The Measurement of Complex Antenna Transfer Functions for Ultra-Wideband Antennas in a Compact Range

Mariesa Nel, Johan Joubert, and Johann W. Odendaal

***Abstract*—Ultra-wideband (UWB) communications technology increasingly plays an important role in modern communications systems. The complex antenna transfer function (CATF) of an UWB antenna provides valuable information that can be used for better UWB channel and communication system designs. Currently only the two-antenna and three-antenna measurement techniques are used to measure the transfer function and impulse response of UWB antennas. In this paper a modified version of the gain-transfer method is presented to enable the characterization of UWB antennas using a compact antenna test range facility (CATR). A double-ridged guide horn (DRGH) antenna is used as UWB transfer-standard and the CATF of the transfer-standard is determined a priori using full-wave simulations. The gain-transfer method to measure the CATF of UWB antennas in a CATR is illustrated with two test cases. In the first test case the measured CATF of an ETS-LINDGREN DRGH antenna was verified with numerical data from a FEKO model of the antenna. The second case compares the CATF of an UWB circular disc monopole antenna measured in a CATR to measured data using two identical antennas in a two-antenna measurement set-up.**

***Index Terms*—Double-ridge guide horn antenna, complex antenna transfer function, ultra-wideband, compact antenna test range.**

I. Introduction

Ultra-wideband (UWB) technology has received worldwide attention since the allocation of a specific frequency band that can be used for ultra wideband communication [1]. UWB communication and radar technology promises high data rates and low power consumption for a wide variety of applications. For antennas designed to operate over very wide frequency bandwidths the general radiation properties normally associated with narrow band antennas (eg. gain, radiation pattern, efficiency, etc.) do not characterize the antennas sufficiently to facilitate effective design of such antennas for UWB systems. A generally accepted method of characterizing UWB antennas is in terms of the directional frequency domain transfer function, $\bar{H}(f,\theta,\varphi)$, and/or the directional time domain impulse response, $\bar{h}(t,\theta,\varphi)$, of such an antenna [1-5]. The variables (θ,φ) represent a general direction in three dimensional space, in polar coordinates. The specific UWB antenna characterization parameters which can be derived from the impulse response and transfer function are listed in [4] as peak value of the envelope, envelope width, ringing, transient gain, frequency domain gain and group delay.

Antennas designed for UWB communication systems need to be measured to validate their theoretically predicted performance. Currently only the two-antenna or three-antenna measurement techniques are used to measure the transfer function [1-2, 6-8] and impulse response [5, 9-10] of UWB antennas.

This paper illustrates a modified version of the gain-transfer method to characterise UWB antennas in terms of their complex antenna transfer function (CATF). The modified gain-transfer method enables the characterization of UWB antennas using a compact antenna test range (CATR) facility.

The gain-transfer method requires a priori gain values for the transfer-standard, usually a standard gain horn antenna. In order to measure the CATF of an UWB antenna the CATF of the transfer-standard is required a priori. A double ridge guide horn (DRGH) antenna is used in this study as UWB transfer-standard. The CATF of the transfer-standard is determined using full-wave simulations. The use of theoretical gain data for standard gain horn antennas have been illustrated and are acceptable practice in the antenna calibration environment, due to the very high accuracy of full-wave simulations [11, 12]. The assumption is made that the same very high simulation accuracy is applicable to the determination of the CATF of the UWB transfer-standard.

