New laboratory for Over-The-Air testing and Wave Field Synthesis

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Abstract

In Ilmenau, Germany, a new laboratory is under construction for testing mobile communication equipment, both satellite and terrestrial. This contribution focuses on Over-The-Air testing of terrestrial mobile terminals and on applications of Wave Field Synthesis in this laboratory. The terrestrial research in the lab will mainly serve scientific purposes, as research into OTA test methodologies, also meant to actively engage in standardisation of OTA practices. Research into Wave Field Synthesis is another. A clear application is to study real-time antenna characteristics of mobile terminals in an OTA setting. With the projected equipment, a state-of-the-art OTA installation will become available.

1 Introduction

A new laboratory is under construction in Ilmenau, Germany, built by the Institute of Integrated Circuits (IIS) of Fraunhofer Gesellschaft. It will be operated jointly by IIS and the Institute for Information Technology of Ilmenau University of Technology for research on mobile communication equipment, both for mobile satellite and terrestrial mobile applications. The Laboratory has two major functional entities, a control room and an anechoic chamber. The control room will contain all the electronic equipment for controlling and managing the measurements in the anechoic chamber. The anechoic chamber has the shape of a truncated cone, Figure 1 (left). For its deployment in mobile satellite research, it is equipped with a high-performance motion simulator. Two large K_u-K_a band transparent windows allow communication with satellite emulators on a tower to the North and with live satellites to the south. During experiments for terrestrial mobile, both windows will be shut and will be covered with absorbers, just as the motion simulator. This contribution presents the installations prepared for the terrestrial mobile research that has its main scientific interests in Over-The-Air (OTA) testing and Wave Field Synthesis (WFS). As of the moment of writing (February 2011) not all negotiations are finalised, so, part of the descriptions regards plans. For OTA and WFS, a large amount of additional equipment will be needed, of which the most important units are the multi channel RF signal generators, the OTA antennas, the field probes, and the positioner. These will be described shortly, after introducing the two major applications, Over-the-Air testing and Wave Field Synthesis.

1.1 Applications: Over-The-Air testing

Over-the-Air testing, as opposed to testing radio communication equipment over cables ("conducted"), is inevitable when the antennas of the device are an important factor in the devices performance and antenna performance cannot be evaluated separately. This means the Device-under-Test (DuT) has to be tested as a unit, operationally and in real-time. For example, for advanced mobile communication concepts like MIMO, where antenna behaviour plays a major role because of scattering of waves in the environment, OTA testing is under serious investigation. In Over-the-Air tests, a realistic and reproducible radio environment is emulated in an anechoic chamber by surrounding the device by multiple antennas that are driven by a set of coupled dedicated signal generators, channel or fading simulators (although a hybrid approach, two-stage or Computational OTA [1,2], is possible if the antennas can be characterised in isolation, which is rare). Their task is to impose temporal dispersion on the radio signal that is transmitted to the device under test, the spatial dispersion being produced by radiating from the surrounding antennas. This requires a separate

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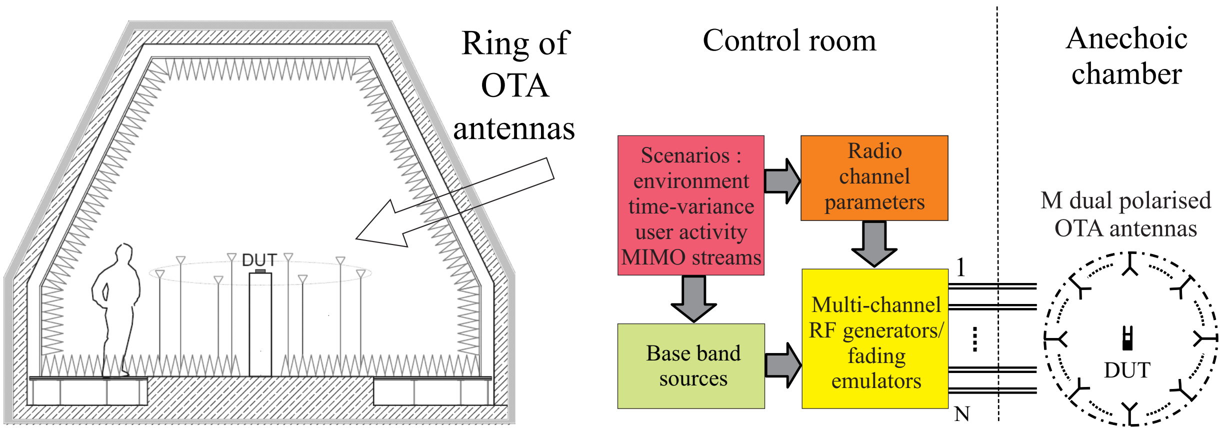

