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Uncovering the Hidden Variability and Challenges in SERF-OPMs Through Structured Magnetometer Benchmarking

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The emergence of Spin-Exchange-Relaxation-Free (SERF) Optically Pumped Magnetometers (OPMs), ranging from single-sensors to fully integrated multichannel systems, has opened new frontiers in biomedical applications and other sensing areas through remote and rapid magnetic field sensing. Without detailed manufacturer specifications, treating these sensors as black boxes can conceal critical limitations, particularly for medical end-users. Understanding the input-output behavior of each individual channel is essential to maintain signal integrity and future diagnostic reliability. This profound insight has emerged from systematic benchmarking studies and rigorous investigations involving Magnetoelectric (ME) sensors, underpinned by extensive fundamental research, accumulated expertise, electronics development, and valuable feedback from medical professionals [1].

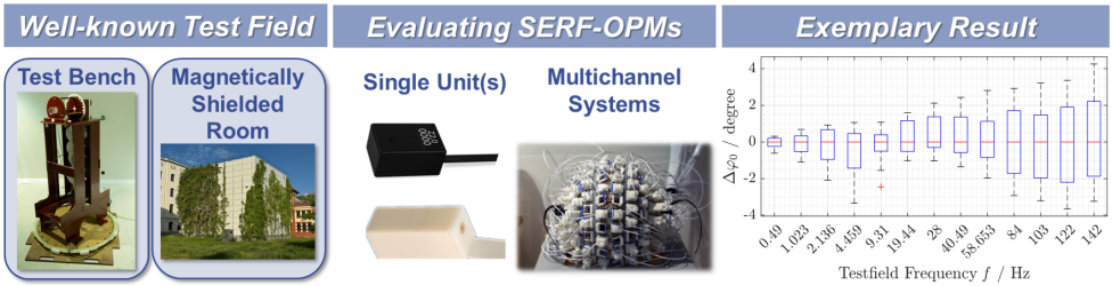

Figure 1: enter image description here

Figure 1: *Overview of our systematic approach for magnetometer characterization. Exemplary result showcase spread of intra-channel phase delays as a boxplot in one multichannel system (triaxial mode, closed-loop) for one axis; the red line denotes the median phase delay across 19 units operating in triaxial mode.*

In this contribution, we present a systematic approach for evaluating highly-sensitive magnetometers within the Berlin Magnetically Shielded Room 2.1 (BMSR-2.1) at the Physikalisch-Technische Bundesanstalt (PTB), Berlin, Germany. Central to this effort is our dedicated test bench (DALAC), which facilitates detailed assessment of key performance parameters within a well-characterized test environment and magnetic test field (cf. Fig. 1) [2]. Using measurement data from commercially available multichannel SERF-OPM systems, we demonstrate the critical and broad importance of a systematic characterization approach in comparison with the biomagnetic gold standard given, SQUID. Besides sensitivity, bandwidth, linear range, gain stability, amplitude response flatness, and time delay are investigated, with particular attention to intra-channel variability (cf. Fig. 1). Without standardized characterization, sensor-specific influences on the sensed signal can compromise data integrity, posing serious risks in high-precision applications like MCG, MMG, MEG, and especially source reconstruction. Therefore, systematic characterization is essential for the reliable biomedical use of SERF-OPMs.

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[1] G. Schmidt et al., Eds.,*Magnetoelectric Sensor Systems and Applications.* Basel, Switzerland: MDPI, 2022.
[2] E. Elzenheimer et al., *Key Metrics and Experimental Test Bench for Assessing Highly Sensitive Magnetometers in Research*, IEEE Sensors, vol. 25, no. 2, pp. 2432-2455, 2025.

Authors: Dr ELZENHEIMER, Eric (Kiel University, Department of Electrical and Information Engineering & PTB, Dept. 8.2 Biosignals); Dr KNAPPE-GRÜNEBERG, Silvia (Physikalisch-Technische Bundesanstalt, Dept. 8.2 Biosignals)

Co-authors: Mr MATZ, Hartmut (Physikalisch-Technische Bundesanstalt, Dept. 8.2 Biosignals); Mr ZERFOWSKI, Jan (Laboratory for Clinical Neurotechnology, Charité —Universitätsmedizin Berlin); Prof. SOEKADAR, Surjo R. (Laboratory for Clinical Neurotechnology, Charité —Universitätsmedizin Berlin); Prof. HÖFT, Michael (Kiel University, Department of Electrical and Information Engineering); Prof. RIEGER, Robert (Kiel University, Department of Electrical and Information Engineering); Dr VOIGT, Jens (Physikalisch-Technische Bundesanstalt, Dept. 8.2 Biosignals)

Presenter: Dr ELZENHEIMER, Eric (Kiel University, Department of Electrical and Information Engineering & PTB, Dept. 8.2 Biosignals)

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