by irradiation and the injected current of DCI have similar structures, both methods can be considered equivalent from an EMC point of view with respect to the outer domain I.

As mathematical instrument to investigate surface currents, Characteristic Mode Analysis (CMA) (Harrington and Mautz, 1971), (Cabedo-Fabres et al., 2007), (Chen and Wang, 2015) is applied. A CMA yields orthogonal basis functions, called Characteristic Modes, in which surface currents can be expanded. Characteristic Modes only depend on geometric and material properties of the test setup and are thus different for HIRF and DCI because of distinct boundary conditions introduced by the DCI adapters (Rothenhäusler and Gronwald, 2017). Based on Characteristic Mode data of HIRF and DCI setups, a basis transformation of the HIRF surface current from HIRF modes to DCI modes is performed, by which expansion coefficients for a DCI surface current expansion follow. Its approximation to the HIRF current is analyzed by means of a relative error measure for complex-valued vector quantities. Unlike in Ückerseifer et al. (2019), the basis transformation algorithm employs only vector-matrix operations and is thus easier to automate for a broad frequency range and arbitrary DUTs including spherical bodies. Apart from the discussed surface current transformations, practical issues concerning the influence of DCI adapter impedance as well as injection and termination adapter positions on the surface current approximation is discussed.

Section 2 starts with a mathematical overview over CMA and its specific modal quantities. They constitute the foundation for a basis transformation algorithm subsequently demonstrated yielding DCI surface currents as approximation to HIRF surface currents. In order to apply this algorithm, section 3 introduces HIRF and DCI test setups for three different canonical DUTs, whose modal properties are determined by a CMA. Finally, section 4 presents computed DCI currents for these DUTs and compares them to HIRF currents in a broad frequency spectrum for different physical configurations of the DCI setup.

### 2 Mathematical Background

The mathematical notation throughout this paper indicates complex quantities with an underscore. In contrast to scalar quantities, vectors and matrices are symbolized by bold variables.

#### 2.1 Characteristic Mode Analysis

Characteristic Mode Analysis for perfect electric conductors (PEC) is commonly based on the Electric Field Integral Equation (EFIE) operator \( \mathbf{Z} = R + jX \) (impedance matrix) set up in the Method of Moments (Harrington, 1967). In a CMA, the generalized eigenvalue problem

\[
\mathbf{X} \mathbf{J}_n = \lambda_n \mathbf{R} \mathbf{J}_n
\]

at a frequency \( f \) with real eigenvalues \( \lambda_n(f) \in (−\infty, \infty) \) and eigenvectors \( \mathbf{J}_n(f) \in \mathbb{R} \) called Characteristic Modes, both quantities of order \( n \in \mathbb{N} \), is solved. The eigenvalues are commonly expressed in a more convenient form with limited value range as the modal significance

\[
s_n = \frac{1}{\sqrt{1 + |\lambda_n|^2}}
\]

with \( s_n \in [0, 1] \), which indicates, how intensively the \( n \)-th Characteristic Mode can contribute to a surface current distribution.

As an example, Fig. 2 shows amplitude-normalized Characteristic Modes \( \mathbf{J}^H_n, \mathbf{J}_n^D \) of a straight wire as DUT in HIRF and DCI configuration. The boundary conditions for the HIRF modes \( \mathbf{J}^H_n \) manifest as vanishing currents at both wire ends, whereas for the DCI modes \( \mathbf{J}^D_n \) non-vanishing boundary currents occur because of DCI adapters attached to each wire end. Similar differences between HIRF and DCI modes occur for more complex bodies as well.

As the \( \mathbf{J}_n \) are linearly independent, they form a basis in which the surface current \( \mathbf{J}^H \) on a DUT resulting from a HIRF test can be expanded. Assuming a test frequency \( f^H \), an expansion in \( M \) Characteristic Modes is set up according to

\[
\mathbf{J}^H(f^H) = \sum_{n=1}^{M} \beta_n(f^H) \mathbf{J}^H_n(f^H) \approx \mathbf{J}^H_{\text{HIRF}}
\]

Here, \( \mathbf{J}^H_n \) denote Characteristic Modes of the HIRF setup and the expansion coefficients \( \beta_n \) are called modal weighting coefficients. Both quantities are provided by numerical software tools.

To investigate whether a DCI surface current \( \mathbf{J}_{\text{DCI}} \) can theoretically approximate a HIRF current distribution, the latter needs to be expandable in Characteristic Modes of the DCI.