II. CATF of the UWB Transfer-Standard

The 1–18 GHz wideband DRGH antenna presented in [13] was chosen as UWB transfer-standard. A photograph of the antenna is shown in Fig. 1. An accurate Method of Moments (MoM) numerical model of the DRGH antenna was implemented using the commercial software package FEKO [14]. The numerical model of the DRGH antenna includes the flared horn section of the antenna, the cavity transition region from ridged waveguide to coaxial transmission line, and a

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M. Nel, J. Joubert and J. W. Odendaal are with the Centre for Electromagnetism, Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, 0002, South Africa (e-mail: mnel@nmisa.org, jjoubert@up.ac.za and wimpie.odendaal@up.ac.za).

female type N connector, which is permanently fixed to the manufactured antenna. The CATF of the DRGH antenna was obtained using a simulation of two identical DRGH antennas (the two-antenna method) to calculate the transmission coefficient, $\bar{s}_{21}(\omega)$, for the two identical antennas separated a distance r between their apertures, as shown in Fig. 2. The distance $r > 7.5$ m was chosen to satisfy the general far-field requirement $r > 2D^2/\lambda$, where D is the maximum dimension of the aperture of the antenna.

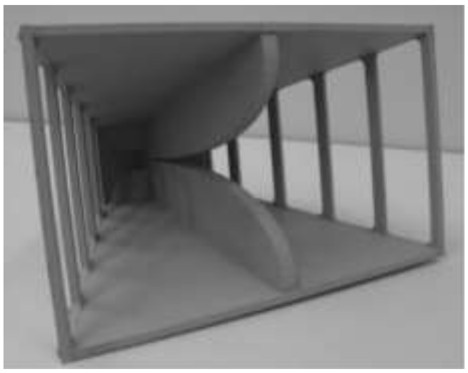

Fig.1. The 1-18 GHz DRGH antenna [13] used as transfer-standard.

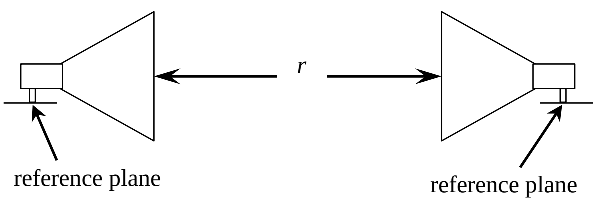

Fig. 2. Schematic diagram of two antenna measurement set-up in anechoic chamber.

The reference plane indicated in Fig. 2 refers to that of the type N connector. The CATF of the DRGH antenna was then calculated using [1]:

$$\bar{H}(\omega)_{Std} = \sqrt{\frac{2\pi r c}{j\omega}\bar{s}_{21}(\omega)e^{+j\omega r/c}}\ , \quad (1)$$

where ω is the angular frequency and c the speed of light.

The theoretical CATF of the DRGH transfer-standard was verified through the measurement of two identical DRGH antennas in an anechoic chamber, separated by a distance $r > 7.5$ m that satisfies the far-field requirement. The distance between the reference planes of the two antennas was determined to acceptable accuracy using the measured time domain transmission response on a vector network analyzer. The distance, r, between the apertures of the two antennas was calculated from the measured time domain response and the electrical lengths of the DRGH antennas (from the reference plane to the aperture). The electrical length of the DRGH antenna was determined using a separate reflection measurement with the vector network analyzer while the aperture of the DRGH antenna was short circuited. Equation (1) was again used to calculate the measured CATF of the antenna. A comparison of the measured and simulated magnitude and unwrapped phase of the CATF of the DRGH antenna are shown in Figs. 3 and 4.

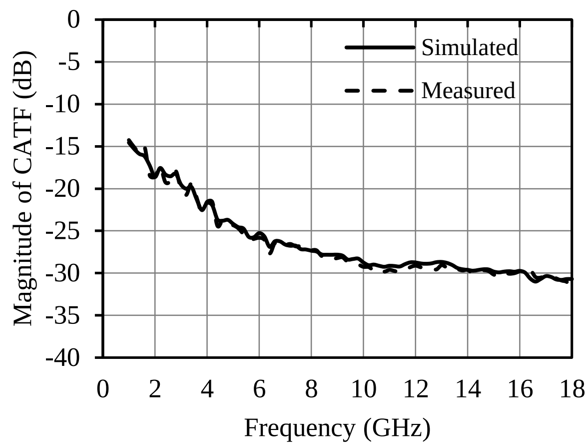

Fig. 3. Comparison of the simulated and measured magnitude of the CATF of the DRGH antenna.

