

Diversity Reception Evaluation for In-Body to On-Body Communication Channel in UWB Low Band

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ABSTRACT

In this paper, a preliminary diversity reception investigation for the in-body to on-body communication channel in UWB low band for wireless capsule endoscope (WCE) application has been carried out through simulation procedure. Spatial diversity antenna, polarization diversity antenna and a combination of both configurations are designed to overcome the shadow fading due to the position variation of the swallowed capsule. Limited to the simulation capability, representative TX antenna positions in the body are designed in terms of symmetry relationship relative to the diversity reception antenna configurations. The values of the diversity gain using classical combination techniques, i.e., selection combining (SC), equal gain combining (EGC), and maximal ratio combining (MRC), have been calculated and compared. Complex correlation coefficient and power imbalance are given to analyze the diversity performance. Different from the multipath fading in the on-body communication channel, a relatively small diversity gain will be expected resulting from the shadow fading in the in-body to on-body UWB communication channel. It is verified that diversity works at its best if fading at the branches is low correlated and the branch signals have a small power difference.

Keywords

Antenna diversity reception, diversity gain, multiple antenna system, spatial diversity, polarization diversity, ultra wideband (UWB), shadow fading, SC, EGC, MRC, in-body to on-body communications, WCE.

1. INTRODUCTION

Fading in body area communications is a significant issue that cannot be ignored. In on-body UWB communications, propagation takes place over the surface of the body by creeping or surface waves [1]. Such propagation may be significantly

affected by the movement of the body parts, which gives rise to multipath propagation paths around the body due to reflections from the body parts as well as the surrounding environment. This fading is referred to as multipath induced fading. The body itself causes the so-called shadow fading due to the shadowing from body obstacles affecting the wave propagation. In general, shadow fading is caused by the change in path length due to the motion of transmitter and/or receiver relative to each other or due to an obstruction or shadowing in the propagation path. In the wireless capsule endoscope (WCE) application [2], the dominant fading in the in-body to on-body communication channel is shadow fading, since it is caused by the change in path property due to the motion of transmitter (capsule). The multipath fading in in-body to on-body communication channel is relatively weak compared to the on-body communication channel. This can also be concluded from the two-path channel model in the UWB low band (3.1–4.8 GHz) in-body to on-body communication [3]. Fading can cause poor performance in a communication system because it can result in a loss of signal power without reducing the power of the noise. Nowadays more and more research attention has been paid to combating the effects of fading in body area communications.

Diversity is a well known method to overcome fading. The principle is the use of multiple uncorrelated channels with independent fading statistics. By using more than one communication channel, the fading can be minimized and the reliability of a signal can be improved. Antenna diversity uses multiple antennas on transmit and/or receive side to achieve the diversity branches. The shadowing fading in the WCE in-body to on-body communication channel can be mitigated using diversity reception, in which two or more uncorrelated signals are received by the separate antennas and combined using a number of different techniques. This implies Single-Input Multiple-Output (SIMO), one transmit antenna (capsule antenna) and multiple receiving antennas (on-body antennas). This process results in an increased signal to noise ratio (SNR) and improves the reliability of the signal. The improvement due to the use of diversity is measured in terms of diversity gain (DG). It is an improvement in the signal strength with diversity over a single antenna with no diversity at a certain level of outage probability [4]. Different strategies for exploiting diversity can be adopted by the receiver: SC, EGC, and MRC. With SC technique, the receiver selects the signal branch exhibiting the best signal quality. With EGC technique, the different signal branches are first aligned in time and then added without any particular weighting. With MRC technique, the different branches are weighted before the combination and the weights are determined to maximize the signal noise ratio (SNR).

