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ABSTRACT: The paper studies the performance of a novel ultra-wideband multiport self-grounded bow-tie antenna and presents simulated embedded radiation efficiencies and correlation at each antenna port, and the diversity gain of the antenna in rich isotropic multipath environment.

INTRODUCTION

Multiport antennas are needed in wireless communications systems using Multiple-input Multiple-output (MIMO) technology to increase the throughput or channel capacity. The embedded radiation efficiencies and the correlation between the antenna ports are main factors determining the diversity gain. Recently it has been shown that the diversity gain (previously defined at 1% CDF-level in [1][2]), represents an equally large improvement at 99% throughput-level [3], in a rich isotropic multipath (RIMP) environment.

The four port self-grounded bow-tie antenna [4]-[8] is a compact ultra-wideband (UWB) MIMO antenna that has been recently developed at the Antenna Group, Chalmers University of Technology; see Fig. 1. This newly developed antenna provides unique features. Besides its compact geometry, the antenna has ultra-wideband frequency of operation, i.e. 0.5–16 GHz. The simulations show that the reflection coefficient is below -7 dB, the mutual coupling below -12.5 dB, and the total embedded radiation efficiency above -1 dB, over the whole bandwidth; see Fig. 2-3.

This antenna is mainly developed for Bluetest reverberation chambers but it can be also used in other applications, e.g. micro base-stations. It is based on the idea of self-grounded monopoles. It is designed using Copper material in CST Microwave Studio and its performance is optimized using genetic algorithm. The antenna has a simple mechanical construction that is easy to manufacture.

To characterize the performance of the four-port self-grounded bow-tie antenna, we extract S-parameters and embedded radiation patterns of each antenna port from CST Microwave Studio for the frequency range of 0.5–16 GHz. From the S-parameters we can calculate the embedded radiation efficiency and total embedded radiation efficiency at each port. The simulated embedded far field functions from CST are then exposed to RIMP environment to calculate correlation and diversity gain. This is done by using a ray-based simulation tool called ViRM-lab. The RIMP environment is emulated by reverberation chambers as explain in [3].

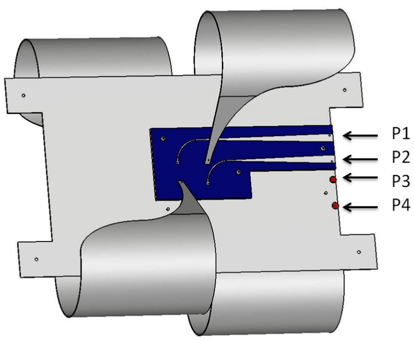

Fig. 1: CST model of 4-port self-grounded bow-tie antenna

RADIATION EFFICIENCY AND CORRELATION USING S-PARAMETERS

We simulate the multiport antenna structure in CST Microwave Studio to get S-parameters between all ports for the whole frequency range; see Fig. 2. For the lossless antenna, the embedded radiation efficiency, the total embedded radiation efficiency and the correlation in RIMP environment can be formulated in terms of the S-parameters.

The embedded radiation efficiency is defined in [2]. The formulas in terms of S-parameters for embedded radiation efficiency e_{rad} and total embedded radiation efficiency $e_{rad_{total}}$ of embedded element number i when there are total N elements, are shown below in (1) and (2) respectively:

$$e_{rad} = \frac{1-\sum_{j=1}^{N}\left|S_{ij}\right|^2}{1-\left|S_{ii}\right|^2} \; ; \; e_{refl} = 1-\left|S_{ii}\right|^2 \qquad (1)$$

$$e_{rad_{total}} = e_{rad} * e_{refl} = 1-\sum_{j=1}^{N}\left|S_{ij}\right|^2 \qquad (2)$$

where e_{refl} denotes mismatch efficiency. Since all antenna petals are symmetrical or anti-symmetrical with respect to each other, they have the same radiation efficiency as shown in Fig. 3. The results plotted in Fig. 3 show comparison of efficiencies which are calculated by using CST itself and by using simulated S-parameters from CST. The results from both are quite similar at high frequencies i.e. above 1 GHz but at 0.5 GHz there are differences between the two calculations. We believe that the embedded radiation efficiency calculations using S-parameters from CST are more accurate. These simulated results can be validated by the measurement results of this antenna.

The correlation between the ports in a RIMP environment is very low, smaller than 0.1, due to the fact that mutual coupling between the ports is lower than -10 dB; see Fig. 4. The correlation can be calculated by using far-field functions [2] or S-parameters. The formula for calculating correlation ρ in terms of S-parameters is shown in (3).

$$\rho_{ij} = \frac{S_{ii}S_{ij} + S_{ji}S_{jj}}{\sqrt{\left[1-\left(\left|S_{ii}\right|^2+\left|S_{ij}\right|^2\right)\right]\left[1-\left(\left|S_{ji}\right|^2+\left|S_{jj}\right|^2\right)\right]}} \qquad (3)$$

The correlation results in Fig. 4 show that only at 0.5 GHz, there is difference in results using two different methods but for higher frequency range i.e. 1-16 GHz, the results look similar. Since we have more samples of S-parameters to show more accurate results compared to limited number of far-field functions due to complexity, we believe that the correlations calculated using S-parameters are more accurate than calculated using far-field functions.

