Title
Oscillator-Based Touch Sensor with Adaptive Resolution

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Publication Date
2013

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

Oscillator-Based Touch Sensor with Adaptive Resolution

A thesis submitted in partial satisfaction

of the requirements for the degree Master of Science

in Electrical Engineering

by

Li Du

2013

ABSTRACT OF THE THESIS

Oscillator-Based Touch Sensor Circuit with Adaptive Resolution

by

Li Du

Master of Science in Electrical Engineering

University of California, Los Angeles, 2013

Professor Frank Chang, chair

In this thesis, an oscillator-based touch sensor detection circuit with adaptive resolution has been proposed. Current popular touch screen detection technologies include resistive, capacitance, infrared based imaging sensor; however, some are designed with a fixed resolution and it is not optimal for nowadays low power requirement.

In order to solve this problem, an oscillator-based touch sensor detection circuit with adaptive resolution has been presented. The circuit detects the touching finger by using a 6 stage ring oscillator to sense the change of the input capacitance. To make the resolution tunable, an 8 bit R-2R DAC has been implemented to change the bias voltage of the ring oscillator which will change the oscillator's resonant frequency as well as system resolution. Finally, a digital processing unit has been designed which is used to analyzes the change of the frequency and transfer information to PC to do post-signal processing

The design is achieved by using TSMC 65nm technology, occupying an area of 0.9mm x 1.1mm, power consumption of 10mW when oscillating at 120MHz, and runs on a digital clock frequency of 100KHz. Test result shows that the system can be very sensitive to detect if a finger touch it or not and the resolution can be adaptive by changing the frequency of the oscillator through DAC's output

The thesis of Li Du is approved.

Sudhakar Pamarti

Kung Yao

M. C. Frank Chang, Committee Chair

University of California, Los Angeles

2013

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List of Acronyms

Acronyms	Meaning	Acronyms	Meaning
APR	Acoustic pulse recognition	JPL	Jet Propulsion Laboratory
ADC	Analog to Digital Converter	LSB	least significant bit
DAC	Digital to Analog Converter	MSB	most significant bit
ESD	Electrostatic discharge	PCB	Printed Circuit Board
HID	Human Interface Device	SAW	Surface Acoustic Wave
HSEL	High Speed Electronics Laboratory	TSMC	Taiwan Semiconductor Manufacturing Company
ITO	Indium Tin Oxide	USART	Universal Synchronous/Asynchronous Receiver/Transmitter

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Acknowledgement

This work has been sponsored in part by grant from the WINTEK Corporation

I would like to express my deepest gratitude to Prof. Frank Chang in Electrical Engineering. He provides me with the inspiration and motivation in this project as well as valuable advice and guidance. During numerous meetings with him, reporting and discussing the progress of the thesis, I learnt quite a lot about how to independently guiding work on research in a productive manner.

I would also like to thank Dr. Adrian Tang from Jet Propulsion Laboratory (JPL). Through the whole designing period, he kept giving me useful suggestions which tends out to be very crucial for the designed touch sensor system

I am also grateful to Phd Candidates Frank Hsiao in High Speed Electronic Laboratory (HSEL) at UCLA who helped me to implement the digital core and USART part in this project.

Finally, I am thankful to my lab-mates who helped in the test and provided me valuable feedback during my presentations

Chapter 1. Introduction

1.1 Motivation

Nowadays, with the development of high performance mobile phone, tablet as well as laptop, the human interface field became more and more popular. Generally, a human interface device (HID) is a method by which a human interacts with an electronic information system either by inputting data or providing output [1]. Usually, it can be an electronic system which tracks the changing property of the people and translate it into certain instruction in the computer, for example, voice recognition, camera based gesture recognition and so on. Among them, one of the most popular HID is touch screen detection system.

Touch screen detection system is becoming more and more popular [2] mainly due to two reasons. First as the technology become more advanced, the requirement for a human to machine or machine to human action is more critical. Traditional ways like keyboard typing is no longer suitable in some cases because of its low speed, large size requirement and inconvenient. Second as mentioned in Article [3], most of touchscreen patents are filed between 1970s-1980s and they have already expired nowadays. So many companies are developing new touchscreen technology based on the previous research result.

One of the most popular techniques nowadays in touchscreen field is capacitance sensing which is to detect the capacitance change between the finger and the sensor nodes. However such a system requires relative high power consumption due to the high resolution needed to overcome the insensitive response when the finger is wet or dirty [3]. That is not the optimal power cost in most cases. In other words, if our finger is clean and the finger capacitance is sensitive to the touch screen, the resolution is over designed. Problem with this extra power consumption due to over resolution has inspired an adaptive resolution touch screen detection system. This system can monitor its current resolution and dynamically change its resolution to reduce power consumption as much as possible. In addition, when adding those adaptive resolution control circuit, we do not want make the circuit to be too complicated which will occupy a large area as well as high manufactory cost. So due to these two reasons, an oscillator based adaptive resolution touch screen detection system has been proposed

1.2 Touchscreen System Structure

A touchscreen system usually contains five components, front panel, touch sensor, touch controller, liquid crystal display as well as system software as shown in Fig.1.1 [4]

Fig.1.1 Touch screen system structure

The front panel usually served as a protected shield for touch sensor. It stops the outside obstacle which will affect the touch sensing detection. The touch sensor is usually a glass based panel that has certain response when finger is close or directly touching on the screen. This panel material generally is electrical conducting and depending on the mechanism of sensing, the actual materials used on the cover glass can be quite different. Most popular technologies for touch sensing nowadays are resistive sensing, capacitance sensing, infrared image based sensing [4]. The detailed implementations of different touch sensing technology will be discussed later. The touch controller is a system which collects signals from the touch sensor and translates it into digital signal that the PC can understand [4]. Then the software on the PC side will do some post signal-processing to get the location of the finger in the screen or understand the customer's instructions. Finally, the liquid crystal display which usually is underneath the cover glass can give feedback to the customer by displaying the request image on the screen

1.3 Major Work and Organization of thesis

This thesis reviews the current development of the touch sensor detection field, and point out one of the potential improvement point in current capacitance sensing touch sensor detection system. Finally, an oscillator based adaptive resolution touch sensor detection circuit has been implemented based on Taiwan Semiconductor Manufacturing Company (TSMC) 65nm technology and we have analysis the sensing result of this circuit to provide the concept of adaptive resolution touch sensing technology

The organization of the thesis is as follows

Chapter 2 gives a general review of the current popular touch sensor detection technologies. These technologies include resistive touch sensor, capacitance touch sensor, Infrared image based touch sensor as well as acoustic pulse recognition based touch sensor. A simple explanation of each implementation and functionality has been discussed in the individual sections

Chapter 3 presents the detailed implementation of our purposed oscillator based adaptive resolution touch sensor system. Specially, the Chapter 3.1 gives a general structure of the touch sensor and explains how the system works. Then Chapter 3.2-3.4 explains the design challenging of each key blocks including six stage ring oscillator, 8bit R-2R Digital to Analog Converter (DAC), high speed counter, as well as digital control core and the general Universal Synchronous/Asynchronous Receiver/Transmitter (USART) module. Finally Chapter 3.5 explains the layout design of the whole chip as well as the die photo of the taped out chip

Chapter 4 shows the test result of the system. Due to the error code in the USART, the internal counter register cannot be read. However, other parts of the circuit has been tested functionally, the result shows that such a system can adaptively change its resolution based on the sensitivity of the current result and a directly finger touching can cause a frequency shift by 20%

Chapter 5 analyses the testing result of this oscillator based touch screen detection circuit. The chip consumes 10mW at 120MHz oscillating frequency and the reasons causing this relative low frequency and large power consumption have been analysis in details in this chapter

Chapter 6 gives a direction about further development of this project, specifically it points out the chance to use this system for a 3D touch sensing technology which has just been demonstrated in industry.

