

TOWARDS A GENERALIZED METHODOLOGY FOR SMART ANTENNA MEASUREMENTS

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ABSTRACT

The huge expansion of mobile communications and the need for high data rate services require more efficient use of the spectrum to increase the capacity of networks and enhance the quality of services. Within that frame, the adoption of Smart Antenna techniques in future wireless systems is expected to have a significant impact on the aforementioned needs. Following the proliferation of the use of Smart Antennas systems there is a growing need for characterization of such systems which is still an open issue. In this work, a generalized methodology for Smart Antenna characterization measurements is introduced. Simulation results from the application of the proposed measurement procedure using a reference array to characterise the smart antenna algorithm subsystem are presented.

1. INTRODUCTION

This contribution begins with a summary of the results derived during ACE phase 1 (WP 1.2-4) [1] concerning methodologies for smart antenna measurements. A general concept of a unified methodology for smart antenna characterization measurements is then presented, followed by a set of operating requirements that should be satisfied by smart antenna designers/manufacturers, in conformance to the proposed measurement methodology. Finally, the description of several basic test cases, as examples of smart antenna characterization measurements, is given in the framework of the proposed measurement methodology.

1.1. Smart antenna classification

Smart antenna systems can be used in different communication systems, from Wireless Local Loops (WLLs) to Mobile Radio Communications Systems such as UMTS and GSM, and Wireless LAN.

Smart antennas can be divided in two different families, depending on the environment of their application [2],[3]:

Smart Antennas for line-of-sight environment (LOS), i.e. for beamforming applications. It includes the following kinds of antennas (in ascending order of complexity) [4],[5]: Multisectorized antennas, Phased arrays, Switched beam antennas and Adaptive antennas. Adaptive antenna technology represents the most advanced smart antenna approach. Adaptive arrays utilize sophisticated signal-processing algorithms to

continuously distinguish between desired signals, multipath, and interfering signals as well as calculate their directions of arrival. This approach continuously updates the transmit strategy based on changes in both the desired and interfering signal locations. The ability to track users smoothly with main lobes and interferers with nulls ensures that the link budget is constantly maximized.

Smart Antennas for multipath (scattering) environment, i.e. for antenna diversity applications (MIMO systems). It includes smart antennas of mobile terminals, with a nearly omni-directional coverage, being used in an urban or indoor environment with strong fading. The benefits of MIMO communication are obtained through a combination of antenna arrays that provide spatial diversity from the propagation channel and algorithms that can adapt to the changing multivariate channel.

Although the general architecture of these two families of antennas is common, the parameters that have to be measured or taken into account for their characterization are different, depending on which of the above two categories they belong to. For example, the total radiation diagram of the antenna array and how it is shaped under the control of the smart antenna algorithm is a basic parameter for the evaluation of a Smart Antenna which is used in a beam forming application. On the other hand, this specific parameter is not of interest when the Smart Antenna is used in a MIMO system. In the latter case, the basic parameter is the mutual coupling between antenna elements as well as the radiation diagram of each individual element when the rest of the array elements are terminated in a matched load resistor.

In this work we are using the adaptive antenna as the generic case of a LOS smart antenna considering the other kinds of antennas in this family as special cases of the specific category.

2. SMART ANTENNA MEASUREMENT PARAMETERS

A smart antenna is more than a single, classical antenna. It is composed of RF circuits, signal processing circuitry and algorithm, antenna elements, and all together establish a communication system that should be characterized. Therefore, the set of measurement parameters that should be carried out include all the subsystems of the smart antenna, but also system

parameters. We can classify the measurement parameters in the following four categories:

2.1. Preliminary subsystem measurements

Antenna subsystem: input impedance, antenna pattern, losses, gain and polarization measurements are required for each of the antenna elements.

RF subsystem: gain, intermodulation products, dynamic range, bandwidth, adjacent channel interference. In transmission: maximum output power, frequency error, error vector magnitude, power dynamic range, adjacent channel leakage power ratio, occupied bandwidth, emitted spectral mask, spurious emissions and peak code domain error. In reception: reference sensitivity level, dynamic range, adjacent channel selectivity, spurious emission etc.

Signal processing subsystem: sensitivity, BER (depending on S/N), processing gain in algorithms etc.