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Diversity has shown successful application in on-body communication systems through experimental or simulated analysis. In [5], experimental measurements at ISM frequency band 2.45 GHz in an anechoic chamber have verified the scattering and fading effects of the body itself in the on-body communication channel and the diversity performance has been discussed as a function of various communication links and body postures. Besides the measurement of space and pattern diversity at 2.45 GHz which obtained useful diversity gain based on specific channel and antenna type, [6] has also estimated the ray arrival angle statistics. Not much work has been carried out for the diversity performance of the in-body to on-body communication systems. This paper will analyze and evaluate the diversity performance of the diversity reception in WCE application in UWB low band. In either the typical mobile wireless communication link or the on-body communication link, multipath propagation environment will affect the overall diversity performance of the antenna. Statistical propagation effects are defined as the power spectrum of the incoming waves or ray angle of arrival (AoA). Angular density functions like Gaussian, Laplacian, and elliptical distribution are chosen to describe some representative incoming waves in mobile wireless communication link [7] or measurement-based AoA estimation in the on-body communication link [6]. In the capsule in-body to on-body communication channel, the shadow fading due to motion of transmitter is the dominant propagation effects rather than the multipath propagation. Therefore, the diversity performance evaluation will base on the shadow fading. In WCE, much of the channel variation is due to the movement of the capsule through the digestive tract after being swallowed. Although simulation requires many computations of various capsule positions, compared to animal/phantom experiments, it is still a simple way to get a preliminary evaluation of the diversity performance. In this paper, the shadow fading of the in-body to on-body communication channel is simulated based on specific transmit and receive antenna designs in UWB low band. Typical transmit positions will be simulated in terms of the relative spatial symmetry relationship with the receive antennas. Spatial diversity and polarization diversity will be adopted at the receive end. The diversity gain is evaluated based on different combining strategies and the results are discussed in terms of the correlation and the power imbalance among the received branch signals.

2. SIMULATION CONFIGURATION AND PROCEDURE

A UWB capsule transmitter antenna has been successfully proposed in [8] and a successful video transmission from inside to outside body has been carried out. A planar Vivaldi UWB antenna design has also been proposed as the on-body receiver antenna in [9] and the very pure linear polarization of the single Vivaldi element is favorable for the polarization diversity reception configuration.

The antenna configurations used for spatial and polarization diversity are shown in Figure 1 (a) and (b) respectively. Space diversity reception scheme uses multiple antennas on receive side to get diversity branches distributed in space. Two or more identical antennas are separated by certain spacing between them to achieve a space diversity antenna. Polarization diversity reception scheme exploits the fact that if two signals are received with orthogonal polarizations, the fading in the signals is uncorrelated. A combination of spatial and polarization diversities is also proposed as shown in Figure 1 (c). The spatial diversity

configuration consists of two parallel Vivaldi elements on the same dielectric substrate plane with a dimension of 130 mm x 130 mm. The spacing distance of these two elements is designed to be compared with 2P and 4C configurations. The diversity performance with different spacing distance in 2S will not be covered here. The polarization diversity configuration consists of a perpendicular placed Vivaldi pair on the same substrate plane. The separation distance of this Vivaldi pair has been verified in [10] and it shows that a good isolation (larger than 15 dB) can be obtained in on-body surface measurement. A combination of spatial and polarization diversities is designed to fully exploit the substrate area. The antenna performance of the combination diversity structure can be traced in [10]. Besides, the transmit antenna is also shown in the same figure which is a conformal trapezoid strip excited broadband hemispherical dielectric resonator antenna and has been elaborated in [8].

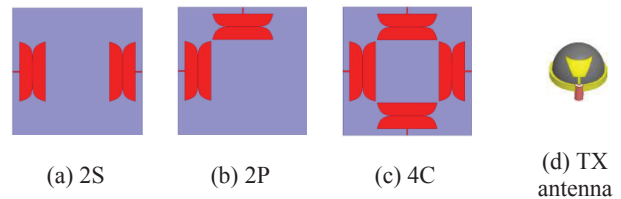
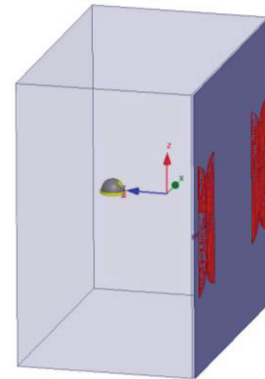
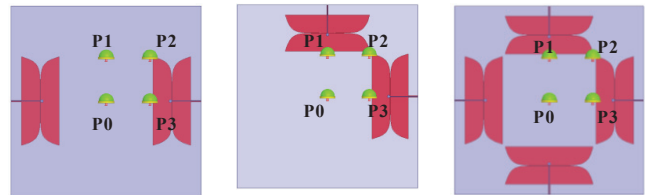


Figure 1. (a) 2S-spatial, (b) 2P-polarization and (c) 4C-combination of spatial and polarization; and (d) transmit (TX) antenna.



