OFDM and TDM Based Sensing Method for Large Projected Mutual-Capacitance Touch Screens

M.G.A. MOHAMED, A. N. RAGHEB, Hossam HASSAN, and HyungWon KIM†
School of Electrical Engineering and Computer Science, Chungbuk National University
{mgamohamed, ahmed, hossam, hwkim}@cbnu.ac.kr

***Abstract*—This paper presents a new technique for reading out projected mutual capacitance touch screen panels. It models touch screen panel as a communication system. Orthogonal frequency division multiplexing (OFDM) is used along with time division multiplexing (TDM) to read out all channels of touch screen panels. Different carrier frequencies are applied to touch screen panel concurrently using OFDM, while the sensing lines are sensed sequentially using TDM. The proposed technique ensures a high frame scan rate by using simultaneous driving signals, and it provides high signal to noise ratio (SNR) by avoiding frequency band with high noise power. Simulation results demonstrate a SNR improvement of 8.2 dB by selecting adequate carrier frequencies.**

I. INTRODUCTION

Recently, large mutual capacitive touch screens receive increasingly high demand for PC monitors, medical devices and electronic whiteboards. However there are a lot of issues with large touch screen panels (TSPs) in achieving acceptable signal to noise ratio (SNR) and high frame scan rate [1, 2].

Many mutual capacitive TSPs usually have diamond transparent metal plates connected serially to form a crossbar architecture. Horizontal and vertical lines are isolated, and form a mutual capacitance. TSPs usually employ thin transparent electrodes in various patterns and materials to optimize the touch sensitivity. When a human body comes close to the TSP, the mutual capacitance amount between the electrodes changes. Therefore the touch position is determined by measuring the changes in all the mutual capacitance values [1].

For small TSPs, the conventional touch screen controllers achieved accepted performance [3]. However large TSPs experience larger display and power supply noise, and have low scan rate because of large number of cells. Concurrent driving methods [4, 5] and differential sensing method [6] have been used to increase the scan rate and SNR.

In this paper, we model touch screen controller system as a communication system. We then introduce to the TSP detection system with two well-known communication methods: orthogonal frequency division multiplexing (OFDM) and time division multiplexing (TDM).

II. TOUCH SCREEN PANEL

A. Touch screen panel modeling

Fig. 1(a) shows electrode pattern of conventional two layer projected capacitance TSP as an example. It has diamond shape transparent Indium Tin Oxide (ITO) plates. These plates are connected serially to form TX lines and RX lines. A TSP can be modeled by a matrix of cells. Each cell has its mutual capacitance (C_M), self-capacitances (C_s) and wire resistances (R_{TX} , R_{RX}) as shown in Fig. 1(b).

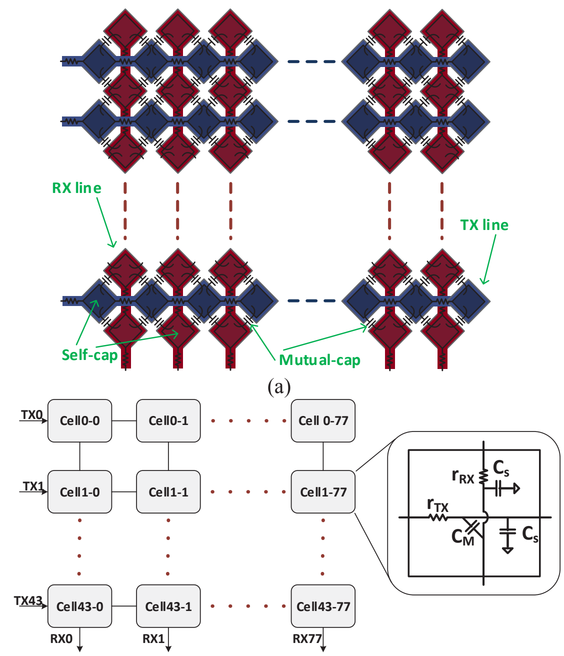

Fig. 1. Touch screen panel model. (a) Diamond metal plate structure for conventional two-layer TSP. (b) Circuit model for TSP.

