Publication III

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Spherical measurement system for determination of complex radiation patterns of mobile terminals

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A prototype of a 'real-time' 64-channel spherical measurement system for determining the complex radiated far fields of active mobile terminals is presented. The system does not require any RF feed cables to be connected to the mobile terminal. Test measurements show that the complex far field can be determined with an acceptable accuracy. The system thus provides, together with the radio-channel data, a basis for realistic and fast estimation of MIMO performance of a mobile terminal.

Introduction: The multiple-input multiple-output (MIMO) technique can be used to increase the capacity of the radio-communication link between mobile terminal and base station in a multipath propagation environment [1]. This requires at least two antenna ports at the mobile terminal. The MIMO performance of the mobile terminal can be estimated using the radio propagation channel data together with the complex (phase and amplitude) radiation pattern data for each antenna port of the mobile terminal [2]. The reliability of the estimation of MIMO performance of a mobile terminal in this way depends amongst others on the uncertainty of the characterisation of the radiation pattern of a mobile terminal in its actual operating conditions.

In this Letter, two problems related to the determination of radiation patterns of mobile terminals are tackled. First, the RF feed cable that connects the mobile terminal and vector network analyser (VNA) is a source of uncertainty in a typical radiation pattern measurement. The influence of the feed cable on the radiation pattern is well known [3], and techniques have been developed to reduce it [4]. Secondly, to determine the radiation pattern of a mobile terminal in its numerous user positions, a relatively large number of radiation pattern measurements is required. The duration of a typical 3-D radiation pattern measurement is in the order of minutes rather than seconds in modern, fast facilities [5]. Therefore, performing for example hundreds of radiation pattern measurements for a mobile terminal may not be feasible in practice. It may neither be feasible to perform radiation pattern measurements with a real person holding the mobile terminal because of the difficulty of keeping the person motionless for the whole duration of the measurement.

To overcome the above-mentioned two problems, a prototype of a system, that provides a basis for real-time determination of the complex radiation pattern of a mobile terminal without an RF feed cable, is presented in this Letter. The proposed system is the spherical measurement system presented in [6] extended with a phase-retrieval capability. This extension is an essential improvement of the system, because it allows the determination of the complex radiation pattern without a feed cable to the mobile phone. Test measurements with the system are reported. First, measurements of a small antenna prototype performed with a VNA are compared to the amplitude-only measurements with a signal generator and a spectrum analyser. It is shown that the phase of the complex field can be retrieved with acceptable uncertainty by the amplitude-only measurement. Secondly, the complex far fields calculated from the amplitude-only data and the complex VNA measurement data are contrasted with the complex far field measured with a 3-D rotation system inside a small, fully anechoic chamber. A good agreement of the complex far fields obtained by all three methods is shown.

Measurement system: The system consists of 32 dual-polarised patch antennas (probes) evenly distributed on a spherical surface with a radius of 0.99 m [6]. Rotation of the mobile terminal or moving the probes during the measurement is not required. The system operates at a frequency range of 1.7 to 1.85 GHz. The system layout, including the phase-retrieval capability, is illustrated in Fig. 1*a*. One of the probes is chosen as the phase-reference channel, and the other 63 channels are so-called measurement channels. With the switching network, each of the measurement channels is consecutively connected to the phase-retrieval network (PRN), shown in Fig. 1*b*, along with the reference channel. A spectrum analyser (SA) consecutively records the four amplitudes $A_{1\text{-}4}$ at the output of the PRN, and from these the phase differences between the voltages at the reference channel (V_R) and each chosen measurement channel (V_M) are calculated. The phase retrieval from four amplitude values is a known technique and has been presented for example in [7]. Each of the retrieved complex-valued voltages is assumed proportional to the electric field at a corresponding probe in a polarisation corresponding to the polarisation of the probe port. The 48 lowest-order spherical vector wave modes are used for the field characterisation [1, 8]. The spherical vector wave coefficients are found by a matrix method using the least squares matching between the modal field and the measured voltages [9].

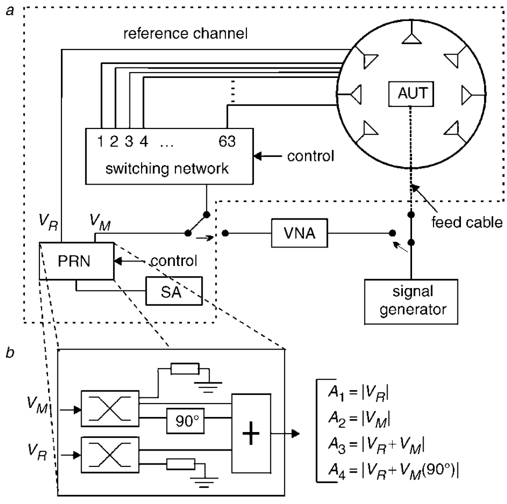

Fig. 1 *System layout and phase-retrieval network*

a Measurement system layout illustrated inside dashed lines. VNA, signal generator and feed cable used for test measurements
b Phase-retrieval network (PRN) illustrated