(a) Side view



(b) Back view (from left to right: 2S, 2P and 4C)

Figure 2. TX antenna position variation configuration

In principle, the in-body channel investigation should employ a heterogeneous human body model so as to accurately explore the wave propagation in the in-body channel. However, due to the high loss characteristic of the human body torso in UWB band, the internal scattering in tissues can be approximately neglected for shadow fading evaluation. Besides, we focus more on the

comparison of different diversity schemes. Therefore, the human body torso tissue will be in this paper approximated to be a homogeneous one using average muscle tissue which could largely decrease the simulation time and enhance the simulation efficiency. In UWB low band 3.1-4.8 GHz. The dielectric parameter of the average muscle tissue can be approximately determined as dielectric constant of 51.5 and average conductivity of 3.2 S/m. The torso tissue-simulating phantom can be shown in Figure 2. The phantom has a dimension of 130 x 130 x 80 mm. Since the orientation of the capsule inside human body is random after being swallowed, which means the orientation of the transmitter antenna is random, the polarization direction of the TX antenna along x, y, z axes will be simulated. The position variation of the TX antenna will be configured in one same plane parallel to the substrate plane with a spacing distance of 50 mm. This configuration is on the basis of the following considerations: 1) after being swallowed, the capsule moves more in the longitudinal plane than in the transverse plane; 2) limited to the simulation time; 3) to compare the different diversity setups it is sufficient and reasonable to focus on the position variation in one same plane; 4) TX positions will be chosen based on the relative symmetry relationship with the receive antennas.

Figure 2 shows the configured TX antenna positions, which are P0, P1, P2 and P3. The four positions are in one same longitudinal plane and have 30 mm spacing between two adjacent positions.

Table 1 lists the TX antenna position symmetry relationship relative to the diversity reception antenna configurations, that is, spatial diversity receive antenna (2S), polarization diversity receive antenna (2P) and combination of spatial and polarization diversities (4C). The TX antenna position symmetry information is important since it significantly influences the power imbalance among the received branch signals. Especially the UWB transmission loss in body torso tissue is much larger than in free space.

Table 1. TX antenna position symmetry relationship relative to the RX diversity antenna configuration

TX Position symmetry	2S	2P	4C
P0	yes	yes	yes
P1	yes	no	no
P2	no	yes	no
P3	no	no	no

The transmission between TX antenna and RX antenna will be simulated using the frequency domain solver Ansoft High Frequency Structural Simulator (HFSS), a commercial full wave simulator software based on the Finite Element Method (FEM) techniques. The path loss property for each TX position will be sampled in UWB low band 3.1-4.8 GHz and then the received signals will be combined according to different combination techniques. The sampling frequency step was set to 10 MHz thus a total of 171 points were collected for each channel measurement.

3. DATA ANALYSIS

The performance of a diversity receiver greatly depends on the correlation between the received signals at the diversity branches.

Low correlation can assure that the received branch signals fade differently or independently. Here we use the complex signal correlation coefficient ρ_s to evaluate the correlation since it is useful in system design as it contains both the phase and amplitude correlations. The complex signal correlation coefficient is defined as [11]

$$\rho_s = \frac{\sum_{k=1}^N V_1(k)V_2^*(k)}{\sqrt{\sum_{k=1}^N V_1(k)V_1^*(k)}\sqrt{\sum_{k=1}^N V_2(k)V_2^*(k)}} \quad (1)$$

The simplified expressions to obtain the diversity-combined signal with SC, EGC and MRC for an N-branch diversity combiner are given in [12] as:

$$v_c(t) = \begin{cases} \max[v_1(t), v_2(t), \dots, v_N(t)] & SC \\ [v_1(t) + v_2(t) + \dots + v_N(t)]/\sqrt{N} & EGC \\ \sqrt{v_1^2(t) + v_2^2(t) + \dots + v_N^2(t)} & MRC. \end{cases} \quad (2)$$

$v_i(t)$ is the received envelope, $v_c(t)$ is the resultant signal envelope.

Comparisons have been made between the three diversity antenna configurations on the basis of the diversity gain realized at 1% probability (or 99% signal reliability) as well as the complex signal correlation coefficient and the power imbalance using the three types of diversity combining schemes.

