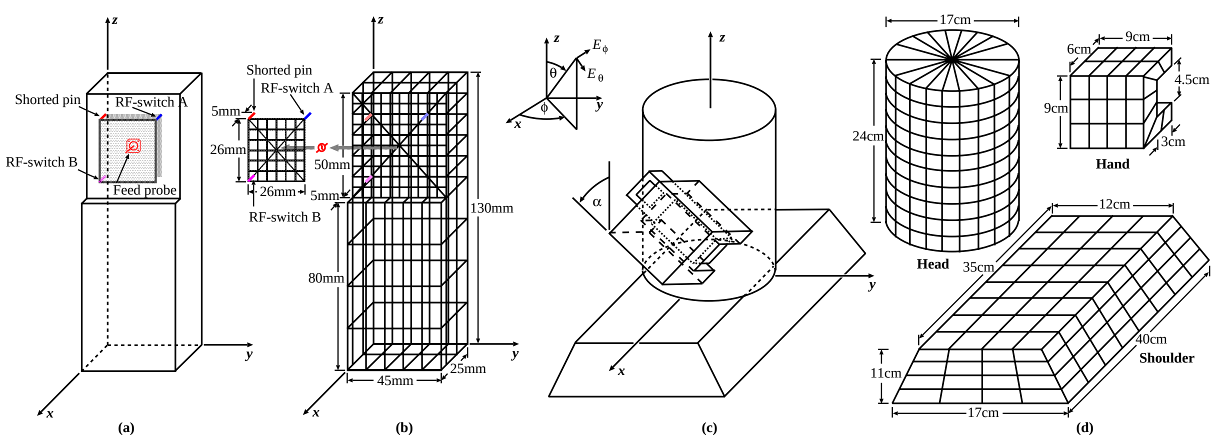

Fig. 1. Configurations of the polarization diversity PIFA (a) experimental model with portable telephone (b) wiregrid model of the antenna and portable telephone (c) experimental model with human phantom (d) wiregrid model of human phantom.

model of head, parallelopiped model of hand, and trapezoidal model of shoulder are assigned as depicted in fig. 1(c). The phantom of the head is placed on the center of the shoulder. The hand is positioned 5mm adjacent to the right-hand side of the head with 60° tilted angle, and the telephone is in the the hand with same orientation.

The antenna and telephone are modeled by conductive wiregrid structure as depicted in fig. 1(b). While the phantoms are modeled by conductive wiregrid loaded with the surface impedance $Z_s = (j\omega\mu/(\sigma + j\omega\epsilon))^{1/2}$, where the conductivity $\sigma = 0.85$ S/m and the complex permittivity $\epsilon_r = 48 - j30$ [2], to simulate the dielectric property of the human tissue as depicted in fig. 1(d).

3. Method of Analysis

3.1 Mean Effective Gain and Correlation Coefficient

The mean effective gain (MEG) G_e [1] of the mobile antenna in multipath environment is expressed by

$$G_e = \int_0^{2\pi}\int_0^{\pi}\left\{\frac{\mathrm{XPR}}{1+\mathrm{XPR}}G_\theta(\theta,\phi)P_\theta(\theta,\phi) + \frac{1}{1+\mathrm{XPR}}G_\phi(\theta,\phi)P_\phi(\theta,\phi)\right\}\sin\theta d\theta d\phi, \tag{1}$$

where $G_\theta(\theta,\phi)$ and $G_\phi(\theta,\phi)$ are the θ and ϕ components of the radiation patterns and $P_\theta(\theta,\phi)$ and $P_\phi(\theta,\phi)$ are the θ and ϕ components of the angular density functions of incident plane waves, respectively.