Test measurements: Measurements were carried out with the small antenna prototype (AUT) presented in [10], consisting of a PIFA antenna on a ground plane with dimensions 40 × 120 mm. First, a sinusoidal 1.7 GHz signal of an RF signal generator was fed to the AUT as shown in Fig. 1*a*, and the measurements were performed with the SA using the PRN (*SA measurement*). Secondly, a transmission-coefficient measurement was carried out with a VNA (*VNA measurement*). This setup is also illustrated in Fig. 1*a*. Finally, the VNA measurement was repeated in a small anechoic chamber (*SAC measurement*), where the field was recorded on a grid with 10° steps in both elevation and azimuth. The balun presented in [4] was used along with additional ferrite beads in all measurements in order to reduce the effect of the feed cable.

Results: The 63 retrieved phase values by the SA measurement ($\phi_{SA,1-63}$) and the phase of the reference channel ($\phi_{SA,64}$), that was initially zero, were compared to the corresponding phases obtained by the VNA measurement ($\phi_{VNA,1-64}$) by calculating $\Delta\phi_{1-64} = \phi_{NORM} + \phi_{SA,1-64} - \phi_{VNA,1-64}$, where ϕ_{NORM} is the normalisation phase determined so that the mean of $\Delta\phi_{1-64}$ is zero. The values of $\Delta\phi_{1-64}$ for four independent measurements of the AUT were determined. As a result of this test, the altogether 256 values of $\Delta\phi$ were found to be approximately normally distributed so that approximately 90% of the values of $\Delta\phi$ were in between −7° and 7°.

Next, from the 64 complex signals obtained by an SA and a VNA measurement the radiated far fields were calculated, and compared to the far fields obtained by an SAC measurement. The radiation patterns of the AUT are shown in Fig. 2 for all three measurement procedures. The amplitude patterns are normalised to the same total radiated power. The 0 dB value in Fig. 2 corresponds to the maximum absolute value of the E_θ component of the three patterns in the *y-z* plane. Moreover, to remove the influence of a slight difference between the location of the mobile phone in the SAC and SA/VNA measurement on the phase pattern, a geometrical correction was applied to the SAC measurement data. The measured far-field values were multiplied with a term $e^{-ik(r+y_0\cos(\theta)+z_0\sin(\theta))}$, where k is wave number, r is measurement distance, y_0 and z_0 are the correction distances in y and z directions and θ is the angle shown in Fig. 2. This correction, that changes the phase reference point in the SAC measurement from (0, 0, 0) to (0, y_0, z_0), was necessary for a reasonable contrasting of the phase pattern obtained by the SAC measurement with those obtained by the SA and VNA measurements.

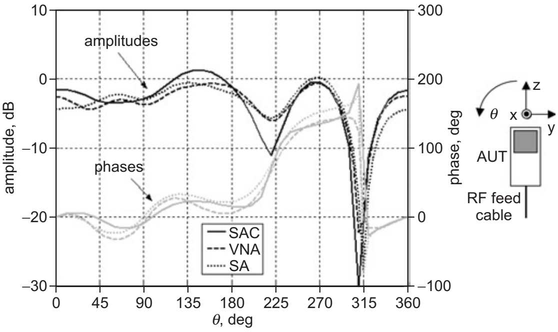

Fig. 2 *Comparison of amplitude and phase pattern of θ component of radiated far field in y-z plane obtained by SA, VNA, SAC measurements*

It is seen from Fig. 2, that there is a relatively good agreement both between the amplitudes and the phases of the three patterns. The amplitude differences between the SA and VNA measurement are generally smaller than those between the SA and SAC measurement. Further, the values of $\Delta_1(\theta, \varphi) = (D_{SA}(\theta, \varphi) - D_{VNA}(\theta, \varphi))/\max(D_{VNA}(\theta, \varphi))$ and $\Delta_2(\theta, \varphi) = (D_{SA}(\theta, \varphi) - D_{SAC}(\theta, \varphi))/\max(D_{SAC}(\theta, \varphi))$ were calculated from the full 3-D far-field data, where $\max(D_{VNA}(\theta, \varphi)) = 4.8$ dB and $\max(D_{SAC}(\theta, \varphi)) = 4.4$ dB. The standard deviations of Δ_1 and Δ_2 were found to be approximately 0.04 and 0.17, respectively. Obviously, the relatively large value of Δ_2 was mainly due to different reflections in the two chambers.

Conclusions: We have presented a prototype of a measurement system that provides a basis for real-time determination of the complex radiation patterns of active mobile terminals. Such a real-time measurement system can be used to investigate temporal fluctuations of the radiated fields of mobile terminals, and, together with the radio-channel data, also to realistically estimate the MIMO performance of a mobile terminal. With the present uncertainties related to the system, the complex far field may be determined with acceptable accuracy. The uncertainty may still be reduced by applying test-zone field compensation techniques for example [11].

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