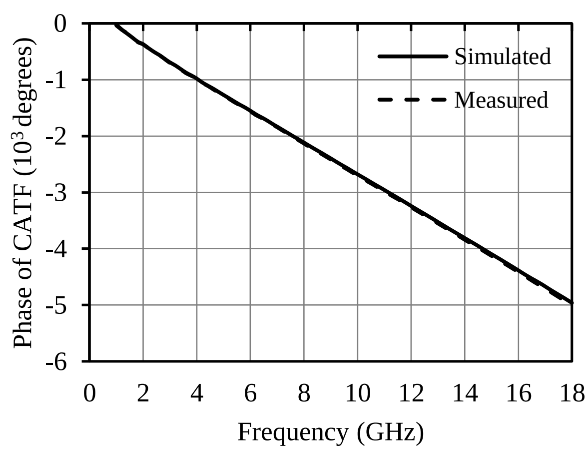

Fig. 4. Comparison of the simulated and measured unwrapped phase of the CATF of the DRGH antenna.

The simulated and measured data appear to correlate well with each other, but for finer detail Figs. 5 and 6 show the actual differences between the simulated and measured magnitudes and phases of the CATF. The difference in magnitude is generally within ±1 dB, and the maximum phase difference (at 18 GHz) is less than 45°, which in both cases are regarded as acceptable. As a final verification the frequency domain gain was calculated from the simulated and measured CATF respectively, using the equation [4]:

$$G(\omega)_{Std} = \frac{4\pi f^2}{c^2}\left|\bar{H}(\omega)_{Std}\right|^2\ . \quad (2)$$

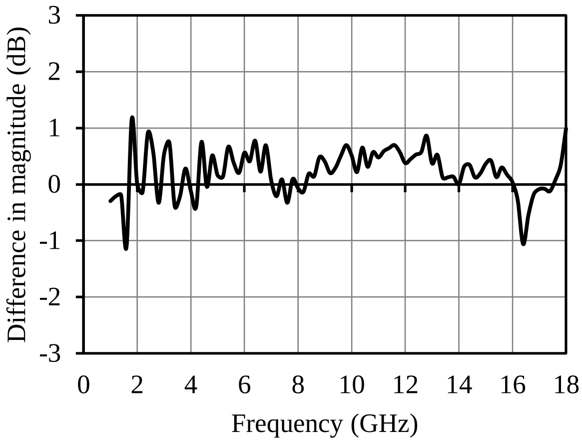

Fig. 5. Difference between the simulated and measured magnitude of the CATF of the DRGH antenna.

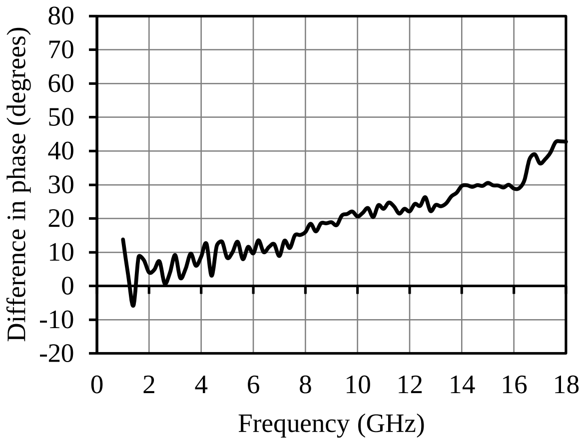

Fig. 6. Difference between the simulated and measured phase of the CATF of the DRGH antenna.