The envelope correlation coefficient ρ_e between two antenna diversity branches can be approximated by [1] $\rho_e = |R_{12}^2|/(R_{11}R_{22})$, where the covariance R_{ij} $(i,\ j = 1,\ 2)$ of the two received voltages resulted from the complex electric field patterns $(E_{\theta i}, E_{\phi i})$ and $(E_{\theta j}, E_{\phi j})$ is

$$R_{ij} = 2KP_H\int_0^{2\pi}\int_0^{\pi}\left\{\mathrm{XPR}\cdot E_{\theta i}(\theta,\phi)E_{\theta j}^*(\theta,\phi)P_\theta(\theta,\phi) + E_{\phi i}(\theta,\phi)E_{\phi j}^*(\theta,\phi)P_\phi(\theta,\phi)\right\}\sin\theta d\theta d\phi. \tag{2}$$

To model the angular density functions of incident plane wave, we assume azimuthal distribution $P(\phi)$ to be uniform and elevational distribution $P(\theta)$ by delta function of $\theta = 90°$. The cross-polarization power ratio (XPR) is defined by the mean incident power ratio of P_V/P_H, where P_V and P_H are mean incident power of vertical and horizontal polarization, respectively.

3.2 Diversity Gain and Diversity Antenna Gain

The diversity gain G_{div} is defined as the difference of the signal level at a certain value of the cumulative distribution function (CDF) (usually at 1%), between the CDF curve of the signal envelope of the diversity combiner output, and that of the single reference antenna output under the Rayleigh fading environment. The probability that the instantaneous combiner output CNR will be below or equal to a level γ is called *outage rate* and can be expressed as [1]

$$P(\gamma) = 1 - e^{\left(-\frac{\gamma}{\Gamma}\right)}Q\left(\sqrt{\frac{2\gamma}{r\Gamma(1-\rho_e)}}, \sqrt{\frac{2\rho_e\gamma}{\Gamma(1-\rho_e)}}\right) - e^{\left(-\frac{\gamma}{r\Gamma}\right)}\left(1 - Q\left(\sqrt{\frac{2\rho_e\gamma}{r\Gamma(1-\rho_e)}}, \sqrt{\frac{2\gamma}{\Gamma(1-\rho_e)}}\right)\right), \tag{3}$$

where Γ is a mean CNR; Q is the Marcum function; r is an either ratio of G_{eA}/G_{eB} or G_{eB}/G_{eA}, whichever is less than unity, G_{eA} and G_{eB} are the MEG of the diversity branch A and B, respectively.

The diversity antenna gain (DAG) includes the correlation coefficient and the MEG characteristics and is defined as a product of an either MEG of the higher branch and a diversity gain [1].

$$\mathrm{DAG} = G_e \cdot G_{div}. \tag{4}$$

4. Results and Discussion

The theoretical results of the following parameters are simulated by the Numerical Electromagnetic Code (NEC2) [3] based on the method of moment at the frequency of 1.8 GHz on xy-plane $(\theta = 90°)$. The inclination angle of polarization diversity PIFA on portable telephone is chosen at $\alpha = 60°$ to realize the practical case.

