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Implementation of a High-Performance Touch Controller and Differential Sensing Circuit

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Abstract— **Projected capacitive touch panels have been widely used in many mobile application systems such as smartphones and tablet PCs. We fabricated projected capacitive-type touch sensors using printed circuit boards. It has equivalent parasitic capacitive loads with a 10” touch panel. In this paper, we discuss projected capacitive touch technologies and their high-performance touch controllers. We introduced the touch system and built a controller unit for touch applications using a 32-bit microcontroller. A fully differential circuit was designed for an analog front end. The controller unit is implemented using a MicroBlaze core on a Field-Programmable Gate Array (FPGA). A Virtex-4 Xilinx FPGA is used for the controller unit.**

Keywords-component; Touch; Multi-touch; Sensor; Projected capacitive touch; Touch controller

I. INTRODUCTION

Recently, smart devices such as the iPhone and the iPad have become very popular [1]. In the smart devices domain, touch technology should satisfy several requirements, including multi-touch, soft feel, low power consumption, and thinness. Since the projected capacitive touch senses the difference in capacitance before and after touch, it has several advantages such as thinness, transparency, softness, and suitability for a touch solution. The projected capacitive touchscreen allows multi-touch sensing resulting in lower degradation of display quality. Since the projected capacitive touchscreen utilizes mutual capacitance that changes based on touch, the touchscreen has advantages such as thinness, transparency, softness, and it can be used in personal electronic devices [2]. With the increase in the size of capacitive touchscreen displays, touchscreens have larger parasitic capacitances [3]. This means that the touch sensing circuits must drive and sense touch electrodes with higher load capacitances of touch sensors. In addition, the processor in the touchscreen has to process more touch workloads while maintaining an acceptable processing time, reporting rate, and power efficiency.

In the touch applications in a smartphone, the touch module has a separate processor from the main high-performance processor (application processor). However, the touch controller should be able to control analog sensing circuits and interface with an Analog-to-Digital Converter (ADC) and a main high-performance processor. The touch panel needs to support multiple simultaneous touch points (~10 points), and the processing time per touch point has to be short. Currently available capacitive touchscreens used in smart mobile devices that have ~400 capacitive nodes typically have a 60–100 Hz report rate and a 10–16.7 ms touch processing time. In addition, the controller unit in the touchscreen application has to perform control and data processing tasks. Control tasks include timing control for touch sensors, sensing circuits, and system interfacing with touch position results using a serial interface circuit.

Conventional touch ICs use an 8 or 16-bit microcontroller [4-6]. For a large touchscreen and simultaneous multiple touch point calculations, the touch system requires a high-performance microcontroller that supports a high-speed clock and a 32-bit Reduced Instruction Set Computer (RISC) architecture [7]. In this work, we propose a touch controller system, with a differential sensing circuit, to sense mutual capacitance of a touch sensor, and a controller design based on a 32-bit microcontroller.

II. MICROARCHITECTURE FOR THE TOUCH CONTROLLER AND TOUCH PANEL

A. Architecture of the Touch System

A typical touchscreen comprises three parts: a touchscreen panel, an Analog Front End (AFE), and a touch controller unit. Figure 1 shows a simplified block diagram of the touch system. The projected capacitive touchscreen measures mutual capacitance. Mutual capacitance is generated between the transmitting electrodes along the x-axis and the sensing electrodes along the y-axis. Mutual capacitance in the touchscreen usually has a very small value, a few tens of picofarads. When a finger touches the screen, it acts as an electrode and decreases the mutual capacitance by altering the overall electric charge distribution on the electrodes. The touch controller consists of a scalar processor, a touch timing controller, a high-speed block-memory, and peripheral units such as a Serial Peripheral Interface (SPI) and a UART interface. The RISC core performs scalar operations and peripheral control. The touch accelerator oversees the peripheral units and the timing controller unit. The system is implemented on a Xilinx FPGA. The touch controller is designed to have a one clock latency memory system using block Random Access Memory (RAM) for minimum delay.

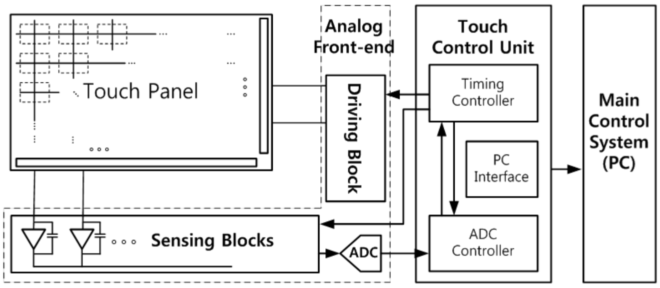

Figure 1. Diagram of a conventional touch system.