Mutual capacitive TSPs usually show the behavior of a band pass filter. It has pass band gain which is affected by the value of the mutual capacitance as shown in Fig. 2. Self-capacitances with wire resistances play the role of a low pass filter and mutual capacitance plays the role of a high pass filter. Fig. 2 shows the measured transfer function of a selected cell in the middle of a 23-inch commercial TSP used in this paper.

B. TSP for testing

While the proposed method can be applied to various types of TSPs, we used a 23-inch commercial TSP with two layer of ITO plates. It consists of 44 TX lines and 78 RX lines forming 44 x 87 channels (also called cells). The parameters used in the model to match the commercial TSP under experiment are C_M = 3.5 pF (touch) and 5 pF (no-touch), Cs = 15 fF, and $r_{TX} = r_{RX}$ = 30 Ω. In our TSP model, the mutual capacitance of each cell decreases when there is a touch event resulting in the reduction of the output voltage. Fig. 2 shows the difference between the touch and no-touch cases.

† The corresponding author is HyungWon Kim.

This work was supported by the Center of Integrated Smart Sensors funded by the Ministry of Science of Korean Government, ICT & Future Planning as Global Frontier Project" (CISS-2014011066). This work is also supported by the industry-university technology development fund sponsored by LINC project of Chungbuk National University (201310645).

978-1-4673-8364-6/16/$31.00 ©2016 IEEE

III. TSP AS A COMMUNICATION SYSTEM

A. System Modeling

TSP can be controlled by OFDM signals along with TDM reception, which resembles a communication system model as shown in Fig. 3. Sine waves with orthogonal frequencies are used as sub-carrier signals, which drive all TX lines concurrently. The change in the mutual capacitance represents how close the touch is and it resembles the message signal $m(t)$ in communication system. TSP itself works as a modulator. It conducts amplitude modulation using the message signal (touch/no-touch) on the corresponding sub-carrier signal.

Reading out one RX line produces a complex signal that is the sum of all sub-carriers after being modulated by all cells (channels) located along the RX line. Therefore the TSP behaves as an OFDM modulator. With the process of an OFDM demodulator for each RX line, we employ a TDM receiver. We implement the TDM receiver with RX switches, which reads one RX line at a time.

The sub-carrier signals of the OFDM model are orthogonal in frequency, and so the receiver can reconstruct all the sub-carriers without interference. TSPs can also benefit from this powerful property of OFDM communication systems. One of the most important benefits is its concurrent process of transmitting and receiving multiple sub-carriers using a small bandwidth – a significantly smaller bandwidth than the classical frequency division multiplexing (FDM). This enables us to increase the TSP frame scan rate by the order of TX line numbers.

Mathematically, the OFDM signals in both communication system and TSP can be expressed as a sum of the carrier signals multiplied by the message signal. The equation of transmitted

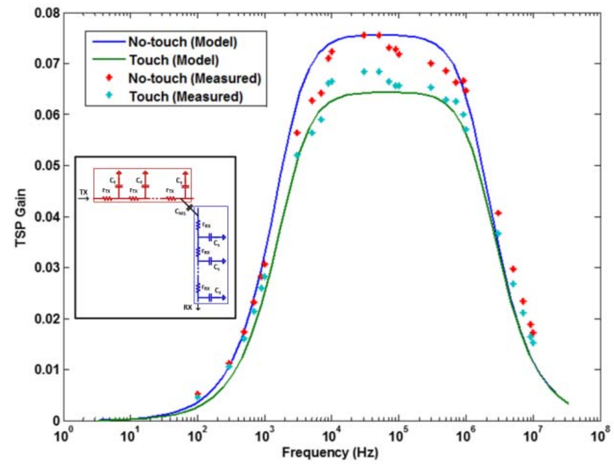

Fig. 2. Transfer function for a selected path on a 23-inches touch screen panel. It has the measured results of the path connecting lines (TX=20 and RX=30) and the simulation results of the model established in cadence environment for the same TSP.