Chapter 2. Current Touch Sensor Detection Technology

2.1 resistive detection based touchscreen

The resistive touch sensor has been very popular during the past ten years. The basic structure of a resistive touch sensor is as shown in Fig.2.1. There are two layers of transparent resistive material. Generally they are Indium Tin Oxide (ITO) or some other kind of resistive polyester materials. The two layers are placed on top of an insulating layer and are separated by spacer layer as shown in Fig.2.1 [5].

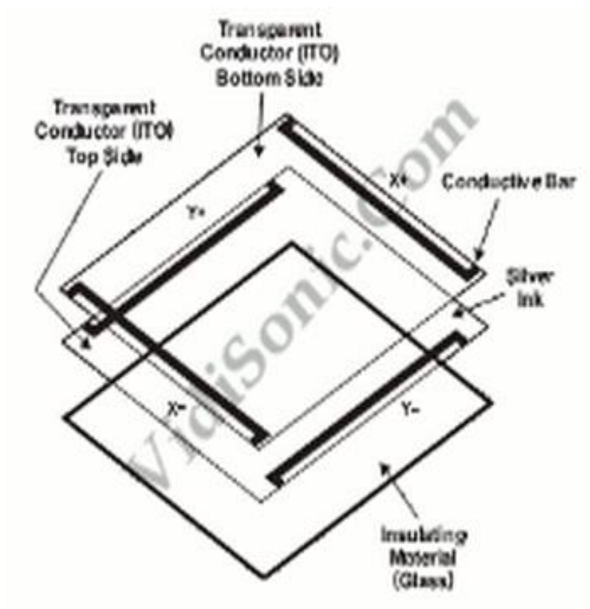

Fig.2.1 resistive touch screen structure

One of the popular detection methods of this structure is called 4-wire resistive touch sensor and the detection procedure is as explained on Fig.2.2 [6] Detection is made by first applying a voltage gradient across top layer along the x direction and then measuring the voltage on the bottom layer. Then applying a voltage gradient across bottom layer along the y direction and measuring the voltage on the top. When a finger is touching the board, it will compress three layers (including the spacer layer), in this case the sensor layer can work like a voltmeter and measure the voltage at the touch point on the applied voltage gradient layer. So from the first measurement, we can calculate the touch point along the x direction and for the second measurement, we get the y direction and based on this information, the location can be calculated.

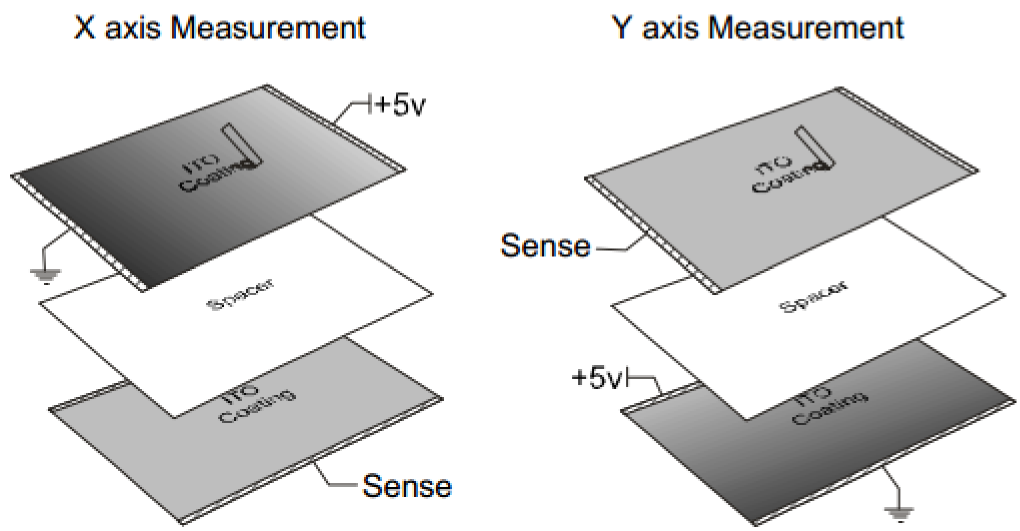

Fig.2.2 Explanation of resistive based touchscreen detection

2.2 Capacitance detection based touchscreen

Capacitance touchscreen usually consist of four multi-layer glasses. The two sides of the glass substrate are covered by uniform conductive ITO. Then usually a silicon dioxide hard coating covered on the front side of ITO as shown in Fig 2.3. The working principle can be described as follow [7] :

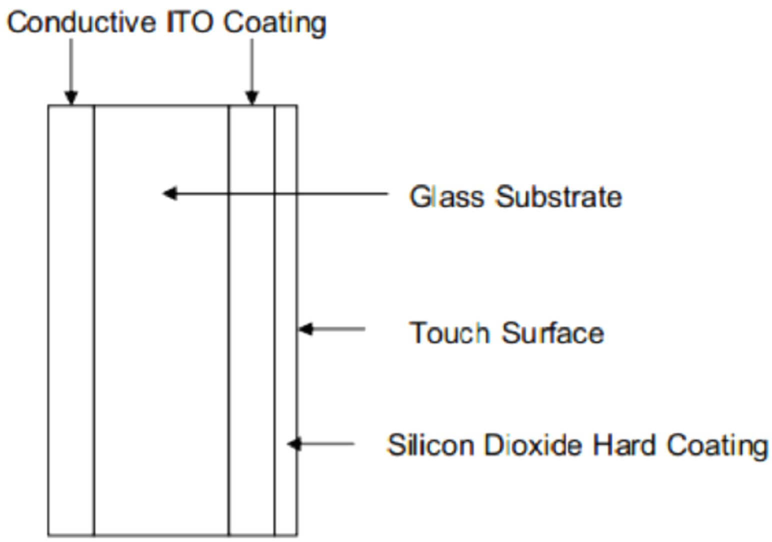

Fig.2.3 Capacitance based touchscreen structure

Because fingers are conductive, so when a finger touches the screen, it will cause the charge accumulation in the touching area across the glass on the conductive material. Usually, touch screen has four sensors on the four corners and measure the amount of charge flowing from each of the sensors to the touch point and send the information to the touch-controller to calculate the position. One of the typical ways to detect that is to apply a voltage on the corner as shown on Fig.2.4, because fingers are connected to ground, so it will attract some current drift to touch point. Theoretically, the total current that drifts from the four electrodes should be proportional to the distance from the touch point to the four corners and based on that it can calculate the relative position [8].

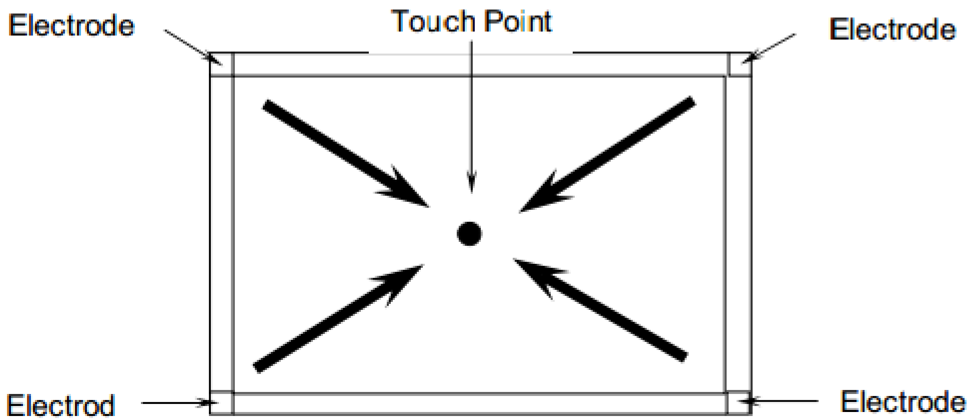

Fig.2.4 Explanation of Capacitance touchscreen detection

However, the above simple detection can only provide single touch point detection, if multi-touch detection needed, it usually has to be a touch sensor array, for example a 16-by-16 sensor array can provide 256 point resolution, and voltage can apply to each rows or columns. When fingers are close to the surface of the sensor, it will change the local electrostatic field which will change the mutual capacitance. So by measuring changed capacitance at every individual point on the grid, we can determine the touch location by measuring the voltage in the other axis. This mutual capacitance detection technology allows us to track multi-finger locations at the same time [9]

.

