Dielectric Assessment Kit

00

0

# APPLICATION NOTE

, 🗅 📴 <mark>E: E:</mark> O. 🐼 E. 🔶 🍋

ither engineering Als Dielectric Assessment Rit

8

# Uncertainty of DAK12 between 4–10 MHz



# Uncertainty of DAK–12 between 4 and 10 MHz

#### 1 Introduction

The SAR standard (Draft IEC 62209-U) has been recently extended to include testing of wireless power transfer (WPT) systems, which operate above 4 MHz. The perform compliance testing according to this standard, accurate dielectric measurements of the tissue simulating media (TSM) are required at the WPT operating frequencies. To achieve this by using the same instrumentations as for the higher frequencies, we have developed a novel algorithm for DAK–12 that reliably compensates for the effect of electrode polarization presents in liquids at these frequencies.

### 2 Objective

The objective of this document is provide the uncertainty budget for measurements of tissue simulating media and its verification for frequencies between 4 and 10 MHz with DAK–12.

## 3 Uncertainty Budget

The uncertainty of dielectric measurements with the DAK probes is composed of contributions which vary for probe type, frequency and material (under test) parameters. The significant factors contributing to the uncertainty include (among others):

- Probe Geometry and Mechanical tolerances
  - Inner / Outer diameter of the dielectric bead; bead permittivity
- VNA Errors
  - S11 noise; S11 phase linearity; S11 amplitude linearity
- Calibration errors
  - Open / Short quality; load homogeneity, temperature, position, electrode polarization effects.
- Numerical Errors
  - Numerical approximations (no. of modes)

The uncertainty budgets were assessed for liquids including saline and head and body simulating media for the frequency from 4 MHz - 10 MHz. The resulting expanded uncertainty (k=2) for DAK-12 is given in the table below:

f	Head / Body Simula	ting liquid	0.1 mol Saline	Solution	
(MHz)	Unc (k=2) %	6	Unc (k=2) %		
	$\Delta \epsilon'$	$\Delta \sigma = \Delta \epsilon''$	$\Delta \epsilon'$	$\Delta \sigma = \Delta \epsilon''$	
3.0	12.7%	3.3%	10.3%	3.2%	
4.0	8.1%	3.3%	6.7%	3.2%	
6.0	5.6%	3.3%	4.7%	3.2%	
8.0	4.5%	3.3%	3.9%	3.2%	
10.0	4.5%	3.3%	3.5%	3.0%	

Table 1.1: Uncertainty budget for DAK-12 for TSM in range 4 MHz-10 MHz

### 4 Verification of Uncertainty Budget

#### 4.1 Measurement Method

For the verification of the uncertainty budget, a series of saline solutions of varying concentrations as well as head tissue liquid were measured with two open co-axial probes (DAK-12 and a 10 mm OCP from Public Health England) and a static conductivity meter. Calibration of the setup was done by using 0.1 mol/l saline solution as load. The calibrated setups (probe & 8753ET VNA) for DAK-12 and 10 mm probe were verified by measuring methanol as reference liquid, prior to measurement of other liquids.

A list of equipment used is as follows:

- DAK-12 Probe
- Open Coaxial Probe (OCP) with 10 mm diameter
- VNA (HP 8753ET)
- Greisinger GMH 5430 conductivity meter

#### 4.2 Static conductivity comparison for saline solutions

As per <sup>1</sup>, saline solutions show frequency-independent, flat behavior below 200 MHz. The conductivity measured with the static conductivity meter is therefore taken as a reference, and the measurements with the two coaxial probes at 4 MHz are compared with those from the conductivity meter. Deviations of less than the uncertainty value are considered acceptable.

Table 1.2 shows the measured static conductivity with conductivity meter and the values from OCP measurements for various concentrations of saline solutions. It also contains the deviation between the two methods.

Electrode polarization effects were compensated for in the case of DAK–12. Possible polarization effects were not compensated for the 10 mm probe, however due to the flangeless design of the 10 mm probe, electrode polarization effects have been reported minimal.

The deviations in static conductivity measured by the two probes are within the uncertainty budget.

<sup>&</sup>lt;sup>1</sup>A. Peyman, C. Gabriel and E. H. Grant, Complex Permittivity of Sodium Chloride Solutions at Microwave Frequencies, Bioelectromagnetics, Vol. 28, p. 264, 2007.

