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Design of Planar Capacitive Transducers for the Detection of Road Surface Wetness

Jakob Döring, Dennis Lepke, Karl-Ludwig Krieger
Institute of Electrodynamics and Microelectronics (ITEM.ae), University of Bremen, Germany
doering@item.uni-bremen.de

Abstract

The increasing level of automation in today's motor vehicles causes road surface wetness detection to steadily gain in importance. One suitable approach is the detection with planar capacitive sensors on a motor vehicle's wheel arch liner. In order to design transducers for the detection of road surface wetness, different figures of merit are analyzed by means of the finite element method (FEM) and set in relation to specific design parameters in this paper. Furthermore, we propose three complementary design domains enabling the distinction of a wide range of wetness levels.

Keywords: Planar capacitive sensors, interdigital transducers, wetness detection, vehicle safety systems, finite element method.

Introduction

Even nowadays, road surface wetness can still be considered a reason for traffic accidents, since it can lead to a significant loss of tire traction. As today's vehicles do not provide direct information about the road's current surface wetness, the driver has to estimate it intuitively and experience-based, which can have fatal consequences in case of misjudgments. Furthermore, knowledge of road surface wetness will gain in importance due to highly or fully automated driving.

In [1], we presented a novel approach for road surface wetness detection with planar capacitive sensors on a vehicle's wheel arch liner. Since a wet road surface causes tires to whirl up water in the form of drops, the sensors can detect the impinging drops and thus indirectly infer road wetness. Due to a correlation of road wetness, wheel speed and the size and quantity of whirled-up water drops, a distinction between wetness levels is basically possible. In order to classify a wide range of wetness levels, one possible approach is to arrange different sensor designs on the wheel arch liner. As the design parameters have a significant impact on its characteristics, the electrode design is essential to meet the application's requirements [2]. Therefore, we present the design of complementary planar capacitive transducers enabling the distinction between wetness levels in this paper.

Preliminaries

In order to design transducers with regard to the classification of a wide range of wetness levels, we use COMSOL Multiphysics for two-dimensional electrostatic FEM simulations. In this paper, we focus on flexible printed circuit boards as they are ideally suited for the integration on a wheel arch liner [1]. Therefore, design parameters that are generally manufacturable are considered in the simulations, as depicted in Fig. 1. As previous work has shown, increasing the ratio of electrode width w to distance d improves SNR [2]. Thus, in consideration of design limitations, the distance is constantly kept at 150 µm in the simulations. Furthermore, we define a fixed electrode area of 50 mm × 50 mm. The fixed electrode distance and area result in a dependency of width w and the number of digits n:

$$w = \frac{a - d \cdot (2 \cdot n - 1)}{2 \cdot n}. \tag{1}$$

Additionally, the active sensing area's length l_{sa}, which is used to determine the approximated absolute capacitance, is dependent on w:

$$l_{\mathrm{sa}} = \ a - 2 \cdot (w + d). \tag{2}$$

In order to meet all boundary conditions n can be varied from 2 to 83 in the simulations.

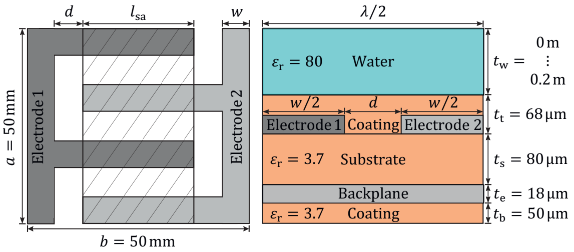

Fig. 1. Schematic top view (left) and cross-section view (right) of an interdigital transducer.

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Discussion

For the classification of different wetness levels, two fundamental figures of merit in sensor design are the dynamic range and the penetration depth. Due to a trade-off between these factors, the choice is essential to meet the application's requirements [1, 2]. In Fig. 2, the penetration depth and the dynamic range are shown against the possible number of digits. With an increasing number of electrode fingers, the penetration depth decreases from around 13 mm to 0.01 mm. Furthermore, the dynamic range significantly increases until a point is reached, where the major part of the electric field progressively concentrates on the coating area due to a declining penetration depth. Since there is no benefit of a greater number of digits for the target application, we focus on the range of 2 to 20 digits, as shown in Fig. 2 (right).