2.3 Infrared image based touch screen

The infrared image based touch sensor generally uses two infrared transmitters on both sides of the screen which can form a cross-horizontal and vertical infrared matrix. Usually, it will combine with another infrared camera at the bottom of the screen which is to detect the reflection light from the touch surface. When an object touches the surface, the diffuser under the screen reflects more light compared with in normal case. So after filtering the original reflector signal, we will see an additional spot from the camera. Depending on the type of diffuser, it can even detect hover and objects placed on the surface [10]. A typical example is shown in Fig.2.5. When the finger touches the screen and changes the reflection signal, it will give a spot on the camera and work well for multi-touch as shown in Fig.2.6

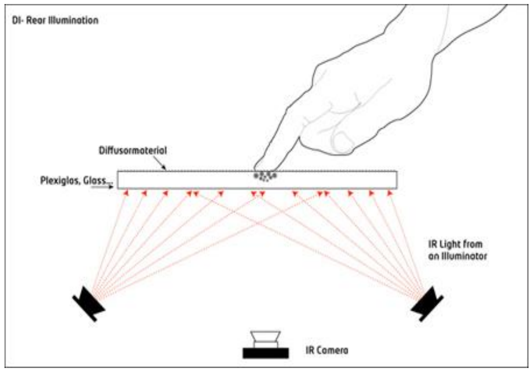

Fig.2.5 Explanation of Infrared Touchscreen Detection

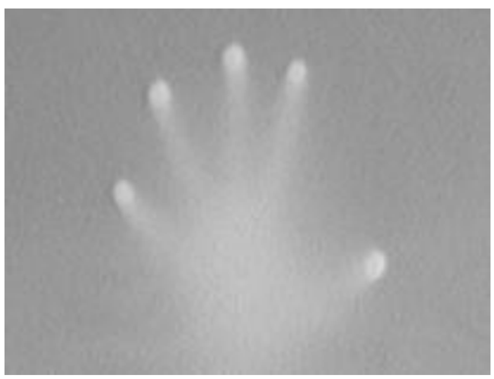

Fig.2.6 Example of Multi-touch of Infrared Touchscreen Detection

2.4 Acoustic Pulse Recognition based touch sensor

Acoustic pulse recognition (APR) is another new technology which has begun to implement in the touch sensor detection system. APR has combined most of the ultimate in optical qualities, durability, and stability of surface acoustic wave (SAW) and infrared technologies [11]. However, the APR theory is not complicated and it simply just recognizes the specific sound created by touching a given position on the glass. The fundamental prerequisite of this technology is that a touch at each position on the glass will generate a unique sound. Several transducers attached to the edges of the touchscreen will detect the sound of the touch and transfer the sound information to the touch screen controller. Then the touch screen controller will compare it with a pre-stored lookup table composed by sounds for every position on the glass. The advantage of the APR is that it just uses a simple lookup table instead of using complicated and expensive signal processing unit to calculate the touch location. Therefore, APR is more cost-effective. Fig.2.7 is a conceptual drawing of an APR touch screen [12]

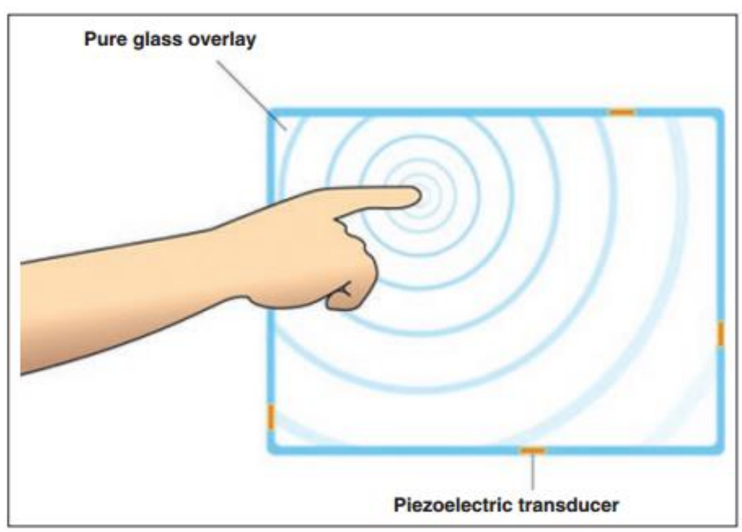

Fig.2.7 Explanation of Acoustic Pulse Recognition Based Touch Sensor

Chapter. 3 Oscillator-based Adaptive Resolution Touch Sensor Design

3.1 General Structure Review

The goal of this design is to implement a simple touchscreen system which can detect the change of the capacitance between the finger (ground) and sensor point. However, as mentioned in Chapter 1, this system must work with an adaptive resolution, which means it will adjust its resolution automatically so as to reduce the power consumption. This innovation will make the power consumption to be optimal. However, on the other hand we cannot make this system structure too complicated which will occupy more areas and cost more money in fabrication.

So instead of using Analog to Digital Converter(ADC) to detect the voltage or input impedance [13],[14] sensed which seems a little harder to tune the resolution for power saving, we provide a ring oscillator structure with its load connect to the touch sensor antenna. So the change of the input capacitance changes the frequency of the ring oscillator. The relationship between the frequency and input capacitance is shown by equation (3.1) where R represents the average charging resistor when the inverter is flipping and the C represents each stage's input capacitance. ΔC represents the capacitance between the finger and the touch sensor. K is a constant value which relates to the stage of the ring oscillator. So whenever the antenna senses the capacitance between the finger and itself, it will reflect on the oscillating frequency as shown in Equation 3.1

$$frequency = \frac{K}{2nR(C+\frac{\Delta C}{n})} \qquad (3.1)$$

Then this oscillator's output will go to a counter, which counts the number of pulse from the oscillator in a certain time period and send it to the digital core. Meanwhile we have another R-2R 8bit DAC to tune the bias voltage of the oscillator which will control the charging current of the oscillator and this voltage will affect the oscillator's charging current which will affect the value of the R in equation 3.1 as well as power consumption. The structure and working diagram of the system is shown in Fig.3.1

