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Results of an intercomparison for free space antenna factor measurements within the German Calibration Service (DKD)

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Abstract. In this paper we discuss the results of an intercomparison for free space antenna factor measurements performed within the German Calibration Service (DKD). Three different types of antennas covering the frequency range from 30 MHz to 26.5 GHz have been calibrated in five different laboratories using different methods and calibration sites to obtain the free space antenna factor. The results agree well within the uncertainties specified by the laboratories suggesting that different approaches and different measurement sites to obtain the free space antenna factor are well compatible.

1 Introduction

Antennas are extensively used in communication systems, remote sensing and navigation but also in wireless energy transmission and electromagnetic compatibility testing and measurement. New antenna applications foster more and more the integration as well as the expansion of the frequency range. Both, the increasing importance of interoperability aspects and the need to decrease energy consumption in complex systems, require the accurate and reliable knowledge of antenna factors for a wide range of antenna types. This requires determination of antenna factors traceable to the International System of Units (SI) including the specification of measurement uncertainties (GUM, 2008). In Germany, three laboratories are accredited for antenna factor measurements by the German Accreditation Service (Deutsche Akkreditierungsstelle – DAkkS). To assess the technical competence of the accredited laboratories an intercomparison was organised by the Physikalisch-Technische Bundesanstalt (PTB), the German National Metrology Institute, within the framework of the German Calibration Service (Deutscher Kalibrierdienst – DKD), which is the association of the accredited laboratories in Germany (PTB-Mitteilungen, 2015).

Among different antenna quantities the free space antenna factor is the most suitable quantity for a measurement comparison of different antenna types. As different approaches for its determination are available and different types of measurement sites are used, goal of the intercomparison was to find out whether this leads to comparable results. Measurements can either be performed on open-area test sites (OATS) or in semi-anechoic chambers (SAC). In both cases, the conductive ground-plane leads to height-dependent antenna properties. The standard-site method (SSM) follows the approach to determine free space antenna factor from site-attenuation measurements in horizontal polarization (determining the minimum transmission attenuation between two antennas with a fixed antenna height of the transmitting antenna and a height scan of the receiving antenna) taking into account the ground reflection. The SSM is used in different national (ANSI C63.5, 2006) and international standards (CISPR 16-1-6, 2014). Alternatively, the calibration can be performed in such a way that the indirect transmission path is minimized, e.g. in a fully anechoic room (FAR) or above a ground plane in vertical or diagonal orientation at a sufficient

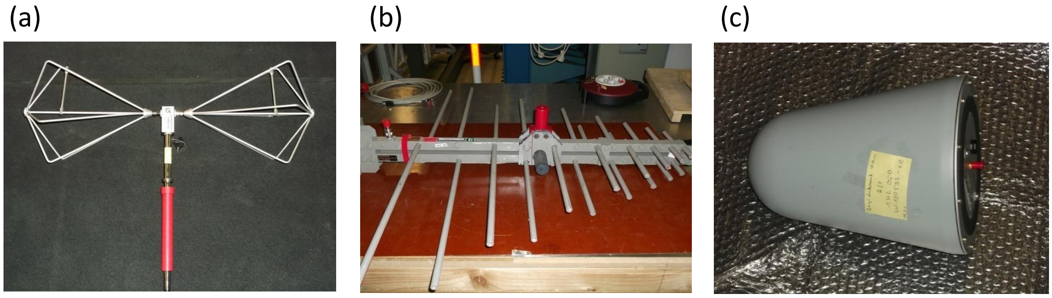

Figure 1. Antennas used as travelling standards. **(a)** SB VHBB9124 with BBAK9137, **(b)** AR® AT1000B and **(c)** R&S® HL050.

