Human Interactions with Loop Antennas at the Wrist Position and Communication Performance Evaluation for Digital Wireless Communications In Urban Mobile Environments

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1. INTRODUCTION

The "watch-type" communicator carried at the wrist position is one of the trend of miniaturization for the cellular phone or other portable communicators in personal communications. It is of great interests to investigate radiation characteristics of the loop antenna, which may be used in this "watch-type" communicator, influenced by the human body. Fig. 1 shows this antenna-body coupling system. A 3-D realistically shaped man model (1.7 m height) with homogenous muscle phantom is constructed. As shown in Fig. 1, the loop antenna may have different position and orientation with respect to the wrist. The loop antenna embedded in the watch belt can also encircle the wrist.

Moreover, to evaluate the performance for a portable communicator (with the antenna) close to the body in urban mobile environments, a modified Doppler power spectrum (MDPS) method is proposed. This method modifies a previously-reported Clarke′s model by combining the cross polarization discrimination (*XPD*) resulted from randomly-oriented scatters and reflectors and the cross power patterns induced by the operator′s body. A computer simulation, combining the MDPS method and a gray coding $\pi/4$-DQPSK modulation with square-root raised cosine (SRRC) filter (NADC-TDMA standard), is established. The performance evaluation is based on bit error rate (BER) simulation for digital wireless communication.

2. THEORETICAL BACKGROUND

(A) *Numerical Model of Human Interactions with Loop Antennas*

The coupled integral equation (CIE's) for the electric field in the body and the antenna current distribution are given by using the dyadic Green's function technique. [1]

$$\frac{-1}{j\omega\varepsilon_o}\int_{ant}\left[\hat{s}\cdot\hat{s}'k_o^2 I(s')+\frac{\partial I(s')}{\partial s'}\cdot\frac{\partial}{\partial s}\right]G(s,s')ds' - \int_{V_b}\hat{s}\cdot\vec{G}(s,\vec{r}')\cdot\tau(\vec{r}')\vec{E}(\vec{r}')dv' = \hat{s}\cdot\vec{E}^i(s) \quad (1)$$

$$\int_{ant} I(s')\hat{s}'\cdot\vec{G}(\vec{r},s')d\mathbf{s}' + \mathbf{PV}\int_{V_b}\tau(\vec{r}')\vec{E}(\vec{r}')\cdot\vec{G}(\vec{r},\vec{r}')dv' - \left[1+\frac{\tau(\vec{r})}{3j\omega\varepsilon_o}\right]\vec{E}(\vec{r}) = 0 \quad (2)$$

where $\vec{E}^i$ is the impressed field from the antenna feeding source. The magnetic frill is employed to model the loop-antenna feeding structure. The CIE′s are solved numerically by the method of moments (MoM) to determine the antenna current and induced E field inside the body. When the antenna current and the induced E field inside the body are solved, the antenna radiation characteristics such as input impedance, antenna current distribution, antenna coverage pattern, and radiation efficiency, can be determined. The antenna input impedance Z_i, input power (to the antenna) P_i, and radiation power absorbed by the body P_{abs} can then be calculated. The total radiation field (to free space) is the sum of the radiation field from the antenna and the scattered field from the body. The radiation power to free space, P_{rad}, can be calculated by integrating the radiation power density over a far-zone spherical surface and the directive gain is then determined. Two important quantities to evaluate human body effects on the radiation performance of the loop antenna are the radiation efficiency and the power gain. The antenna pattern will be distorted by the body blocking effect and the antenna directive gain *G* will be significantly changed from that in free space. There are two different antenna radiation efficiencies, η_{rb} defined by the radiation power absorbed by the body and $\eta_{r\Omega}$ defined by the antenna ohmic loss. All the above quantities are expressed as follows.