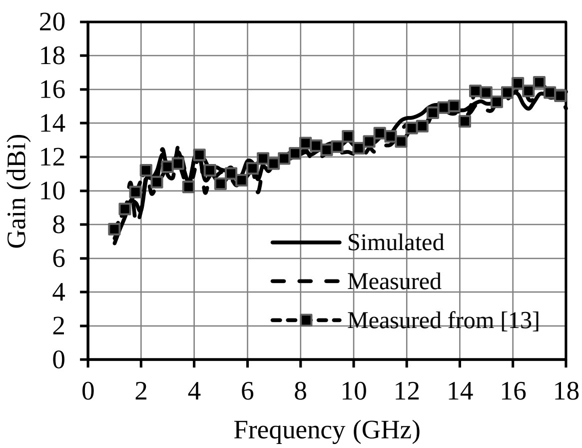

Fig. 7. Comparison of the gain of the standard DRGH antenna obtained from: the simulated CATF, the measured CATF, and the measured far-field gain for the same antenna as published in [13].

In Fig. 7 the calculated gains from the simulated and measured CATF are compared to the measured gain from [13] for exactly the same antenna, and all three sets of data were found to agree satisfactorily over the entire 1–18 GHz bandwidth.

III. Measurement of the CATF in a CATR

The DRGH antenna characterized in the previous section can be used as transfer-standard to determine the CATF of an unknown antenna-under-test (AUT) in a CATR facility using a modified gain-transfer method. The most important issues to consider is the positioning of the transfer-standard antenna and the AUT in the quiet zone of the CATR before measurements are performed, and secondly the equation used to calculate the CATF of the AUT from the measured data.

The absolute reference point in the quite zone of the CATR is critical to accurately determine the phase of the CATF. A theodolite was used to accurately position both the transfer-standard and the AUT at exactly the same position in the CATR, such that the reference point was located in the centres of the radiating apertures for both the antennas. The apertures of the antennas were thus positioned in the same reference plane, and on the same centre line, so that they will both be exactly the same distance away from the reflector. Fig. 8 shows a schematic diagram of one of the antennas in the CATR. The distance r from the reflector to the reference point where the radiating apertures were positioned was exactly the same for the transfer-standard and the AUT, respectively. The absolute value of r is not important when employing the gain-transfer method, as long as both antennas are placed exactly the same distance away from the reflector.

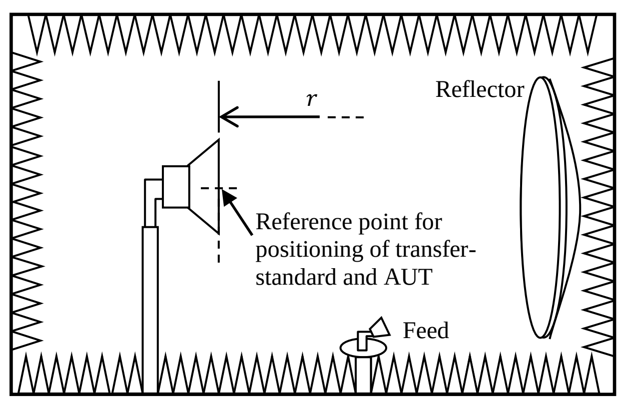

Fig. 8. Schematic diagram of measurement setup in the CATR.

Secondly, the gain-transfer equation is slightly modified to determine the CATF of the AUT as follows:

$$\overline{H}(\omega)_{AUT} = \overline{H}(\omega)_{Std} \frac{\bar{s}_{21}(\omega)_{AUT}}{\bar{s}_{21}(\omega)_{Std}}, \quad (3)$$

where $\overline{H}(\omega)_{Std}$ is the known CATF of the transfer-standard, $\bar{s}_{21}(\omega)_{Std}$ the complex transmission coefficient that was measured in the CATR with the transfer-standard, and

$\bar{s}_{21}(\omega)_{AUT}$ the complex transmission coefficient that was measured in the CATR with the AUT.