Figure 1: Artist's impression of inside of anechoic chamber (left), schematic of signal generation (right)

(fading) generator per antenna as the radiation from an antenna mimics the Line-of-Sight component or independent reflections of the signal from objects. Figure 1 (right) gives a schematic impression of how an OTA set-up would look like. In our case, N is 16 or 24 and M ranges from 48 to 100. With the scenario control, both MIMO and Cognitive Radio device testing are catered for.

1.2 Applications: Wave Field Synthesis

The aim of wave field synthesis is to generate well-defined arbitrary wave fields. This is in use for a long time already in near-field antenna measurements for transforming the measured field close by to far-field conditions [3], be it with virtual arrays for essentially CW signals in post-processing, not in real time. In our lab, the generation will be in real-time, allowing communication with the DuT as needed for OTA. However, also "simple" CW signals, as opposed to modulated communication signals, can be used for synthesis when clean monochromatic wave fronts would be needed, either planar or curved. Note that for broadband sources too, curved waves can be generated, emulating sources or scatterers at close range. Research applications are manifold, for instance, direction-finding devices, interference reduction studies with steerable antennas, and we see many opportunities for research in Cognitive Radio [4]. Use as a near-field antenna measurement range with simultaneous reception on all OTA antennas is principally possible with large additional investments.

2 RF signal generators

Besides the generic specifications with respect to RF signal quality, a set of requirements specifically for channel emulation and wave field synthesis was drawn up. Actually, our call for tender issued two sets of requirements, for Basic Performance and High Performance Mode (HPM), the first being the bare minimum to be fulfilled and the latter the intended configuration. Bids are judged against how much can be realised of the HPM. In Table 1, the first number of the connectivity specifies how many base station antennas can be emulated for OTA tests of MIMO systems, or the number of independent sources for wave field synthesis or the number of (primary and secondary) users in Cognitive Radio tests. The second number is the required number of RF outputs to connect to the OTA antennas. The RF band is much wider to the lower end than that of the antennas, considering conducted tests too. The RF power is high for traditional conducted tests, but, in OTA more than 40 dB free space loss and additional cabling/switching losses have to be accounted for. For conducted tests, an expanded range of the output attenuators is demanded, down to -120 dBm. The number of taps refers to the implementation of time-variant channels as tapped-delay lines, the number of independent taps needed depending on the bandwidth. For emulation of diffuse scattering on the channel, a very high number of taps might be needed. In this case, a frequency domain approach would be desirable.

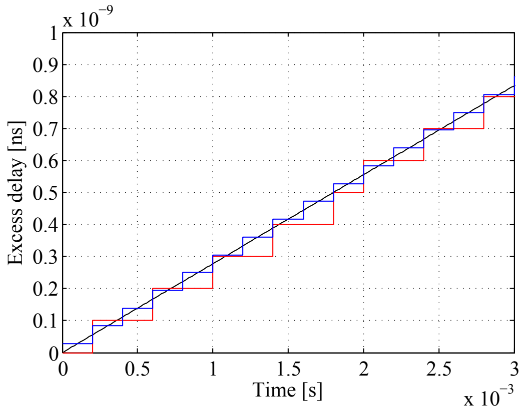

Figure 2: Effect of finite delay resolution and update rate on emulated variable delay

Table 1: Specifications for signal generators

Specification	Basic Mode	HPM
Connectivity	2×16	4×24
Signal bandwidth	45 MHz	120 MHz
RF Band	0.35–3 GHz	0.35–6 GHz
RF output power	+5 dBm	+20 dBm
No. taps per channel	30	30
No. taps per antenna	> 40	> 40
Delay resolution	100 ps	30 ps
Phase resolution	0.1°	0.1°
Channel update rate	80 kHz	100 kHz