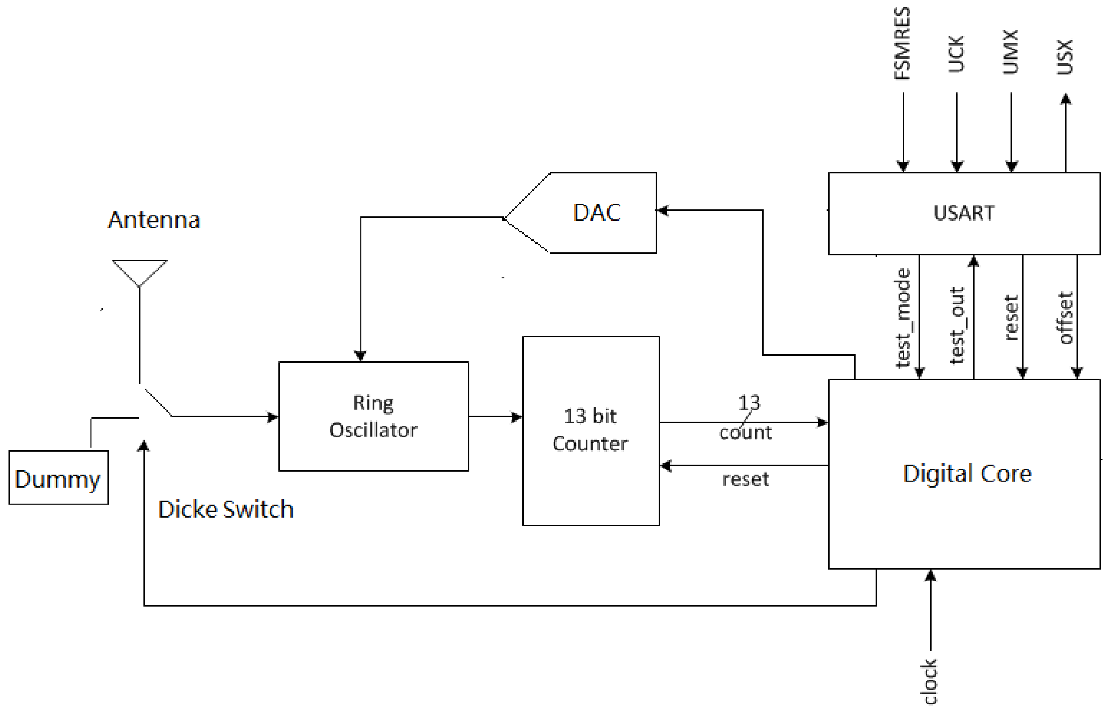

Fig.3.1 System Structure of the Oscillator Based Touch Sensor

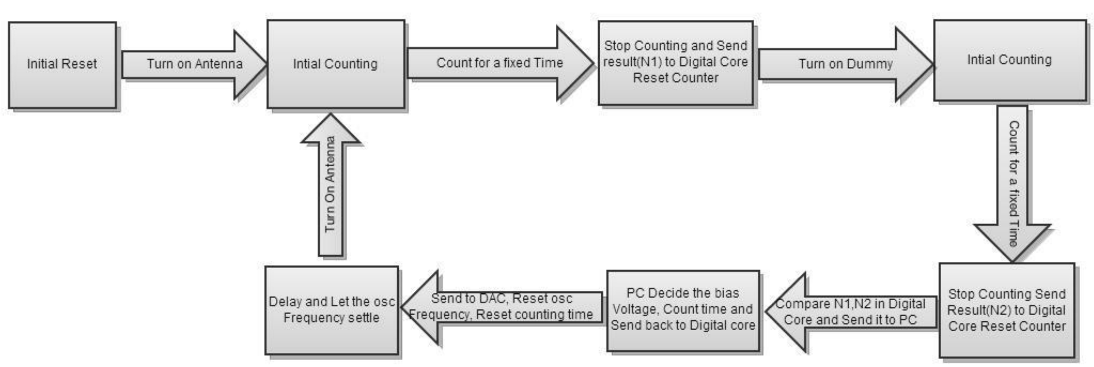

Fig.3.2 System Diagram of the Oscillator Based Touch Sensor

When the chip is powered up, it will first reset all the register. Then the Dicke switch turns to the antenna side and the counter starts counting the oscillator's output. After a fixed time (programmable by the digital core), the counter stops and sends the counted result to digital core. Digital core sends a signal to inform the Dicke switch to turn to the dummy pad, and then the counter starts counting for the same time period and sends the count result to digital core.

If the dummy pad is perfectly match to the environment capacitance of the antenna and no finger is touching, we would expect a close value between the 1st count result and the 2nd one. If the difference is big, it means there is an additional capacitance in the antenna path.

After that, the digital core will pass the difference of the two counter results to PC and at the PC side, an algorithm will be used to reverse calculate the input relative capacitance as well as the distance between the antenna and the finger. Then the PC will decide if the resolution is too high based on the result from other 3 sensor, if it is too high, it will give a low value of the DAC code which will lower the frequency of the oscillator so as to reduce the power consumption and it will also send the required counting time period to digital core for the next cycle and digital core will send all blocks and begin another measurement.

The Universal Synchronous/Asynchronous Receiver/Transmitter (USART) uses four pins, FSMRES, UCK, UMX, USX, to communicate with the PC.

3.2 Six Stage Differential Ring oscillator design

As mentioned in the Chapter 3.1, the capacitance measurement is provided by the ring oscillator. In order to make it more robust and the ring oscillator gain is sufficient large, we design a six stage differential ring oscillator. Each stage schematic is shown in Fig.3.3

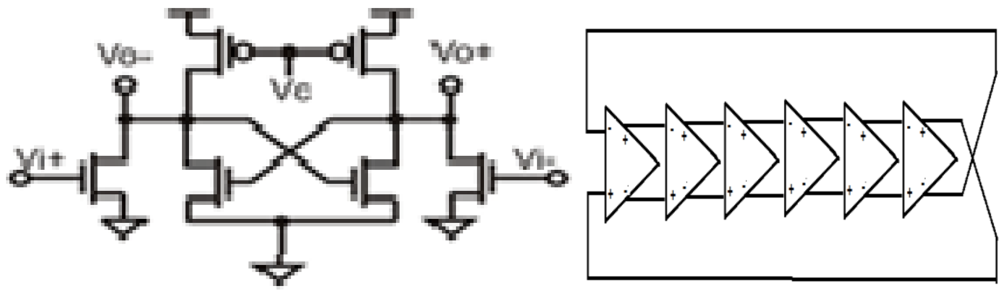

Fig.3.3 Six Stage Ring oscillator Structure

The top two PMOS transistors can set the charging current by changing the gate biasing voltage. The bottom four NMOS transistors have two pairs. One diode connect pair is used to flip the output of the inverter. The other cross-couple one forms a positive feedback and used to speed up the inverter flipping.

3.3 8 bit R-2R DAC

In order to make the oscillator frequency to be tunable, we need to provide a tunable voltage at the inverter's bias point. A typical R-2R DAC can provide a high output voltage dynamic range as well as enough resolution and the R-2R ladder is not expensive and relatively easy to manufacture since only two resistor values are required [15]. Since the requirement of the resolution is not very high, it will not occupy a large area for matching. So we pick this structure as our 8bit DAC structure. The structure of a general R-2R DAC is shown in Fig.3.4

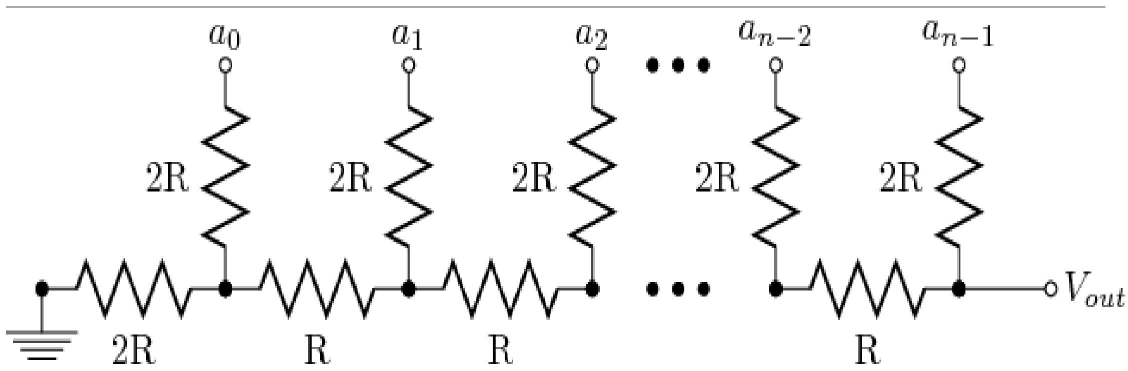

Fig.3.4 The R-2R Resistor Ladder Network

As shown in Fig.12, The DAC's Most Significant Bit (MSB) is a_{n-1} and Least Significant Bit (LSB) is a_0. These bits are all driven come from digital input. By changing from 1 to 0 or 0 to 1 for each digital input, we can achieve $2^n - 1$ voltage steps

