

Using capacitive and proximity sensing in Digital Photo Frames

By Archana Yarlagadda, applications engineer, and Ben Kropf, applications engineer, Cypress Semiconductor Corp.

Executive Summary

A Digital Photo Frame (DPF) is a technologically-advanced replacement of traditional photo albums and frames. Hard-copy photos were the only option when using analog cameras. The growth and proliferation of digital cameras has rendered analog versions all but obsolete. Digital photo frames provide many ways to store and display images of different formats, transfer photos to printers or other electronic devices, play videos, and have remote control over all these without a computer.

The basic digital photo frame has a multimedia chipset to handle image storage and conversion. The frames often provide video and audio output and have flash memory storage to store the images and files. They have an LCD, usually integrated in a modular form, to display all images. The block diagram of a basic DPF is shown in Figure 1.

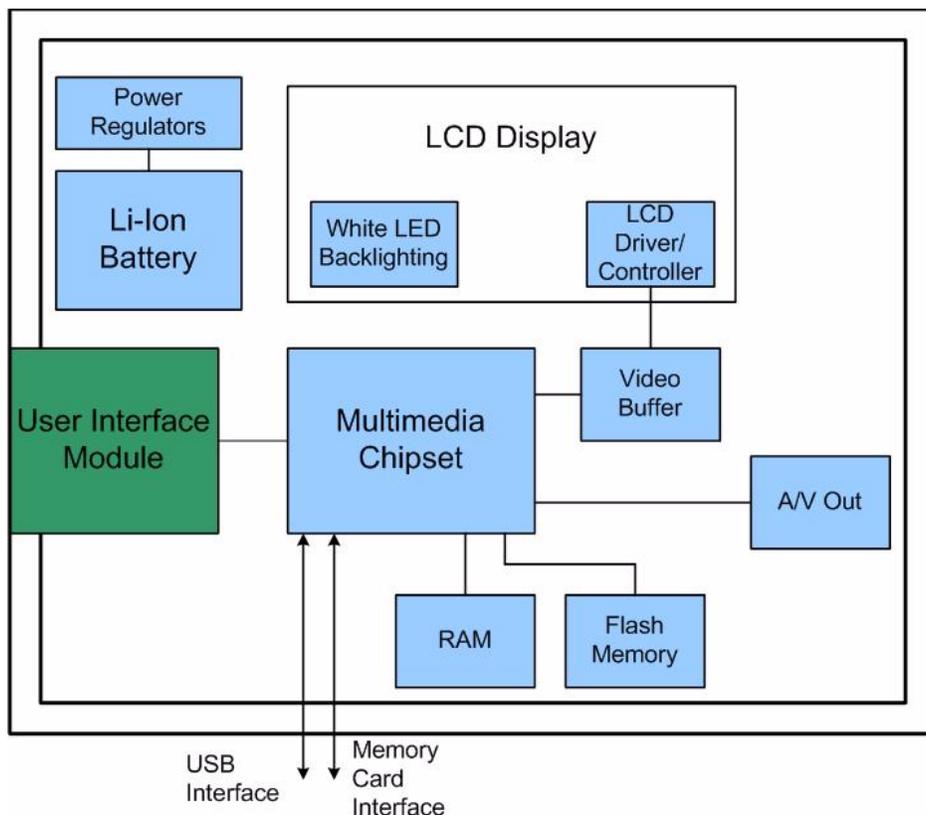


Figure 1. Digital photo frames have a multimedia chipset along with an LCD display module. Some frames have a lithium ion battery. The user interface is a key component of the frame.

This article discusses one aspect of digital photo frames that is becoming more complex as the photo frames themselves are becoming more complex. This is the user interface. A user has to have a way to control the frame and access all of the features that it has. More specifically, this article discusses how to eschew mechanical buttons in favor of capacitive buttons and proximity sensing. When mechanical buttons are used, they must either be on the back or the front of the frame. When on the back, they can be somewhat hard to access by the user. For a frame that hangs on a wall, putting the buttons on the back likely is not even an option. If the buttons are on the front, it is likely that they will harm the aesthetic appeal of the frame, which is often made to be as attractive as possible.