2.2. Algorithm measurement

Characterization of the capacity of interference rejection of the algorithm, where the following cases can be considered: one desired user and one interferer, varying the angular position of the desired user and interferer, one desired user and two interferers, with the same strategy. Obviously, in a real situation the number of interferers is greater than one or two, and the position of these ones are random. These measurements should contribute to a characterization of the adaptive algorithm in terms of the speed of convergence of the adaptive algorithm (speed of the algorithm), stability (convergence) of the algorithm and maximum speed of the desired user.

2.3. Smart Antenna measurements

After carrying out the measurements described previously, it is necessary to evaluate the right performance of the smart antenna. In a generic case (adaptive antenna) there is not a fixed radiation pattern, but it depends on the environment. Thus it is important to establish some pre-defined and known situations in order to evaluate the antenna system. The following aspects should be taken into consideration in order to define the measurement procedure:

- Smart antenna may work in reception and transmission with different algorithms; therefore measurements in both operating modes have to be carried out.
- Smart antennas do not end in a RF connector, so most of the measurements should be done on digital signals. This implies that the classical measurements may not be realized, that a reference signal is difficult to get and other associated problems.
- Smart antenna pattern varies with the desired user and interference relative positions. This implies that a set of representative test case scenarios of user and interferences should be defined.

- It is necessary to stop the adaptive process of the smart antenna's algorithm in order to be able to measure the radiation pattern of the antenna, both in reception and transmission mode

2.4. Communication system measurements

The final parameters concern improvement in quality and coverage, which means improvement in C/I and gain. In an adaptive process these parameters vary with the environment conditions and in a phased array or beam switching antenna there is also a variation depending on the beam. These parameters could be estimated from antenna performance, but finally it is convenient to carry out system measurements (in a final stage of the product).

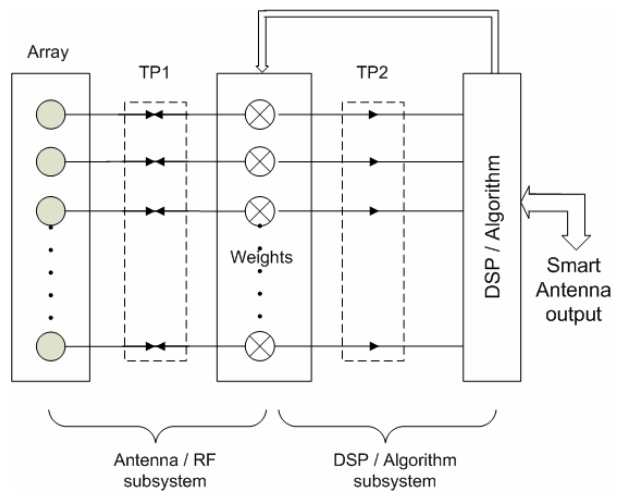


Figure 1. Smart antenna block diagram

3. PROPOSED MEASUREMENT PROCEDURE

The aim of this work is mainly focused on the definition of a procedure for measurements described in section 2.3. We can consider the Smart Antenna as a system, which includes two individual subsystems as depicted in Fig. 1:

- Antenna/RF subsystem
 - Digital Signal Processing (DSP)/algorithm subsystem.
- It is obvious that the performance and the characteristics of a Smart Antenna depend on the performance and the characteristics of these individual subsystems.

Generally, there are two methods to approach the problem of characterizing the Smart Antenna through measurements:

- Characterization based on the system level performance
- Separate characterization of the individual subsystems.

In the first case the Smart Antenna measurements refer to the operation of the whole system. Therefore, the engineer that designs a telecommunication system which uses Smart Antennas does not have the

possibility to choose from a variety of Smart Antennas based on their characterization, because such characterization refers to the whole telecommunication system. In order to tackle the above restrictions we suggest the second methodology based on the characterization of the individual Smart Antenna subsystems.

Following this approach, it is necessary to define, develop and incorporate some test (or reference) subsystems into the measuring procedure, which will replace the corresponding (actual) subsystems.

Two test subsystems should be developed:

- The Antenna/RF test subsystem
- The DSP/algorithm test subsystem

For the characterization measurements of the DSP/algorithm subsystem, the antenna subsystem is replaced by the corresponding test subsystem (reference antenna) and the performance of the algorithm is measured when it is (the algorithm) applied to the specific reference antenna subsystem. In a similar way, for the characterization measurements of the Antenna/RF subsystem, the DSP/algorithm subsystem of the antenna under test is replaced by the DSP/algorithm test subsystem and the measurements are taken under its control.