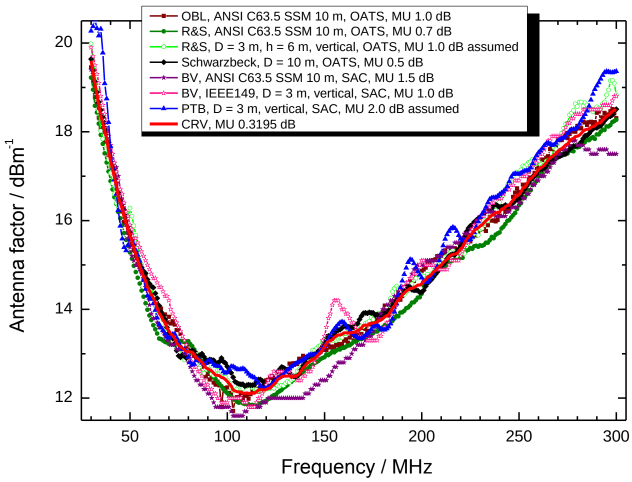

Figure 2. Results of intercomparison for SB VHBB9124 with BBAK9137.

height. Standards such as IEEE 149-1979 (ANSI/IEEE 149-1979, 2002) and SAE ARP958D (SAE ARP958D, 1999) use these simpler approaches. In all cases, the antenna calibration can be based on two-antenna methods (calibrating two equal antennas or using a known reference antenna) or the three-antenna method (measuring pairs of three unknown antennas).

Finally, three accredited and three non-accredited laboratories took part in the intercomparison. As measurement artefacts three different antenna types were chosen covering the most common types of measurement antennas: the biconical antenna Schwarzbeck VHBB 9124 with antenna elements BBAK 9137, the logarithmic-periodic antenna Amplifier Research AR® AT1000B and the logarithmic-periodic antenna Rohde & Schwarz® HL050.

The free-space antenna factors were measured in the frequency range between 30 MHz and 26.5 GHz using different calibration methods (SSM and free-space calibration with vertical or diagonal orientation) in different calibration sites (SAC and OATS). The compatibility according to CEI IEC 60359 (IEC 60359, 2001) of the free-space antenna factors of the participants was ensured.

In the next chapter we describe the travelling standards, the intercomparison schedule and the approach taken for data evaluation. In the following three chapters we then present the results for the three different antennas and draw conclusions in the final chapter.

2 Intercomparison

2.1 Travelling standards

For the lower frequency range between 30 and 300 MHz a biconical antenna Schwarzbeck VHBB 9124 with antenna elements BBAK 9137 as shown in Fig. 1a was measured with a step width of 1 MHz.

For the intermediate frequency range between 200 and 1000 MHz a logarithmic-periodic antenna Amplifier Research AR® AT1000B was circulated. The antenna is shown in Fig. 1b. As this antenna type has a phase center position that depends on frequency, the antenna factor was determined with regard to a mark on the antenna. The antenna was measured with a frequency step width of 5 MHz.

In the upper frequency range between 800 MHz and 26.5 GHz, the logarithmic-periodic antenna Rohde & Schwarz® HL050 shown in Fig. 1c was measured with a frequency step width of 50 MHz. As this antenna has a frequency dependent phase center position as well, the antenna factor was determined with regard to the antenna tip.

2.2 Time schedule

The antennas were first measured at Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, then at Berg & Lukowiak GmbH (OBL) in Hüllhorst, then at Schwarzbeck Messelektronik OHG (SB) in Schönau, then at Rohde & Schwarz Messgerätebau GmbH (R&S) in Memmingen, then at Bureau Veritas CPS Germany GmbH (BV) in Nürnberg and finally at TESEQ GmbH (Teseq) in Berlin. Due to restricted capabilities, at PTB only the VHBB 9124 with antenna elements BBAK 9137, at B&L only the VHBB 9124 with antenna elements BBAK 9137 and the Amplifier Research AR® AT1000B and at Teseq only the Rohde & Schwarz® HL050 have been measured. The measurement

