New Intuitive Metrics for Diversity Performance Evaluation of Multi-element Antenna Systems

Vasileios C. Papamichael[1] **and Petros Karadimas**[2]

[1]Department of Electrical Engineering, Technological Educational Institute of Western Greece and Wireless Systems Performance (WiSPer), Patras 26441, Greece
[2]Department of Computer Science and Technology, University of Bedfordshire, Luton LU1 3JU, UK

Abstract— Diversity performance of multi-element antenna (MEA) systems is evaluated using several metrics. The most common are the diversity antenna gain (DAG), the effective diversity gain (EDG) and the actual diversity gain (ADG). These metrics calculate the performance by comparing the MEA system with the reference antenna at a fixed outage probability level, i.e., usually at 1% outage level. As fixed outage levels are just an indication of probability of occurrence of specific signal levels, they provide limited insight into realistic deep-fade cases. Thus, we introduce three novel metrics, namely, the fading mitigation gain (FMG), the reliability percentage (RP) and the generalized diversity antenna gain (GDAG) for characterizing diversity performance when deep fades take place in one or more of the diversity branches. Based on the aforementioned metrics, intuitive knowledge on the diversity performance of MEA systems is provided.

1. INTRODUCTION

The mitigation of multipath fading is an issue of primary importance in wireless communications systems. Multi-element antenna (MEA) systems combat fading through diversity combining, which potentially increases the received power.

Until now, several metrics for the diversity performance have been proposed, with the most important being the diversity antenna gain (DAG) [1], the effective diversity gain (EDG) [2] and the actual diversity gain (ADG) [3]. They are derived by comparing the cumulative distribution functions (CDFs) of the received signal-to-noise ratio (SNR) of the MEA and that of a reference antenna at a specific outage probability level (usually 1% outage probability level). Their only difference lies on the choice of the reference antenna. The DAG is based on comparing the MEA with an isotropic, dual polarized reference antenna and is thus a metric of universal applicability when deriving diversity performance. The EDG arises by comparing the MEA with one of its single elements having 100% efficiency and the ADG by comparing the MEA with an arbitrarily selected antenna. Thus, both EDG and ADG are not of such universal applicability as the DAG, as they are strongly dependent on the chosen reference antenna.

As the CDF just presents probabilities of specific SNR levels, DAG, EDG and ADG do not account for performance provided by a MEA system when only deep fades take place in one or more of the diversity branches. Performance in such cases only would be a better indicator of how effectively the MEA system combats fading. Moreover, the estimated percentage of the cases where the MEA's received SNR is greater than that of the reference antenna would also provide further insights into the performance of MEA systems. Thus, in this paper, three new intuitive metrics focusing on deep-fade cases are proposed. The first metric is called *fading mitigation gain* (FMG) and accounts for the performance when at least one of the diversity branches of the MEA system has 20 dB less power with respect to the average received power of the reference antenna[1]. It is thus a random variable. The second is called *reliability percentage* (RP) and accounts for the percentage of the cases when the MEA system has greater received power compared with that of the reference antenna. The third is called *generalized diversity antenna gain* (GDAG) and arises after weighting the two DAGs, i.e., the DAG (weighted by RP) when the MEA received power is greater than that of the reference antenna and the DAG (weighted by 1-RP) when is lower. An isotropic dual polarized reference antenna is considered as in [1], thus, for consistency, we maintain the term DAG in GDAG. The MEA systems and propagation environments are jointly modeled by using the stochastic approach presented in [4].

The remainder of this paper is organized as follows: In Section 2, the three new metrics, i.e., the FRG, RP and GDAG are defined. In Section 3, relevant results are presented considering a two-port compact MEA system and Section 4 draws the conclusion.

[1]Considering equal noise powers between the reference antenna and the MEA system, we can consider the received power instead of the SNR.

2. NEW PERFORMANCE METRICS

2.1. Fading Mitigation Gain (FMG)

We consider A as the difference in dB of the mean received power of the reference antenna $E\{P_{ref}\}$ and a predetermined power threshold K, such that a deep fade region has resulted with respect to the mean received power of the reference antenna, e.g., $K = 20\,\mathrm{dB}$ for a 20 dB deep fade region. Thus,

$$A_{\mathrm{dB}} = E\left\{P_{ref}\right\}_{\mathrm{dB}} - K_{\mathrm{dB}}. \tag{1}$$

We define FMG over A as the power gain in dB that the MEA system provides when the received power of at least one of the MEA's ports is below A. Thus,

$$\mathrm{FMG}_K = \left. P_{\mathrm{div,\,dB}} \right|_{\text{at least one of} P_1 \ldots P_n \leq A_{\mathrm{dB}}} - A_{\mathrm{dB}} \tag{2}$$

where P_{div} is the power of the combined signal according to the selected diversity scheme. In (2), we use the subscript K in FMG, i.e., FMG_K, because FMG has an obvious dependence on K. It is also obvious that FMG_K is a random variable.

