An Analysis of Electrode Patterns in Capacitive Touch Screen Panels

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***Abstract*—In the design of capacitive touch-screen panels, electrodes are patterned to improve touch sensitivity. In this paper, we analyze the relationship between electrode patterns and touch sensitivity. An approach is presented where simulations are used to measure the sensitivity of touch-screen panels based on capacitance changes for various electrode patterns. Touch sensitivity increases when the touch object is positioned in close proximity to fringing electric fields generated by the patterned electrodes. Three new electrode patterns are proposed to maximize field fringing in order to increase touch sensitivity by purely electrode patterning means. Simulations showed an increased touch sensitivity of up to 5.4%, as compared with the more conventional interlocking diamonds pattern. Here, we also report empirical findings for fabricated touch-screen panels.**

***Index Terms*—Electrode patterns, projected capacitive touch screen panel.**

I. Introduction

BURGEONING home and portable computing has dramatically increased the demands for touch screen panels (TSP) in the form of mobile phones, tablets, mobile computing, and home appliances. As a result, there has been a significant drive to develop increasingly sensitive TSPs.

Since the early generations of touch screen devices, which employed resistive technology, new methods using capacitive [1], infrared [2] and surface acoustic wave [3] technologies have been developed. Today, projected capacitive TSPs dominate the market due to their durability, optical clarity and multitouch capabilities [4].

Nonetheless, projected capacitive TSPs have their limitations. Such devices need to detect changes in capacitance as small as a few fF. These signals can be easily masked by external electromagnetic interference or noise, the bulk of which originates from the display underneath the touch panel. This results in low signal-to-noise ratios (SNR), which hinders the detection of fine point objects such as styluses [4].

In addition, screen resolution is limited as scan times for capacitive TSPs scale rapidly with the sensor matrix size [5], producing a trade-off between response time and touch resolution. One potential solution here is to employ sub-pixel interpolation between touch detection points [6]. This, however, requires sufficient SNR to achieve reasonable interpolation accuracies.

To improve the SNR, enhanced noise immunity circuits have been developed [7]–[9]. Alternatively, touch sensitivity can be improved via patterning sensor electrodes [10]–[12]. Most of these electrode pattern designs are proprietary and little literature is available on the design process.

In this paper, the following are discussed. Section II covers a brief overview of the operation of projected capacitive TSPs. Section III presents our simulation method to analyse the relationship between electrode patterns and touch sensitivity. New electrode patterns are then proposed in Section IV. An experimental method to measure touch sensitivity corresponding to the designed electrode patterns is presented in Section V, along with the experimental results.

II. Overview of Projected Capacitive Technology

Projected capacitive TSPs typically consist of a dielectric layer coated with electrode lines on each side, as shown in Fig. 1(a). The electrodes are usually made of indium tin oxide or fluorine tin oxide, due to their concurrent high transparency ($>$ 95% @ 550 nm) and high electrical conductivity ($<$ 100 ohms/sq).

The electrodes are biased and are termed the driving electrodes. Those on the remaining side are connected to a sensing circuit, and are henceforth termed the sensing electrodes. This stimulates a uniform electric field with fringing fields at the electrode intersections, as illustrated in Fig. 1(b). Both fields contribute to the mutual capacitance between the electrodes and each electrode intersection corresponds to a touch coordinate.

When a touch is applied, the conductive object interacts with the fringing fields, causing them to shift. This reduces the mutual capacitance as shown in Fig. 1(c). It is this change in mutual capacitance which is used to determine the location [7].

Typically, electrodes are patterned to improve touch sensitivity and a commonly used design is the interlocking diamonds electrode pattern [4] in Fig. 1(d). This pattern is usually implemented on a single electrode layer using bridge electrodes at the overlapping regions between the driving and sensing electrodes, as shown in Fig. 1(d). These bridge electrodes are separated from the driving electrodes by a dielectric material [13].