In this work we focus on the first part of the above general concept for smart antenna measurement procedure, i.e. on the characterization of the DSP/algorithm subsystem using a reference array (Antenna/RF test subsystem).

3.1. Operating requirements

Trying to define a generalized procedure for smart antennas characterization, one of the main problems we are facing is the fact that proper operation of the algorithms of the smart antenna systems requires the use of modulated signals. Thus, the smart antenna characterization measurement setup must have the capability to generate signals properly modulated according to the specifications of the system where the smart Antenna Under Test (sAUT) is to be used. For this reason, a number or various “smart antennas test beds” have been developed which are dedicated for specific telecommunication systems. In these cases the measurements are limited to the performance evaluation of the specific system when some operating and/or environmental (channel) parameters are changing.

We consider that the measurement procedure should be simple, without requiring complicated and expensive devices (e.g. UMTS generator/analyzer) except of those already used in a laboratory for conventional antennas measurements. On the other hand, the measurement results should be normalized in order to be independent of the specifications (modulation and coding schemes) of the particular communication system where the sAUT is to be applied. In this way, measurement results

obtained from different smart antennas could be comparable.

In order to be able to apply the proposed measurement procedure to a smart antenna, it is necessary to have some specific test ports (TP) available on the antenna under test. The positions of these ports are presented in the general block diagram of the smart antenna in Fig.1. From TP1 the measuring system can measure the signals (magnitude and phase) at the antenna elements feeding points. At this port the appropriate connectors and circuitry should provide the capability to substitute the antenna subsystem of the sAUT with a test antenna subsystem (reference antenna). From TP2 the measuring system measures the corresponding signal during receiving mode, after the weighting action of the algorithm. Another important operating requirement is that the sAUT shall be able to operate in a test mode where its algorithm can run without the need of detecting modulated signals. In this case, measurements of the algorithm performance can be conducted using CW signals in controlled environment (anechoic chamber). In the example of the measurement test case given in the next section, the parameter that is measured is the signal to interference ratio (C/I) that can be achieved when the algorithm of the sAUT is running, as a function of the angular distance between the transmitting point of the desired signal and the interferer.

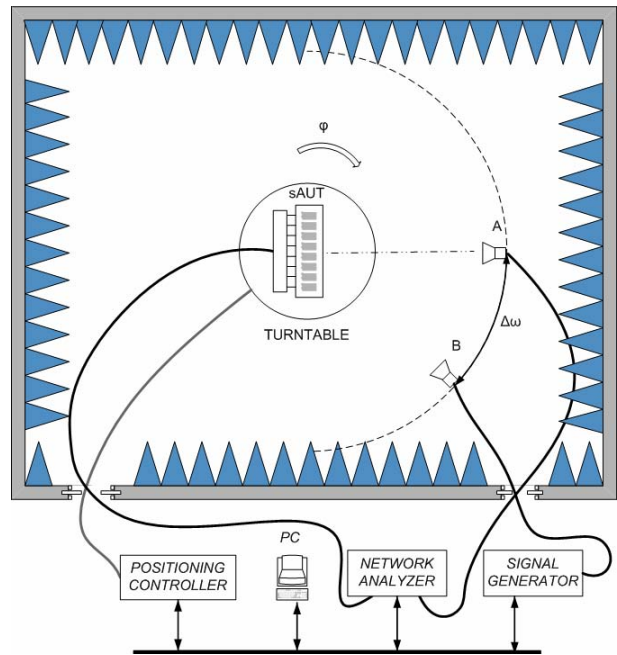


Figure 2. The measurement setup

3.2. Measurement setup

In Fig. 2, the measurement setup of the proposed procedure is presented. In fact, this is a typical setup for conventional antennas measurement in far field

measurement sites (anechoic chamber). Position-A is the transmitting point of the desired signal and position-B (at the same distance from sAUT and in angular distance $\Delta\omega$ from position-A) is the corresponding point of the interferer. The angle $\Delta\omega$ can be changed according to the scenarios of the test case. The sAUT is rotated around an axis vertical to the plane of the measurements (e.g. azimuth plane) as a conventional antenna during radiation diagram measurements. The angular step of this rotation is defined by the required measurement resolution and the capabilities of the positioning system (e.g. 1 degree). The running algorithm has to be paused during each rotation step and at the end of this step it shall resume running in order to track the desired signal with the main lobe of the radiation diagram and the interferer with null, thus maximising the derived link budget. At the end of every step the signal received at the output of each antenna element (TP1) and the corresponding weighted signals at TP2 are measured (amplitude and phase) and stored, then the power of the composite signal is derived and stored with the corresponding value of the angle of rotation. Before the beginning of the next step the algorithm stops running and the gain of the antenna at the directions towards position-A (desired signal) and position-B (interferer) is measured. In this way the C/I achieved in every measurement position is calculated and presented as a function of rotation angle φ .