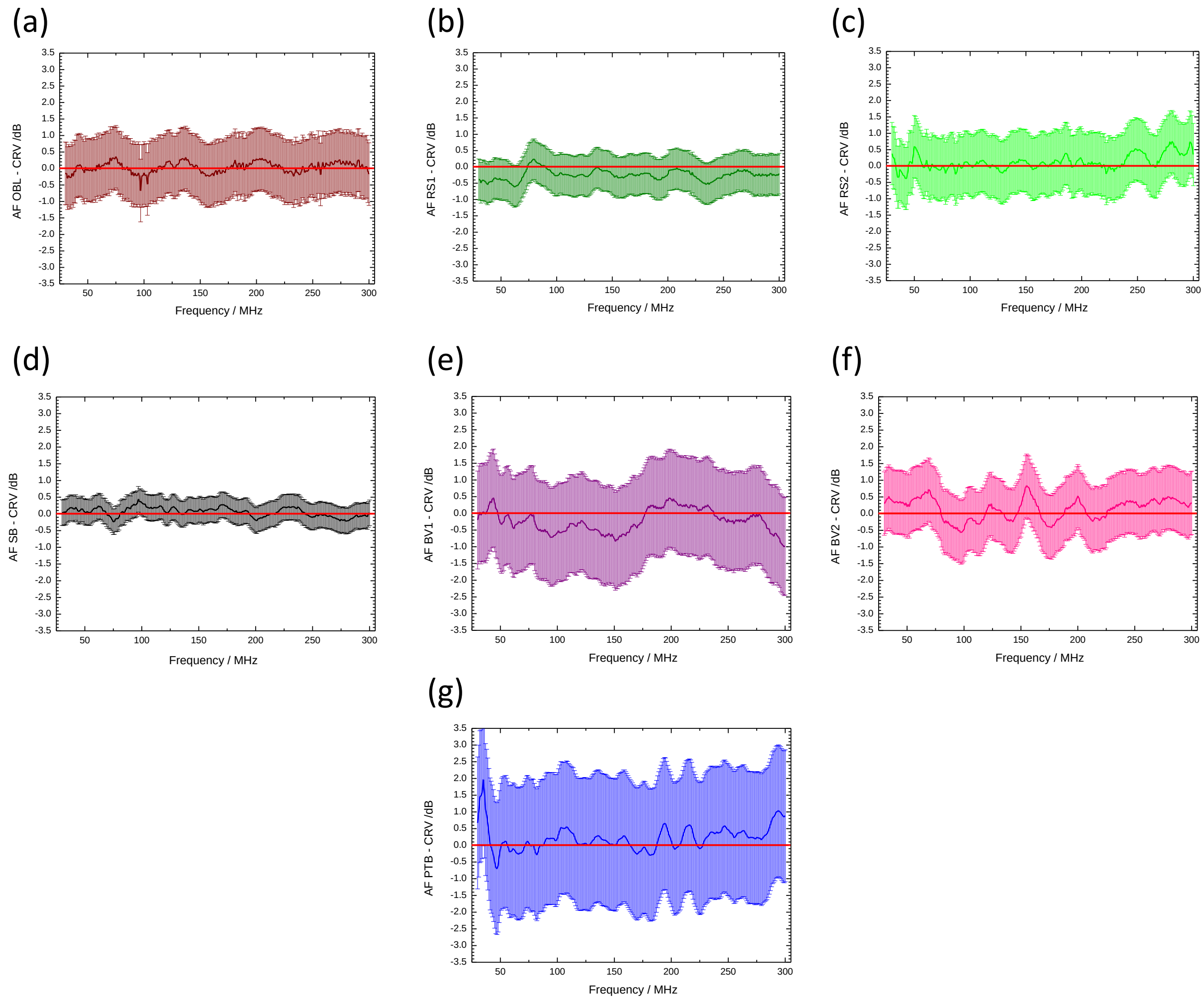

Figure 3. Results of intercomparison for the different participants and measurement constellations for SB VHBB9124 with BBAK9137 **(a)** OBL ANSI C63.5 SSM 10 m OATS, **(b)** R&S ANSI C63.5 SSM 10 m OATS, **(c)** R&S 3 m vertical OATS, **(d)** SB 10 m OATS, **(e)** BV ANSI C63.5 SSM 10 m SAC, **(f)** BV IEEE149 3 m vertical SAC, and **(g)** PTB 3 m vertical SAC.