Figure 3 to Figure 6 show the cumulative distribution functions (CDF) versus the power path loss in orientations P0, P1, P2 and P3 respectively obtained with the three diversity antenna configurations 2S, 2P and 4C. In each cumulative distribution function figure, the CDF traces of each signal branch as well as the combined signals are plotted in the same figure. For a given CDF value 0.01 (99% reliability level), the difference between the strongest channel trace and each one of the combined signals represents the DG for the relative combining technique. It can be noted that in Figure 4 the trace of one of the channel branch is nearly consistent with the SC signal in polarization diversity and combination diversity. This is because one the received branch signals is always stronger than the other one/ones in 2P and 4C due to the orientation P1. Therefore, with the SC technique, the receiver always selects the best signal and no or very small diversity gain will be achieved. The difference between the two received branch signals in Figure 4 (a) is due to the incomplete symmetry when the TX feed axis aligns with the x axis. In Figure 4 (c) with the SC technique, the receiver always selects the signal from antenna 2 and the performance with the SC technique is always better than that with the EGC technique. This is because the big power difference between the branch signals and the branch with very low power level introduces additional noise and very less improvement to the desired signal is achieved, which results in overall decrease in the output SNR. The power difference between different branch signals greatly depends on the TX antenna orientation. Different TX antenna position will result in different channel loss and the resulting signal loss will be much larger than the free space transmission loss due to the highly lossy characteristics of body tissue in UWB band. Besides, different polarization direction of the TX antenna will also influence the branch loss but will be much less than that due to the position variation. The CDF shown in Figure 3 to Figure 6 has included all contributions due to the TX antenna polarization variation. TX antenna position variation is designed as shown in Figure 2.

Position symmetry relationships relative to the RX diversity antenna are also given since a good symmetry relationship can lower largely the power imbalance. Positions P0 to P3 essentially cover the possible symmetry/asymmetry relationship to the RX diversity antenna configurations 2S, 2P and 4C.

Power imbalance is not the only factor affecting the diversity gain. Diversity gain will also greatly depend upon the correlation among the branch signals. But it is not the case that the more the branches are uncorrelated, the higher is the diversity gain. Two uncorrelated branch signals may have a very big power imbalance.

Table 2 summarizes the diversity gain and the power imbalance at 99% reliability level as well as the complex signal correlation coefficient for different diversity antenna configurations with TX antenna position variation. There we can notice that for 2S, at P2, even the correlation coefficient is as low as 0.02 but with a large power imbalance 41 dB, there is no diversity gain obtained for any combining technique. The DG for SC and MRC is zero and the value for EGC is a negative value. This is mainly due to the large power imbalance. The up limit for the negative DG value for 2-branch EGC is -3 dB which can be derived based on Equation (2). We can also notice that for 2S at P3, for 4C at P1 and P2, negative DG values are obtained for EGC technique. For the 4C combination diversity scheme, the DG value will be based on the strongest channel trace while the complex signal correlation coefficient and the power imbalance will be based on every two branches. For the sake of implicitly, value range will be given in the format of minim~maximum for 4C. From the table results, it can be read: 1) DG of 2S configuration is relatively smaller than that of 2P and 4C configurations; 2) DG of 2P configuration shows good values and no zero/negative value is achieved; 3) DG for 4C at P0 is as high as 13 dB with MRC; 4) P0 is a symmetric position for all diversity antenna configurations and a relatively good diversity gain can be obtained; 5) no matter what kind of diversity antenna configuration and no matter what kind of combining technique, MRC obviously gives the best DG values.

On the basis of the calculation, it can be concluded that the diversity performance is seriously affected by the diversity antenna configuration as well as the TX antenna position variation. Polarization diversity antenna configuration 2P gives better DG values. It can assure a relatively small power imbalance as well as a low correlation even in terms of a generalized random TX antenna position, both for symmetric position and asymmetric position. In fact, diversity works at its best if fading at the branches is uncorrelated and the branch signals have the same average power level [4]. Moreover, due to static channel with shadow fading, the achieved DG is around 5 dB for the best diversity antenna configuration 2P which is lower than that with the dynamic non-line-of sight channel with multi-path fading [5]. This conclusion agrees with that in [5] for an on-body shadowed waist/ankle link in the sitting posture. For the 4C configuration, it is the fact that additional noise will be definitely introduced no matter how large is the improvement to the desired signal. However, obviously, with diversity reception or SIMO, the cost and complexity of the receiver is increased if they are equipped with multiple antennas. Therefore, 4C is not a cost-effective configuration for in-body shadow fading channel. Spatial diversity (with multiple antennas) is not an efficient configuration neither in terms of power imbalance as well as the receiver complexity and limited available volume.

