Full-wave Analysis and Equivalent Circuit Extraction for Capacitive Touch Panels: Theory and Measurements

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Capacitive touch sensors are indispensable components of the user interface of personal electronic devices such as smartphones, tablet computers and wearable health monitors. These sensors are ordinary circuits, whose usual copper wires are replaced by optically transparent (OT), practically invisible, conductors such as Indium Tin Oxide (ITO).

With the market for personal and wearable electronic devices as competitive as ever, the stricter specifications imposed on touch sensors and other OT circuits test the limits of current design tools, motivating further research on the optimal performance bounds of OT circuits and the topologies that meet those bounds under given fabrication constraints. These topologies, either in ITO or even their opaque version with copper, can be modeled by means of full-wave analysis [Lee et al., *IEEE J. Display Tech.*, vol. 10, no. 5, May 2014] or as multi-conductor transmission lines [C. Paul, *Analysis of Multiconductor Transmission Lines*, Wiley-IEEE Press, October 2007]. However, an important element of touch panel characterization is the accurate incorporation of the user interaction with the panel through appropriate touch models.

This paper makes the following three contributions to the relevant literature: first, we provide a thorough comparison between full-wave and multi-conductor transmission line based touch panel analysis, illustrating how the latter significantly accelerates the analysis of large panels with minimal effects on numerical accuracy; second, we introduce human touch models of varying detail (from anatomical to simple R-C models); finally, we introduce a measurement process for the capacitance matrix of touch panels that is fairly robust, allowing the experimental evaluation of our touch models of several panel geometries.

This work enhances our understanding of the electro-quasistatic physics of touch panels, illustrates the role of full-wave and circuit based analysis in their design and optimization, and, most importantly, introduces experimentally verified human touch models.