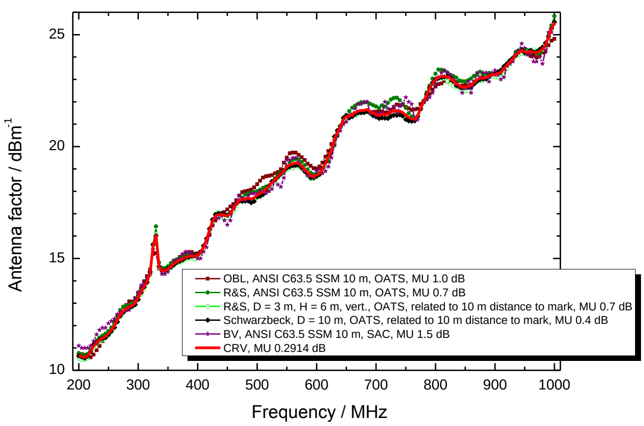

Figure 4. Results of intercomparison for AR® AT1000B.

campaign took place from September 2011 until January 2012.

2.3 Data evaluation

The intercomparison was evaluated based on the measurement results reported by all laboratories that were able to calibrate the distinct antenna. According to Cox et al. (2002) a comparison reference value CRV and its uncertainty $U(\mathrm{CRV})$ were calculated based on the antenna factors AF_i and the measurement uncertainties $U(\mathrm{AF}_i)$ reported by the individual laboratories:

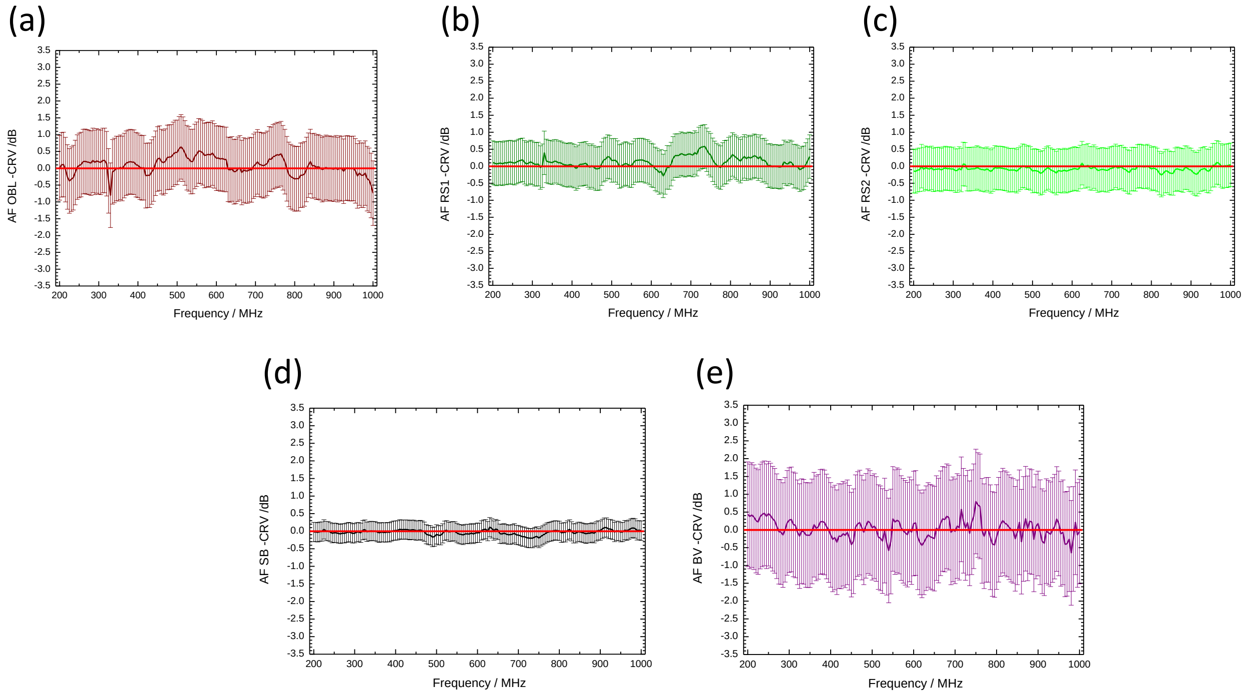

Figure 5. Results of intercomparison for the different participants and measurement constellations for AR® AT1000B. **(a)** OBL ANSI C63.5 SSM 10 m OATS, **(b)** R&S ANSI C63.5 SSM 10 m OATS, **(c)** R&S 3 m vertical OATS, **(d)** SB 10 m OATS, **(e)** BV ANSI C63.5 SSM 10 m SAC.