Conc. (mol/l)	Temp (°)	Static cond. (S/m)	OCP cond. 4 MHz	(S/m),	Deviation (	%)
			DAK-12	10mm OCP	DAK-12	10mm OCP
0.010	22.00	0.111	0.116	0.111	-0.5 %	0.0 %
0.027	21.99	0.291	0.290	0.291	-0.4%	0.0%
0.050	22.03	0.518	0.516	0.513	-0.3%	-0.9%
0.080	21.99	0.809	0.809	0.803	0.0%	-0.7%
0.100	21.99	1.003	1.006	1.004	0.3%	0.2%

Table 1.2: Conductivity values measured with conductivity meter (static) and with two different open coaxial probes (at 4 MHz).

#### 4.3 Permittivity / Conductivity comparison with 50 MHz results for saline solutions

As per the reference 1, saline solutions show a frequency independent flat behaviour below 200 MHz. Permittivity and Conductivity Comparison Between Probes for Head Tissue Liquid Measurements on broadband head tissue simulating liquid with the two coaxial probes are seen to give similar results: the curves with the 10 mm probe and DAK–12 are close. Figure 1.1 compares permittivity and conductivity measurements of broad band head liquid below 50 MHz.



Figure 1.1: Permittivity and conductivity of broad band head liquid, measured with the 10 mm probe and DAK-12.

	ttivity		
	10 mm probe		DAK-12
Liquid	(4 MHz)	Deviation	(4 MHz)
HBBL	75.77	-0.3 %	76.01

Conductivity						
	10 mm probe		DAK-12			
Liquid	(4 MHz)	Deviation	(4 MHz)			
HBBL	0.6858	0.4 %	0.6833			

Table 1.3: Permittivity and conductivity of liquids at 4 MHz, measured with the 10 mm probe and DAK-12. Deviation from DAK-12 is calculated.

The deviations between the two probes at 4 MHz, as shown in Table 1.3 above, are within the uncertainty budget and the permittivity smooth with frequency confirms that validity of the approach.

#### 5 Conclusions

DAK–12 has been successfully extended down to 4 MHz for TSM by the developed algorithm for electro polarization compensation. The uncertainty budget has been assessed and verified. We will continue to evaluate and improve the algorithm for other liquids and materials.

#### 6 Additional Information : Recommended Settings

Following measurement settings are recommended for low frequency measurements with DAK 12 probe: (Table 1.4)

Settings	Value				
Frequency Segments	2.5 - 9.5 MHz : 0.5 MHz steps				
	10-295 MHz : 5.0 MHz steps				
	300-3000 MHz : 50.0 MHz steps				
Averaging	3 traces				
Filter	ON				

Table 1.4: Recommended Settings for low frequency measurements with DAK 12 probe

Recommended VNA settings are shown in Figure 1.2 and Figure 1.3.