B. Projected Capacitive Touch Panel

Currently, the most common types of projected capacitive touch panels use add-on technology. Sensors are placed on separated films, glass substrates, or panels. “Add-on” means that the separated touch panel is added onto the display panel (out-cell). A touch sensor is an array of Indium Tin Oxide (ITO) transparent conductors. ITO is used for its high transparency and good electrical characteristics. For the sensor pattern, a diamond shape is widely used for its geometrical advantages [8]. Conventional add-on touches have either two substrates, or one substrate and a cover plate as shown in Figure 2. The thickness of the touch substrate and cover plate is normally 0.5–1.2 mm, and the entire module is 1–2.4 mm thick. There are many subclasses of the add-on type, such as GFF, GG, G1F, and G2 (G and F represent glass and film, respectively). For example, GFF implies that there is a cover Glass (G) and x/y electrodes are on each Film (F) substrate. In order to reduce cost and thickness, companies developing touch panels are progressing toward cover-plate integrated touch panels that do not require a separate G2 sensor [9].

A projected capacitive-type touch uses two values: self-capacitance and mutual capacitance. Self-capacitance is an amount of electrical charges between individual ITO electrodes (horizontal and vertical electrode) and the ground. When a finger touches a touch module, self-capacitance increases because it behaves as another electrode along with the sensor electrode. The increased value is relatively higher than that of the mutual capacitance. In this work, the self-capacitance increased by a finger is under 10 % of the capacitance for a one-channel ITO electrode.

When a user touches the module, the finger acts as another charge conducting electrode and the mutual capacitance between the two electrodes (driving and sensing electrode) decreases because the total electric field is altered by the finger; an initial electric field is conducted from the transmitting electrode to the sensing electrode before the finger touches the module [10].

The AFE circuit converts Cm to voltage, as shown in Figure 2, which shows a fully differential sensing circuit and a timing diagram. The circuit is composed of a fully differential amplifier, integration capacitors, and switches. The circuit also has a 1-pF feedback capacitor, and the Cm value decreases by 10% when a finger touches the touchscreen. The output voltage variation when a finger touches the panel is in the range of 20–50 mV, as obtained from the Simulation Program with Integrated Circuit Emphasis (SPICE) simulation.

III. DESIGN OF THE TOUCH CONTROLLER UNIT

The touch controller unit as shown in Figure 3 consists of a microcontroller (MicroBlaze), a 32-kB data and instruction memory, a 32-bit Instruction/Data Local Memory Bus (ILMB, DLMB), an Data-side On-chip Peripheral data Bus (DOPB), an Universal Asynchronous Receiver/Transmitter (UART), an AFE timing controller, an ADC interface, and an SPI controller.

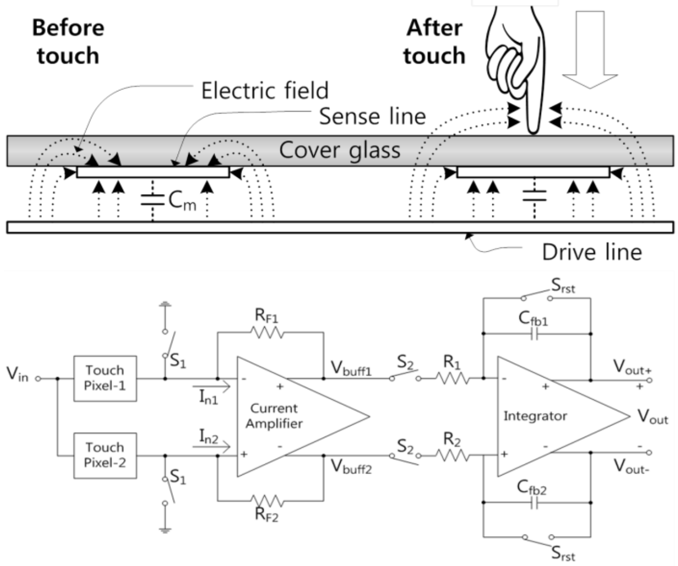

Figure 2. Mutual capacitance and differential sensing circuit.