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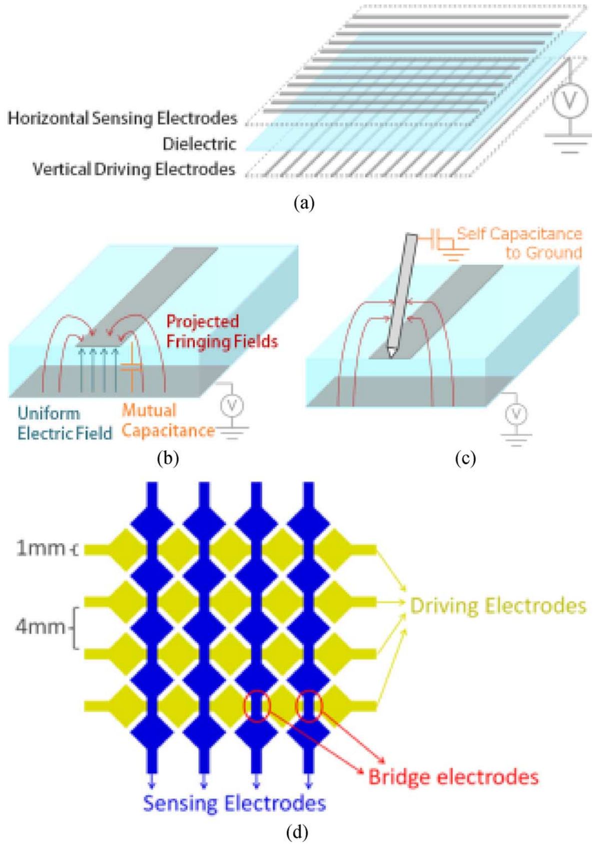


Fig. 1. (a) Layers in a typical capacitive touch panel design. (b) Electric field between driving and sensing electrodes without touch object. (c) Electric field between driving and sensing electrodes with touch object. (d) Interlocking Diamonds electrode pattern design.

III. Electrode Pattern Analysis

In our analysis of the electrode patterns, simulations were first undertaken using COMSOL Multiphysics (v. 4.3a) to assess how the geometry of conventional interlocking diamonds electrodes affects touch sensitivity. Fig. 2(a) and (b) show a modeled 3×3 diamond TSP. The change in capacitance between the driving (yellow) and sensing (blue) electrodes due to the introduction of a stylus, ΔC, was recorded. The simulation was repeated with the stylus positioned at 289 locations around the central touch coordinate as illustrated in the 17×17 dot array in Fig. 2(c). Table I shows the simulated data. A 2D Gaussian is fitted and the peak amplitude used as a measure of touch sensitivity.

Similar simulations for rectangular electrode patterns were also considered, the results of which are likewise presented in Table I. The TSP with the interlocking diamonds pattern has a touch sensitivity some 11% higher than that of the rectangular pattern.

For comparison, we plot the magnitudes of ΔC for the interlocking diamonds pattern in Fig. 3(a) with the geometry of the electrode pattern in Fig. 3(b). There is a strong correlation between the high touch sensitivity regions and the location of fringing electric fields, or where edges of both electrodes meet as highlighted (red) in Fig. 3(b).

Simulations corresponding to the resultant electric field plots in Fig. 3(c) and (d) produced ΔC magnitudes of 10.33 fF and

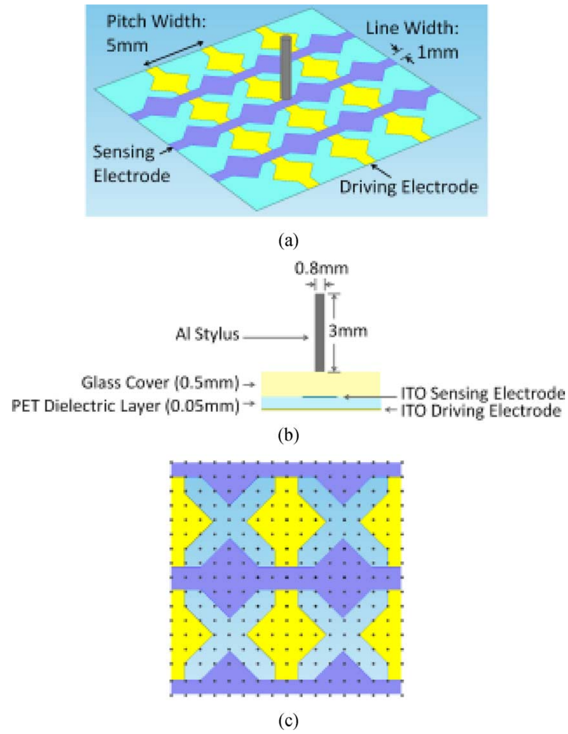
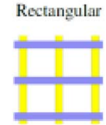
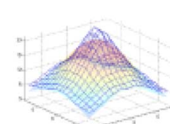
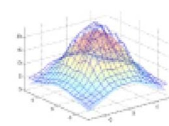