4. CONCLUSIONS

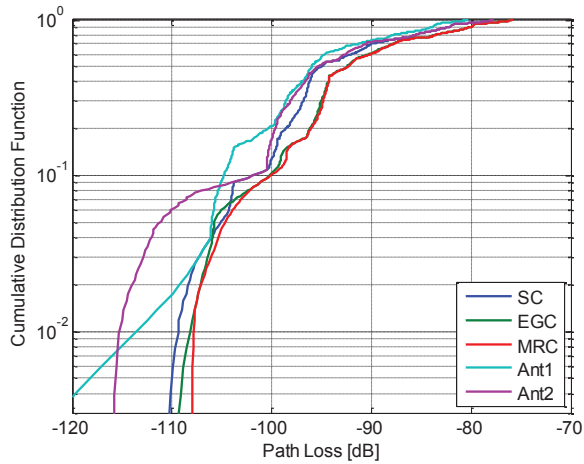
This paper evaluates the diversity performance for shadow fading in in-body UWB communication channel in WCE application through simulation procedure. Three different diversity reception antenna configurations are designed involving spatial diversity, polarization diversity and a combination of the spatial and polarization diversities. The values of the diversity gain for the three classical combination techniques and several representative positions of the TX antennas in the body have been calculated and compared. Correlation coefficient and power imbalance are given to analyze the diversity performance. The polarization diversity has been found to give the best diversity gain in the in-body to on-body shadow fading UWB channel. A general improvement around 5 dB DG has been resulted in the signal reliability which suggests the applicability of a diversity scheme to in-body to on-body UWB communication systems. A further experimental measurement based on animal/phantom is expected to carry out for the diversity scheme verification.

5. REFERENCES

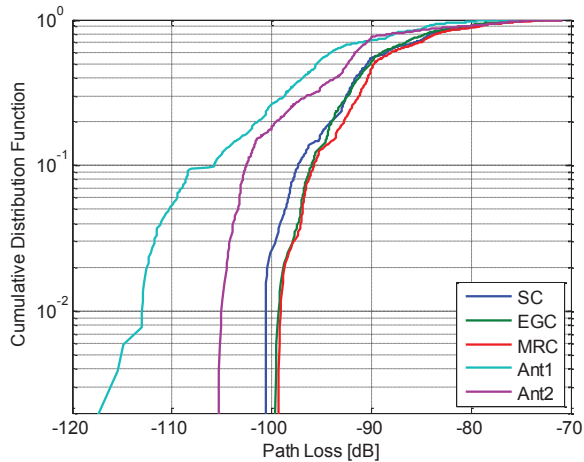
- [1] Wang J., and Wang Q. 2012. *Body Area Communications: Channel Modeling, Communication Systems, and EMC*. Wiley-IEEE Press.
- [2] Qureshi W. A. 2004. Current and future applications of the capsule camera. *Nature Rev. Drug Disc.* (vol. 3, May 2004).
- [3] Shi J., Anzai D., and Wang J. 2012. Diversity performance of UWB low band communication over in-body to on-body propagation channel. In *6th European conference on Antennas and Propagation* (Prague, Czech Republic, March 26-30, 2012), EUCAP.
- [4] Vaughan R G., and Andersen J Bach. 1987. Antenna Diversity in Mobile Communications. *IEEE transaction On Vehicular Technology*, Vol. VT-36. ,No. 4.
- [5] Serra, A.A., Nepa, P., Manara, G., and Hall, P.S. 2007. Experimental investigation of diversity techniques for on-body communication systems, In *IET Seminar on Antennas and Propagation for Body-Centric Wireless Communications* (London, United Kingdom, April 24, 2007).
- [6] Hall, P.S. 2008. Diversity in On-Body Communications Channels. In *International Workshop on Small Antennas and Novel Metamaterials* (Chiba, Japan, March 4-6, 2008), iWAT.
- [7] Diallo A., Luxey C., Thuc P. Le, Staraj R., and Kossiavas G. 2008. Diversity Performance of Multiantenna Systems for UMTS Cellular Phones in Different Propagation Environments. *International Journal of Antennas and Propagation*. Volume 2008, Article ID 836050.
- [8] Wang Q., Wolf K., and Plettemeier D. 2010. An UWB capsule endoscope antenna design for biomedical communications. In *3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies* (Rome, Italy, November 07-10, 2010), ISABEL.
- [9] Wang Q., Hahnel R., Zhang H., and Plettemeier D. 2011. Wearable Vivaldi UWB planar antenna for in-body communication. In *Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies* (Barcelona, Spain, October 26-29, 2011), ISABEL.
- [10] Wang Q., Hahnel R., Zhang H., and Plettemeier D. 2012. On-body directional antenna design for in-body UWB