$$P_{rad} = \oint_S \tfrac{1}{2}\mathrm{Re}[\vec{E}^r\times\vec{H}^{r^*}]\cdot d\vec{s}\ ;\quad G(\theta,\phi)=\frac{\frac{1}{2}\mathrm{Re}(\vec{E}^r\times\vec{H}^{r^*})}{P_{rad}/(4\pi r^2)}\ ;\quad \eta_{rb}=\frac{P_{rad}}{P_{rad}+P_{abs}}\ ;\quad \eta_{r\Omega}=\frac{R_r}{R_r+R_{ohm}} \quad (3)$$

where R_r and R_{ohm} are the antenna radiation resistance and ohmic loss resistance. Note that when the antenna is in free space, there is no body absorption effect and hence the η_{rb} is equal to 1. The antenna power gain G_p and the average power gain G_{avg} can be obtained as

$$G_p = \eta_{rb} \times \eta_{r\Omega} \times G; \qquad G_{avg} = \frac{1}{8}\sum_{i=1}^{8} G_p(\theta = \frac{\pi}{2}, \phi_i); \quad \phi_i = i \times \frac{\pi}{4} \tag{4}$$

The average power gain, G_{avg}, over the eight equal-angle positions in the H-plane is appropriate for evaluating the antenna performance in wireless communications. It is important to note that the power gain defined under the antenna ohmic-loss and the body absorption radiation efficiencies associated with (4) should be used to evaluate the antenna performance in the communication link budget.

(B) *Performance Evaluation for Digital Wireless Communications in Urban Mobile Environments*

To evaluate the communication performance of the portable communicator influenced by the body in urban mobile environments, an approach called the MDPS method is proposed in [2-3]. As shown in Fig. 1 (right), by combining the cross-polarization effects of the propagating radio-wave and the operator′s body coupling effects on the pattern and polarization variation of the portable antenna radiation, a modified channel model is proposed. It is by using the discrete effective gain in every resolution angle band to modify the Clarke′s isotropic scattering model with the method of equal distance (MED), in which the difference between two adjacent discrete Doppler frequencies is equidistant. Now, due to operator′s body effects, the antenna radiation pattern is varied according to frequency. If the received field is assumed be vertically polarized, the corresponding Doppler coefficients can be modified as follows [4].

$$C_i = \sum_j p(\alpha_j)\frac{xpd}{1+xpd}[G_V(\alpha_j) + \frac{1}{xpd}G_H(\alpha_j)] \quad f_i \le f_m \cos(\alpha_j) < f_{i+1} \textbf{ for all } j$$
$$i = -N, -N+1, \ldots, N \text{ and } j = 1,2,\ldots,J \tag{5}$$

$p(\alpha)$: probability density of the wave incident on the mobile receiving antenna

$f_i = -f_m + (i+N)\Delta f$: discrete Doppler frequency

$\Delta f = f_{i+1} - f_i$: equal difference between two adjacent discrete Doppler frequency

f_m : maximum Doppler frequency

$G_V(\alpha)$: azimuth vertical-polarization (E_θ) antenna gain pattern as a function of the angle α

$G_H(\alpha)$: azimuth horizontal- polarization (E_φ) antenna gain pattern as a function of the angle α

xpd : cross-polarization discrimination in the linear scale and equal to $10^{XPD/10}$

$2N+1$: number of discrete Doppler frequencies

J: number of the incoming wave rays in the H-plane with equal spacing angle

The Doppler power spectrum determines the time domain fading waveform and fade-slope behaviors. By properly shaping the spectrum of white noise weight by the root-square of the corresponding Doppler coefficients and inversely fast Fourier transform (IFFT), the base-band fading signal can be obtained. It is multiplied by the applied gray coding SSRC π/4-DQPSK modulation signals, as illustrated in Fig. 2. To obtain the maximum Doppler frequency, it is assumed that the carrier frequency f_c = 900 MHz, the mobile traveling velocity v = 90 Km/hr (or 25 m/sec), and the data rate R=48.6Kbps. These parameters imply that the maximum Doppler frequency $f(= v/\lambda) = 75\ Hz$. The value of XPD is assumed as 3.7 dB and the incident waves are distributed with a uniform distribution $p(\alpha) = 1/2\pi$ over 0 to 2π. In the channel, a multiplicative component, $n_m(t)$, is generated by the MDPS method as described in the beginning of the section. A white Gaussian noise, $n_a(t)$, is added to the standard NADC-TDMA digital modulation signal. In the receiver, a shaping filter had a SSRC response is to match the transmit filter. For convenience, it is assumed that the carrier recovery is perfect and zero symbol timing jitter to have an ideal coherent matched-filter receiver. To calculate the BER, a decision is generated by a minimum distance criterion that is optimal in the sense of equally likely signals over AWGN channel. Since the modulation signals are also equal-energy, the decision can be taken according to $\hat{\theta}_k = \tan^{-1}(\hat{Q}_k / \hat{I}_k)$. Let the $\delta\theta_k$ be defined as the modulo-2π-difference between the estimated phase $\hat{\theta}_k$ and the corresponding phase from the transmitter θ_k. If the absolute value of $\delta\theta_k$ is higher than $\pi/4$ and less than $3\pi/4$, it can be claimed that a one bit error occurs; if the absolute value of the $\delta\theta_k$ is higher than $3\pi/4$, a two-bit error is claimed to occur.