Fig. 2. (a) 3D view of simulation model. (b) Cross-sectional view of simulation model. (c) Different stylus locations.

TABLE I
Simulation Results for Rectangular and Interlocking Diamonds Electrode Patterns.

Electrode Pattern	3D Plots of ΔC values against Stylus Locations & Best-fit Gaussian	Best-fit Gaussian Parameters
Rectangular 		Peak Amplitude = 21.196fF $R^2 = 0.9511$
Interlocking Diamonds 		Peak Amplitude = 23.544fF $R^2 = 0.9392$

17.62 fF, respectively. A detailed look at these figures shows that there is a larger interception, and hence, distortion, of the electric field lines between the driving and sensing electrodes when the stylus is nearer to a fringing field, thus resulting in a larger change in capacitance of about 70%.

IV. Electrode Pattern Design

The analysis of the interlocking diamonds design demonstrated, unequivocally, that touch sensitivity increases near fringing fields. By exploiting this principle, we have developed three new electrode patterns (termed; 1-square, 4-square, and 5-square), designed to maximise the number of such fringing fields and hence increase touch sensitivity. These patterns are displayed in Fig. 4(a). The simulations in Section III were repeated for these new patterns and their simulated touch

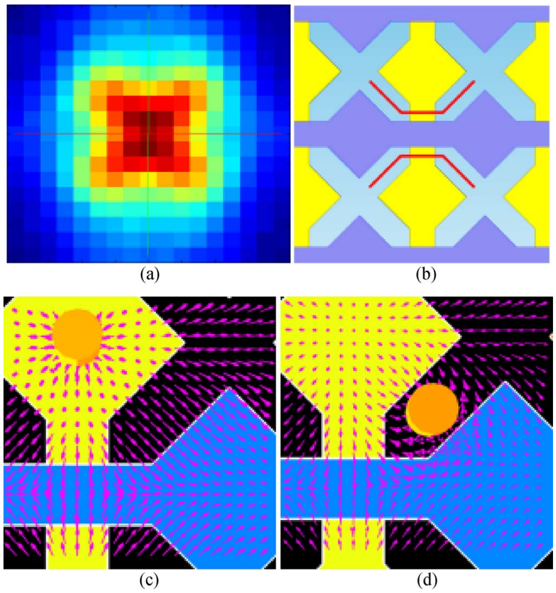


Fig. 3. (a) 2D Plot of ΔC values from simulations against stylus location. (b) Loci of fringing fields in interlocking diamonds pattern. (c) Electric field of TSP with stylus away from fringing field. (d) Electric field of TSP with stylus near to fringing field.