wireless communication, In *6th European Conference on Antennas and Propagation* (Prague, Czech Republic, March 26-30, 2012), EUCAP.

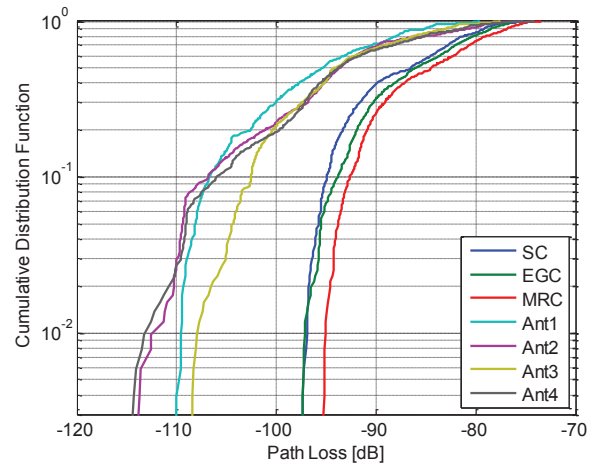
- [11] Turkmani M. D., Arowojolu A. A., Jefford P. A., and Kellett C. J. 1995. An Experimental Evaluation of the Performance of Two-Branch Space and Polarization Diversity Schemes at 1800 MHz. *IEEE Transactions on Vehicular Technology*, Vol. 44, No. 2.
- [12] Khan I. 2009. Diversity and MIMO for body-centric wireless communication channels. Ph.D. thesis, University of Birmingham.