4. ANTENNA/RF TEST SUBSYSTEM

Aiming to measure and characterize the performance of the algorithm of the sAUT we have to substitute its antenna array (Antenna/RF subsystem) with a reference array the so called “Antenna test subsystem”. This test subsystem can be connected using the appropriate connectors provided in port TP1 to by-pass the built-in antenna elements of the sAUT.

Theoretically, the proposed reference array should be an array of infinitesimal dipoles as many as the elements of the sAUT array. The spatial position of each element should be selected so that the Array Factor (AF) of the reference antenna is the same as the one of the sAUT. Actually, we propose a reference array constructed with quarter wavelength monopoles over a conductive ground plane.

4.1. Reference array design

The knowledge of the AF is very useful for the characterization and the evaluation of a phased array antenna because it reflects the behavior of the antenna in terms of the phases and the amplitudes of the signals that drive the elements while the AF is independent from the radiation diagrams of the elements.

An arbitrary three dimensional array of N elements has an array factor given of [6],[7]:

$$AF(\theta, \varphi) = \sum_{n=1}^N I_n e^{j(\zeta_n + \delta_n)} \quad (1)$$

where I_n is the magnitude and δ_n is the phase of the weighting of the n th element and ζ_n is the relative phase of the incident wave at the element. It can be found using the formula:

$$\zeta_n = \frac{2\pi}{\lambda} (x_n \sin \theta \cos \varphi + y_n \sin \theta \sin \varphi + z_n \cos \theta) \quad (2)$$

where x_n, y_n, z_n are the coordinates of the n th element in the 3D space. Assuming that we study an unknown array with a number of elements placed in the same plane (azimuth), the relative phase of the incident wave at the n th element is given by:

$$\zeta_n = \frac{2\pi}{\lambda} (x_n \cos \varphi + y_n \sin \varphi) \quad (3)$$

The relative phase of each element depends only on its position. In order to construct a reference antenna with the same array factor as the sAUT, we need to measure the phase ζ_n for each element (using the TP1 port of the sAUT) at two different angles φ . Then the exact position of the element can be derived by calculating the values of x_n and y_n using Eq. 3.