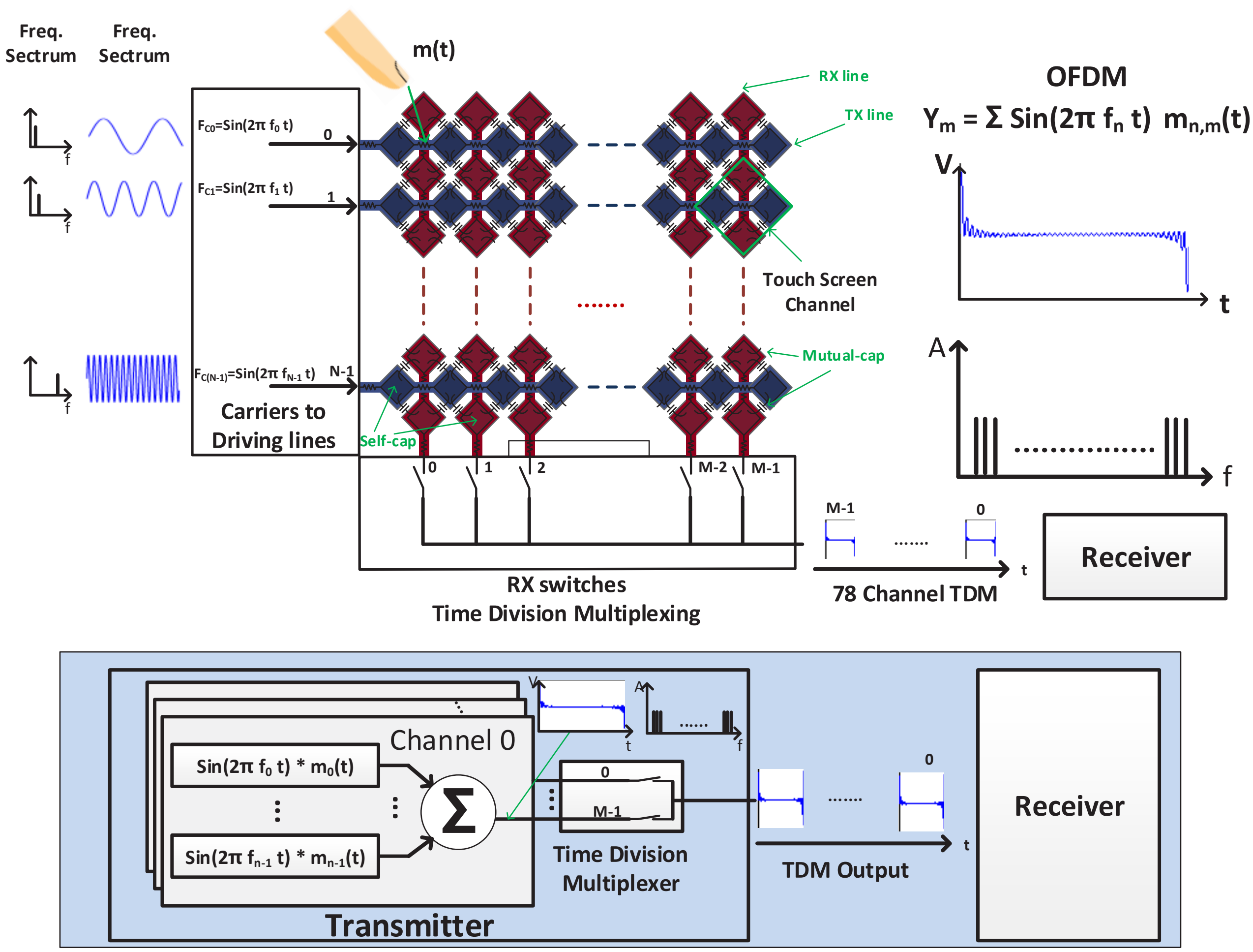

Fig. 3. Touch screen panel controller system as OFDM+TDM communication system.

