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Increasing the volume of test zones in anechoic chamber MIMO Over-the-Air test set-ups

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1. Introduction

The purpose of Over-the-Air (OTA) testing is assessing the system performance of devices under test by emulating realistic radio environments. OTA testing is primarily important for systems whose performance is strongly influenced by the interaction between antenna and radio environment, as clearly applies to, for instance, mobile MIMO terminals. In the past, a much narrower definition was used. In the context of applications to mobile communications, "OTA" was understood as determining the TIS (Total Integrated Sensitivity) and TRP (Total Radiated Power) values for mobile SISO handsets. Present activities do not consider transmitted or received power itself but which communication performance the device under test is able to achieve with that power. The metrics to assess such performance are still discussed in ETSI 3GPP RAN4 [1]. The essence of Over-the-Air testing is the emulation of realistic radio environments, in order to assess the communication performance of devices under test with their antennas in interaction with the environment, especially with the advent of MIMO. To this end, the communication signals are to be convolved with the spatio-temporal characteristics of the mobile radio channel before they are received by the test object. Roughly speaking, two main categories of methods are considered in the present standardisation process for OTA testing of MIMO terminals [2]:

1. set-ups in stirred-mode reverberation chambers
2. set-ups in shielded/anechoic rooms

The first method is operationally convenient. These chambers are claimed to emulate isotropic wave fields, when averaged over time, with a close to Rayleigh-distributed temporal dispersion. However, it is hard to determine the instantaneous spatio-temporal signature of such chambers, i.e. those actually experienced by devices-under-tests. Also, the temporal dispersion cannot easily be modified. Details can be found in a 3GPP Technical Report [3]. The second category is the one under consideration in this contribution, especially the "Ring of probes method". The terminal under test is surrounded by antennas driven by channel emulators, preferably in a shielded, anechoic room. A popular concept is to use 8 antennas arranged in a circle (Fig. 1). The channel emulators are the most expensive bits, apart from the room, as these should be capable of performing real-time convolutions of incoming data signals, potentially wide-band, with the time-variant filters that emulate the channel influences. Their number is directly linked to the number of antennas to be driven. Additionally, when for instance emulating a BS with 4 Tx antennas, four independent convolutions with different channels have to be performed for a single output to an antenna.

Apart from choosing the test method, at least two major other issues are to be solved. Finding ways to calibrate MIMO OTA test set-ups is one. Another is the question how large and complex a MIMO OTA test set-up at least must be or, on the other hand, would still be feasible. Calibration for SISO tests was already a topic, but for MIMO the problems seem much larger. Nevertheless, this matter we will not discuss here. In this paper, aspects of the latter question will be treated, presenting a simple and relatively cheap modification to the antenna constellation of OTA test set-ups that increases the useful volume of the test zone.

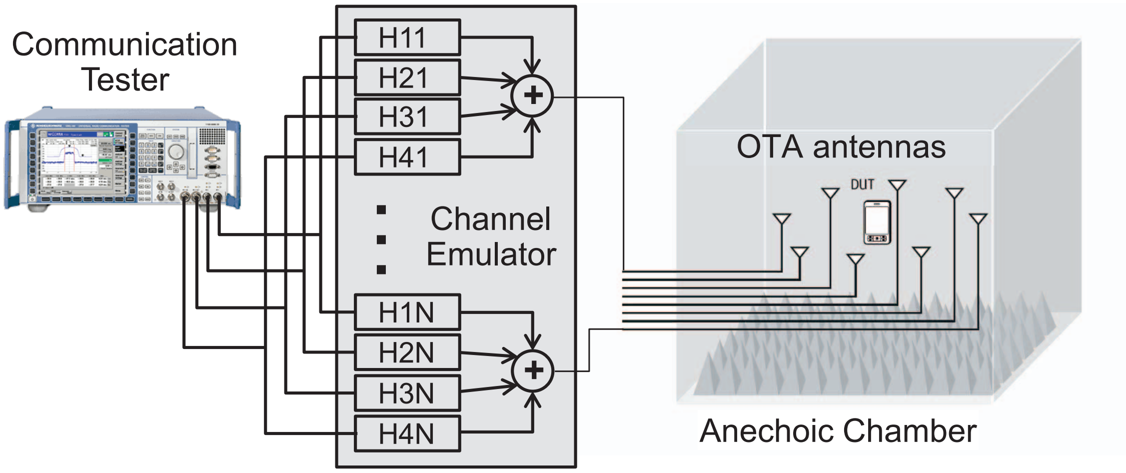

Figure 1: Schematic of OTA test set-up in anechoic chamber, here for 4 independent communication channels to the DUT in the centre of the antenna ring; blocks "H" perform time-variant filtering.