Especially the high delay resolution and channel update rate raised eyebrows with the suppliers. Indeed, for mobile channel emulation it seems overdone. The reason for specifying it is the emulation of wide-band Doppler shifts generated by fast moving sources. Figure 2 illustrates the situation for a mobile source at 300 km/h and a carrier frequency of 2.1 GHz. Note, the wide-band Doppler-effect is essentially a time-variant delay (black straight line), or a time-variant frequency dependent phase shift. The design of the signal generators is such that the channel's transfer function is constant between channel updates and so will be the emulated delay. The linearly increasing delay is approximated by an irregular staircase function (red curve), the heights of the steps multiples of the minimum delay resolution and the duration of the steps discretised at the channel update rate, 5 kHz in Figure 2. A delay increment of 100 ps causes a phase jump of about 75°, too high for accurate synthesis. If the channel emulator is capable of a high channel update rate, one solution is to compensate the carrier phase at any possible update instance (blue curve); the relative error over bandwidth of this compensation equals the relative bandwidth (not shown). The delay or phase jumps can thus be reduced to approximately the rate of change divided by the update rate.

3 Antennas

The main requirements were 48 dual-polarised antennas in a ring of 3 m diameter, with an additional 52 for free configuration, usable in transmit and receive mode, that enable the generation of high precision wave fields. According to Hill [5] and Laitinen et alii [6], an area of circumference of $48 \times \lambda/2$ with good field quality can be obtained with 48 antennas (ø1.1 m @ 2.1 GHz), which is confirmed by our own simulations, Figure 3 [7]. Further were specified:

- Cross polarisation discrimination between both polarisations better 35 dB
- Common phase centre for both polarisations
- Coupling between neighbouring antennas less than −35 dB
- Backscatter from antenna less than −30 dB
- Antenna frequency range 0.8–3 GHz (optionally to 6 GHz) with a gain of at least 0 dBi

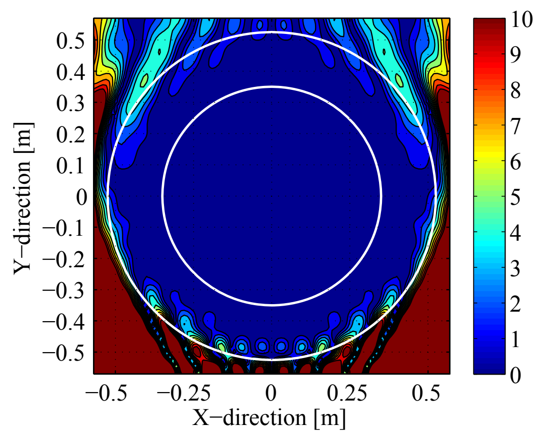

Figure 3: Simulated deviations from plane wave (1° per contour) for 48 antennas

The first two requirements assure that arbitrarily polarised wave-fields can be emulated with high accuracy. The last three requirements are connected. For well-defined wave fields, the backscatter from 48 antennas and the coupling between them must be kept low. The solution chosen is to envelop small antennas in RF absorbing material, but this should not go at the expense of gain or bandwidth. In that respect, the lower bandwidth limit is a compromise.

4 Field calibration and positioning

With the electronics in the control room and the antenna ring hung from the ceiling of the anechoic chamber, the antenna cables are long, and, although selected for high stability, no experience is available how much relative drift the cables show. So, calibration procedures have to be developed over time. (Note, calibation of MIMO OTA setups is a critical issue [1]). For calibration, two field probes will be available with a very small active volume and connected by optic fibres, both securing little field disturbance. The generated fields will be scanned by translating the probes through the measurement area with a positioner with an excursion in all three dimension from -0.3 m to $+0.3$ m, with an absolute accuracy of 1 mm and a differential one of 0.01 mm.

5 Conclusion

We presented a new laboratory for research into OTA and Wave Field Synthesis for testing applications (in real-time) in which antenna performance is crucial. With the projected equipment, a state-of-the-art OTA installation will become available.

6 References

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