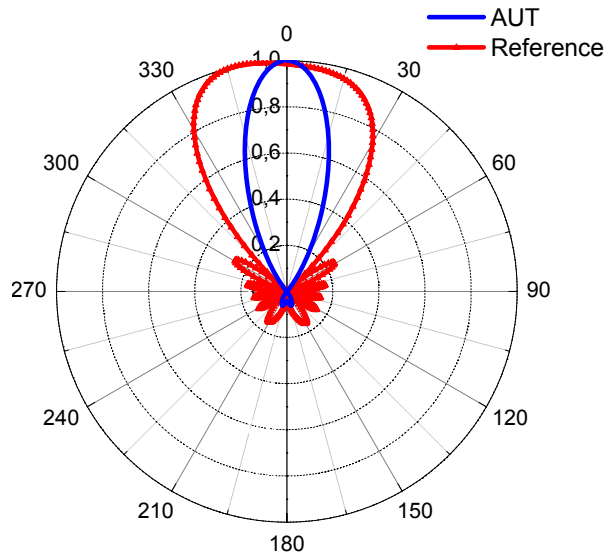


Figure 3. Array radiation pattern

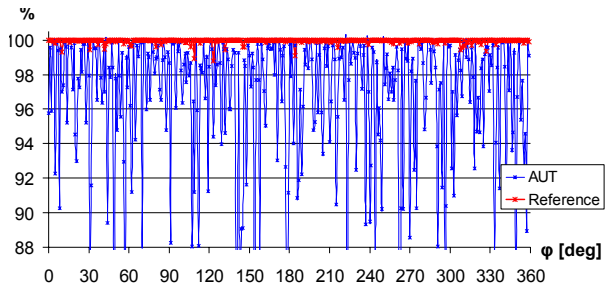


Figure 4. Algorithm quality factor T

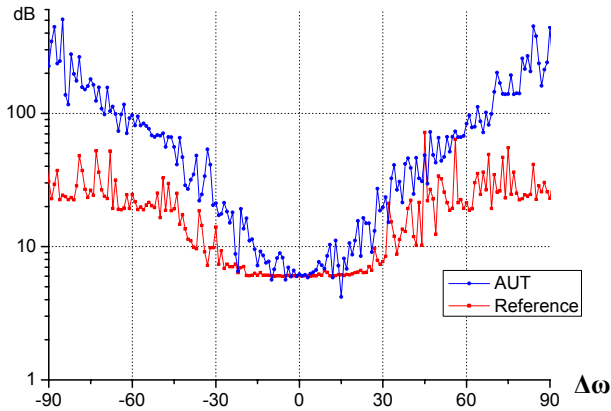


Figure 5. Desired signal to interference Ratio (C/I)

5. MEASUREMENT EXAMPLE

In order to clarify the measurement procedure we present the simulation results for measurements conducted on a smart antenna having a linear array with eight elements, operating in 2.4 GHz ISM band. We consider that the smart antenna algorithm steers the antenna pattern towards the direction of the desired signal without changing the pattern's shape, by controlling only the phase applied at the array's elements. We assume that the algorithm in every step achieves to target the main lobe to the optimum direction with uncertainty ± 2.5 degrees. The results are presented following the proposed step of measurements. Every step is repeated two times, one with the reference array connected and the other using the built in array of the sAUT:

Step1: There is only one transmission of the desired signal at the position A ($\varphi=0$ degrees). The algorithm of the sAUT targets the position A. Then having the algorithm paused we measure the sAUT radiation diagram presented in Fig. 3. Note that the reference array has wider beamwidth than the AUT.

Step2: With the same conditions the measurements are repeated, but at the end of each angular step the algorithm is activated as described in the measurement procedure. The derived amplitude of the summation of the weighted signals measured at TP2 port is recorded as function of the rotation angle. The accuracy that the

algorithm achieves in targeting the position of the desired signal is proportional to the derived amplitude of the received composite signal. The ratio of this amplitude to the corresponding one of the ideal targeting gives the quality factor T , presented in Fig. 4 as a function of rotating angle. From this figure it can be seen that the factor T for the AUT array has larger deviations comparing with the reference array.

Step3: In the anechoic chamber in addition to the transmission of the desired signal there is a transmission of interferer at position-B with amplitude half of the desired and phase difference 180 degrees. The derived power ratio between the received desired signal and the interference (C/I) as a function of angular distance $\Delta\omega$ is presented in Fig. 5 for $\Delta\omega$ varying from -90 to 90 degrees. From this figure it can be seen that using the reference array, the sAUT fails to have C/I more than 10 dB if the interferer angular distance from the desired signal is less than ± 35 degrees. But using the AUT array the corresponding angle is smaller (± 25 degrees).

6. CONCLUSIONS

In this paper a generalized methodology for Smart Antenna characterization measurements is introduced. The basic operating requirements that should be satisfied by a smart antenna in order to comply with the proposed measurement procedure are presented. For the reference antenna subsystem, the use of a reference array which has the same array factor with the antenna under test has been proposed. In the framework of the proposed measurement methodology the description of some basic test cases and the corresponding simulation results as examples of smart antenna characterization measurements are given.

7. REFERENCES

- [1] Sierra Castañer M., et al., "Recommendations on Smart Antenna Measurement Procedures", *ACE-Deliverable A1.2D6*, Dec.2005
- [2] Sanayei S., Nosratinia A., Antenna selection in MIMO systems, *IEEE Communications Magazine*, Vol. 42, 68-72, Oct 2004
- [3] Gesbert D., Akhtar J., Breaking the barrier of Shannon's capacity: An overview of MIMO wireless systems, *Elektronikk Telenor's Journal*, January 2002.
- [4] Godara L.C., "Applications of antenna arrays to mobile communications", *Proceedings of the IEEE*, Vol. 85, 1195-1245, August 1997
- [5] Lehne P.H. and Pettersen M., An overview of smart antenna technology for mobile communications systems, *IEEE Commun. Surveys*, Vol. 2, 2-13, 1999
- [6] Shen L.C., Kong J.A., *Applied Electromagnetism*, PWS Publishing Company 3rd edition, 1995
- [7] Balanis C., *Antenna Theory Analysis and Design*, John Wiley & Sons 2nd edition, 1996