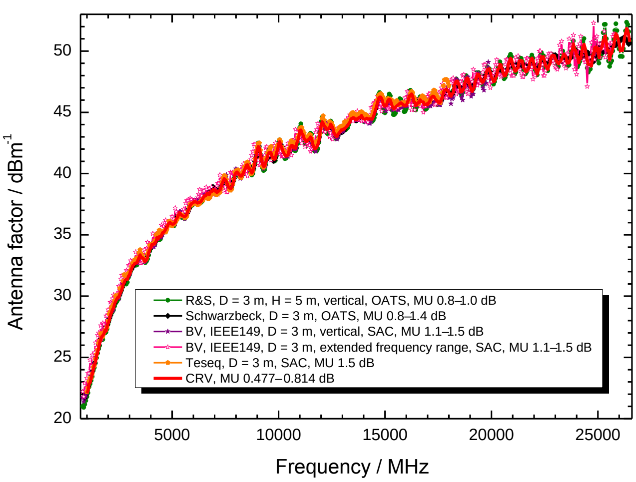

Figure 6. Results of intercomparison for Rohde & Schwarz® HL050.

$$\mathrm{CRV} = \sum_i w_i \cdot \mathrm{AF}_i$$

$$\text{with } w_i = \left(\sum_i \frac{1}{U^2(\mathrm{AF}_i)}\right)^{-1} \cdot \frac{1}{U^2(\mathrm{AF}_i)} \tag{1}$$

$$U(\mathrm{CRV}) = \sqrt{\sum_i w_i^2 U^2(\mathrm{AF}_i)} \tag{2}$$

The weighting factor w_i results in a higher contribution of the laboratories with lower uncertainties to comparison reference value CRV.

From the antenna factors AF_i and the measurement uncertainties $U(\mathrm{AF}_i)$ reported by the individual laboratories and the comparison reference value CRV a degree of equivalence DoE and its uncertainty $U(\mathrm{DoE})$ has been calculated using

$$\mathrm{DoE}_i = \mathrm{CRV} - \mathrm{AF}_i \tag{3}$$

$$U(\mathrm{DoE}_i) = \sqrt{U^2(\mathrm{AF}_i) - U^2(\mathrm{CRV})} \tag{4}$$

as a measure for the deviation from the expected result of each laboratory.

3 Results for biconical antenna Schwarzbeck VHBB 9124 with antenna elements BBAK 9137

The calibration results for the antenna VHBB 9124 with antenna elements BBAK 9137 are shown in Fig. 2. The antenna has been measured with the SSM according to ANSI C63.5 at OBL, R&S and BV, whereas it has been measured in vertical or diagonal orientation by R&S, Schwarzbeck, BV and PTB. The SSM measurements at a distance of 10 m between the antennas were performed in OATS (OBL, R&S) and in an SAC (BV). The free space measurements were performed at a distance of 3 m between the antennas with vertical orientation (R&S, PTB, BV – according to IEEE 149) and at