FILE MEASUREMENTS HELP Setup Laibrate Measure UN Vector Network Analyzer Keysight PNA Keysight FieldFox Planar 804 Planar 804 Planar 804 Planar 804 Planar 814 Cobalt C1220 Planar 814 Cobalt C1220 Planar 814 Planar 805 Planar 854 Planar 854 Planar 5530 Planar 57530 Planar 57530 Planar 57530 Planar 57530 Planar 57530 Planar 57530 Planar 57530 Planar 57530 Planar 204 Ronde & Schwarz 20X <b>Frequency Range</b> M 0.009	A Probes Ses Probes Ses Prob	gments Probes DAX - 12 (5 Gr DAX - 12 (5 Gr DAX - 12 (5 Gr DAX - 12 (5 Gr DAX - 12 (4 Mr	15 15 14: - 50 GH2) 14: - 20 GH2) 14: - 3 GH2)				Dielectric In Dielectri Body Boron Butanol DMSO Eccosto Ethaned Ethanol Head Methan	Materials nport c Material: ck liol		Create	E: Tempera 0 10 20 30 40 50	xport ature (°C)		iheck
Keysight RNA         Milesure         Milesure           Keysight RNA         Keysight RNA         Keysight Relations           Planar 304         Planar 804         Planar 804           Planar 804         Planar 804         Planar 804           Planar 804         Planar 804         Planar 806           Planar 814         Cobalt Ci220         Planar 814           Cobalt Ci220         Planar 814         Planar 814           Planar 814         Planar 7505         Planar 7505           Planar 75050         Planar 55065         Planar 55065           Planar 75330         Planar 75300         Planar 7530           Planar 78140         Fagurery Range         Keysight Regerery Range	B Probes Ses	gments Materia Protes DAK - 12 (5 Gr DAK - 12 (6 Gr DAK - 35 (200 DAK - 12 (4 Mr	15 Hz - 50 GHz) Hz - 67 GHz) MHz - 20 GHz) Hz - 3 GHz)	}			Dielectric In Dielectri Body Boron Butanol DMSO Eccosto Ethaned Ethanol Head Methan	Materials nport c Material: ck liol		Create	E: Tempera 0 10 20 30 40 50	xport ature (°C)	c	Theck
Vector Network Analyzer Keysight PNA Keysight PNA Planar 304 Planar 804 Planar 804 Planar 806 Planar 814 Cobalt C1220 Planar 814 Planar 854 Planar 860 Planar 850 Planar 5508 Planar 5508 Planar 5508 Planar 5508 Planar 5730 Planar 2508 Planar 2508	4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	Probes DAX - 12 (5 G DAX - 12 (5 G DAX - 35 (20 DAX - 35 (20 DAX - 12 (4 MH	Hz - 50 GHz) HHz - 67 GHz) MHz - 20 GHz) Hz - 3 GHz)	<b>,</b>			Dielectric In Dielectri Body Boron Butanol DMSO Eccosto Ethaned Ethanol Head Methan	Materials nport c Materials ck liol	;	Create	E Tempera 0 10 20 30 40 50	xport ature (°C)		Theck
Keysight PeldFox       Planar 804       Planar 804       Planar 804       Planar 804       Planar 804       Planar 814       Cobalt C1220       Planar 814       Planar 814       Planar 814       Planar 850       Planar 850       Planar 7500       Planar 55085       Planar 75300       Planar 75300       Planar 75300       Planar 7530       Planar 720X       A Rohde & Schwarz 2XX       A Rohde & Schwarz 2XX       Mar 0.009	4 4 5 6 6 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8	DAK - 12 (5 GF DAK - 12 E G DAK - 35 (200 DAK - 12 (4 MH	4z - 50 GHz) iHz - 67 GHz) MHz - 20 GHz) 4z - 3 GHz)	}			In Dielectri Body Boron Butanol DMSO Eccosto Ethanol Head Methanol	nport c Material: ck liol Dl	:	Create	E Tempera 10 20 30 40 50	ixport ature (°C)		Theck
Keysipit FieldFox           Planar 304           Planar 804           Planar 804           Planar 804           Cobalt C1220           Planar 814           Cobalt C1220           Planar 814           Planar 814           Planar 824           Planar 834           Planar 850           Planar 55085           Planar 55005           Planar 75300           Planar 7330           Planar 7330           Planar 7330           Planar 711300           Rohde & Schwarz 2VX           A Rohde & Schwarz 2XX           A Frequency Range           Mm         0.009	4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	DAK - 12E (5 G DAK - 35 (200 DAK - 12 (4 MH	iHz - 67 GH2) MHz - 20 GH2) Hz - 3 GH2)	}	Ī	Ī	Dielectri Body Boron Butanol DMSO Eccosto Ethaned Ethanol Head Methan	c Materials ck liol			Temper 0 10 20 30 40 50	ature (°C)		
Planar 304           Planar 804           Planar 804           Planar 808           Planar 814           Cobalt C1220           Planar 814           Planar 814           Planar 814           Planar 814           Planar 850           Planar 850           Planar 85043           Planar 55043           Planar 55043           Planar 55043           Planar 55030           Planar 57530           Planar 57530           Rohde & Schwarz ZVK           A Rohde & Schwarz ZXX           A Rohde & Schwarz ZXX           Marcus Planar 2005	4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	DAK - 3.5 (200	MHz - 20 GHz) łz - 3 GHz)	, ,	Ī	Ī	Body Boron Butanol DMSO Eccosto Ethaned Ethanol Head Methan	ck iol			0 10 20 30 40 50			