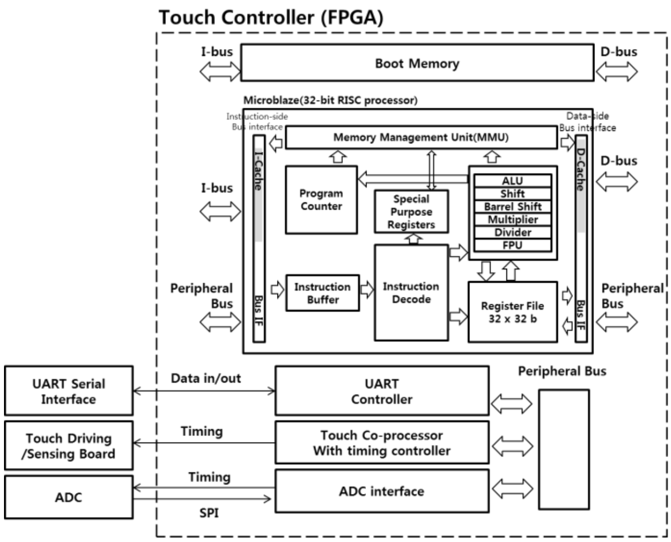

Figure 3. Architecture of the Touch controller.

Microblaze is a soft processor core from Xilinx, which has RISC architecture. MicroBlaze has thirty-two 32-bit general-purpose registers, a 32-bit instruction word with three operands and two address modes, a 32-bit address bus, a single-issue pipeline, and an optional floating-point unit [11]. The touch timing controller and other peripheral units are connected to the microcontroller using DOPB. The OPB bus includes an OPB arbiter that incorporates the features outlined in the IBM on-chip peripheral bus arbiter core for 32-bit implementation [12].

Mutual capacitance voltage is converted into digital data using an ADC. The digitized Cm is transferred to the SPI. The SPI controller decides the conversion sequences in the ADC. To synchronize the ADC with the transmitting and sensing circuits in the AFE, the touch co-processor generates a “Start” signal. At the rising edge of the “Start” signal, a stimulus pulse is generated at the driving circuit, and the pulse is applied to the driving channels on the touchscreen panel. The stimulus pulse forms mutual capacitances between the driving and sensing electrodes on the touch panel. The AFE contains eight-channel fully differential sensing units. All the switches in the AFE are controlled by the timing controller in the touch controller unit.

IV. Evaluation Results

A. Touch panel implementation

We fabricated the touch panel using printed circuit boards. The panel has an equivalent panel load of a 10” touch panel. The panel load is 1.5 nF in the sensing channel and 2.5 nF in the driving channel. There are 15 driving channels and 20 sensing channels. The analog circuit board, with an AFE, has driving and differential sensing blocks. For the high parasitic capacitance of 1.5 nF in the sensing electrodes, an 18 V high-level driving voltage is used. The driving and sensing timing controller and serial interface controllers are implemented on a Xilinx FPGA. For analog voltage to digital data conversion, a 16-bit ADC is used. Sensing circuits that are implanted on the printed circuit board are shown in Figure 4.

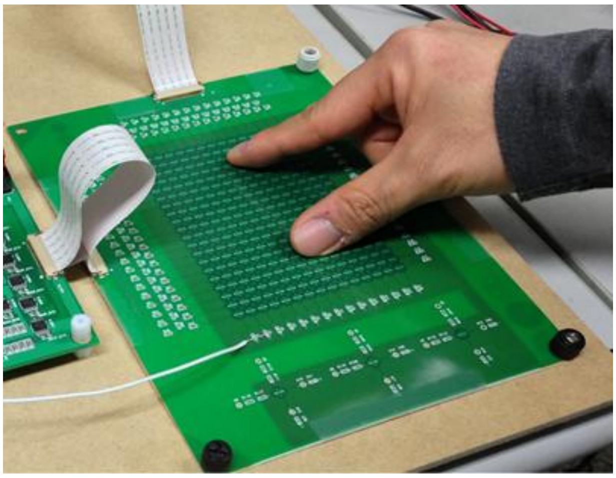

Figure 4. Touch panel with the equivalent panel load and a 10” touchscreen.

B. Timing Controller

Timing simulation results for the timing controller and the ADC interface are shown in the Figure 5. The Xilinx ISE simulator is used for the timing simulation. For the driving circuit, an excitation pulse timing is generated and switch control signals are synchronized with the excitation pulse. Sensing circuits have differential multiplexers and the timing controller generates their control signals as shown in the Figure 5.

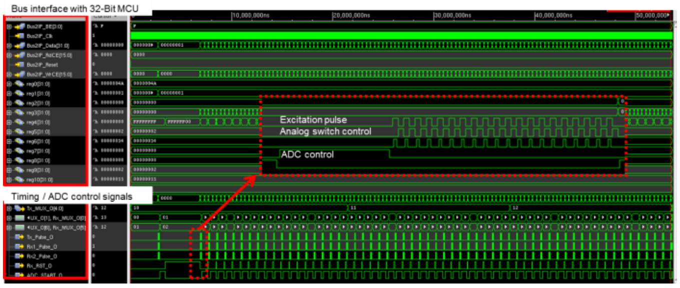

Figure 5. Timing simulation results for the proposed touch controller.