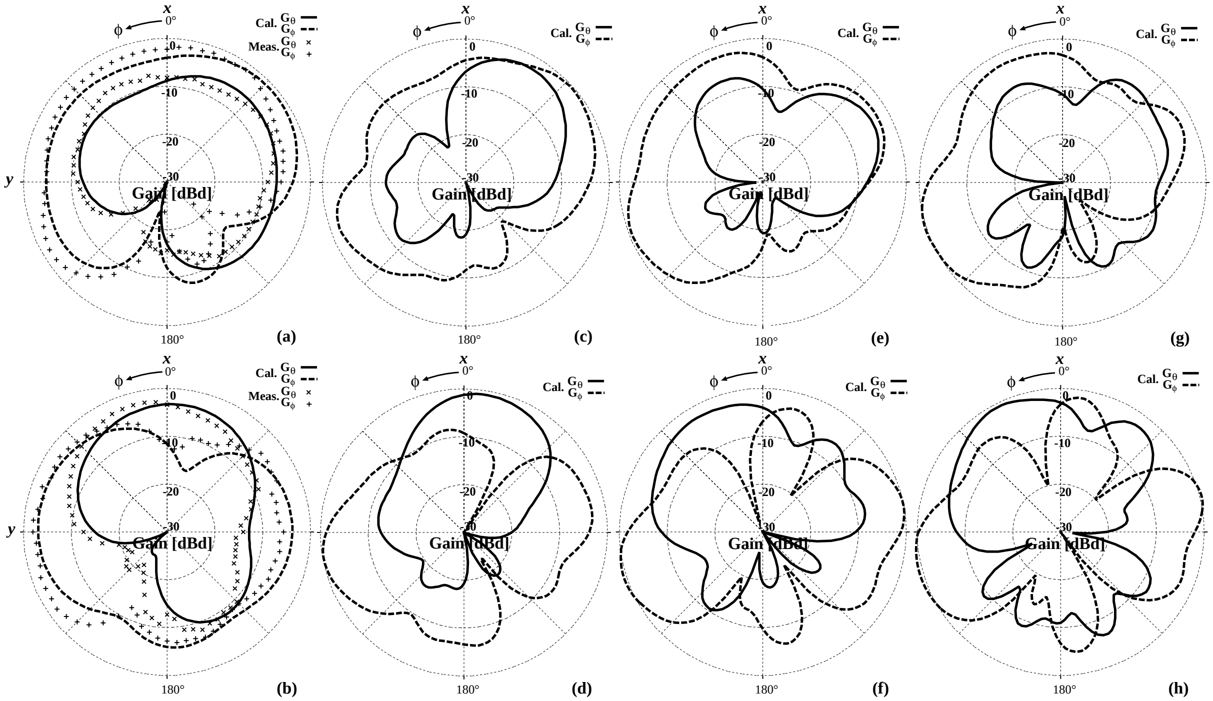

Fig. 2. The radiation patterns on xy-plane of antenna at tilted angle $\alpha = 60°$; on a portable telephone (a) A shorted (b) B shorted; with head (c) A shorted (d) B shorted; with head and hand (e) A shorted (f) B shorted; with head, hand, and shoulder (g) A shorted (h) B shorted.

4.1 Gain

The gain patterns of the antenna on portable telephone when $\alpha = 60°$ and RF-switch A shorted is shown in fig. 2(a), the maximum of both G_θ and G_ϕ direct toward the direction $\phi = 315°$. However, the amplitude of G_ϕ is approximately 5 dB higher than that of G_θ. When RF-switch B shorted, G_ϕ has its maximum at $\phi = 0°$ whereas the counterpart has its maximum in the broadside direction. The amplitude of the pattern is almost the same. These results have been verified by the experiment.

When head, hand and shoulder are cumulatively taken into account of the power patterns of the antenna on a telephone, the power patterns in fig. 2(c) to 2(h) are gradually changed. It might be concluded that the patterns calculated with the human interaction posses narrower beamwidth and increasing number of lobes.

4.2 Mean Effective Gain and Correlation Coefficient

Fig. 3(a) compares the mean effective gain of the antenna on telephone with those included the human interaction. It is relevant to the gain patterns that the mean effective gain decreases as the XPR increases. The effect of human interaction can increase the mean effective gain about 1.5 dB when RF-switch B shorted.

Fig. 3(b) shows the correlation coefficient in difference cases. The case of antenna on telephone is almost constant at around 0.15. The practical case, with head, hand and shoulder, the correlation coefficient is in the range between 0.06 to 0.16.

4.3 Diversity Gain and Diversity Antenna Gain

The diversity gain of antenna on telephone, calculated at XPR = 10 dB, is 9.6 dB whereas that includes human interaction is reduced, by 1.3 dB, to 8.3 dB due to the large difference of MEG between each branch as depicted in fig. 4(a). At other values of XPR = -10 dB and 0 dB, the diversity gain of both cases are still in between 8.3 dB to 9.8 dB.