2. Wave field synthesis

Geometric channel models generally use the concept of specular paths for the field components that determine the channel behaviour. In essence, these paths are plane waves. Emulating incoming waves simply by radiating from the antenna closest to the required direction of travel effectively means discretising the angular spectrum of the channel model and launching curved wave fronts that decay with distance, unlike plane waves. These effects can be circumvented by the use of wave field synthesis. On the one hand, this can be seen as driving multiple OTA antennas like a synthetic array to generate well-defined wave fronts in the near field. On the other hand, plane wave synthesis can be treated as the reciprocal of plane wave analysis, the near-field far-field transformation in near-field antenna scanning. Analogous to the near-field scanning practice, sampling at half wavelength intervals is not needed to have high field synthesis quality, be it that this can only obtained in a limited area, often called "sweet spot" or "test/quiet zone", see Figure 2, left. Those familiar with near-field antenna measurements will appreciate the notion that the circumference C of the test zone is given by the wavelength λ and the number of sample points N, according to: $C \approx (N-1)\lambda/2$ [4]. For plane wave synthesis, the same relationship holds. Therefore, accurate emulation over a given aperture or volume requires a minimum number of OTA antennas. It is anticipated that for actual testing, the required test zone size could be substantially larger than the terminals dimensions. Upcoming MIMO OTA test standards will very likely call for testing handheld terminal with head and hand phantoms rather than without, seen the influence such phantoms have. A minimum test zone size of approx. 0.3 m across seems reasonable for enclosing the whole of head, hand and terminal under test, requiring 16 antennas at 2.1 GHz. Laptops with opened lid that host LTE-USB dongles could easily demand test zone diameters of 0.5 m, requiring around 24 OTA antennas for the 2 GHz band.

3. Creating a three-dimensional test zone

The result of a 2D set-up with simple OTA antenna has 2D characteristics too, meaning, the test zone lies in the plane of the antenna array. Out of this plane, typically wave front curvature becomes noticeable, shown in Figure 2 to the right, as the emulated wave resembles a cylindrical wave, still causing amplitude decay over the test zone [6]. Of course, the larger the diameter of the ring of OTA antennas compared to the size of the test zone, the smaller the effect of wave front curvature and that of amplitude decay (the latter due the relatively smaller distance variation). Nevertheless, the OTA ring should fit the anechoic chamber which normally limits the diameter to a couple of meters.

With line sources, a constant amplitude over the test zone is achievable as Hill reported already in 1988 on 2D plane wave synthesis [6]. Therefore, replacing the single OTA antennas by small vertical

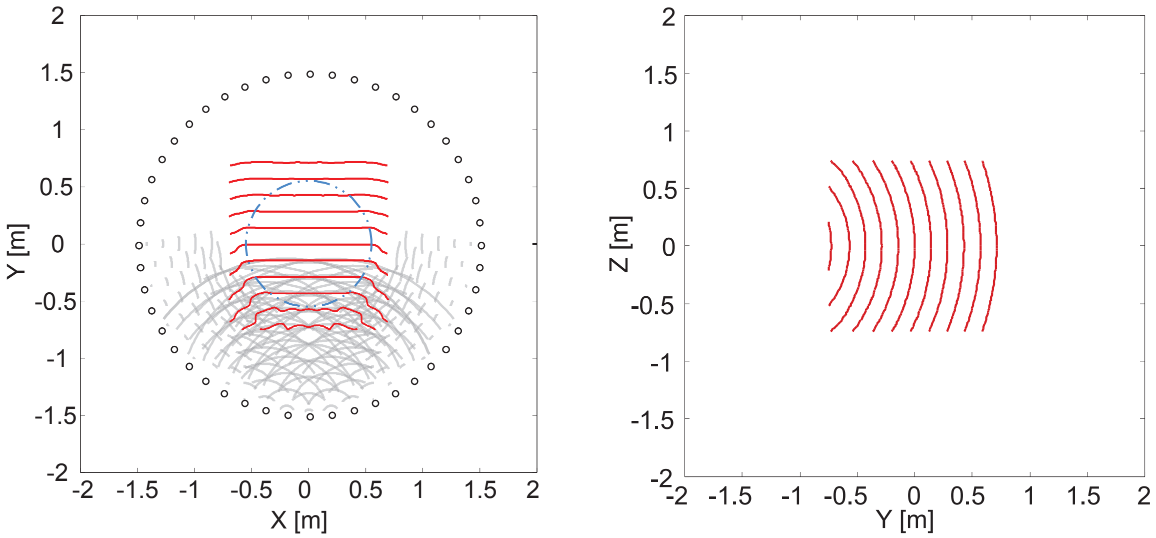

Figure 2: Left: principle of Wave Field Synthesis (2.1 GHz); grey: fields OTA antennas; red: wave fronts emulated field; blue: test zone. Right: wave fronts emulated field in plane through Y normal to X

arrays could result in the same, if the array fields in the test zone are close to those of line sources. An important consideration is to keep the vertical structure passive, for instance using power dividers and phase shifters to excite the elements of the vertical array, not requiring extra emulators. The example below will show this is indeed possible.For an OTA ring of 16 antennas, stacks of three vertically mounted antennas were simulated instead of single antennas. The resulting fields of these three take the place of the fields of the original single antennas in the synthesis algorithm [6]. The ring diameter was taken to be 1.5 m which means neighbouring antennas are 4 wave lengths apart at 2.1 GHz. At this frequency, with 16 antennas, the test zone diameter is about 0.34 m. The antenna elements in the stack were separated by 2 wavelengths as this simplified the tuning of the excitations. For this tuning, a cylindrical field was used as reference field in the synthesis [6]. The results of plane wave synthesis with effectively 5 stacks of the 16 show straightened wave fronts (Fig. 3) and a fairly even amplitude distribution. Within a sphere of 0.3 m in diameter the maximum variation was 0.7 dB.