3. EM COMPUTATION AND COMMUNICATION SIMULATION RESULTS

The dimensions and relative positions to the body of the loops in Fig. 1 are as follows (f = 900 MHz):

- X-oriented rectangular loop: a=3 cm, b=1.5 cm, wire radius=0.072 cm, perimeter=0.53λ, relative position (d, w, h)=(-5, 26.5, 84.5) cm
- Y-oriented rectangular loop: a=3 cm, b=0.75 cm, wire radius=0.072 cm, perimeter=0.442λ, relative position (d, w, h)=(-5.5, 28, 84.5) cm
- Z-oriented rectangular loop: a=4 cm, b=4 cm, wire radius=0.072 cm, perimeter=0.941λ, relative position (d, w, h)=(-10, 26.5, 84.5) cm

Computational results show that, at 900 MHz, the body absorption efficiency of the x-, y-, and z-oriented loop worn on the wrist is about 6%, 16%, and 12%, respectively. Fig. 3 shows the 2-D E_θ and E_ϕ power patterns of the loop antennas in the H-plane. The average power gain of the x-, y-, and z-oriented loop antenna worn on the wrist is about -17dB, -12dB, and -13dB for the E_θ component and -13dB, -20dB, and -7dB for the E_ϕ component. Overall, the z-oriented loop antenna has the largest average power gain for the E_ϕ component in the H-plane.

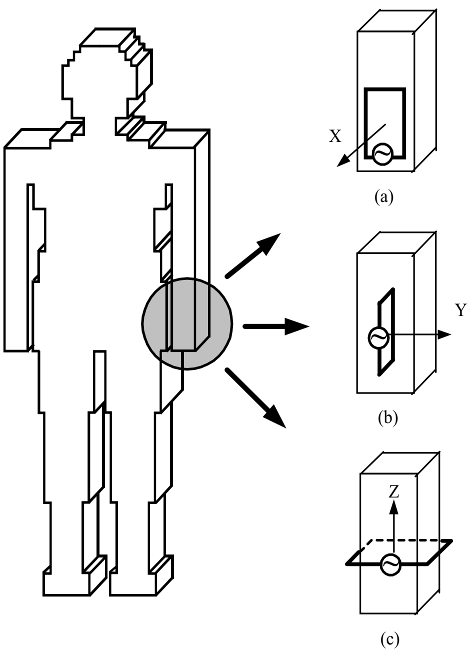
Fig. 4 shows the BER simulation results for the loop antennas of with different orientation at the wrist position (Fig. 1) and a referenced dipole antenna in free space. It is observed that due to the body effects, for BER = 10^{-3} in a system planning (assuming XPD = 3.7 dB), the z-oriented loop needs about 7 dB more receiving power than that of the dipole antenna in free space. The x- and y-oriented loops needs about 10 dB and 15 dB more receiving power. This implies that, for watch-type communicator applications, the z-oriented loop antenna (encircle the wrist) may be the preferred choice for wireless communications. The above simulation results can be very useful for the portable antenna design and communication link-budget consideration in mobile communication systems.

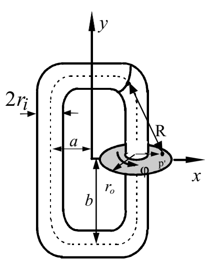
REFERENCE

[1] W.-T. Chen and H.-R. Chuang, "Numerical Computation of Human Interaction with Arbitrarily-Oriented Superquadric Loop Antennas in Personal Communications," *IEEE Trans. Antenna and Propagation*, special issue on Wireless Communications, vol. 46, no. 6, pp. 821-828, June 1998.