Fig. 4(b) illustrates the diversity antenna gain in terms of XPR. The diversity antenna gain

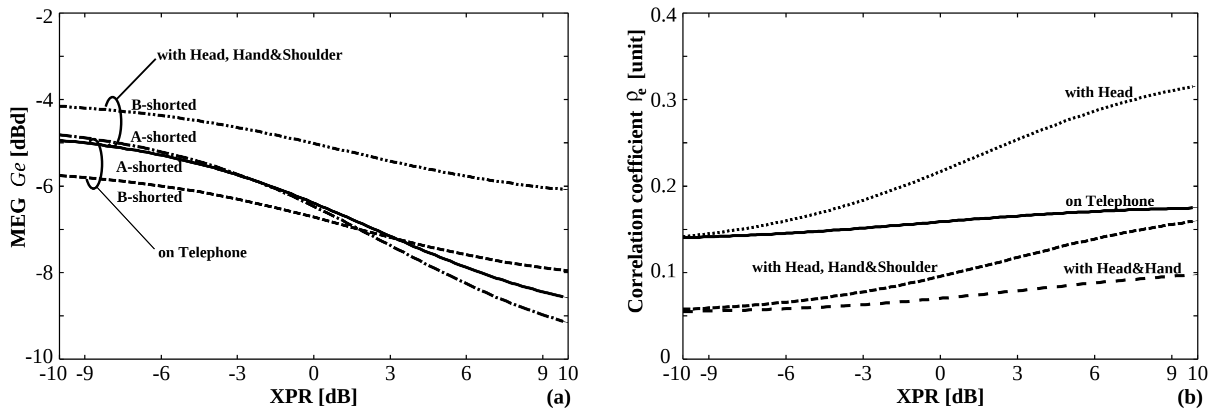

Fig. 3. The differences of (a) mean effective gain and (b) correlation coefficient, vs. XPR.

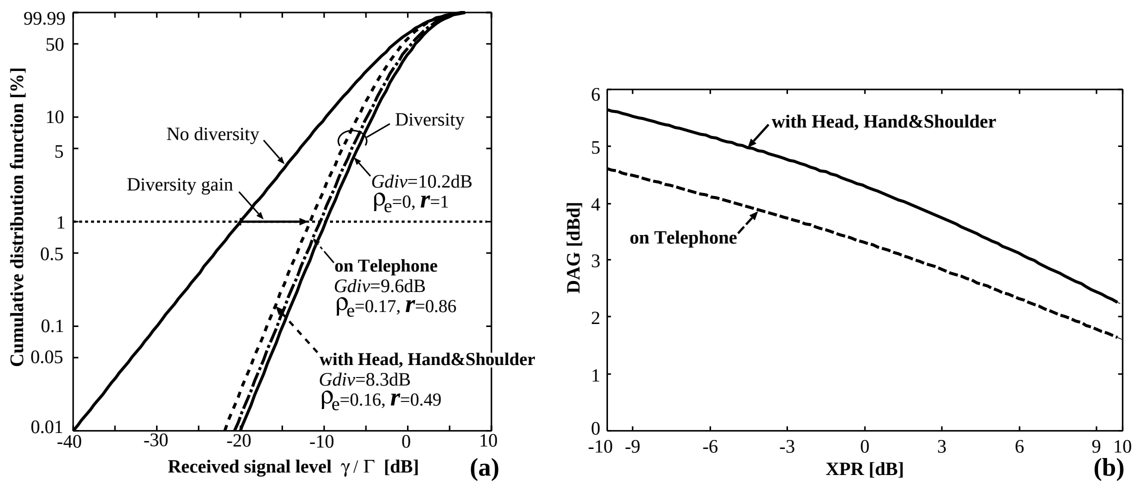

Fig. 4. (a) diversity gain differences due to ρ_e and r at XPR = 10 dB (b) diversity antenna gain vs. XPR.

with the human interaction is 0.6 to 1.0 dB higher.

5. Conclusions

Characteristics of polarization diversity PIFA on a portable telephone have been comparatively investigated without and with that taken into account of the human interaction. It was found that the gain patterns, correlation coefficient, diversity gain, and diversity antenna gain have been notably altered. These results are effective in statistical evaluation the communication performance of this antenna in the mobile multipath environmnet.

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