Planar 804           Planar 808           Planar 814           Cobalt C1220           Planar 814           Planar 850           Planar 75085           Planar 55085           Planar 7530           Planar 781300           Rohde & Schwarz ZVH           Rohde & Schwarz ZXX           Frequency Range           Mn         0.009	b b b b b b b b b b b b b b b b b b b	DAK - 12 (4 Mł	4z - 3 GHz)	<b>}</b>			Boron Butanol DMSO Eccosto Ethanol Head Methan	ck liol pl			10 20 30 40 50			
Planar 808           Planar 814           Cobalt C1220           Planar 814           Planar R54           Planar R54           Planar R54           Planar R54           Planar S5085           Planar 55085           Planar 75330           Planar 75300           Planar 781300           Rohde & Schwarz ZVK           A Rohde & Schwarz ZXX           A Rohde & Schwarz ZXX           Min Cugency Range           Min 0009	6 6 7 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8		ł	}			Butanol DMSO Eccosto Ethanol Head Methan	ck liol pl			20 30 40 50			
Planar 814           Cobalt C1220           Planar R54           Planar R54           Planar R56           Planar R50           Planar S5043           Planar S5045           Planar S5030           Planar S5030           Planar S7530           Planar S7530           Planar S7530           Rohde & Schwarz ZVK           A Rohde & Schwarz ZXX	b b b b b b		ł	<b>}</b>			DMSO Eccosto Ethaned Ethanol Head Methan	ck liol Dl			30 40 50			
Cobalt C1220 Planar R140 Planar R54 Planar R60 Planar S5085 Planar S5085 Planar S5085 Planar TR1300 Rohde & Schwarz ZVH Rohde & Schwarz ZVX A Rohde & Schwarz ZXX A Frequency Range Min 0.009	۵ ۵ ۵ ۵ ۵		,	}			Eccosto Ethaned Ethanol Head Methan	ck liol ol			40 50			
Planar R140 Planar R54 Planar R54 Planar S5085 Planar S5085 Planar S530 Planar TR1300 Rohde & Schwarz ZVH Rohde & Schwarz ZVX ▲ Rohde & Schwarz ZXX ▲ Rohde & Schwarz ZXX ▲ Rohde & Schwarz ZXX			ł	}			Ethaned Ethanol Head Methan	iiol ol			50			
Planar R54           Planar R60           Planar S5048           Planar S5035           Planar S7530           Planar S7530           Planar S7530           Rohde & Schwarz ZVH           Rohde & Schwarz ZVX           A Rohde & Schwarz ZXX           A Rohde & Schwarz ZXX           A Rohde & Schwarz ZXX           Manar Stagenerge Range           Min         0.09	4 4 4 4 4			}			Ethanol Head Methan							
Planar R60       Planar 55048       Planar 55085       Planar 57530       Planar TR1300       Rohde & Schwarz ZVH       Rohde & Schwarz ZXX       A Rohde & Schwarz ZXX       A Rohde & Schwarz ZXX       Min     0.009	4 4 4 4		۲	7			Head Methan							
Planar 55048 Planar 55085 Planar 75300 Rohde & Schwarz ZVH Rohde & Schwarz ZXX ▲ Rohde & Schwarz ZXX ▲ Rohde & Schwarz ZXX ▲ Rohde & Schwarz ZXX	4 4 4		7	7			Methan							
Planar 55085           Planar 57530           Planar Thi300           Rohde & Schwarz ZVH           Rohde & Schwarz ZXX           A Rohde & Schwarz ZXX           A Rohde & Schwarz ZXX           Minder & Schwarz ZXX           Minder & Schwarz ZXX           Minder & Schwarz ZXX	۵ ۵						meenan							
Planar S7530 Planar TR1300 Rohde & Schwarz ZVH Rohde & Schwarz ZXX A Rohde & Schwarz ZXX A Frequency Range Min 0.009	Þ			/										
Planar TR1300 Rohde & Schwarz ZVK Rohde & Schwarz ZXX A Rohde & Schwarz ZXX A Requency Range Min 0.009							f (MHz)				tan(δ)	Refl.R	Refl.I	% Tol.
Rohde & Schwarz ZVH Rohde & Schwarz ZXX  Rohde & Schwarz ZXX  Frequency Range Min 0.009		Frequency Seam	ents				300				0.9472			
Rohde & Schwarz ZXX  A Rohde & Schwarz ZXX  Frequency Range  Min  0.009	₽	Frequency segm					250	577	47.50		0.9249			25
▲ Rohde & Schwarz ZXX           ▲ Frequency Range           Min         0.009		New Segme	ent Delete S	Segment Check	Use	Calibration					0.02-10			
▲ Frequency Range Min 0.009		Start f (MHz)	Stop f (MHz)	Resolution f (MHz)	Point	Active	400	57.2	41.94		0.7333			
		Start (Williz)	5top ( (will 12)				450				0.6622			
		4				$\mathbf{r}$	500	56.51		0.9439				
		10				$\checkmark$	550	56.21	20.00	0.0479				
		300	3000			$\checkmark$	1	50.51	50.50	0.9470	0.5501	-		
Measurement S11							Selected	Medium 1	olerances					
Manufacturer Website http://www.r	hde-schwarz.com/en +						% Tol.				0.000.00			
							-				0.000 %			
Source Power U	dBm	Current coam	ont may number	of points: 4001			Start	(WIF12)			0.000 MI			
VISA Address TCPIP0:-1	9 254 241 47 inst0	Calibratable	Range: 2.5 - 5000	MHz			Stop f	(MHz)			0.000 MI			
		Measureable	Range: 85 - 2985	MHz				R	eset All			Rese	t Band	

Figure 1.2: Recommended Frequency Segments



Figure 1.3: Recommended VNA Settings