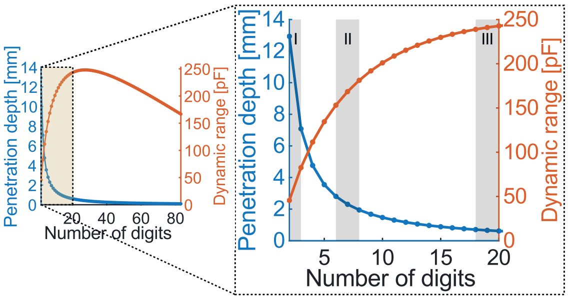

Fig. 2. Penetration depth and dynamic range against the number of digits.

In order to classify between different wetness levels, we exemplarily choose three design domains (I-III, Fig. 2) suitable for the application's requirements. For a more detailed analysis of the three domain's characteristics, Fig. 3 shows the sensitivity $\Delta C/C$ for an increasing water layer thickness t_w from 0.005 mm to 6 mm against the studied number of digits. Furthermore, the difference between the asymptotic capacitance and the capacitance at different water layer thicknesses $\Delta C_\infty = C(t_\mathrm{w} \to \infty) - C(t_\mathrm{w})$ is shown, displaying the remaining part of the dynamic range.

Due to its high penetration depth (> 7 mm), the first design domain enables to distinguish between greater water layer thicknesses. In contrast to the other domains, the dynamic range is more evenly distributed within these thicknesses. Although the domain's dynamic range is small in comparison, for t_w of 2 mm there are still about 25 % of it left, as shown in Fig. 3. However, there are disadvantages regarding the classification of smaller water layer thicknesses.

The second domain covers a wide classification range of water layer thicknesses. Besides the dynamic range, which approximately doubles, the sensitivity significantly increases for all water layer thicknesses. Due to the lower penetration depth of about 2 mm – 3 mm, the upper distinction limit is decreasing, as depicted in Fig. 3. On the other hand, the difference between smaller water layers widens, enabling even to distinguish in the range of micrometers.

In order to distinguish between very small water layer thicknesses with a good resolution, the third domain is proposed. Here, the maximum in dynamic range and sensitivity for given boundary conditions is approximately reached. Especially the high difference for very small water layers is advantageous. Since there is always a trade-off, the increasing number of digits leads to a penetration depth of about 600 μm to 700 μm in this domain. Therefore, the asymptotic capacitance is reached early, resulting in disadvantages with regard to greater thicknesses.

In summary, the three proposed design domains are complementary regarding the distinction of various wetness levels. Hence, they enable to cover a wide range of wetness levels.

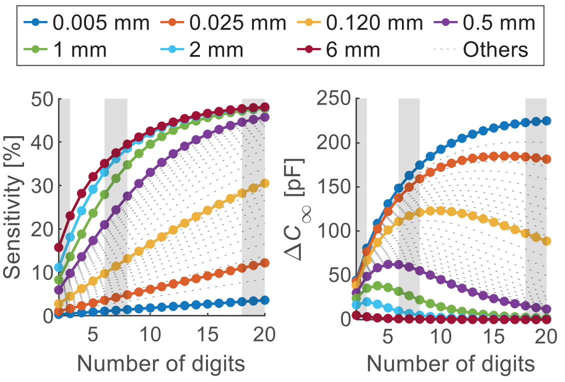

Fig. 3. Sensitivity and difference between the asymptotic capacitance and the capacitance at different water layer thicknesses against the number of digits.

Conclusion

In this paper, we presented the design of complementary planar capacitive transducers for the detection of road surface wetness. By means of FEM simulations different figures of merit were analyzed and set in relation to the specific design parameters. Furthermore, we exemplarily proposed three design domains enabling the distinction of a wide range of wetness levels due to their characteristics.

References

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