Capacitive buttons work very well for digital photo frames for a variety of reasons. First, capacitive buttons generally bring a significant cool-factor to any product. Second, they allow the buttons to be placed on the front of the frame for easy access without ruining the look of the frame. Additionally, using capacitive buttons can decrease some costs of the system by eliminating the cost of the mechanical buttons and simplifying some of the manufacturing processes.

Using capacitive buttons for the user interface of a digital photo frame does not solve all problems. One issue that still remains is that capacitive buttons that are “invisible” can be somewhat unintuitive. This is where proximity sensing is desirable. Proximity sensing can be used to bring up a menu on the screen and light LEDs to show where the Capsense buttons are located.

Adding capacitive and proximity sensing to a digital photo frame will increase the consumer appeal to the device and avoid wear and tear of the mechanical buttons. This article discusses the method of adding capacitive and proximity sensing to a digital photo frame and how adding one device to the existing circuit will make it happen.

Capacitive Sensing

Adding capacitive sensing to a digital photo frame, or other display, involves embedding a printed circuit board (PCB) behind or within the frame. Capacitive elements are laid out on the PCB in the form of copper pads. There is a very small capacitance between these pads and a grounded mesh on the PCB that surrounds them. When a user “pushes” these capacitive pads, or buttons, there is an increase in the capacitance between the copper pad and ground. This is due to the electrically conductive nature of a human finger. Therefore, detecting these capacitive button presses becomes an exercise in detecting small changes in small capacitances.

There are a variety of ways to accomplish this. Important factors in choosing a capacitive sensing method are noise immunity, resolution, accuracy, and measurement time. It is also very beneficial to choose a method and device that allow a great degree of flexibility. For example, being able to dynamically trade off resolution for measurement speed (and vice versa) is quite useful. It is often best to choose an integrated circuit that has all of the necessary hardware on-chip to do capacitive sensing. This is a much simpler approach than designing a unique circuit from the ground up.

A digital photo frame generally requires at least five buttons to implement the user interface. These buttons may be an on/off switch and several navigation buttons. However, another advantage of using capacitive buttons is that it is not difficult to add more once the first few have been added. For example, if five capacitive buttons have been added on the frame, there is no reason not to have 10 buttons on the frame. There is very little added cost to adding more capacitive buttons. This is not the case with mechanical buttons. Therefore, a typical digital photo frame with capacitive buttons may have five to seven buttons and a “slider” control created out of five to seven more capacitive elements. This makes a total of about 12 to 15 capacitive elements. Additionally it is important to ensure that the device that measures these elements can scan each of the elements and process the data within about 15 ms. This corresponds to an update rate of about 60 Hz and allows for an acceptable latency between button pushes and the execution of their corresponding functionality.

An important consideration when adding capacitive buttons to a digital photo frame is the overlay added on top of the PCB with the capacitive buttons. This overlay is the actual frame that the user sees. Therefore, it must be as aesthetically pleasing as possible. When determining the design of the frame, there are two key factors that must be accounted for. The first is the material that the frame is made out of and the second is the thickness of the frame on top of the PCB with the capacitive elements. The sensitivity of a capacitive element decreases as the thickness of the overlay increases. This is because the greater distance between the finger and the element decreases the amount of capacitance that the finger can add. The material of the overlay also has an effect on the capacitive coupling of the finger. Materials with higher permittivity allow the capacitive elements to be more sensitive to finger presses.

A good device to use for capacitive sensing in a digital photo frame application is the CY8C21434 PSoC[®] Mixed-Signal Array. This device is very similar to a standard 8-bit microcontroller in that it has a CPU, flash, RAM, GPIO, an ADC, and standard digital and communication peripherals. In addition to these resources, this device has specialized analog hardware specifically designed for capacitive sensing. It also has a useful analog input muxing architecture that allows any GPIO pin to function as an analog input. This allows this PSoC device to measure a large number (up to 24) of capacitive sensors.