978-1-4673-8364-6/16/$31.00 ©2016 IEEE

OFDM signal $y(t)$ is:

$$y_m(t) = \sum_{n=0}^{N-1} m_{n,m}(t)\sin(2\pi f_n t) \quad (1)$$

$$m_{n,m}(t) = f\left(C_{M(n,m)}\right) \quad (2)$$

where N and M are the numbers of TX lines and RX lines respectively. $y_m(t)$ is the output at each RX_m line (where, m =0,1,…, M-1). $m(t)$ represents the data (touch strength), which is a function of the mutual-capacitance C_M. The carrier frequency f_n (where, n =0, 1, 2…, N-1) of each TX_n line is an orthogonal sine waves.

In order to read out the entire OFDM signals from each RX line, TDM is conducted using RX switches. Each set of OFDM signals are selected by each RX switch and passed to an OFDM demodulator as expressed by Eq. (3).

$$S(t) = \sum_{m=0}^{M-1} y_m(t)u_m(t) \quad (3)$$

Here $S(t)$ is the final output of all RX-lines produced by the TDM process. $u_m(t)$ represents the switching function of the TDM. Considering the ambient noise $N_m(t)$:

$$S(t) = \sum_{m=0}^{M-1}(y_m + N_m(t))u_m(t) \quad (4)$$

In order to detect the touch strength with high SNR, the sensing circuit needs to extract all the frequency component accurately and minimize the effect of noise.

IV. System Implementation

A. OFDM+TDM Detector

As explained in the previous section, RX lines are sensed sequentially in case of using one sensing circuit which is more applicable for large TSPs because of difficulty in implementation of a large number of sensing circuits on chip.

Regular RF receiver has one tuned filter and one demodulator because only one channel is selected at a time, however in case of TSP, all channels (cells) need to be read out in short time to achieve high scan rate. Therefore simultaneous channel detection is required to reduce the scan time. Fig. 4(a) shows the system implementation with multiple tuned filters in order to read out all channels covering all TX lines simultaneously. In this way, the channels over all TX lines for each RX line are frequency-multiplexed (OFDM), while the channels (cells) over all RX lines for each TX line are time-multiplexed (TDM).

A more efficient implementation of the simultaneous channel detection is using a fast frequency transform (FFT) engine (Fig. 4(b)). An FFT can simultaneously read out all cells over one RX line. It, however, still needs time-multiplexing to read different RX lines.

B. Improvement of frame scan rate

The proposed OFDM+TDM technique can significantly improve frame scan rate of TSP compared to the conventional techniques, which use square wave driving signal. The conventional techniques suffer from a low scan rate due to their sequential driving and channel sensing. In contrast, the proposed technique provides high scan rate by using concurrent

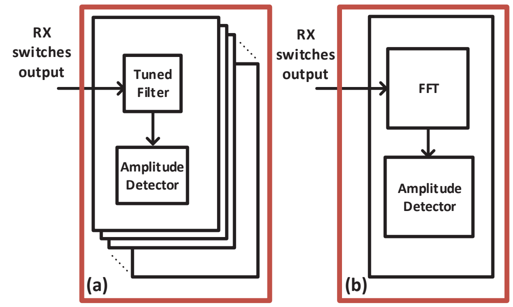

Fig. 4. System implementation of touch screen panel controller using the concepts of OFDM and TDM systems.

