Characterization Of Multi-Port Eleven Antenna For Use In MIMO System

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1. Introduction

MIMO (multiple-input multiple-output) is the use of multiple antennas (diversity antennas) at both the receiving and the transmitting sides of a radio communication link to enhance performance in a multi-path fading environment. MIMO systems are characterized by their maximum available capacity, and the multi-port antennas can be characterized by a diversity gain for a certain combination algorithm. Considering a two-antenna diversity receiver, the so-called diversity gain can be defined as the increase in SNR (signal-to-noise ratio) due to an appropriate combination (selection, maximal-ratio or equal-gain combining scheme, etc.) of the two received signals, and can be distinguished as apparent and effective diversity gain, depending on whether we use as a reference one of the two elements of the diversity antenna or an ideal single antenna (with radiation efficiency of 100%), respectively [1]. The reverberation chamber is basically a metal cavity that is large enough to support many resonant modes at the frequency of operation, and all modes can be stirred by a number of means inside the chamber in order to create a Rayleigh distributed transfer function between the transmitting and receiving antennas [2], which represents an isotropic multi-path environment of a similar type as can be found in urban and indoor scenarios, but with a uniform elevation distribution of the incoming waves [3]. The antenna performance in such an isotropic multi-path environment is characterized by its radiation efficiency, which can be measured fast and accurately in a relatively small reverberation chamber [4]. The diversity gain of multi-port antennas can also be measured in a straight forward manner inside it [5]-[6]. Besides, measurements in Bluetest® reverberation chamber are even fast, accurate and repeatable when compared with anechoic chambers of equal or larger size, provided the chamber has efficient stirring methods [1]. This reverberation chamber has been used to characterize a number of different antennas for MIMO and diversity systems, as described in [7]-[8].

The Eleven antenna is a new coaxially-fed wideband feed that can cover a decade bandwidth, and it has been developed as feed for reflector antennas and in particular for radio telescopes. The four-port (1x4 model: 1 polarization times 4 ports, as shown in Fig.1 left) version of an L-band Eleven antenna has been studied in [9], showing that the mono-pulse tracking is an intrinsic capability of this single-polarized multi-port antenna. Further more, this capability can readily be extended to its dual-polarization counterpart by adding an extra orthogonal Eleven antenna, resulting in an eight-port antenna (2x4 model: 2 polarizations times 4 ports, as shown in Fig.1 right).

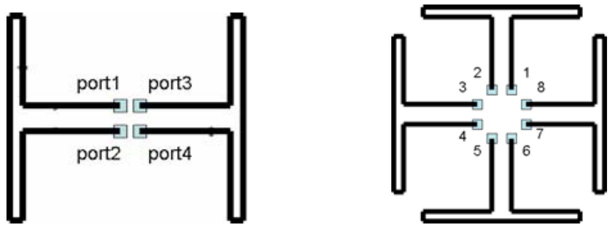

Figure 1 L-band 1x4(left), 2x4(right) Eleven antenna model

2. Measurement Setup and Procedure

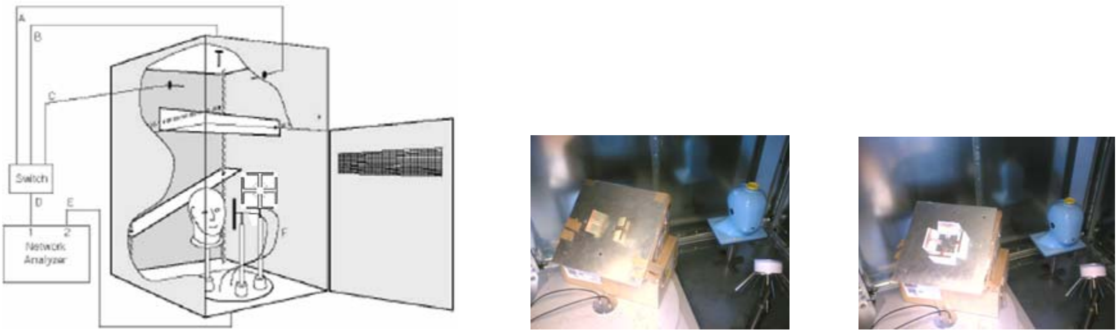

Figure 2 Setup for measuring 3x4 (left) and 3x8 (right) MIMO system. The antenna is a 1x4 and 2x4 port Eleven antenna, respectively, and the 3 opposite antenna elements in the MIMO systems are the three orthogonal wall antennas in the reverberation chamber.