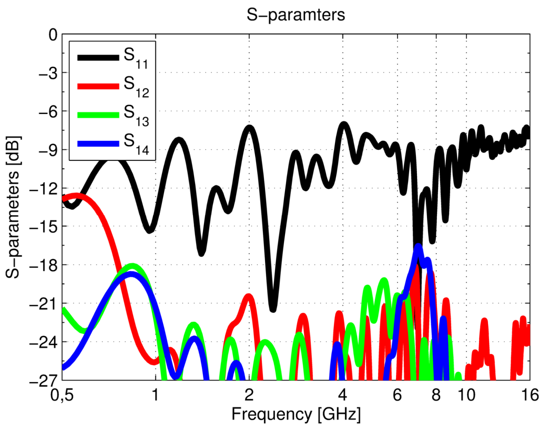

Fig. 2: Simulated S-parameters of 4-port self-grounded bow-tie antenna from CST.

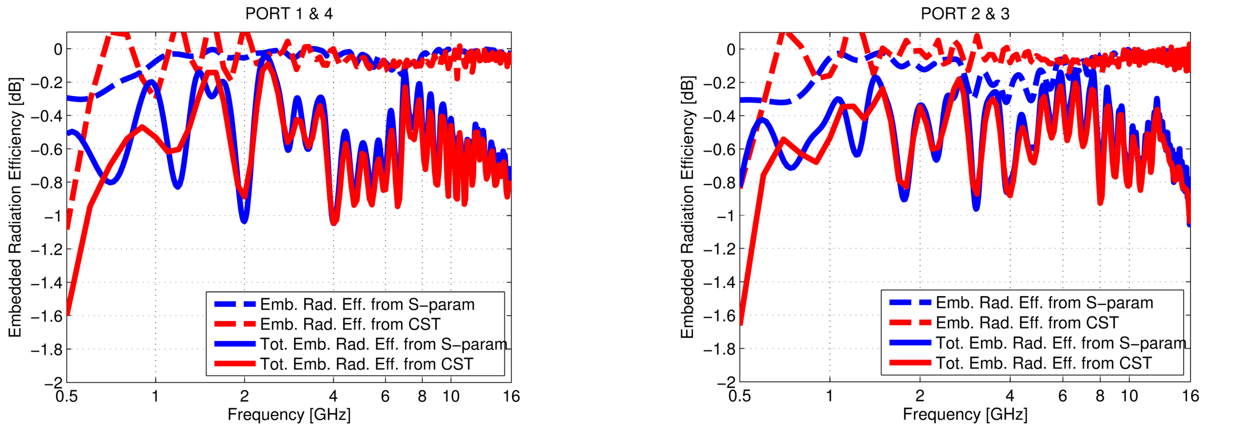

Fig. 3: Embedded radiation efficiencies of ports 1 &4 (left) and ports 2 & 3 (right) calculated by CST (red color) and calculated by S-parameters from CST (blue color).

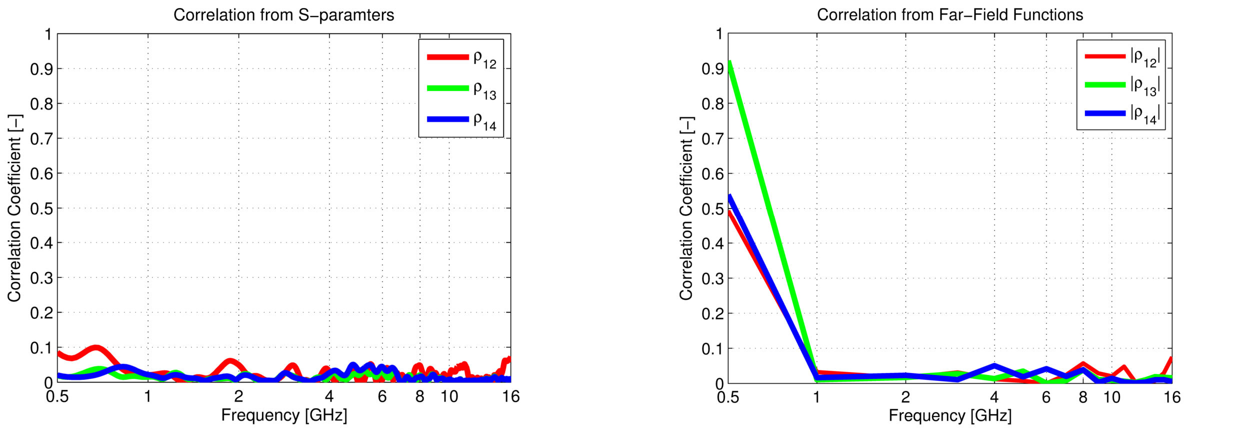

Fig. 4: Correlations using S-parameters (left) and using embedded far-field functions (right) between port 1 and port 2, 3, and 4.