Measured timing results are shown in Figure 6. The switch 1 pulse has the same pulse width and negative phase as the driving pulse. The switch 2 pulse has the same phase but a narrower pulse width as compared to the driving pulse.

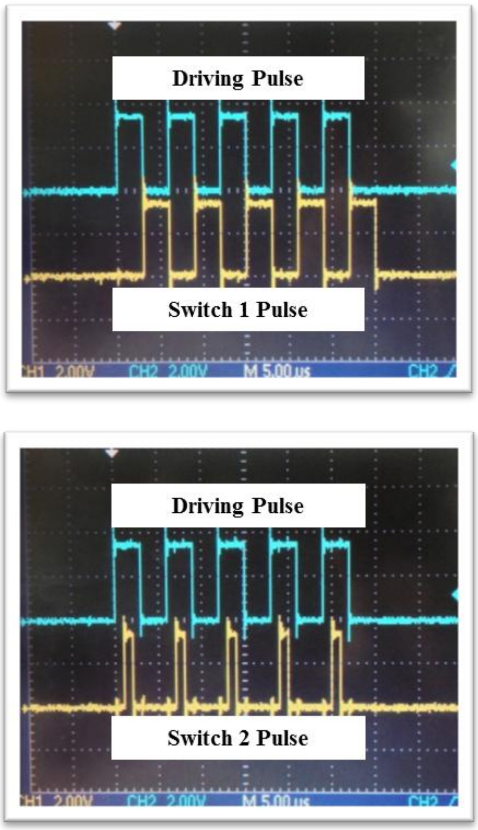

Figure 6. Measured timing signals of the driving circuit and switch control signals.

C. Differential Sensing Circuits

Differential sensing circuits are implemented on the printed circuit board as shown in Figure 7. It consists of 30:2 multiplexers, switches for the switched capacitor circuit, two-stage amplifiers, and a capacitive to voltage integrator. Output of the integrator is connected to the ADC board. Processed results of the touch panel's raw data for two finger touch, is shown in Figure 8.

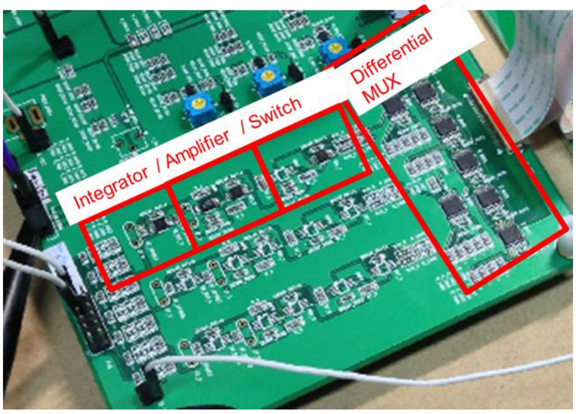

Figure 7. Photo of implemented differential sensing circuit.

The touch data is processed similar to digital image processing. The touch controller has digital image-processing blocks such as thresholding logic, digital median filters, digital Finite Impulse Response (FIR) filters, and dedicated position-calculating logics. These image processing blocks use floating-point operations, and their accuracy and speed affect the accuracy of the touch position and touch response time. For high accuracy of the touch, the touch controller uses floating-point operations. The touch image data has a poor Signal-to-Noise Ratio (SNR); thus, the touch controller must have dedicated algorithms to enhance the touch SNR.

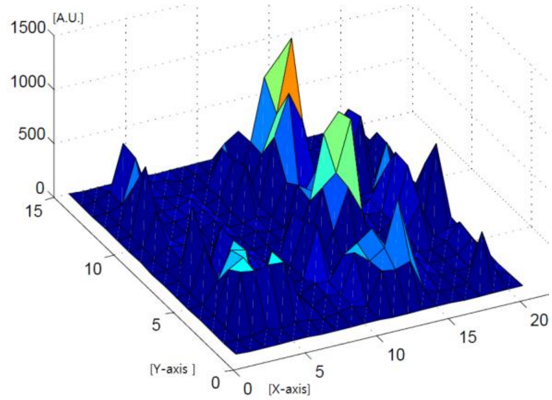

Figure 8. Processed Multi-touch (using two fingers) recognition with the proposed touch system.

V. CONCLUSIONS

In this work, we introduced a projected touch-screen system. We presented a high-performance touch controller that can detect multi-touch positions. The processor implemented on an FPGA using a touch timing controller, serial interface controller units, and a 32-bit RISC controller. With an analog driving and sensing board, we evaluated the touch performance of a 10" touch panel. Mutual capacitances were measured for multi-touch sensing and a touch algorithm was used to calculate multi-touch points. For the sensing circuit, a fully differential sensing circuit was designed.

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