4. Discussion

Costs are connected to performing wave field synthesis for shaping wave fields, compared to discretising the angular spectrum by radiating over single antenna (directions). A larger burden is placed on the generators, as a synthesis of wave field components over five antennas results in signals being sent out in parallel over five emulators. In other words, each emulator has to process up to a five-fold amount of components. In the case of SCME models or similar, in which many taps of a cluster have exactly the same delay, the effect is not so large. The use of vertical antenna arrays instead of single OTA antennas for improving the volume of the test zone, as advocated in the former Section, calls for more RF output power due to losses in splitters and phase shifters. This is not trivial as still channel emulators are dedicated to connected tests and do not even reach 0 dBm.

Of a different order is the discussion whether OTA testing of MIMO terminals cannot be done much simpler, especially cheaper, that is, with less equipment/overhead and in shorter time. Still, the trend in channel modelling is to expand existing channel models. Please note channel modelling is ”channel emulation in software”. Winner has added elevation to the model and COST IC1004 intends to incorporate cross-polarisation on the channel in the COST2100 model. Transferred to channel emulation: including polarisation doubles the number of emulator/antenna combinations and adding elevation at least triples this (doubled) amount again. A ring of 16 antennas easily becomes one of 96. Considering that a popular set-up consists of 8 antennas with attempts being made to reduce this number even fur-

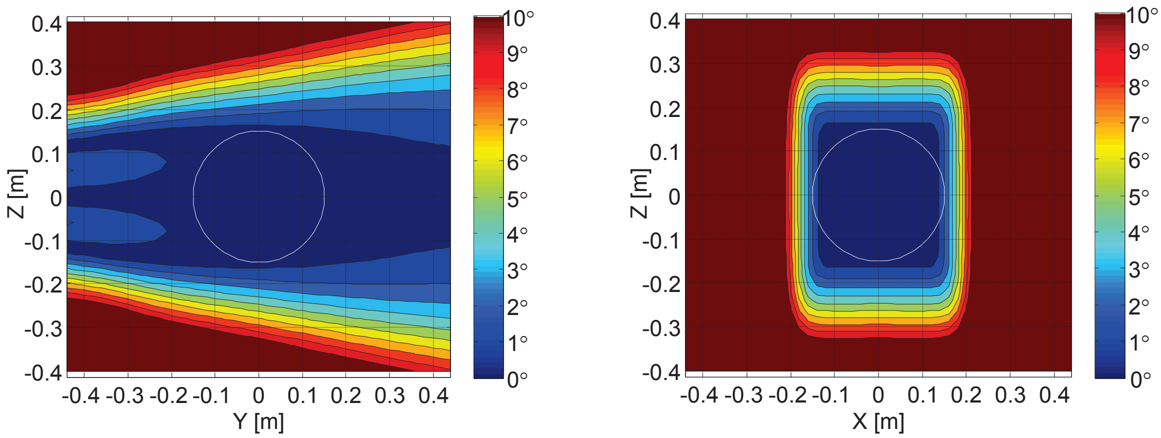

Figure 3: Deviation of wave front direction from planar, each contour 1°, in planes normal to OTA array, at 2.1 GHz. Left: along propagation; right: normal to propagation. White circles are 0.3 m in diameter

ther, a large gap exists between theoretical considerations and technologically/economically acceptable constellations. However, it may be that this gap cannot be bridged by new developments in field emulation. For instance, the method of ”pre-faded signal synthesis” of Kyösti et al. [7] is radically different from plane-wave synthesis. It is stochastic synthesis, concentrating on the main statistics of clusters of scatterers instead of on individual specular field components and it is optimised on basis of the spatial correlation spectrum. Nevertheless, the area over which this type of synthesis is accurate is very similar to that for plane wave synthesis. Thus, a minimum number of OTA antennas is required. So, if simplifications are possible, these must be based on considerations which field properties are irrelevant for system operation. e.g. for LTE.

5. Conclusion

Through the use of small vertical arrays in wave field synthesis for MIMO OTA test set-ups, the effective volume of the test zone has been increased with respect to the shape of the emulated wave fronts. Also, the decay of the emulated field over distance has been reduced. Passive networks can be used for exciting the array elements, meaning that no additional channel emulators are needed.

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