The method proposed to measure the CATF of UWB antennas in a CATR are illustrated with two test cases. In the first test case the CATF of an ETS-LINDGREN (P/N 3115) DRGH antenna was determined in the CATR. This antenna was chosen because it operates over the same 1-18 GHz bandwidth as the standard antenna, and also because of the availability of a very accurate numerical FEKO model for the antenna which enabled the verification of the measured results by comparison to simulated data. As a second test case the CATF of a circular disc monopole with a microstrip line feed (similar to that in [15]) was determined in the CATR. This antenna was chosen because it is a very typical small UWB printed antenna and operates over the standard 3.1-10.6 GHz UWB bandwidth. Fig. 9 shows the dimensions of the antenna, which was printed on Rogers RO4003 substrate with ε_r = 3.38 and a thickness of t = 0.813 mm. Two identical antennas were manufactured, for use in a two-antenna measurement set-up, as verification for the measurement procedure in the CATR.

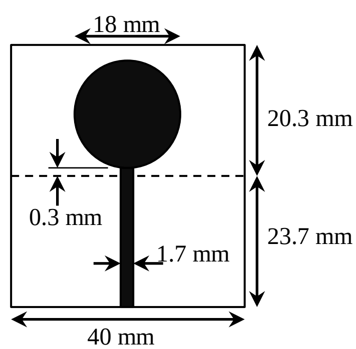

Fig. 9. Dimensions of the printed circular disc monopole antenna.

The CATF was measured after careful positioning the transfer-standard and the AUT in the CATR. The measured and simulated magnitude and unwrapped phase of the CATF of the ETS-LINDGREN antenna are shown in Figs. 10 and 11, and the differences between the FEKO simulated and measured magnitudes and phases of the CATF are shown in Figs. 12 and 13. The absolute difference in magnitude is again within ±1 dB over most of the bandwidth, and the maximum phase difference is less than 35°, which in both cases are regarded as acceptable. To place the phase difference in context - a difference of 1 mm in relative positioning of the two antennas in the CATR is equivalent to a 22° phase error at 18 GHz.

As illustration (and additional verification) of other UWB antenna characterization parameters that can be determined from the CATF, the frequency domain gain and group delay for the ETS-LINDGREN antenna were calculated from the simulated and measured CATF and are shown in Figs. 14 and 15. The agreement between the different sets of data is good.

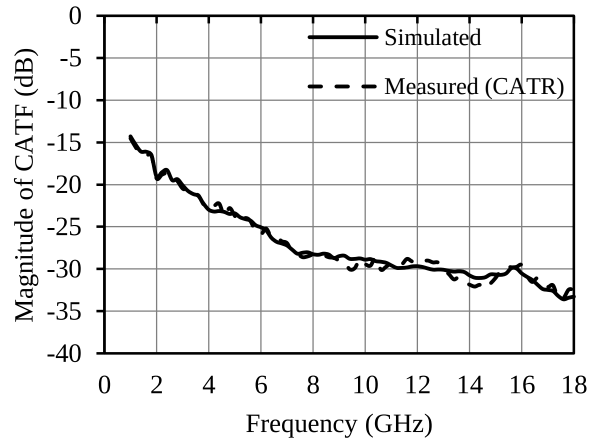

Fig. 10. Comparison of the simulated and measured magnitude of the CATF of the ETS-LINDGREN antenna.

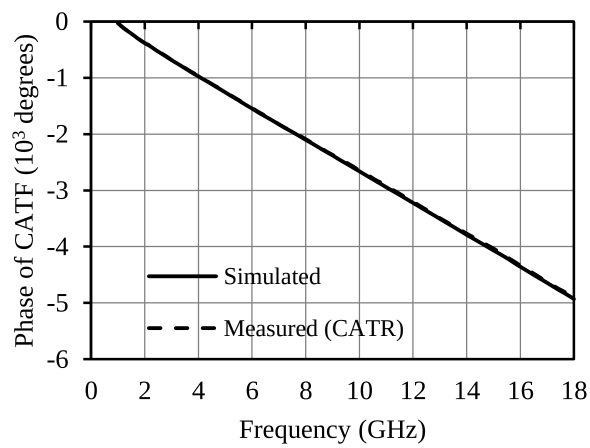

Fig. 11. Comparison of the simulated and measured unwrapped phase of the CATF of the ETS-LINDGREN antenna.