2.2. Reliability Percentage (RP) and Generalized Diversity Antenna Gain (GDAG)

The RP is defined as the percentage of cases where the MEA's received power is greater than the reference antenna's ones. Based on the RP, we define GDAG as

$$\mathrm{GDAG} = \mathrm{RP} \cdot \mathrm{DAG}_1 + (1 - \mathrm{RP}) \cdot \mathrm{DAG}_2 \tag{3}$$

where DAG_1 is the diversity antenna gain evaluated when the MEA's received power is greater than the reference antenna's ones and DAG_2 when is lower.

3. RESULTS AND DISCUSSION

As a case study, we consider the two-port MEA system depicted in Fig. 1. It comprises of two inverted-F elements which have selected due to their wide bandwidth, high efficiency, omni-directional radiation pattern and ease of fabrication. For more details about this system see [5]. The configurations depicted in Fig. 1 were simulated using IE3D, a commercial method of moment based electromagnetic field solver [6]. Also, an isotropic, dual polarized reference antenna was employed [1].

FMG_K is evaluated from (1) and (2) using the stochastic electromagnetic-circuit methodology under an isotropic propagation scenario [4]. Maximal ratio combining (MRC) is the employed diversity scheme. In Fig. 2 the CDF of the FMG_K is illustrated when $K = 20\,\mathrm{dB}$ and $E\{P_{ref}\} = 0\,\mathrm{dB}$. FMG_{20} is more than 6.3 dB for 90% of the cases when the power of at least one of the received signals is below the 20 dB deep fade characterized by A. It is important to mention that 20 dB deep fades take place in only 4.8% of the whole ensemble of received powers. For other cases with less than 20 dB deep fades, FMG_K is even better. Useful statistics are also the mean value of FMG_{20} which is 13.8 dB and its standard deviation which is 5.2 dB. Thus, on average, in the 20 dB deep fade region, the combined signal will be only 6.2 dB less than that of the reference antenna whereas the signal of a single port antenna will be less by 20 dB. Such informative insights into the diversity performance of MEA systems cannot be provided by DAG, EDG or ADG.

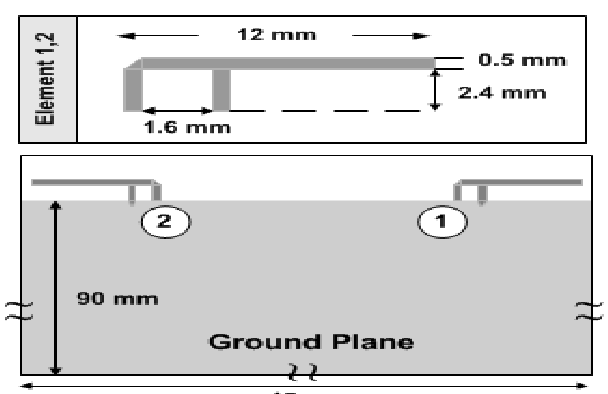

Figure 1: The layout of our two-port MEA system.

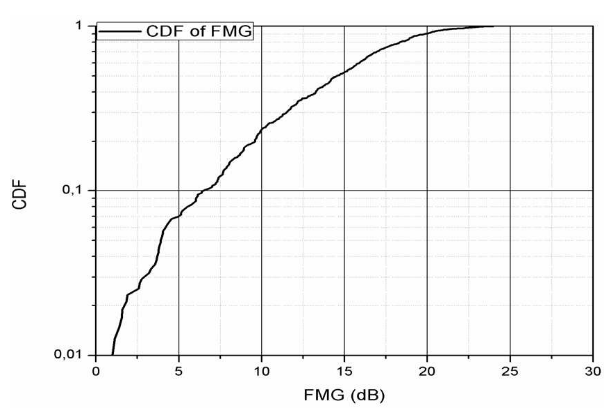

Figure 2: The CDF of FMG_{20} under MRC diversity.