[2] F.-L. Lin and H.-R. Chuang, "Performance Evaluation of a Portable Radio close to the Operator's Body in Urban Mobile Environments, " to be published in *IEEE Trans. Vehicular Technology, March,* 2000.

[3] F.-L. Lin and H.-R. Chuang, "Computer Simulation of Human Body Effects on Communication Performance of a Portable Radio in Urban Mobile Environments Based on EVM and BER Evaluation," 1999 IEEE Vehicular Technology Conference, Amsterdam, Sep., 1999.





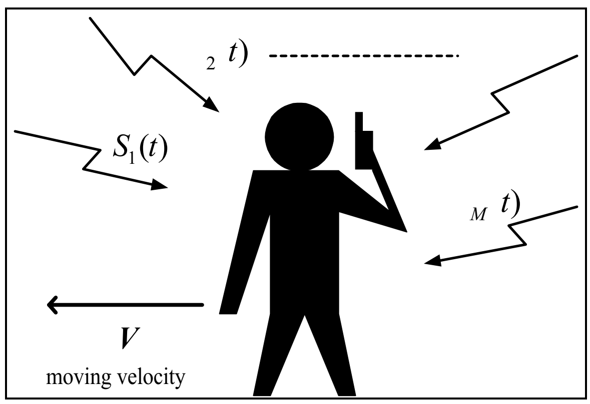


Fig. 1 Three configurations of rectangular loop antennas (modeled by superquadric loops) worn on the wrist of a human body : (a) x-oriented loop, (b) y-oriented loop. (c) z-oriented loop, and the illustration of a portable radiophone held by the operator in the mobile environments (with moving velocity v).

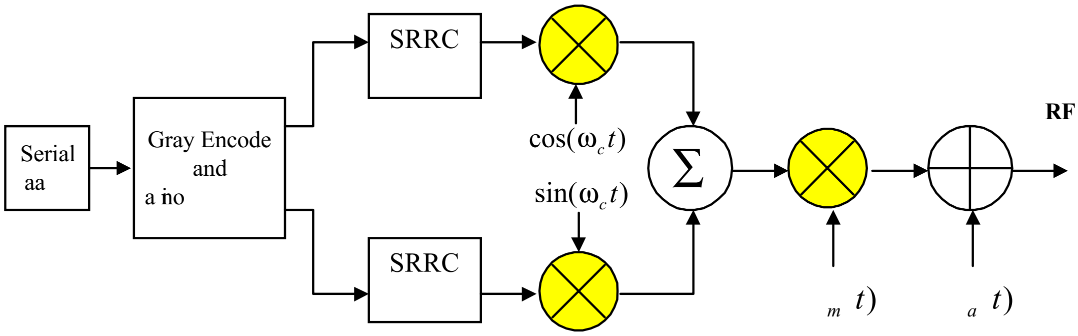


Fig. 2 Block diagram of an SRRC gray coding π/4-DQPSK fading signal generator.