The relationship between output voltage V_{out} and input digital codes $V_{digital}$ is shown in equation 3.2

$$V_{out} = V_{ref} \times \frac{V_{digital}}{2^N} \qquad (3.2)$$

3.4 High Speed Counter Design

3.4.1 Counter Specification

One of the other challenging blocks in this system is to design the high speed counter. A typical ring oscillator can easily oscillate up to several gigaherz[16] and the higher frequency the ring oscillator is, the smaller parasitic capacitance it will have. The resolution is related to the speed of the oscillator as shown in Equation 3.3

$$C_{min} = \frac{T_{osc}}{t_{counting}} \times C_{parastic} \qquad (3.3)$$

$t_{counting}$ is a fixed time period for counter to count which is related to the response time of the touch screen. In this project, we make it tunable, and set a typical value of 1us. T_{osc} is the time period of the oscillator and $C_{parastic}$ is the parasitic capacitance associated with the ring oscillator. It can be either the bonding capacitance between the antenna and the input, or the capacitance between the input and ground plane. So from this equation, it reveals that the higher frequency of the oscillator as well as the smaller the parasitic capacitance, the more accurate resolution we can achieve.

However, the highest oscillating frequency is limited by the counter speed. This is because if the oscillator runs too fast, the counter cannot setup in one clock cycle. So in order to speed up the counter, a pipeline counter structure has been implemented

The target max frequency of the ring oscillator is 1GHz, and the default sample time period is 0.5us. In this case, the count numbers N can be calculated as shown in Equation 3.4 which requires 11 bit counter but we pick it into 13bit to give enough design margin

$$N = \frac{f_{osc}}{f_{sample}} = 2000 \qquad (3.4)$$

3.4.2 Counter Structure

In order to make the counter run as fast as possible, we target to design a pipeline counter. Notice that when the oscillation time is over, there is a signal to stop the counter counting, so we do not require the counter to provide final value in one clock cycle because the counter already stops to counting. In this case, we can wait until the final value in the counter is settled and then obtain from the register.

Based on the above analysis, an asynchronous counter ,shown in Fig.3.5 [17] below, may be the best choice, because the speed of the counter in this case is only defined by each stage setup& hold time and doesn't relate to the whole bit numbers.

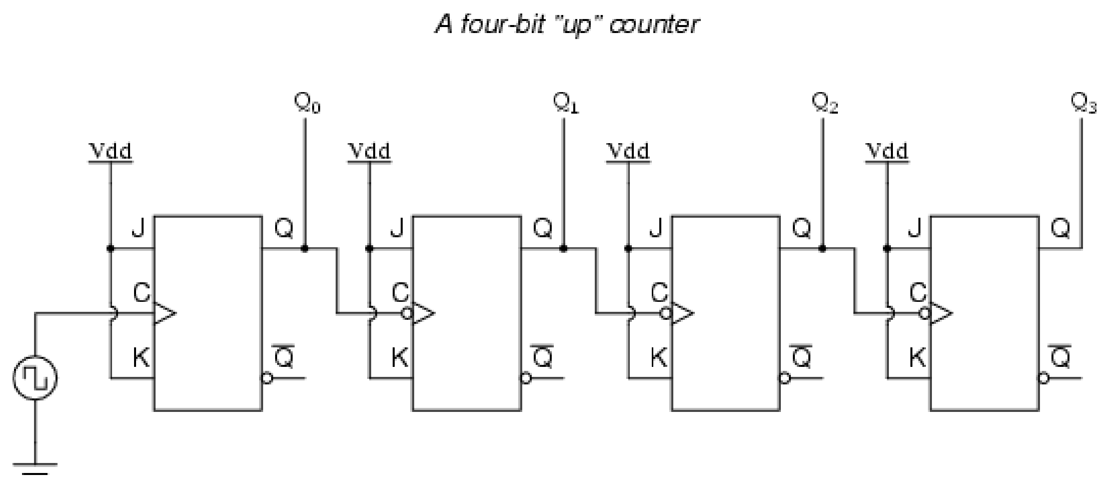

Fig.3.5 Asynchronous Counter Structure

However, in order to save the register number, we use the following structure which does a 4bit add operation in each stage as shown in Fig.3.6. The EN signal comes from the digital core which is to enable or disable the input latch of the counter and it is delayed and sent to a 13bit register to sample the final output

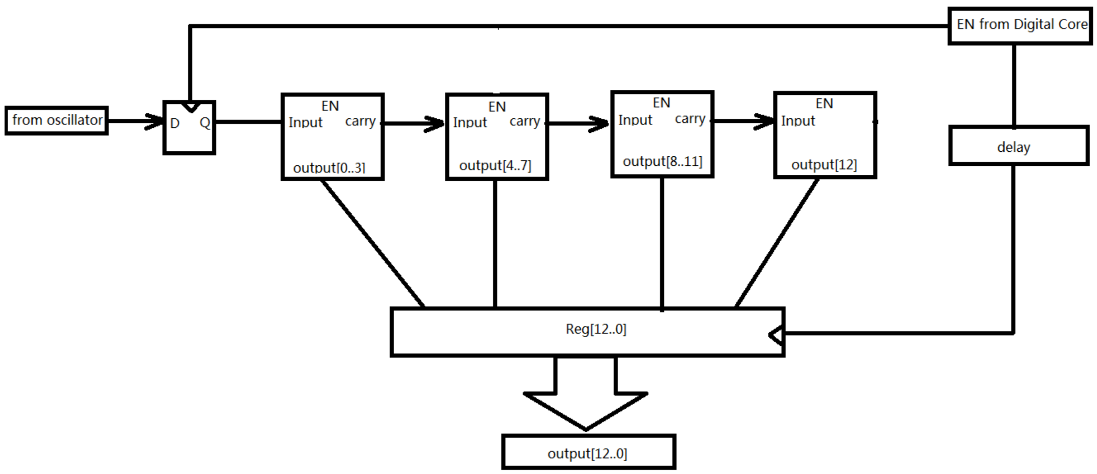

Fig.3.6 Counter Structure in the touch sensor circuit

3.5 Digital Core and USART Design

For the digital core and USART, it is designed by Phd student: Frank Hsiao HSEL

The digital core is used to control the whole chip, including controlling the Dicke switch between the antenna and dummy pad, start &stop counter, talking with the PC through USART, as well as providing different mode for testing.

The USART is a serial-to-parallel interface inside the chip, which communicates with a microcontroller. The microcontroller works as a medium between chip and the PC. The handshaking operation between USART which serves as a slave and the microcontroller which serves as a master is shown in Fig.3.7.