The measurement of the total radiation efficiency of a single antenna or the embedded radiation efficiency of any single element in an array is based on a relative measurement method. First of all, a calibration need be done to calibrate the errors due to the chamber and instrumentation. Secondly, we measure the relative average received power of a reference antenna (P_{ref}) with known radiation efficiency, in the presence of the AUT inside the chamber as well. Both the reference antenna and the AUT should be separated at least half wavelength away from each other as well as from any other objects in the chamber. Third, we measure the relative average received power of the AUT (P_{AUT}) while keeping all objects inside the chamber as much similar as possible as before. The total radiation efficiency turns out to be as follow, when mismatch term is included [10],

$$e_{rad} = \frac{P_{AUT}}{P_{ref}}\left(1-\left|\overline{S_{22}}\right|^{2}\right) \tag{1}$$

The measurement of diversity gain at a certain CDF (Cumulative probability Distribution Function) level, usually 1%, can be performed the same time as the radiation efficiency is measured. Based on all received power by the AUT and the reference antenna, we do proper normalization in the post-processing and plot CDF curves of a theoretical Rayleigh reference, of every branch of the multiport antenna, and by selection combining the power samples received on all branches (ports). Usually at 1% CDF level in the plot, the difference in dB between every branch and the selection-combined MIMO indicates the apparent diversity gain, while the difference between the theoretical Rayleigh reference and the selection-combined MIMO indicates the effective gain. These two quantities are associated by the radiation efficiency [10],

$$G_{eff} = e_{rad} \cdot G_{app} \tag{2}$$

Additionally, the measurement of the maximum available capacity of a MIMO system is also a relative measurement and can be performed simultaneously as well. Based on Shannon's theory, the general formula for the maximum available capacity (bits/sec/Hz) of a MIMO system with a transmit antenna with M ports and a receive antenna with N ports can be expressed as [8],

$$\tilde{C}_{MxN} = \log_{2}\left(\det\left(I_{M} + \frac{SNR}{M}\tilde{H}_{MxN}\,\tilde{H}^{*}_{MxN}\right)\right) \tag{3}$$

where I is a unit matrix, $\tilde{H}_{MxN}$ is a normalized complex channel matrix, and $\tilde{H}^{*}_{MxN}$ is the complex conjugate transpose of the channel matrix. The normalization of the channel matrix must be done with respect to the square root of the average received power of a reference antenna with 100% radiation efficiency located in the same environment, when the same total power is transmitted from the opposite side of the environment [10]. When all elements in the channel matrix are completely uncorrelated and have 100% efficiency, the available capacity can reach its theoretical maximum. In reality, however, there are always mutual coupling between closely located antenna branches, and this coupling causes both an efficiency reduction and coupling losses, which will degrade the maximum available capacity.

3. Results and Discussions

First of all, we would like to clarify a number of definitions that we use for the measurement.

Reflection-coupling efficiency e_{rc}: the efficiency due to the reflected power at the excited port plus all the coupled powers to the adjacent ports; the *average reflection-coupling efficiency* is defined as the difference between 1 and the sum of the reflected and coupled powers averaged over all ports.

Radiation efficiency e_r: the efficiency barely due to conduction and dielectric losses inside the antenna; if it is averaged over all ports, then we call it the *average radiation efficiency*.

Embedded element efficiency e_{emb}: the efficiency of each port while all other ports being terminated with 50 ohm load; it includes all contributions of losses such as reflection due to mismatch, mutual coupling and conduction-dielectric losses. The *embedded element efficiency* can be written as a product of the r*eflection-coupling efficiency* and the r*adiation efficiency*,

$$e_{emb} = e_r \cdot e_{rc} \tag{4}$$

The measured efficiencies and capacities for both 2x4 and 1x4 models at 1.57GHz are summarized in the following table.

Table 1 Measured efficiencies averaged over all ports, and corresponding capacities (1.57GHz)

	2x4 model	1x4 model
Average return loss [dB]	-9.7	-14.8
Average coupling loss [dB]	-9.8	-12.0
Average e_{rc} [dB]	-1.0	-0.44
Average e_r [dB]	-0.6	-0.24
Average e_{emb} [dB]	-1.6	-0.68
Theoretical max capacity (SNR=15dB) [bps/Hz]	18.3	14.3
Measured max capacity (SNR=15dB) [bps/Hz]	15.9	12.7
Capacity reduction due to average e_{rc} [bps/Hz]	-1.0	-0.4
Capacity reduction due to average e_r [bps/Hz]	-0.6	-0.2

The measured maximum available capacities (SNR=15dB) versus frequency over L-band for both 2x4 and 1x4 models are plotted in Fig.3. It can be seen that the capacity reaches its maximum at the frequency where the embedded element efficiency of the antenna is best. The capacity is lower for the 1x4 antenna than for the 2x4 antenna; however, these two curves are very similar in shape.