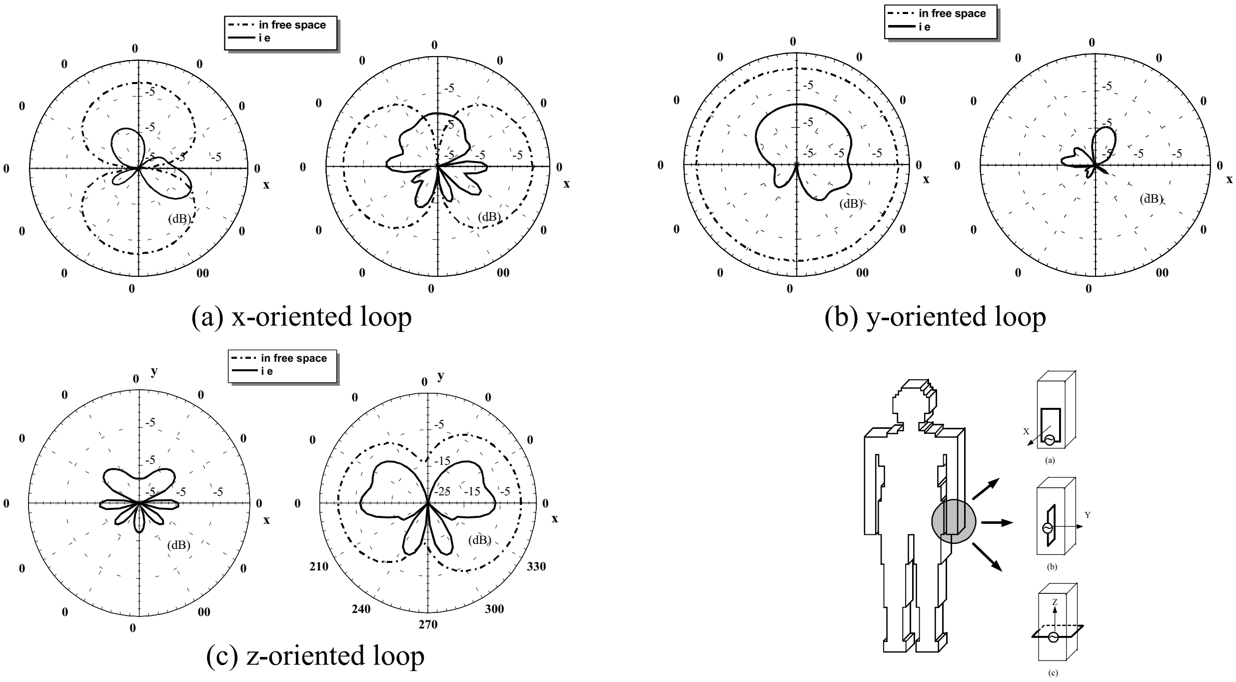


Fig. 3 2-D E_θ (left) and E_ϕ (right) power patterns of rectangular loop antennas at the wrist position and in free space at 900 MHz: (a) x-oriented loop, (b) y-oriented loop, and (c) z-oriented loop.

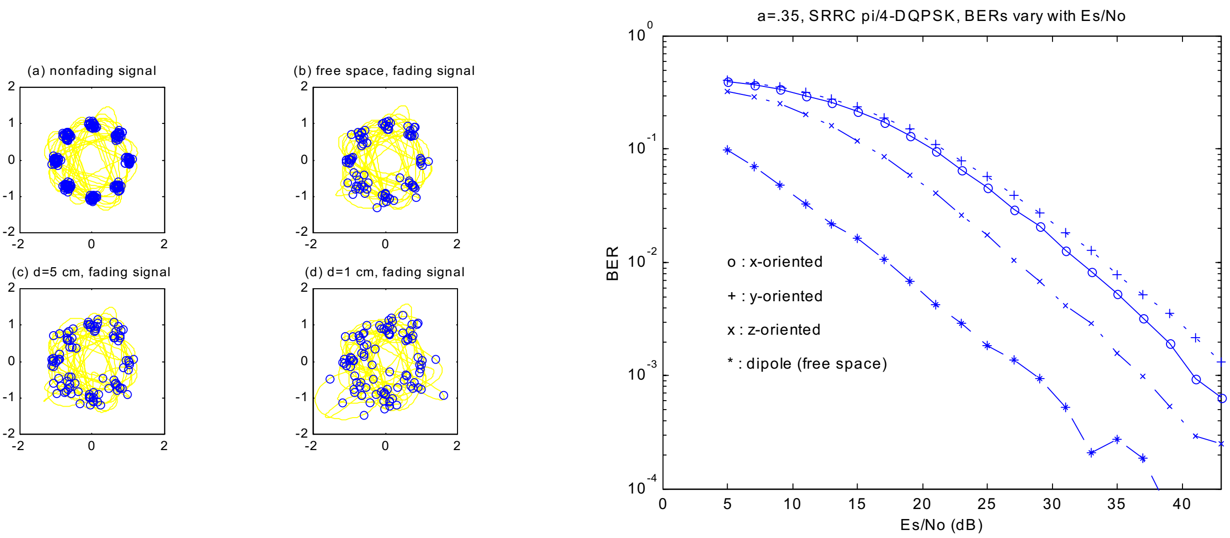


Fig. 4. Comparisons of simulated data on constellation diagrams and BER for the watch-type communicator with rectangular loop antennas at the wrist with a referenced free-space dipole antenna in urban mobile environments for 900 MHz digital wireless communications ($\alpha = 0.35$, SRRC gray coding π/4-DQPSK)