Modelling the capacitive coupling of sensors applied to the contactless inspection of planar electronics

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Abstract

A model aimed to describe the capacitance between probe electrodes and the conductive parts of planar electronic devices is presented. The probe electrodes are the constitutive part of a sensor chip used in an inspection system which is exclusively based on capacitive coupling and employed for the inspection of devices such as flat panel displays and printed electronic circuits. Finite element (FE) simulations of the sensor signal are used to determine the model parameters and to verify the obtained results. The capacitive coupling for arbitrary configurations of parallel arranged conductor tracks and various distances between the tracks and the sensor chip is reproduced by the model. Absolute values of the capacitance with deviations below 5\% can be obtained.

Keywords: flat panel display (FPD); planar electronic device; contactless inspection system; capacitive coupling; finite element (FE) simulation; nonmatching grids

1. Introduction

The growing demand for flat panel displays (FPDs), detector panels and printed electronic devices as well as the increased technical requirements have prompted the manufactures to intensify their inspection and testing efforts in order to succeed in the market [1]. One possibility to carry out such an inspection is to exploit the capacitive coupling between probe electrodes and the conductive parts of the planar electronic devices. By moving the electrodes across the surface of a device a measuring signal is obtained which is proportional to the capacitance and, therefore, allows to resolve the geometry and the device defects. The capacitance mainly depends on the design of the probe electrodes, the distance to the device surface and the configuration of the conductive parts of the device. An accurate analytical model of the capacitance will serve as a flexible tool to study sensor characteristics such as resolution and signal strength, parameter dependencies and to simplify signal post processing. The model presented within this report marks the first step towards an analytical model of the capacitive coupling for devices exhibiting two-dimensional arranged conductor tracks. Here, the focus lies on configurations of parallel arranged conductor tracks. The studied sensor design is adopted from an inspection system prototype which is currently tested on liquid crystal display (LCD) backplanes and detector panels.

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2. General conditions

2.1. Inspection method

Figure 1a shows one electrode of the sensor chip used in the prototype system along with the connection for signal readout. The electrode, in the following referred to as sensor electrode, is encompassed by a lateral shielding which is extended to the full size of the sensor chip (≈ 1 cm²). The distances between the sensor electrodes and the device surface typically lie in the range of 5 μm to 25 μm. To carry out the inspection, an AC voltage signal is applied to the conductor tracks of the devices. While the sensor chip is kept at a fixed distance and moved across the devices, the displacement current

\[ I_{\text{dis}} = C_{\text{sen, track}} \cdot \frac{dU_d}{dt} + U_d \cdot \frac{dC_{\text{sen, track}}}{dt} \]  

is measured. \( U_d \) and \( C_{\text{sen, track}} \) denote the voltage and capacitance between the sensor electrode and the tracks.

2.2. FE simulations

In order to study the sensor characteristics under well-defined conditions and to determine the model parameters, finite element (FE) simulations of the sensor signal based on the nonmatching grid approach [2] were conducted. This method allows for a full incorporation of the sensor movement and reduces the simulation effort drastically, since separate meshes can be generated for the sensor chip and the conductor track region. Figure 1b shows a comparison between measurement and FE simulations for a configuration of conductor tracks of different widths and distances.

To determine the capacitance at the different sensor positions, the charge at the sensor electrode is calculated from the simulation of the electric field distribution while constant voltages (Dirichlet boundary condition) are applied to the tracks. A track thickness of 0.5 μm is assumed.

3. Results

Figure 2 illustrates the effect of a decreasing track distance on the capacitance between the sensor electrode and the central conductor track of a regular track configuration. Additionally, the capacitance of an ideal parallel plate capacitor with plate sizes corresponding to the geometrical convolution of the sensor and track area is shown. For a sensor distance of 5.5 μm, the capacitive coupling between the sensor electrode and the track reduces to the capacitance obtained from the convolution, as the track distance decreases. In contrast, at a distance of 25.5 μm, even for a track distance of 0.5 μm, a distinctive deviation from the convolution is observed, although the configuration can be described as an ideal parallel plate capacitor [3]. For a fixed sensor distance, the charge accumulated at the surface of the sensor electrode is given by [4]

\[ Q_{\text{sen}} = \varepsilon_0 \int E(\mathbf{x}) \cdot d\mathbf{A} = \varepsilon_0 \int E_3(x, z = \text{const}) \cdot d\mathbf{A}. \]
The electric field always incidents perpendicular to the sensor electrode surface, thus, only its z-component \( E_3(x, y, z) \) is different from zero. Due to the parallel arrangement of the tracks and the extension of the lateral shielding, \( E_1 \) is independent of \( y \). A can be expressed by a circle function (half circle) for the radius of the sensor electrode \( \varepsilon_0 x = \mu_m \) and a distance of 25 \( \mu_m \). Track widths and distance are indicated by the grey bars. Curves are offset for clarity.