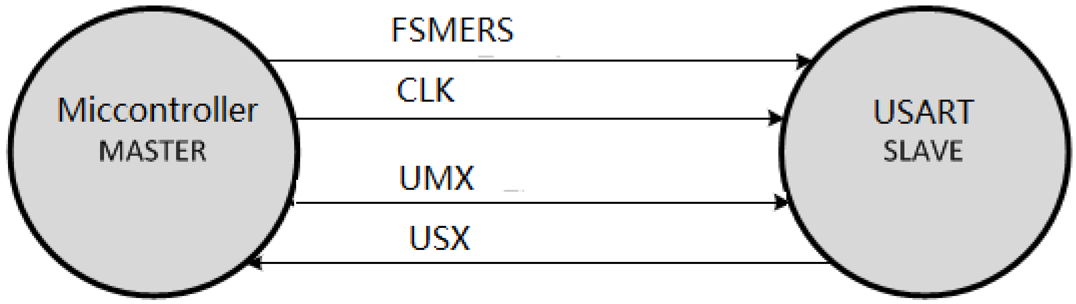

Fig.3.7 USART and Microcontroller Handshaking Operation

The microcontroller initiates the communication by sending a “1” to USART through the wire UMX, and then sending the data through UMX port. The USART recognizes 1st “1” in the UMX which will be regarded as a ready signal of packet. Then it will keep receiving each bit. Once the USART finishes reading all the 41bit data, it starts to implement the functions. After another two clock cycle, it will begin to answer to the microcontroller which feedback 24bit data to microcontroller through USX and the microcontroller will transfer data to PC

3.6 System Layout and die photo

The final circuit layout is shown in Fig.3.8 below and it occupies 0.9mm*1.1mm area. The analog part of the circuit which includes Dicke Switch and Oscillator is located in the left part of the circuit, where the digital part including USART, counter as well as the digital core is located in the right part of the circuit. The mixed signal DAC is in the middle between analog and digital core

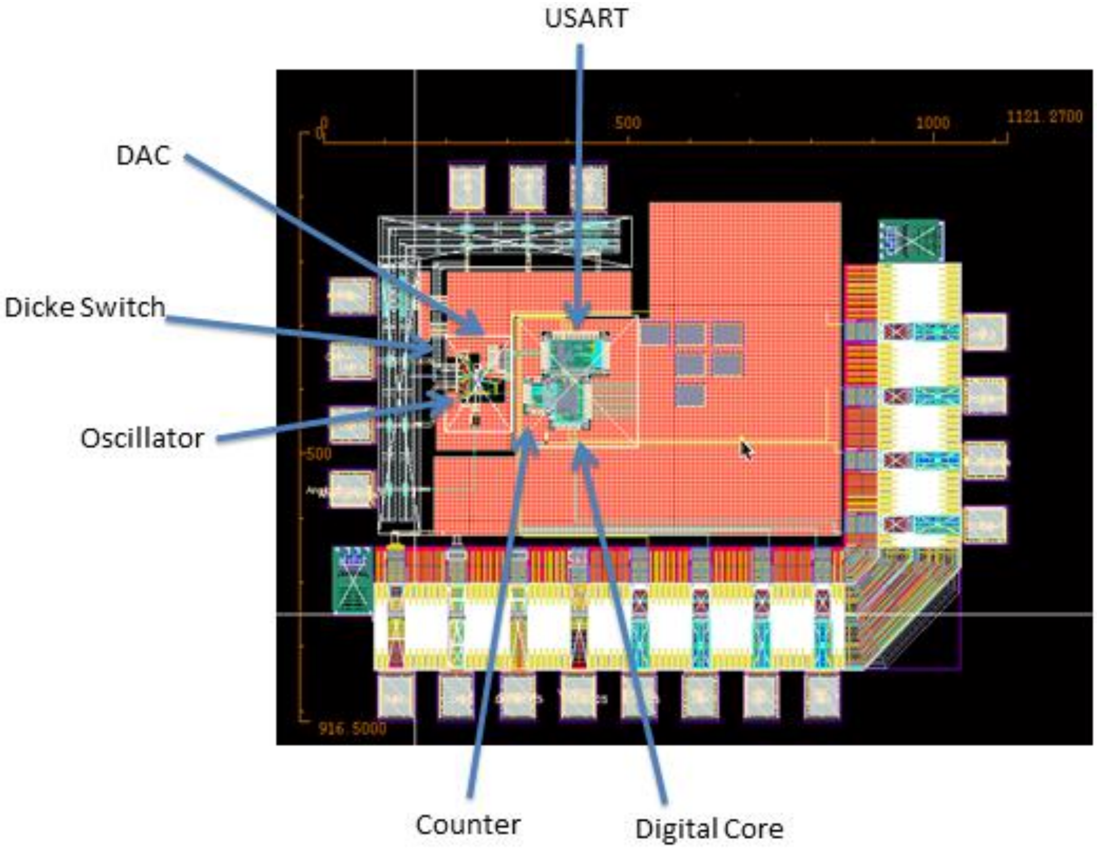

Fig. 3.8 Layout of the touch sensor chip

The chip is taped out based on TSMC 65nm technology and the die photo is shown in Fig. 3.9

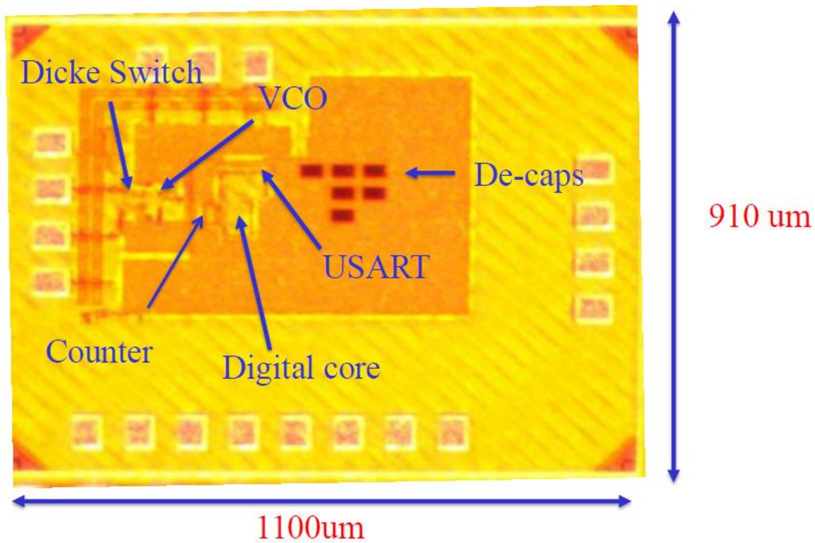

Fig.3.9 Die photo of the touch sensor circuit

Chapter 4. Test of the touch sensor circuit

4.1 Test Environment Setup

In order to verify our circuit works correctly, a prototype chip has been fabricated and test. The test is based on one touch sensor chip. However, the actual implementation can be multiple sensor nodes in order to calculate the location of the finger accurately. Test equipment includes power supply, frequency generator served as digital clock, microcontroller, PC, as well as scope. The test environment is shown in Fig. 4.1