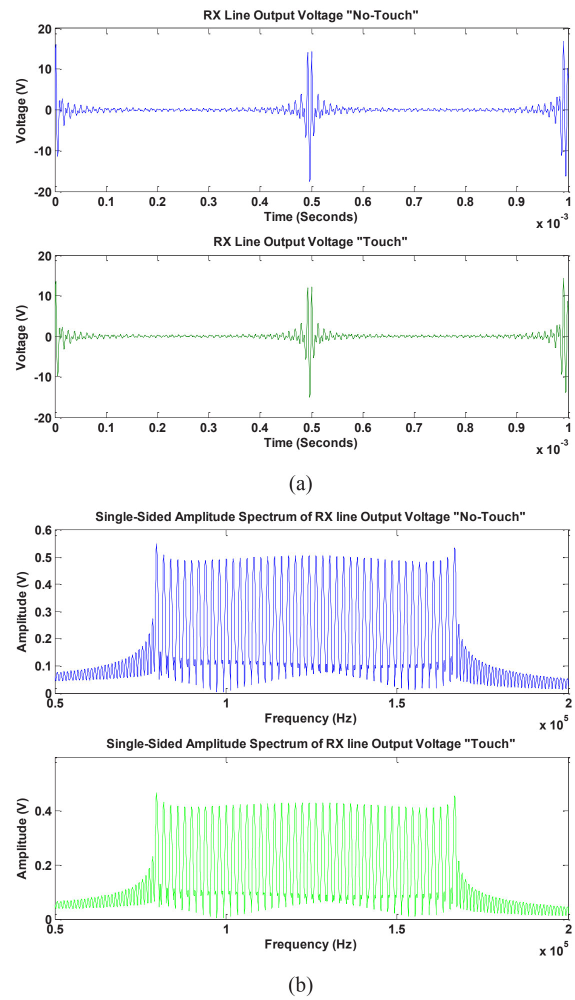

Fig. 5. Simulation results for RX line output with touch and no-touch cases. (a) Time domain signal. (b) Frequency spectrum.

driving scheme based on OFDM. The lower bound of its scan rate is determined by the lowest frequency of its concurrent sine waves. We select the range of the sine waves within the pass band region by analyzing the target TSP as in Fig. 2, so the maximum detection SNR can be achieved.

If we employ only one receiver circuit, the frame scan rate can be expressed by Eq. (5). On the other hand, if we employ N_{rcv} multiple receiver circuits, we can further speed up the frame scan rate. Eq. (6) gives the frame scan rate improvement.

$$frame\ scan\ rate = \frac{f_0}{M} \quad (5)$$

$$frame\ scan\ rate = \frac{f_0}{M} \times N_{rcv} \quad (6)$$

978-1-4673-8364-6/16/$31.00 ©2016 IEEE

C. Improvement of SNR

Overcoming ambient noise is the most challenging issue in touch screen controller design. The proposed technique provides an efficient method of avoiding the ambient noise. It selects the frequencies of the sine waves by avoiding the frequencies of the ambient noise. For example, Fig. 6 shows real noise measured from a 23-inch TSP. It shows high noise power at around 20 KHz and 100 KHz. By avoiding the frequency region where the noise is concentrated, we can achieve an improved touch strength and detection SNR.

V. System Performance

We used the model shown in section II for a commercial 23-inch TSP with 44 TX lines and 78 RX lines to demonstrate the performance improvement of the proposed technique. We selected the frequencies of the 44 sine waves (carriers) in the pass band region (Fig. 2) of the TSP to maximize the received signals and the touch strength.

Fig. 5 shows the simulation results of the output of an RX line with sine waves of 80 KHz ~ 168 KHz with a frequency step of 2 KHz applied to all TX lines. To measure the touch strength, we measured two cases. All cell are set to be touched in one case and not touched in the other case. We then calculate the amplitude difference in the frequency spectrum over all selected frequencies.

In order to calculate SNR for the proposed system, we measure the noise variance at each RX line without driving sine waves at TX lines. As the noise measurement in Fig. 6 illustrates, we observed that the frequency response of noise shows a static pattern. Therefore we can select a frequency range in the region where the noise power is lowest.

By summing up the measured noise and the simulation results of RX line output, and using the equations proposed in [7] to calculated the SNR, Fig. 7 shows the SNR values for all cells driven by the selected frequencies. In this case the lowest SNR is 51.35 dB.

Next we selected a different frequency range in order to improve SNR. Fig. 8 shows the SNR values for all cells with frequency range of 300 KHz to 388 KHz with a frequency step of 2 KHz. In this case the lowest SNR is 59.55 dB. This experiment shows an improvement 8.2 dB in the worst case SNR by analyzing the noise pattern and selecting a better frequency range. In addition, compared to the conventional method [8], the proposed technique gives an SNR enhancement of 13.1 dB. Table I shows a comparison with a conventional technique [8].

VI. Conclusions

In this paper, we proposed a scanning technique for projected mutual capacitance touch screens using a communication system model. Orthogonal frequency division multiplexing along with time division multiplexing are used to read out all cells of touch screen panel. An OFDM receiver can be used to detect the change in carrier amplitude which represents the mutual capacitance change. Simulation results proved that the proposed method improves SNR by selection of adequate carrier frequencies to avoid high noise power.