DIVERSITY GAIN SIMULATIONS IN MULTIPATH ENVIRONMENT USING VIRM-LAB

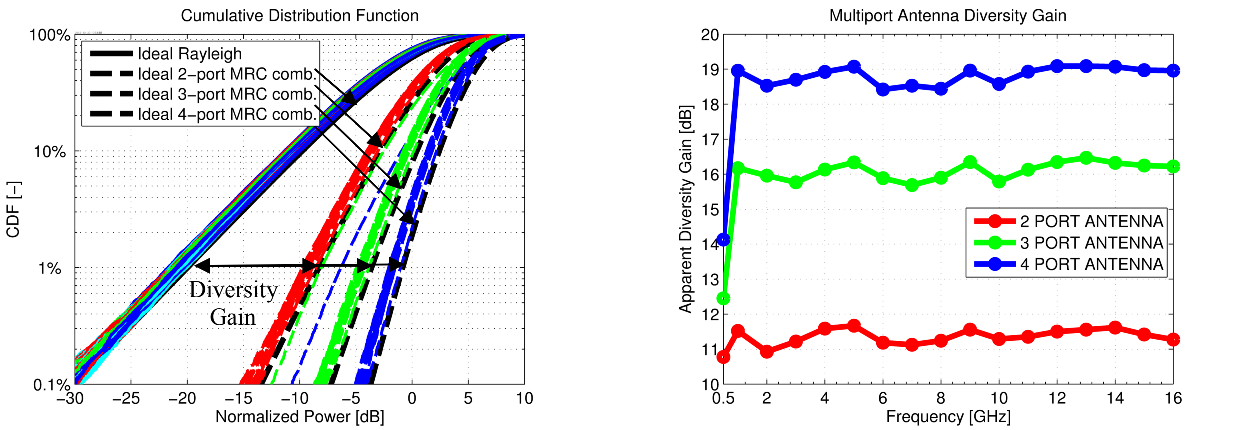

Fig. 5: CDF of each antenna port and 2, 3, and 4-port MRC combined diversity channel (left), and Apparent diversity gains at 1% CDF-level over UWB for 2-port, 3-port, and 4-port diversity antenna (right).

The self-grounded bow-tie antenna can be used as a 2-, 3-, or 4-port MIMO antenna. Maximal ratio combining (MRC) scheme has been used to determine the diversity performance of this antenna. The antenna diversity gain in RIMP environment is obtained by simulations using a ray-based simulation tool called ViRM-lab [9]. We use a set of 20 incoming waves having randomly distributed amplitude, phase, polarization, and angle of arrival (AoA). The amplitude is Rayleigh distributed while phase, polarization angle, and AoA are uniformly distributed in a 3D space. The antenna far-field patterns are exposed to these incoming waves which combine constructively and destructively, and result in a voltage sample at each antenna port. We collect 100,000 voltage samples at each antenna port by simulating 100,000 realizations of such a set of 20 incoming waves which are completely random.

Using these 100,000 complex-Gaussian distributed voltage samples from each antenna port, we can plot cumulative distribution function (CDF); see Fig. 5 (left). In RIMP environment, the diversity gain of an antenna is typically defined at 1% CDF-level. To evaluate diversity gain, we choose the optimal combination scheme i.e. MRC. The apparent diversity gain is defined as the difference of power-levels in dB between the CDFs of the antenna port with best efficiency and the diversity combined channel, typically at 1% CDF-level; see Fig. 5 (left).

CONCLUSIONS & DISCUSSION

The diversity gains calculated at 1% CDF-level from Fig. 5 (left) are plotted in Fig. 5 (right) for the whole frequency range show that there is a clear improvement in the diversity gains of the antenna when we increase the spatial diversity from 2-ports to 3-ports and 4-ports diversity antenna. The improvement is seen over the whole wide bandwidth, which makes this antenna very useful for many practical applications. The antenna diversity gain is quite close to the ideal MRC-combined 2-port, 3-port, and 4-port diversity antennas i.e. 11.7 dB, 16.4 dB, and 19.1 dB respectively. This is due to very high embedded efficiencies (Fig. 3) and very low cross-correlation between the antenna-ports (Fig. 4). At 0.5 GHz, the apparent diversity gain is very low, see Fig. 5 (right). This is due to the fact that cross-correlation between the antenna ports is very high at 0.5 GHz, see Fig. 4 which is a direct result of high mutual coupling between the antenna ports at 0.5 GHz; see Fig. 2.

ACKNOWLEDGMENT

This work has been supported in part by The Swedish Governmental Agency for Innovation Systems (VINNOVA) within the VINN Excellence Center Chase.

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