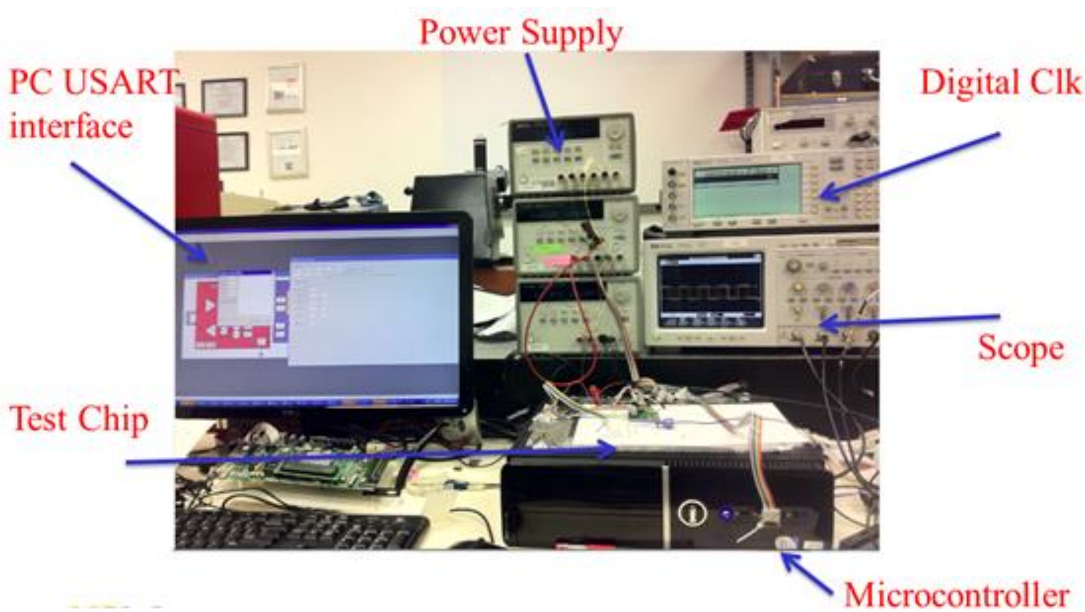

Fig.4.1 Test environment setup of the touch sensor

4.2 Test Results

Due to some error coding in the USART design, the PC cannot read out the counter output value. However, other parts work functionally and the verified result is shown in Fig.4.2. The Dicke Switch Signal in the scope represents the on and off of the Dicke Switch, when it is 1, it turns to the antenna part. When it is 0, it turns to the dummy part. Also as we can read in the Fig.4.2, at the end of each cycle, after the counter finished counting, it sends a trigger signal to the USART to tell the PC that the data is ready for reading.

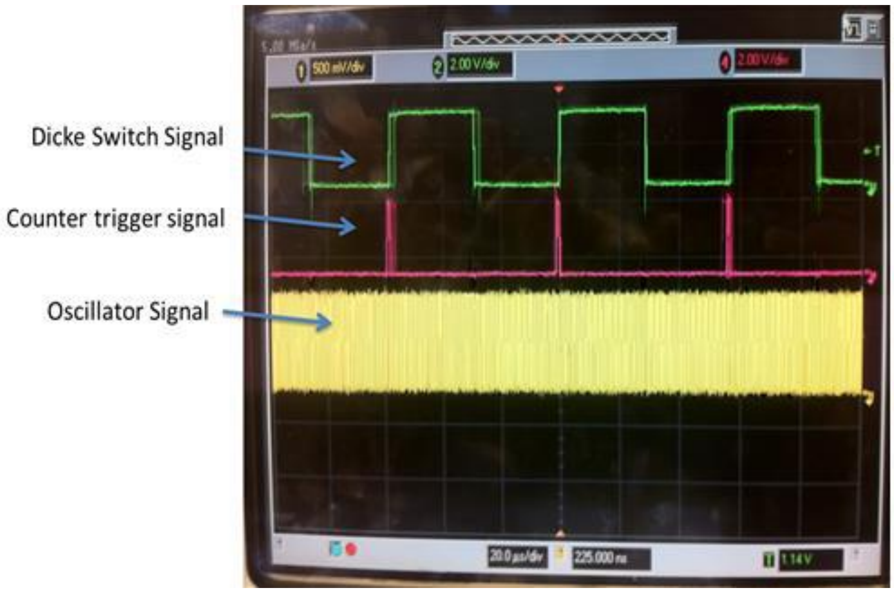

Fig.4.2 Functionality verification of the chips

The DAC's input vs oscillator's frequency and power consumption are also two important specifications since it is the key for us to achieve adaptive resolution as well as adaptive power consumption. So to test these two parameters, we sweep the DAC's input by the PC and check the frequency and power consumption. The result is shown in Fig.4.3 and Fig.4.4

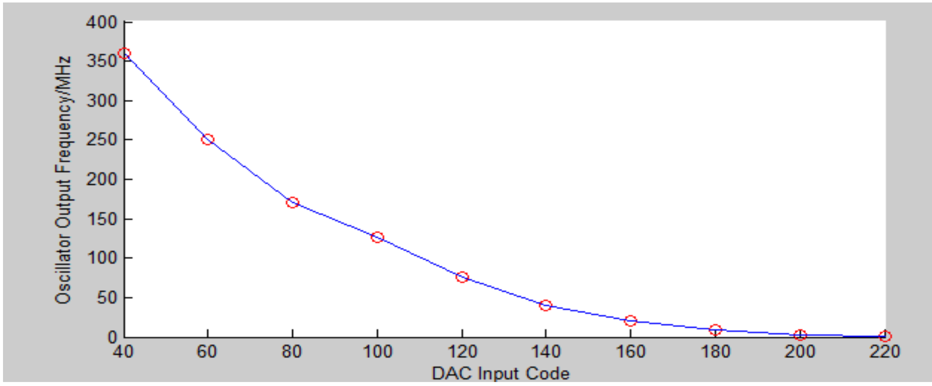

Fig.4.3 DAC Input Code vs Output Frequency

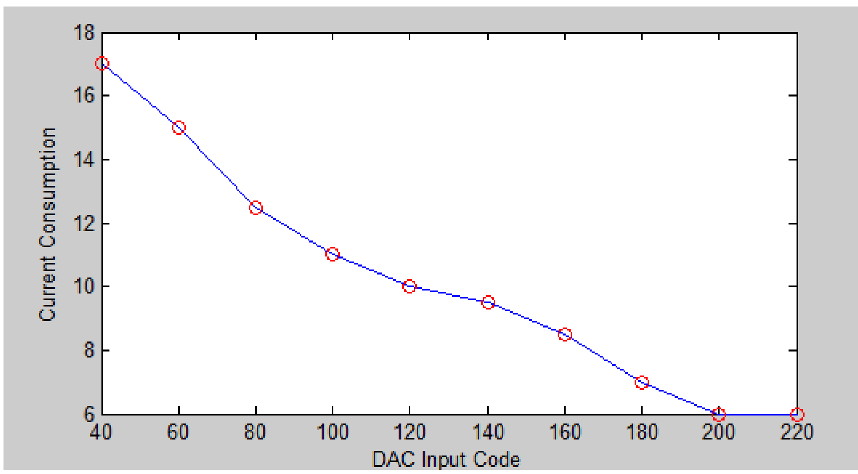

Fig.4.4 DAC Input Code vs Current Consumption

From these two curves, we can see the frequency can be tuned between 1MHz to 350MHz and by changing the frequency, the chip current consumption also verified from minimum 6mA to maximum 17mA which prove the idea to adjust the resolution to optimal the power consumption

One of the other important facts is to verify that for different objects, the touch sensitivity is different. A comparison of directly finger touching, finger with plastic glove touching, and finger with wool glove touching is shown as follows.