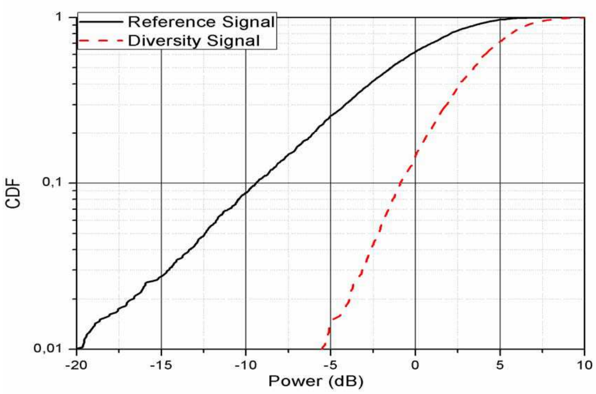

Figure 3: The CDFs of the reference antenna and the MEA system power when the MEA system's power is greater than the reference antenna's.

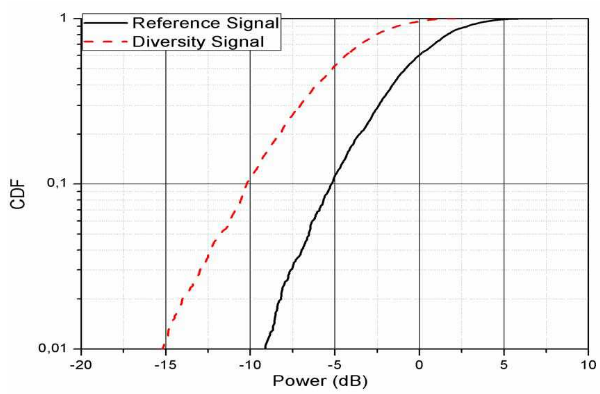

Figure 4: The CDFs of the reference antenna and the MEA system power when the MEA system's power is less than the reference antenna's.

The remaining two metrics which have evaluated are the RP and the GDAG According to its definition in Section 2, RP was evaluated as 51%, which means that for almost half of time the MEA system performs better than the reference antenna. The GDAG is calculated from (3) using the data plotted in Figs. 3 and 4. It is found to be 4.5 dB at 1% outage probability level. More specifically, DAG_1 is 14.8 dB and DAG_2 is -6.1 dB. The latter means that when the reference antenna outperforms the MEA system, the loss in DAG is only 6.1 dB and when the opposite holds the gain is 14.8 dB. For the same MEA system, the DAG as defined in [1], was calculated in [4] and was found to be 7.8 dB. That value, as well those provided by EDG and ADG, hide information as provided by RP, DAG_1, DAG_2 and GDAG. GDAG is thus a more realistic diversity performance indicator, since it gives the average value of gain according to its sophisticated definition.

4. CONCLUSION

In this paper, the diversity performance of MEA systems was revisited. Three novel informative metrics provided new insights into diversity performance. FMG characterizes the performance in deep-fade regions, where, in fact, their occurrence is the only reason of using MEA systems. The ultimate performance indicator is the GDAG which takes into account both the "good" and "bad" scenarios of operation of MEA systems. Based on our analysis and results, the commonly used metrics DAG, EDG and ADG give an opportunistic picture of the diversity performance since they do not exclusively focus on the "bad" scenarios, i.e., when the reference antenna outperforms the MEA system. As a matter of fact, in 49% of the time the reference antenna provides more power than our two-port MEA system and this necessitates the use of GDAG to characterize performance.

REFERENCES

1. Ogawa, K. and J. Takada, "An analysis of the effective performance of a handset diversity antenna influenced by head, hand, and shoulder effects — A proposal for a diversity antenna gain based on a signal bit error rate and analytical results for the PDC system," *Electronics and Communications in Japan*, Part 2, Vol. 84, No. 6, 852–865, 2001.
2. Kildal, P., K. Rosengren, J. Byun, and J. Lee, "Definition of effective diversity gain and how to measure it in a reverberation chamber," *Microwave Optical Technology Letters*, Vol. 34, No. 1, 56–59, 2002.
3. Plicanic, V., B.-K. Lau, A. Derneryd, and Z. Ying, "Actual diversity performance of a multiband diversity antenna with hand and head effects," *IEEE Transactions on Antennas and Propagation*, Vol. 57, No. 5, 1547–1556, May 2009.
4. Papamichael, V. and C. Soras, "Generalised selection combining diversity performance of multi-element antenna systems via a stochastic electromagnetic-circuit methodology," *IET Microwaves, Antennas and Propagation*, Vol. 4, No. 7, 837–846, Jul. 2010.
5. M. Karaboikis, V. Papamichael, G. Tsachtsiris, C. Soras, and V. Makios, "Integrating compact printed antennas onto small diversity/MIMO terminals," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 7, 2067–2078, Jul. 2008.
6. Zeland Software Inc., IE3D, http://www.zeland.com/.