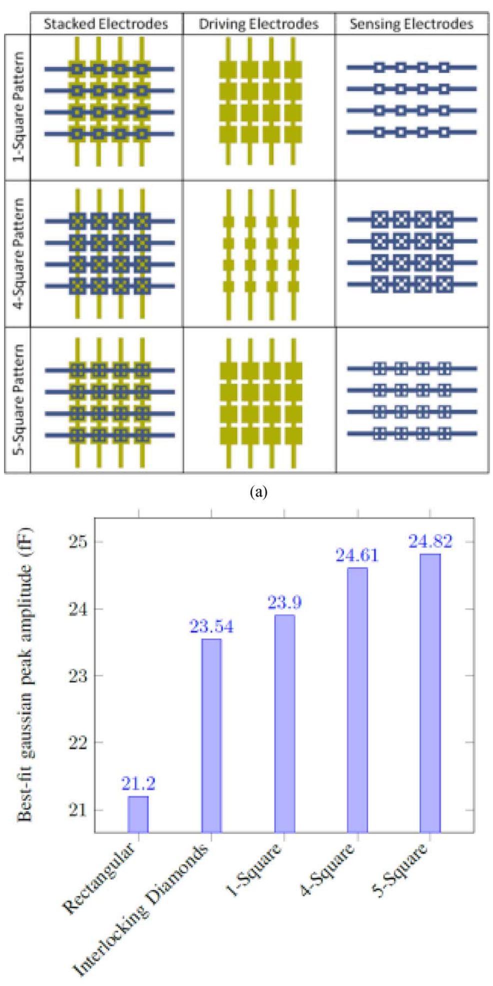
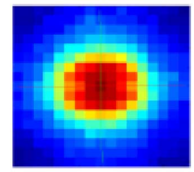
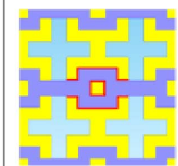
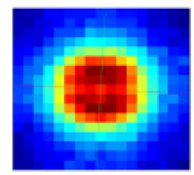
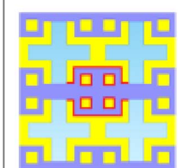
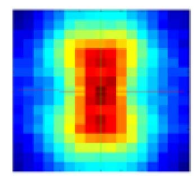
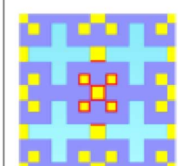


Fig. 4. (a) New electrode pattern designs. (b) Touch sensitivity for each electrode pattern from simulation results.

TABLE II
COMPARISON OF 2D PLOTS OF ΔC VALUES WITH LOCI OF FRINGING FIELDS FOR VARIOUS ELECTRODE PATTERNS.

Electrode Pattern	2D Plots of ΔC values against stylus locations	Loci of fringing fields
1-Square		
4-Square		
5-Square		

sensitivities are compared in Fig. 4(b). The simulation results for the newly designed electrode patterns indeed showed an increased touch sensitivity of 1.5%, 4.5%, and 5.4% for the 1-square, 4-square, and 5-square electrode patterns, respectively, as compared to the touch sensitivity for the interlocking diamonds. This agrees with our expectations since the newly designed patterns have higher densities of fringing fields which result in higher touch sensitivity. However, implementing these patterns on a single electrode layer may not be feasible due to the large overlapping regions between the driving and sensing electrodes.

As exemplified in Table II, there is a correlation between the high touch sensitivity regions and the loci of the fringing fields, which corroborate our hypothesis that touch sensitivity increases when the touch object is nearer to fringing fields.

V. EXPERIMENTAL METHOD AND RESULTS

In order to verify our simulations, TSPs with interlocking diamonds and 5-square electrode patterns were fabricated and their touch sensitivity compared. TSPs were fabricated by thermally evaporating patterned Au electrodes on both sides of glass substrates. Contact wires were attached using silver dag. Typical TSPs are shown in Fig. 5(a) and (b); the dimensions of these samples are shown in Fig. 5(c) and (d).

A. Experimental Method

A Keithley 4200 was used to measure the capacitance between the pair of driving and sensing electrodes corresponding to the (2,2) touch coordinate, as shown in Fig. 6(a). This was done by applying a 50 kHz AC voltage sweep at intervals of 50 mV between -1 V and 1 V to the driving electrode.

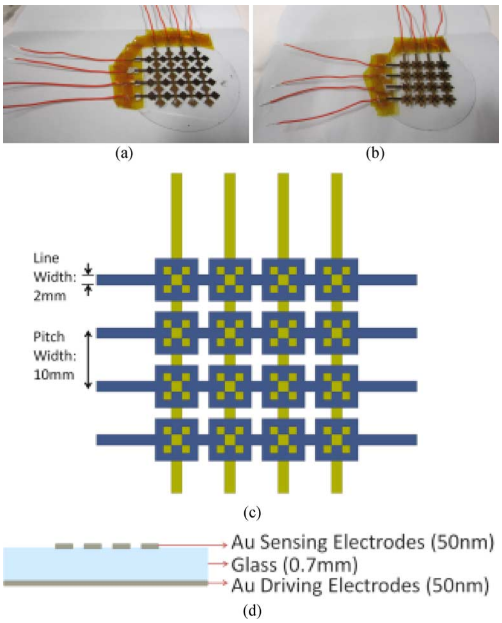


Fig. 5. (a) Fabricated TSP with interlocking diamonds electrode pattern. (b) Fabricated TSP with 5-square electrode pattern. (c) Top view of fabricated TSP. (d) Cross-sectional view of fabricated TSP.