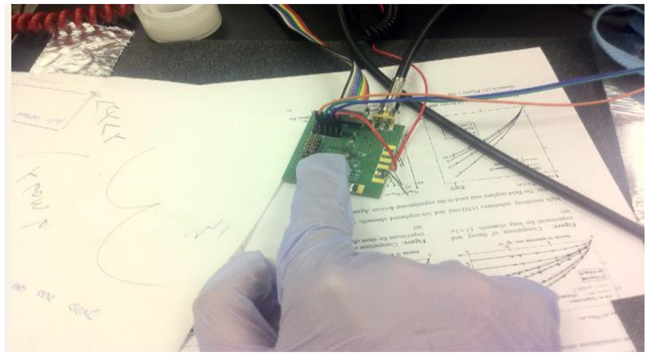

Fig.4.5 The picture of touching in test

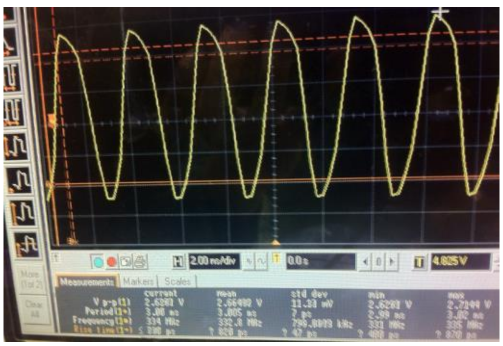

Fig.4.6 without touching

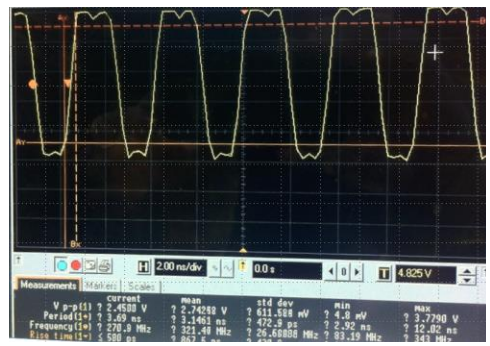

Fig.4.7 finger directly touching

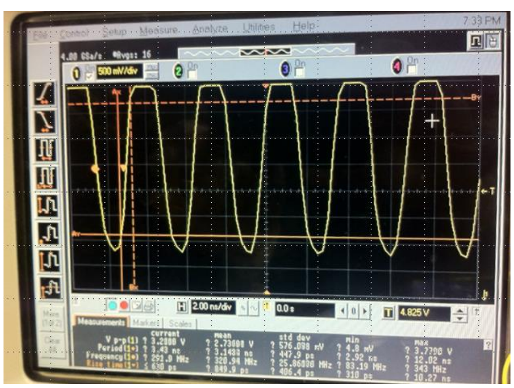

Fig.4.8 plastic glove touching

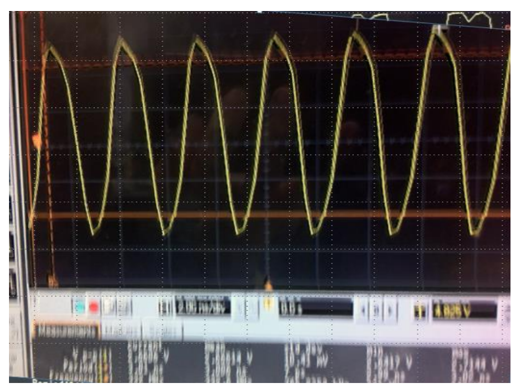

Fig.4.9 wool glove touching

From the Fig.4.6-Fig.4.9, we can see when the finger directly touches on the sensor, it changes the shape and frequency of the oscillator's output dramatically. However, when touching with glove on it, the change became smaller. When we use the wool glove touching it, it almost does not change the oscillator's output. A list of the frequency of the oscillator's output is shown in Table. 4.1

Touching Method	Output Frequency/ MHz	Frequency Deviation/%
No touch	334	0
Finger directly touch	270	20
Touch with plastic glove	292	13
Touch with wool glove	332	0.5

Table 4.1 oscillator output with different kind of touching method

So in this way, PC side can apply some algorithm that to automatically verify the detection resolution and if it is too sensitive, it reduced the frequency so as to save the power.

The jitter of the ring oscillator becomes another critical issue, because such a jitter may affect the calculation of the frequency. As measured shown in Fig. 4.10, the peak to peak jitter is 236ps while the average jitter is 38ps

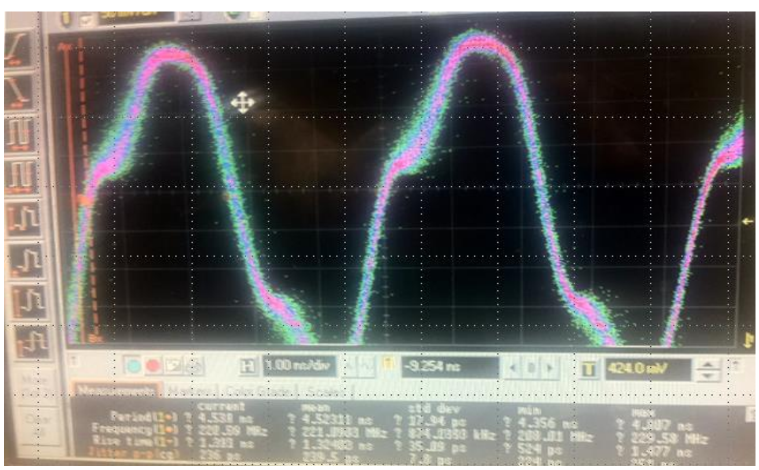

Fig.4.10 Jitter measurement of the chip working at 220MHz

Such a jitter's effect in the final result can be mostly reduced because the counter will counter up to 10us and then stop which will serve as an integrator to eliminate jitters.

The chip testing result is shown in Table 4.2

Process		TSMC65nm	
Die Area		1.1m*0.9mm	
Core Area		0.35mm*0.25mm	
Test Result	Min	Typical	Max
Power Supply Voltage	0.8V	1V	1.2V
Current Consumption	6mA	10mA	17mA
Oscillator Frequency Ranging	1MHz	120MHz	360MHz

Table 4.2 Summary of the chip performance test

Chapter 5. Result Analysis

In summary, this project has successfully demonstrated a very sensitive oscillator based touch screen detection circuit. Test result shows that different kinds of touching will cause a different frequency shift, which proves the useful of adaptive resolution control. The chip consumes 10mW when working at 120MHz. which limits the resolution and cost relative large power consumption. Several results causes such problem as follows

1. The load of the output capacitance is too large

Although in simulation, we can run the oscillator speed up to 2GHz, however the actual measured maximum frequency is only around 350MHz which shows a large parasitic capacitance. The large parasitic capacitance comes from two parts, one is the on chip electrostatic discharge (ESD) protection which are two diodes connecting between input to ground and input to voltage supply. Each of the diodes contributes around 1pF which reduced oscillation frequency a lot. The other part is the PCB parasitic capacitance, according to the calculation, it would cause roughly around 1.2pF parasitic capacitance from input to the ground.

2. The number of the ring oscillator stage is not optimal

So in this project, we designed the ring oscillator with 6 stages in order to make sure the ring oscillator has sufficient gain to oscillate, however this is the optimal design, it can shrink to 3 stages.

Chapter 6. Conclusions and Future Research

This master's thesis focuses on the design of the touch sensor circuit. It starts with a general introduction about the current touch sensor detection circuits and their popular methods to detect the finger touch. Then it proposes an adaptive resolution structure which can optimize the power consumption of the touch sensing

This proposed touch sensor detection circuit is based on a 6 six stage ring oscillator with two of the input pins connect to two sensor pad, when finger touching it, it changes the parasitic capacitance of the ring oscillator so as to effect the frequency. A high speed digital counter has been implemented to count the output of the ring oscillator for a fixed period and transfer this data to PC to do post signal processing and determine if the resolution is too high or not. Then it will send command through USART to change the frequency of the ring oscillator through a R-2R DAC so as to adaptively control the resolution.

A prototype chip is fabricated based on TSMC 65nm technology. Testing result shows the chip consumes a 10mW at 120MHz and proves the adaptive resolution concept

The further work of this project should carry on reduce this kind of touch sensor's power consumption as well as the jitter effect on sensitivity. Methods to improve those two important specifications include shrinking oscillator stage numbers from 6 to3, increase the integration time for counter to count as well as build multiple sensing channels on one chip. Also algorithm for location estimation should be carried out based on the sensing information from multiple sensors in different places

This work can be further developed to achieve a 3D touchscreen detection system, which has just been demonstrated in industry [19]. This is mainly because compared with using ADC to do voltage sensing for touch sensor detection, oscillator based touch sensing works at a very high frequency which can be radiated into space so as to sense the environment change of space. So based on this idea, future work should be carried on how to design a plane antenna on the PCB boards which can radiate the signal into space.

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