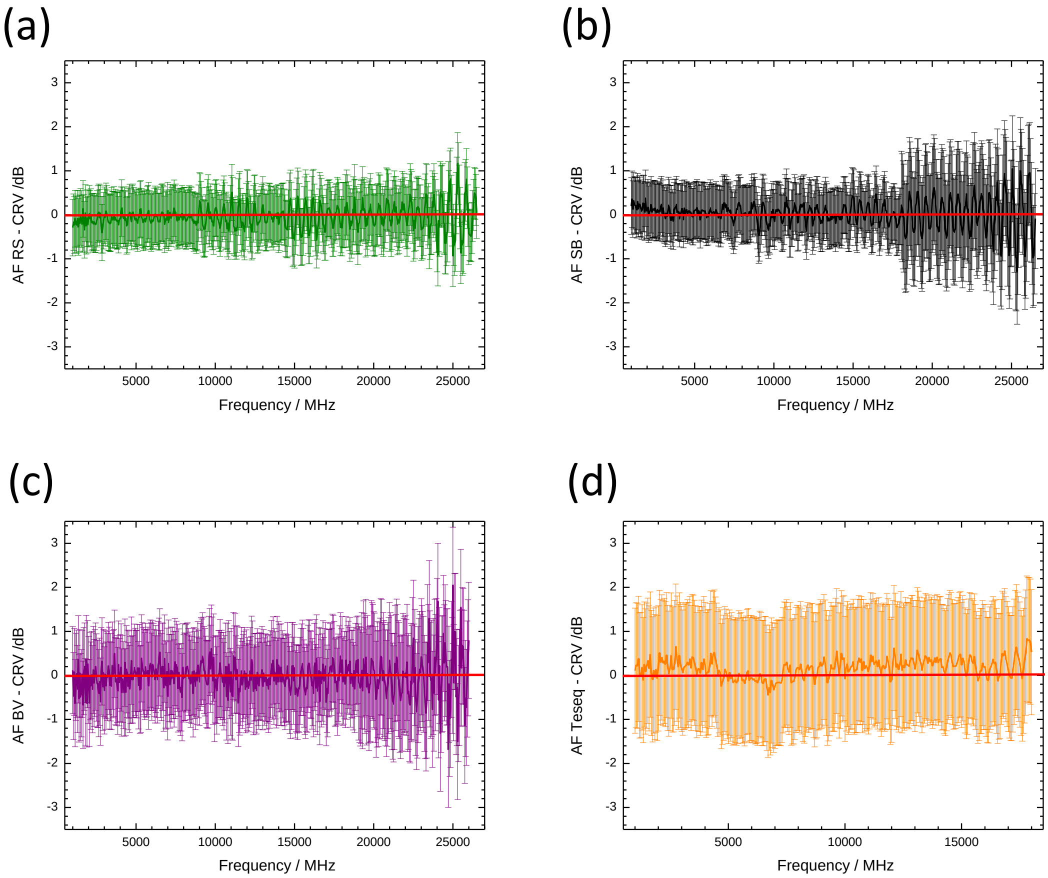

Figure 7. Results of intercomparison for the different participants and measurement constellations for Rohde & Schwarz® HL050. **(a)** R&S OATS 3 m vertical, **(b)** Schwarzbeck OATS 3 m, **(c)** BV IEEE 149 3 m vertical SAC, **(d)** Teseq 3 m SAC.

a distance of 10 m in diagonal orientation (SB). The degrees of equivalence for the individual laboratories are shown in Fig. 3. The results of all laboratories agree well with the calculated comparison reference value within their specified measurement uncertainties.

4 Results for logarithmic-periodic antenna Amplifier Research AR® AT1000B

In Fig. 4 the calibration results for the antenna Amplifier Research AR® AT1000B are shown. Measurements have been performed with the SSM according to ANSI C63.5 at OBL, R&S (both on OATS) and BV (in SAC), whereas a free space measurement has been performed in vertical (R&S) and diagonal (SB) orientation at a distance of 3 m (R&S) and 10 m (SB). The degrees of equivalence for the individual laboratories are shown in Fig. 5. The results of all laboratories agree well with the calculated comparison reference value within their specified measurement uncertainties.

5 Results for logarithmic-periodic antenna Rohde & Schwarz ® HL050

The results for the antenna Rohde & Schwarz ® HL050 in the upper frequency range are shown in Fig. 6. All measurements have been performed at a distance of 3 m in vertical (R&S, BV, Teseq) or diagonal (SB) orientation without height scan on an OATS (R&S, SB) or in a SAC (BV, Teseq). For the individual laboratories the degrees of equivalence are shown in Fig. 7. The results of all laboratories agree well with the calculated comparison reference value within their specified measurement uncertainties.

6 Conclusions

The intercomparison between different laboratories calibrating antennas in Germany showed that the calibration results for the free space antenna factor are compatible although different calibration methods and different types of calibration sites are used. The specified measurement uncertainties are realistic.

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