(a) 2S-spatial diversity

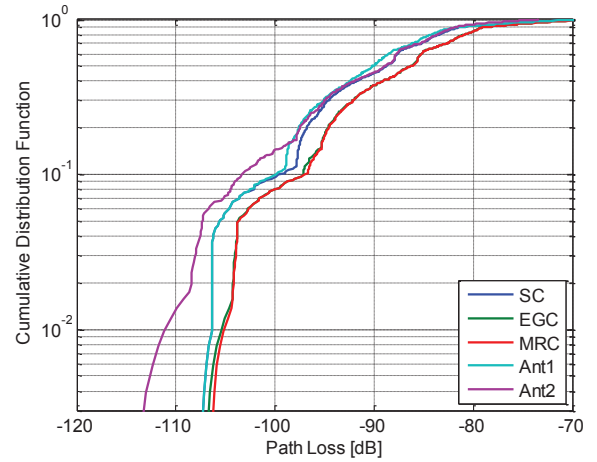


(b) 2P-polarization diversity

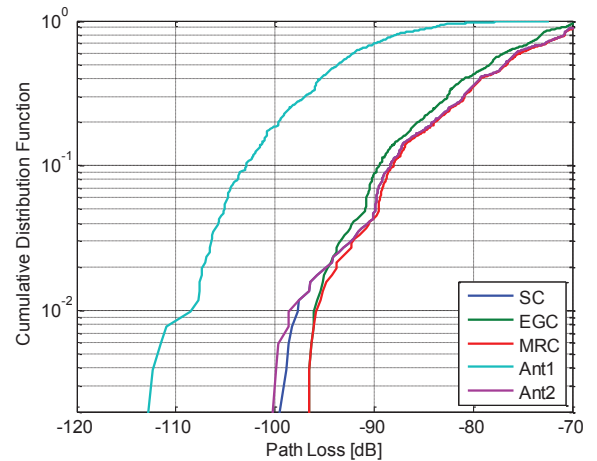


(c) 4C-combination of spatial and polarization

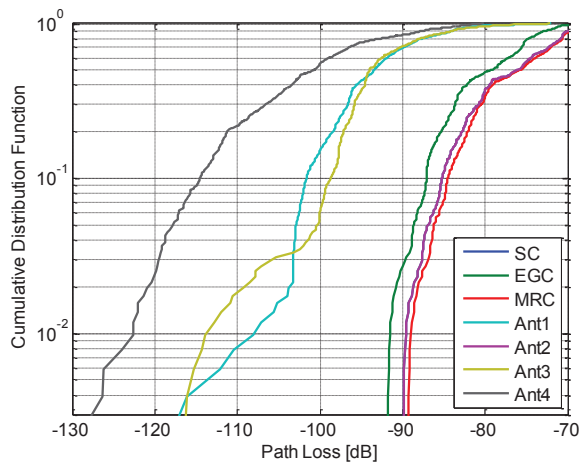
Figure 3. Cumulative distribution functions in orientation P0 obtained with (a) 2S-spatial diversity, (b) 2P-polarization diversity and (c) 4C-combination of spatial and polarization.



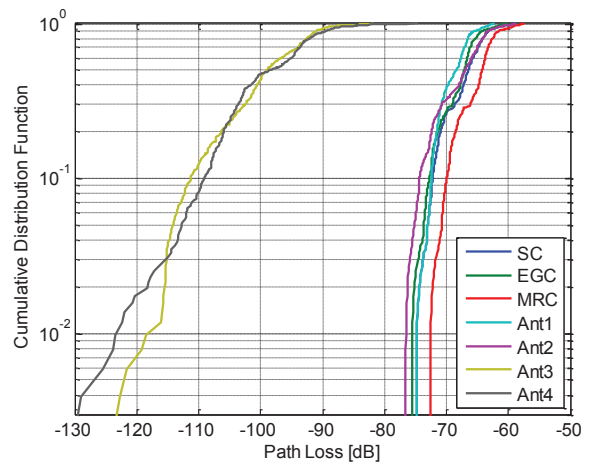
(a) 2S-spatial diversity



(b) 2P-polarization diversity



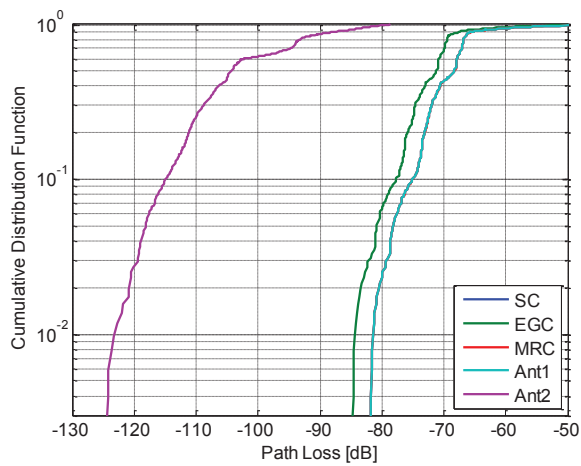
(c) 4C-combination of spatial and polarization



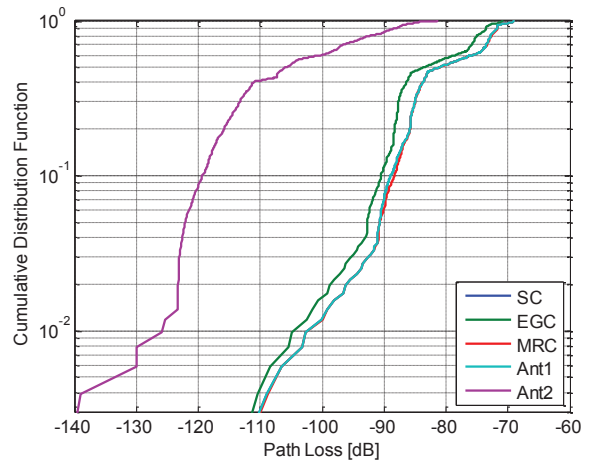
(c) 4C-combination of spatial and polarization

Figure 4. Cumulative distribution functions in orientation P1 obtained with (a) 2S-spatial diversity, (b) 2P-polarization diversity and (c) 4C-combination of spatial and polarization.