The movement of the sensor electrode is now included by a shift \( (\Delta x_0) \) of the sensor function yielding the position dependent charge at the sensor electrode,

\[
Q_{\text{sen}}(x_0) = Q_0 \int_{-R}^{R} E_3(x, z = \text{const}) \cdot f_{\text{sen}}(x - x_0) \, dx = Q_0 \int_{-\infty}^{\infty} E_3(x_0 - x', z = \text{const}) \cdot f_{\text{sen}}(x') \, dx'.
\]

\( Q_{\text{sen}}(x_0) \) is equal to the convolution of \( f_{\text{sen}} \) and \( E_3 \), since \( f_{\text{sen}} \) is symmetric and only defined for \( |x| \leq R \). Thus, the problem reduces to the approximation of the electrical field strength in dependence of the geometrical parameters of the track configurations, if other influences e.g., of the sensor electrode gap can be neglected. Figure 3a shows the sensor function \( f_{\text{sen}} \) and the approximations of the electric field strength for a regular track configuration. A comparison between FE simulation and model is shown in Fig. 3b. The results for a track width and distance of 10 \( \mu_m \) are illustrated in Fig. 4a. All simulations are normalized to the capacitance of an ideal parallel plate capacitor encompassing the sensor area. The convolution of the sensor function and the field approximations are normalized to the sensor area. The FE simulations indicate that due to the capacitance to the sensor electrode only the direct neighbouring tracks of a track determine the field distribution, as long as their width is comparable to or larger than

Figure 2: Capacitance of the sensor electrode to the central conductor track of regular track configurations (FE simulation) and of an ideal parallel plate capacitor with plate sizes corresponding to the geometrical convolution of the sensor electrode and track area. Track widths and distance are indicated by the grey bars (NN = next neighbouring). (a) Sensor distance 5.5 \( \mu_m \). (b) Sensor distance 25.5 \( \mu_m \).

Figure 3: (a) Sensor function and approximation of the electric field strength (normalized to the sensor function). (b) Comparison between model and FE simulation for a track width of 50 \( \mu_m \) and a distance of 25 \( \mu_m \). Illustrated for sensor distances of 5.5 \( \mu_m \), 15.5 \( \mu_m \) and 25.5 \( \mu_m \). Track widths and distance are indicated by the grey bars. Curves are offset for clarity.
the sensor electrode size. In this case, the width does not affect the capacitive coupling to the central track. For a sensor distance of 5.5 μm, the field strength can be assumed to vanish at the corners of the neighboring tracks. For larger sensor distances, the reduced capacitance allows the field to spread out leading to cutoff positions (c) in the range of the neighboring tracks (Fig. 3a). Nevertheless, these positions are still well described by linear functions of the track distance. Figure 2a shows that the maximum value of the capacitance does not markedly change, as the track distance is reduced. In terms of a convolution of the sensor electrode area and the electric field strength, this translates to a constant electric field extended to the size of the track. Thus, the field strength in dependence of the track width is modeled correspondingly (b). For larger sensor distances, the constant part has to be reduced in proportion to the sensor electrode distance reaching 50% of the track widths for a distance of 25 μm (Fig. 3a). This leads to a reduction of the maximum value of the capacitance for small track distances, as observed in Fig. 2b. For all sensor distances, the approximation of a linear decreasing field strength (x) yields good results. Only for distances distinctly larger than 50 μm, the linear characteristic has to be replaced by functions of higher order. The ratio between the maximum value of the linear rising and the constant part of the approximated field strength (a/m) is incorporated as an additional parameter (Fig. 3a). For a sensor distance of 5.5 μm, the ratio shows a linear dependence on the track distance, the dependence on the track width can be neglected. For larger sensor distances, the parameter becomes a function of the track width and distance. However, a functional description can easily be obtained, since a well-defined dependence on the geometric parameters is deduced from the FE simulations. Figure 4b finally shows the application of the model to an asymmetric arrangement of conductor tracks. The approximation of the field strength is obtained by using the parameters of the two corresponding symmetric cases.

![Graph](image)

Figure 4: (a) Comparison between model and FE simulation for (a) a track width and distance of 10 μm and (b) an asymmetric arrangement of conductor tracks. Illustrated for sensor distances of 5.5 μm, 15.5 μm and 25.5 μm. Track widths and distances are indicated by the grey bars. Curves are offset for clarity.

4. Conclusion

The capacitance of sensor electrodes designed for the inspection of planar electronic devices to various configurations of parallel arranged conductor tracks is investigated by FE simulations. It is demonstrated that the capacitance, which determines the measuring signals can be modeled based on an approximation of the electrical field strength. The model involves only three parameters exclusively determined by the geometry of the track configurations. For arbitrary configurations of parallel arranged conductor tracks the capacitance is described accurately. As a next step, the model has to be extended to configurations of two-dimensional arranged tracks.

References