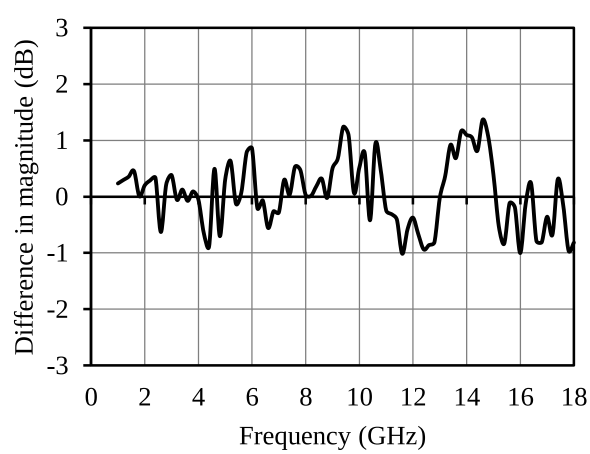

Fig. 12. Difference between the simulated and measured magnitude of the CATF of the ETS-LINDGREN antenna.

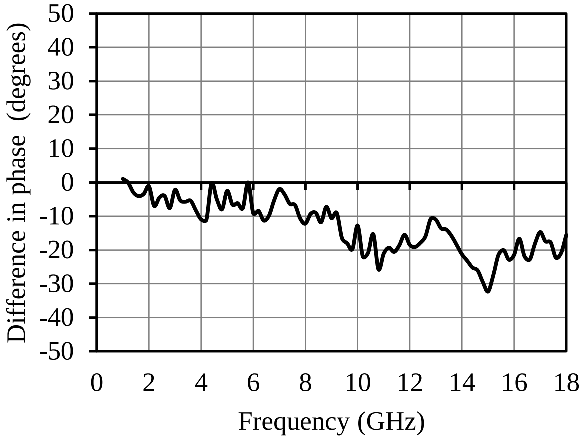

Fig. 13. Difference between the simulated and measured phase of the CATF of the ETS-LINDGREN antenna.

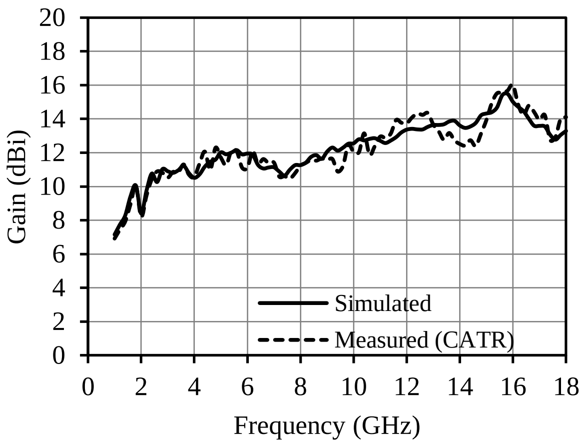

Fig. 14. Comparison of the gain of the ETS-LINDGREN antenna obtained from the simulated and measured CATF.

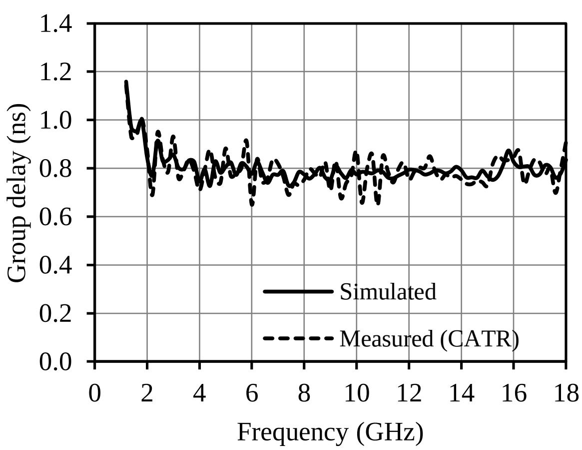

Fig. 15. Comparison of the group delay of the ETS-LINDGREN antenna obtained from the simulated and measured CATF.