The capacitive sensing technique used by the CY8C21434 device employs switched capacitor and sigma-delta techniques. Figure 2 shows a simplified version of the circuit used for the capacitive sensing. The sensor (C_x) is used as a switched capacitor. It is rapidly switched between being connected to V_{DD} and to the input, which is roughly equal to V_{Ref} . The average current being sourced on to C_{Mod} is proportional to the capacitance of the sensor, the switching frequency, and the voltage difference between V_{DD} and V_{Ref} . The switching frequency and the voltage difference remain constant. Therefore, the sourced current is dependent primarily on the capacitance of the sensor.

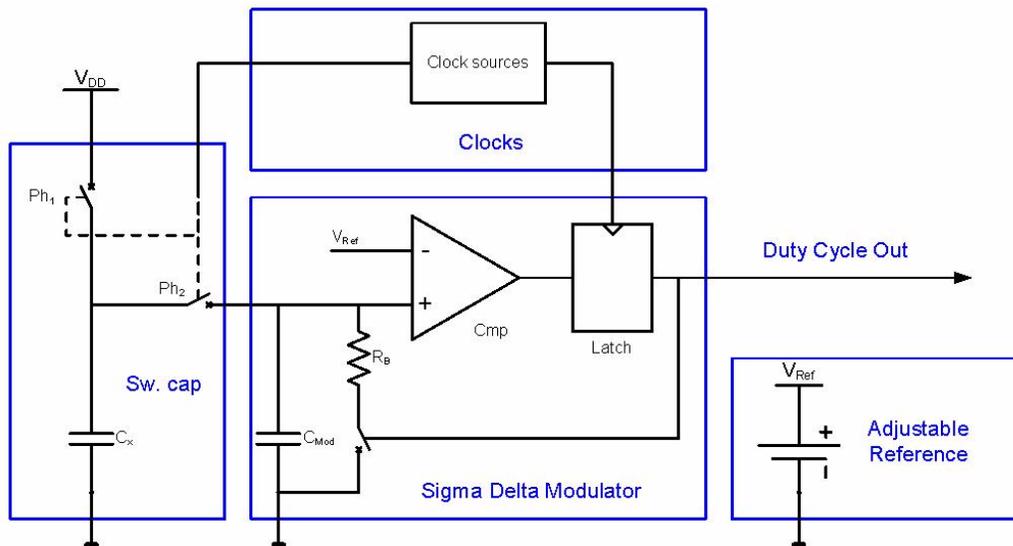


Figure 2. The circuit in the CY8C21x34 measures capacitive changes using a delta-sigma modulator. C_x is the capacitive sensor being measured. The output duty cycle from the modulator is measured over a time period using a counter.

The circuit in Figure 2 is designed such that the voltage on the capacitive sensors remains close to V_{Ref} . This is accomplished by the negative feedback provided by the resistor, R_B . Whenever the voltage on C_{Mod} increases above V_{Ref} , the comparator trips and causes R_B to sink current off of C_{Mod} , which causes the voltage on C_{Mod} to decrease until the comparator trips again, which tri-states the feedback resistor, R_B . This circuit effectively converts capacitive changes in the sensor into digital duty cycle changes at the output of the comparator. This comparator output is then integrated over a time period to provide a digital value output. This value is the “counts” measured on the sensor.

This hardware circuit is advantageous for two reasons. First, there is a relatively low impedance path from the input to ground. This greatly reduces the noise in the measurements. Second, the switched capacitor circuit employs pseudo-random switching. The average switching frequency is controlled, but instantaneous switching frequency is variable. This reduces the peak radiated EMI from the capacitive sensing circuit by spreading the radiated frequencies over a larger band.

Today’s capacitive sensing devices are designed to be reconfigured with the programming integrated development environment as well as simplify matching of GPIOs to capacitive sensors on the board. Additionally, the use of software modules for the entire capacitive sensing system simplifies tuning the system as well, including resolution, switching frequency, measurement period, and reference voltage. Such reconfigurable at the development level allows users to adjust the settings to best measure the capacitive sensors for a particular PCB.

Once capacitive user controls (buttons and sliders) have been added to a digital photo frame design, the consumer appeal is increased by taking out the mechanical buttons. However, there is also an inconvenience introduced into the user interface. The “invisible” buttons are now no longer very intuitive. When a user simply looks at the frame, it may be difficult to guess how to interact with it, since no user controls are visible. The user may guess that they are supposed to touch the frame somewhere, but even then they may touch the wrong location on the frame where there are no capacitive elements.