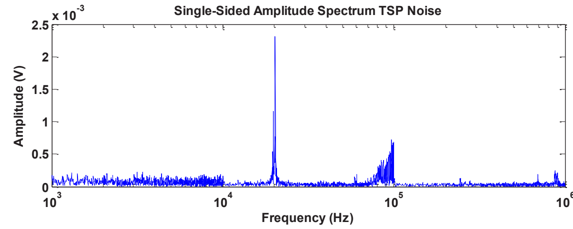

Fig. 6. Frequency spectrum of measured RX line output noise.

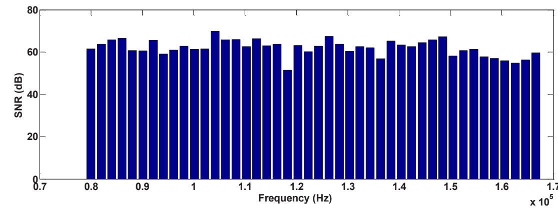

Fig. 7. Calculated SNR for the 44 cells located in the selected RX line in case of using carrier frequency in range of 80 KHz – 168 KHz.

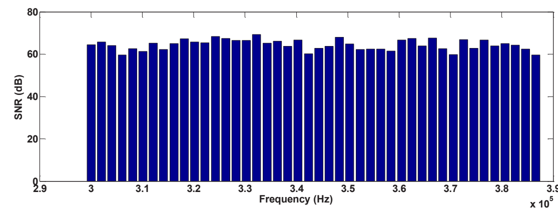

Fig. 8. Calculated SNR for the 44 cells located in the selected RX line in case of using carrier frequency in range of 300 KHz – 388 KHz.

TABLE I
COMPARISON OF USING SQUARE WAVE DRIVING AND OFDM+TDM

	Conventional Method [8]	Proposed Method
Excitation signal	Square wave	Sine wave
Scan Rate	$\frac{f \times N_{rcv}}{N_{integration} \times N_{tx} \times N_{rx}}$	$\frac{f_0}{M} \times N_{rcv}$
SNR Improvement	Increasing no. of integrations (reducing scan rate)	Avoiding noise band
	Differential sensing	

References

[1] G. Barrett and R. Omote. (2010) Projected-Capacitive Touch Technology. *Information Display*. 16-21.

[2] A. Ng and P. H. Dietz, "The Need for Speed in Touch Systems," *SID Symposium Digest of Technical Papers,* vol. 44, pp. 547-550, 2013.

[3] J.-E. Park, D.-H. Lim, and D.-K. Jeong, "A Reconfigurable 40-to-67 dB SNR, 50-to-6400 Hz Frame-Rate, Column-Parallel Readout IC for Capacitive Touch-Screen Panels," *IEEE Journal of Solid-State Circuits,* vol. 49, pp. 2305-2318, 2014.

[4] M. G. A. Mohamed and H. Kim, "Concurrent Driving Method with Fast Scan Rate for Large Mutual Capacitance Touch Screens," *Journal of Sensors,* vol. 2015, pp. 1-10, 2015.

[5] M. G. A. Mohamed, H. Kim, and T.-W. Cho, "A Fast Sensing Method using Concurrent Driving and Sequential Sensing for Large Capacitance Touch Screens," *Journal of the Institute of Information and Electronics Engineers,* vol. 52, pp. 674-682, 2015.

[6] I.-S. Yang and O.-K. Kwon, "A touch controller using differential sensing method for on-cell capacitive touch screen panel systems," *IEEE Transactions on Consumer Electronics,* vol. 57, pp. 1027-1032, 2011.

[7] "Buttons, Sliders and Wheels :Sensor Design Guide," ATMEL, Ed., ed. ATMEL, 2011.

[8] T.-H. Hwang, W.-H. Cui, I.-S. Yang, and O.-K. Kwon, "A highly area-efficient controller for capacitive touch screen panel systems," *IEEE Transactions on Consumer Electronics,* vol. 56, pp. 1115-1122, 2010.

978-1-4673-8364-6/16/$31.00 ©2016 IEEE