The results for the second test case, an UWB circular disc monopole with a microstrip line feed are presented in Figs. 16 and 17. The CATF of the monopole antenna was measured in the CATR and the measured results of magnitude and phase are compared to measured results obtained from a two-antenna measurement set-up, using two identical monopole antennas.

The phase results are within ±45° of each other over the entire frequency band except around 9-10 GHz, and the magnitude results are within ±1 dB over the majority of the band, with some exceptions around 6 GHz and 9-10 GHz. It is normally more difficult to accurately measure small antennas like the printed disc monopole, which has a very small vertical ground plane and an omni-directional radiation pattern, as opposed to highly directional DRGH antennas, hence the slightly larger difference in data sets for the second test case.

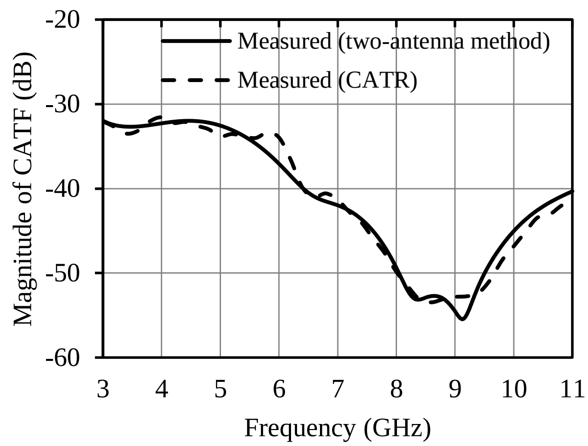

Fig. 16. Comparison of the magnitude of the CATF of the disc monopole antenna, obtained from a two-antenna measurement and a CATR measurement.

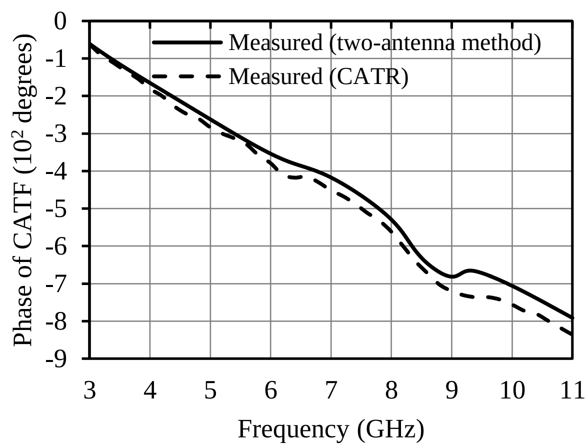

Fig. 17. Comparison of the phase of the CATF of the disc monopole antenna, obtained from a two-antenna measurement and a CATR measurement.

IV. Conclusion

A modified version of the gain-transfer method was presented to enable the characterization of UWB antennas using a compact antenna test range facility. The gain-transfer method requires the CATF for the transfer-standard a priori. A

DRGH antenna was used successfully as UWB transfer-standard and the CATF of the transfer-standard was determined using full-wave simulations.

The gain-transfer method to measure the CATF of UWB antennas in a CATR was illustrated with two test cases. In the first test case the measured CATF of an ETS-LINDGREN DRGH antenna was verified with numerical data from a FEKO model of the antenna. A circular disc monopole with a microstrip line feed was considered as the second test case. The CATF of the disc monopole was measured in the CATR and the results compared to measured data using two identical antennas in a two-antenna measurement set-up. Both experiments yielded acceptable results.

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