The proposed design solution for this quandary is to add capacitive proximity sensing to the same application. The beauty of this is that all of the necessary hardware to do this is already in the design. All that is needed is just one more GPIO on the CY8C21434 device.

Proximity Sensing

The proximity sense in a digital photo frame can be used to pop up a menu on the LCD and light up LEDs when a user’s hand is close to the frame. This makes the buttons clearly visible in a way that is intuitive to the user. The distance at which the proximity gets activated can be set by either extensive calculations of electrical field lines or by close approximation using the output signals obtained. The approximation method also requires an understanding of how the sensitivity of the sensor changes with different conditions.



The sensitivity of the proximity sensor in a digital photo frame mainly depends on the type of proximity sensor, the presence of metal, the scan speed, and noise levels.

Type of Proximity sensor

Proximity sensing can be implemented with a wire sensor or a long PCB trace connected instead of a capacitive pad, which was explained in the capacitive button section. The sensitivity of such a sensor is much lower than the regular capacitive buttons and changes with the distance of the user's hand. Since the detection of the hand is based on the capacitance change due to change in electric field, any stray capacitance or objects affecting the electrical field around the wire will affect the range of the proximity sensor.

Using a wire sensor is often not an optimal solution for mass production due to manufacturing cost and complexity. In such cases, a long copper trace on the PCB can be used for the proximity sensor. This method facilitates mass production, but it is not as sensitive as a wire sensor.

Presence of Metal

In some DPF designs, there may be metal close to the frame. This metal may be for magnetically attaching the frame to the LCD, or it may be metal in the LCD module itself. In these cases, the effective range of proximity sensing will reduce due to the presence of the metal. Reduction in sensitivity of the sensor is due to the interference of the metal with the electric field lines of the sensor, thus reducing the capacitance added by the hand. A shield electrode can be used to decrease the effect of the metal on the proximity sensor. Although not very useful for DPF devices, the presence of a shield electrode will also avoid false triggering due to the presence of water, ice, or humidity changes.

One method of implementing a shield electrode is to design a double-sided PCB with the proximity and capacitive sensors on the front side, and the shielding electrode(s) on the backside. A hatched copper pour can be used as a good shield electrode on a multilayer PCB board. Large, solid ground fill areas inside the proximity sensor should be avoided, as it decreases the sensitivity.

Scan Speed

The scan speed, which is essentially the switching frequency, affects the count output of the sensor. Slower scanning speeds will have the benefits of improved signal-to-noise-ratio (SNR) and better immunity to power supply noise and temperature changes. The CY8C21434 device used for this project provides four scanning speed options, which are Slow, Normal, Fast and Ultrafast. The sensing circuit is implemented with scanning speeds of 3 MHz, 6 MHz, 12 MHz, and 24 MHz, respectively, for the four scanning modes. The "difference counts" obtained for the four scanning modes at distances of 10", 8", 6", 4", and 2" are shown in Figure 3. The "difference count" is a baseline count value subtracted from the counts measured on the sensor. Each peak in the graph corresponds to the distance of the hand, with the 10" distance having the smallest peak and the 2" distance the largest peak in the graphs. Notice that the Ultra Fast scanning speed (24 MHz) is dominated by noise and unwanted spikes, and its reading for 10" would thus be unreliable. From the graphs, it is clear that slower scan speeds (switching frequencies) provide more sensitivity at all distances.

For a proximity sensor, the scanning speed should be very slow, but for capacitive buttons, faster scanning speeds are possible. Since both of these functions in the digital photo frame are proposed, the optimal scan speed must be chosen for both types of sensors. As the scan speed is implemented in firmware, it is a straightforward process to change the scan speed to hone in on the optimal speed.