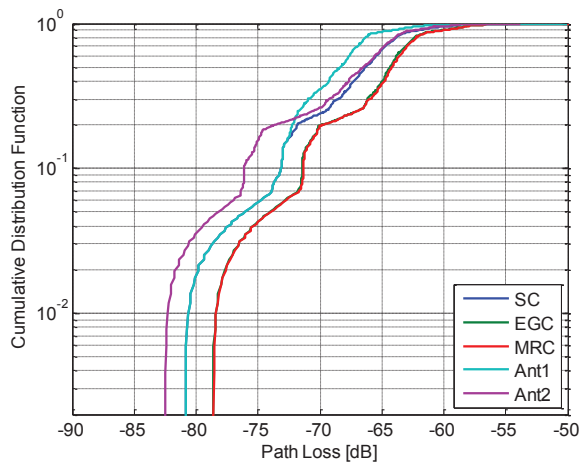
Figure 5. Cumulative distribution functions in orientation P2 obtained with (a) 2S-spatial diversity, (b) 2P-polarization diversity and (c) 4C-combination of spatial and polarization.



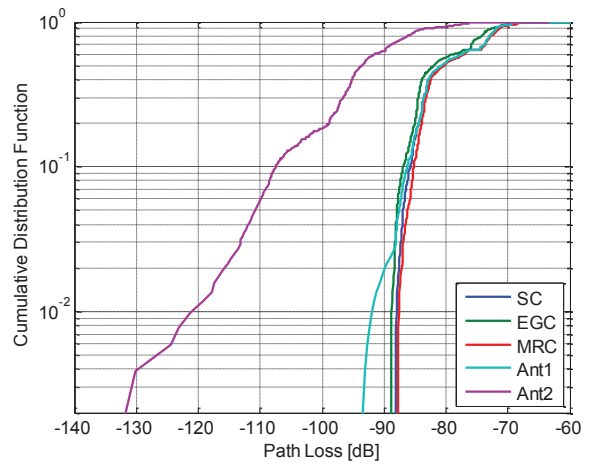
(a) 2S-spatial diversity



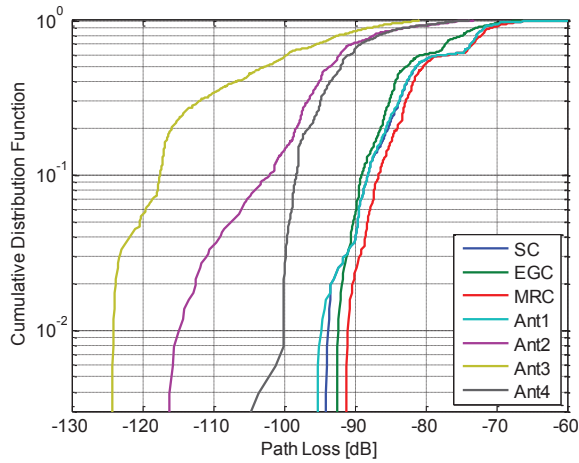
(a) 2S-spatial diversity



(b) 2P-polarization diversity



(b) 2P-polarization diversity



(c) 4C-combination of spatial and polarization

Figure 6. Cumulative distribution functions in orientation P3 obtained with (a) 2S-spatial diversity, (b) 2P-polarization diversity and (c) 4C-combination of spatial and polarization.

Table 2. Diversity gain, complex signal correlation coefficient and the power imbalance for different diversity antenna configurations with TX antenna position variation.

Diversity antenna configurations	Orientation	DG (dB)			ρ_s	Power imbalance (dB)
		SC	EGC	MRC		
2S	P0	4.0	5.1	5.8	0.76	1.8
	P1	0.0	1.1	1.4	0.06	5.0
	P2	0.0	-2.8	0.0	0.02	41.0
	P3	0.0	-2.5	0.0	0.35	24.0
2P	P0	4.7	5.4	5.7	0.12	8.0
	P1	0.8	2.5	2.7	0.30	10.0
	P2	0.0	3.0	3.0	0.60	2.0
	P3	4.3	3.6	4.6	0.30	28.0
4C	P0	11.0	11.5	13.0	0.05~0.70	1.0~5.0
	P1	0.0	-2.8	0.7	0.19~0.85	6.0~33.0
	P2	0.0	-0.3	2.1	0.12~0.69	1.8~50.0
	P3	1.2	2.5	3.8	0.18~0.80	4.5~24.0