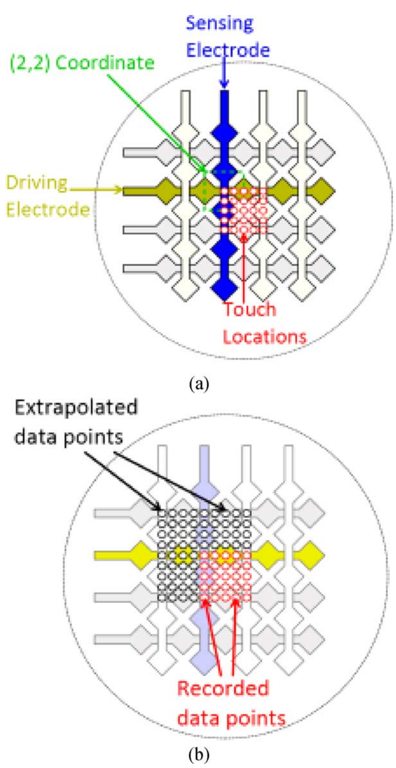
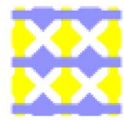
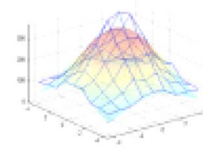
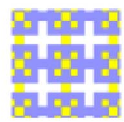
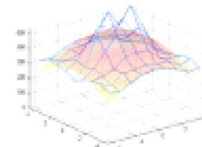


Fig. 6. (a) Touch locations in experimental setup. (b) Extrapolated data points for experiment.

Touch events were applied at several positions around the (2,2) coordinate [Fig. 6(a)], and the measurement process was repeated at each position. The changes in capacitance, ΔC, were then calculated for each touch location.

TABLE III
EXPERIMENTAL RESULTS FOR MOCK TSPS WITH INTERLOCKING DIAMONDS AND 5-SQUARE ELECTRODE PATTERNS.

Electrode Pattern	3D Plots of ΔC values against Touch Locations & Best-fit Gaussian	Best-fit Gaussian Parameters
Interlocking Diamonds 		peak amplitude = 374.832fF $R^2 = 0.9159$
5-Square 		peak amplitude = 537.056fF $R^2 = 0.6859$

B. Experimental Results

ΔC for each TSP are plotted against touch locations and tabulated in Table III. Due to the clear morphological symmetry, additional data points, as shown in Fig. 6(b), were extrapolated and included in the plots.

The 5-square TSP had a touch sensitivity which is 43% higher than that of the interlocking diamonds TSP, in agreement with our earlier simulation results. The differences in magnitudes between the experimental results and the simulation results are most likely attributed to the difference in electrode dimensions in the fabricated TSPs and those in the simulations. Moreover, different touch objects, whose intrinsic conductivity adjust the sensitivity, were used in the simulations and the experiment.

VI. CONCLUSION

Through simulations and empirical analysis of conventional interlocking diamonds capacitive TSP patterns, we have shown that there is a correlation between the presence of fringing fields and touch sensitivity. Based on this, three new electrode patterns were designed and presented. Further simulations showed that the designed electrode patterns indeed resulted in improved touch sensitivities by up to 5.4%. Experiments done on a fabricated TSP with the designed 5-square electrode pattern demonstrated an improvement in touch sensitivity as well, thus supporting the simulation results.

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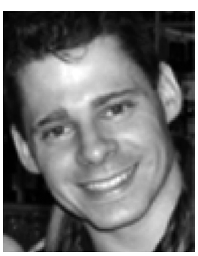

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