Noise Levels

The DPF can be placed anywhere in the room and there will be metal, electric fields and emissions, or human interference around it. This causes changes in the electrical field lines and thus the capacitance value detected by the sensor. These interference sources cause count changes in the output that are not desired and thus form noise. The threshold for the detection of the proximity sense should be higher than the noise counts. For the hardware implemented, tests were done to check the noise counts on the proximity sensor with a metal frame around the proximity sensor. There were other electronic items and human movement around the test module, like in the real world. Figure 4 shows the measurements of the proximity sensor over a period of time. The graph obtained shows six peak-to-peak counts of noise in the system over the measurement window in the graph. A minimum SNR of 5:1 is essential for capacitive sensing applications. Therefore, at least 30 counts or more should be the threshold for detecting the hand. As it can be observed in Figure 3, reliable detection of a hand can be done at 8" or closer. The 10" distance does generate 30 counts or more of signal.

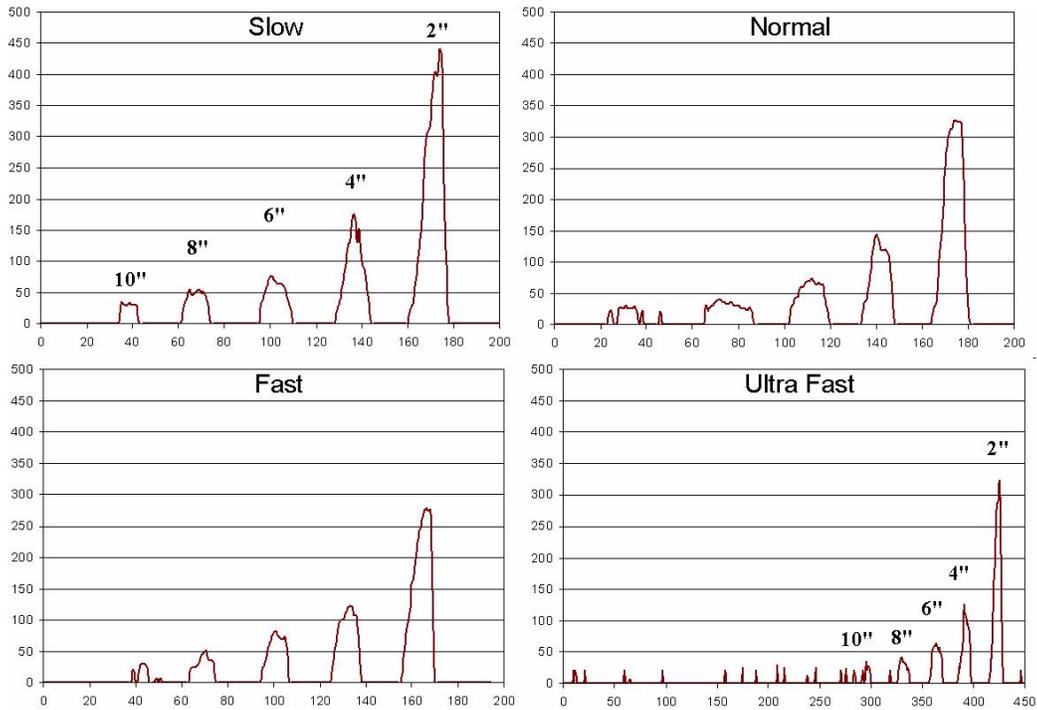


Figure 3. These measurements are captured with a hand at 10", 8", 6", 4", and 2". More difference counts are generated when the hand is closer. Slower scan speeds provide more sensitivity and less noise. Ultra fast scanning does not reliably detect the hand due to the noise spikes in the counts.