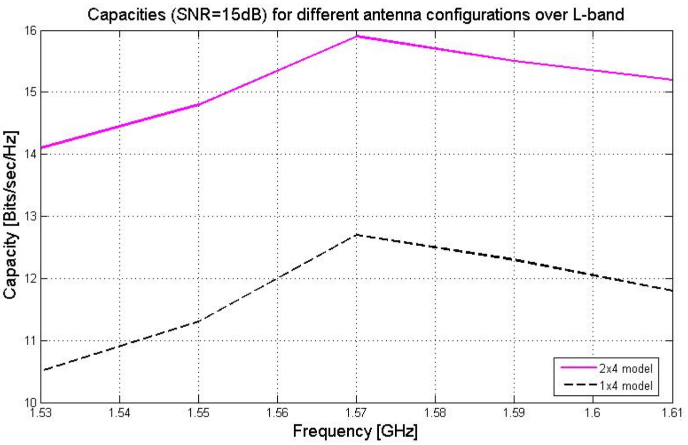

Figure 3 Measured capacities vs. frequency (SNR=15dB)

4. Conclusion

The multi-port Eleven antenna is capable of forming sum and difference patterns necessary for the mono-pulse tracking in satellite communications systems. In the present paper, the MIMO characteristics of two lab models of the L-band multi-port Eleven antenna has been measured, such as the radiation efficiency, diversity gain and maximum available capacity. The results indicate that at a certain channel SNR level the 2x4 model has inherently larger maximum available capacity than the 1x4 model. In particular, the capacity reaches its maximum when the embedded element efficiency of the antenna is highest. In addition to the tracking capability for use in satellite communications terminals, the multi-port diversity Eleven antenna can also be potentially employed in MIMO systems.

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References

[1] Per-Simon Kildal, Kent Rosengren, “Correlation and Capacity of MIMO Systems and Mutual Coupling, Radiation Efficiency, and Diversity Gain of Their Antennas: Simulations and Measurements in a Reverberation Chamber”, *IEEE Communications Magazine*, December 2004, vol. 42, no. 12, pp. 102-112, Dec. 2004.

[2] Per-Simon Kildal, Charlie Orlenius, “Characterization of Mobile Terminals in Rayleigh Fading By Using Reverberation Chamber”, *18th International Conference on Applied Electromagnetics and Communications (ICECom)*, Oct.12-14, 2005.

[3] K. Rosengren, P.-S. Kildal, “Study of Distributions of Modes and Plane Waves in Reverberation Chamber for Characterization of Antennas in Multipath Environment”, *Microwave and Optical Technology Letters*, vol. 30, no. 20, pp 386-391, 20 September 2001.

[4] K. Rosengren, P-S. Kildal, “Characterization of antennas for mobile and wireless terminals in reverberation chambers: Improved accuracy by platform stirring”, Microwave and Optical Technology Letters, Vol. 30, No. 20, pp 391-397, 20 September 2001

[5] K. Rosengren and P.-S. Kildal, “Radiation efficiency, correlation, diversity gain, and capacity of a six monopole antenna array for a MIMO system: Theory, simulation and measurement in reverberation chamber”, Proceedings IEE, Microwave Antennas Propagation, vol. 152, no. 1, pp.7-16, February 2005. See also Erratum published in August 2006..

[6] Per-Simon Kildal, Kent Rosengren, “Electromagnetic Analysis of Effective and Apparent Diversity Gain of Two Parallel Dipoles”, *IEEE Antennas and Wireless Propagation Letters*, vol.2, no.1, pp. 9-13, 2003.

[7] L. Garcia-Garcia, B. Lindmark, N. Jaldén, and C. Orlenius, “MIMO capacity of antenna arrays evaluated using radio channel measurements, reverberation chamber and radiation patterns”, IET Microwaves, Antennas and Propagation, Vol 1. Issue 6, pp. 1160-1169, Dec. 2007.

[8] Diallo, P. Le Thuc, C. Luxey, R. Staraj, G., Kossiavas, M. Franzén, P.-S. Kildal, "Diversity characterization of optimized two-antenna systems for UMTS handsets", to appear in EURASIP Journal on Wireless Communication and Networking, Hindawi Publishing Corporation, 2008.

[9] J.Yin, J.A.Aas, J.Yang, P.S.Kildal, “Monopulse tracking performance of multi-port Eleven antenna for use in satellite communications terminals”, Proceedings of *2nd European Conference on Antennas and Propagation*, Nov. 2007.

[10] Per-Simon Kildal, Charlie Orlenius, “Chapter 58: Multipath Techniques for Handset/Terminal Antennas”, *Antenna Engineering Handbook (4th Edition, J.L.Volakis)*, McGraw-Hill Professional, 2007.