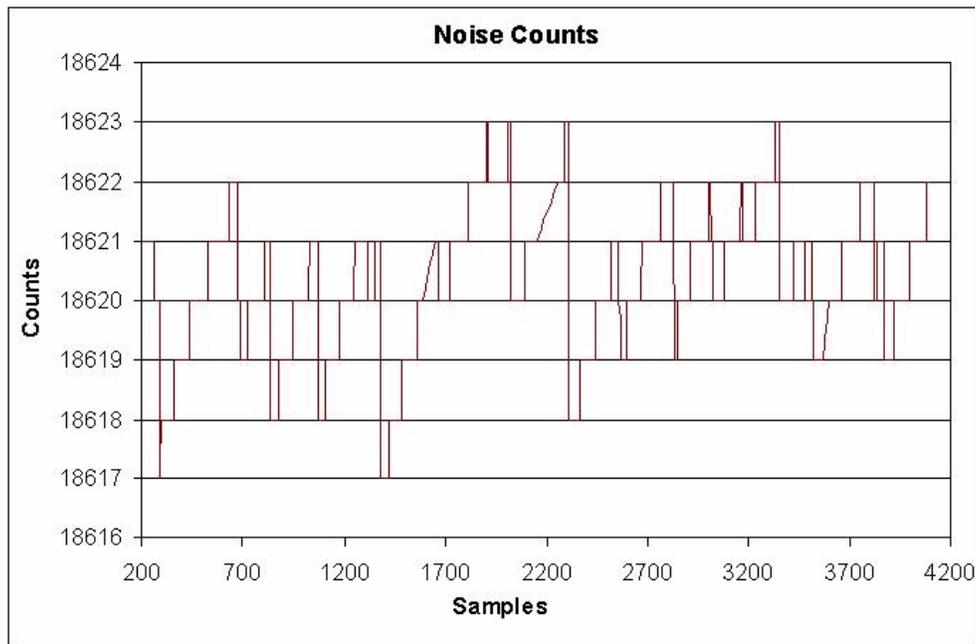


Figure 4. This graph shows the values measured from the proximity sensor with no hand near it. This graph establishes that the peak-to-peak noise in the counts is 6. This helps the designer determine the minimum threshold for detecting a hand.



Other parameters

Other environmental parameters like temperature, humidity, and vibration also cause changes in the sensitivity of the proximity sensor. For a regular digital photo frame these parameters need not be considered and are thus not discussed in this article.

Conclusion

This article has examined how adding a simple mixed-signal device to a digital photo frame product can greatly transform the user's experience with that product. Adding capacitive buttons enhances the cool-factor of the product and surmounts some of the product's user-interface challenges. Once capacitive buttons have been added to a design, adding proximity sensing as well is a relatively easy endeavor.

Although this article focused on digital photo frame design, the same design principles and techniques are very useful for other products that feature LCD displays along with user interfaces.

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
<http://www.cypress.com>

© Cypress Semiconductor Corporation, 2007. The information contained herein is subject to change without notice. Cypress Semiconductor Corporation assumes no responsibility for the use of any circuitry other than circuitry embodied in a Cypress product. Nor does it convey or imply any license under patent or other rights. Cypress products are not warranted nor intended to be used for medical, life support, life saving, critical control or safety applications, unless pursuant to an express written agreement with Cypress. Furthermore, Cypress does not authorize its products for use as critical components in life-support systems where a malfunction or failure may reasonably be expected to result in significant injury to the user. The inclusion of Cypress products in life-support systems application implies that the manufacturer assumes all risk of such use and in doing so indemnifies Cypress against all charges.

PSoC Designer™, Programmable System-on-Chip™, and PSoC Express™ are trademarks and PSoC® is a registered trademark of Cypress Semiconductor Corp. All other trademarks or registered trademarks referenced herein are property of the respective corporations.

This Source Code (software and/or firmware) is owned by Cypress Semiconductor Corporation (Cypress) and is protected by and subject to worldwide patent protection (United States and foreign), United States copyright laws and international treaty provisions. Cypress hereby grants to licensee a personal, non-exclusive, non-transferable license to copy, use, modify, create derivative works of, and compile the Cypress Source Code and derivative works for the sole purpose of creating custom software and/or firmware in support of licensee product to be used only in conjunction with a Cypress integrated circuit as specified in the applicable agreement. Any reproduction, modification, translation, compilation, or representation of this Source Code except as specified above is prohibited without the express written permission of Cypress.

Disclaimer: CYPRESS MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARD TO THIS MATERIAL, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Cypress reserves the right to make changes without further notice to the materials described herein. Cypress does not assume any liability arising out of the application or use of any product or circuit described herein. Cypress does not authorize its products for use as critical components in life-support systems where a malfunction or failure may reasonably be expected to result in significant injury to the user. The inclusion of Cypress' product in a life-support systems application implies that the manufacturer assumes all risk of such use and in doing so indemnifies Cypress against all charges.

Use may be limited by and subject to the applicable Cypress software license agreement.