Capacitive Touch Switches for Automotive Applications

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Executive Summary

Switches and buttons for automotive application have design constraints not even imagined by non-automotive engineers. They have to work for:

- A wide range of temperature.
- A wide range of humidity
- Constant contamination from driver, passengers, and the environment.
- The lifetime of the vehicle.

They also have to be cost-effective, ruling out hermetically sealed switches. Converting to capacitive touch switches provides an implementation with no mechanical parts, the ability to conform to surfaces, and flexible backlighting. Potential applications include: touch switches on top of gauges, touch sense door entry, windshield touch switches, and other dashboard applications. This article will address key topics such as the physics behind touch sense capacitance and how to measure capacitance, the use of IO Analog Multiplexers (IAM) and how every pin can be a capacitive input, and how to implement capacitive touch sensors in automotive designs, among others. With no mechanical parts and easily conforming to curved surfaces, touch sense capacitor switches can be an ideal technology for today's automotive applications

Design Constraints

It isn't easy being an electrical engineer in the automotive industry. Mechanical engineers that focus on cams, compression and horsepower are the norm, and often times electrical engineers are considered to be glorified wire harness designers. More importantly, higher expectations are placed on automotive designs, above and beyond most any other industry. Last weekend I went with a neighbor down to the computer store to buy a new keyboard. His computer is two years old and the keyboard no longer functions well. We got in his car and he became irate that one of the radio buttons broke. Mind you, the car is 12 years old and the keyboard is only two years old, but he has higher expectations of his automobile. We all do.

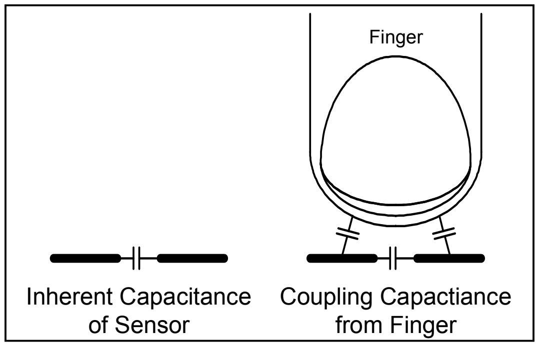
Switches and buttons for automotive application have design constraints not even imagined by non-automotive engineers. They have to contend with:

- A wide range of temperature.
- A wide range of humidity
- Constant contamination from the driver and passengers

Today's cars have far more switches and buttons than earlier models. Not only are there more, but they also need to be easily installable into increasing more contoured control surfaces. They also have to be cost effective, ruling out hermetically sealed switches. One approach gaining momentum is to convert to capacitive touch switches (cap sense). With no mechanical parts, as well as the ability to conform to contoured surfaces, cap sense switches provide the reliability and cost point required by the automotive industry.

Shown in figure 1, a capacitive switch is essentially a capacitor formed from two adjacent traces; physical laws dictate that capacitance exists between them. If a conductive object, such as a finger, is brought in close proximity to these plates, a parallel capacitance couples with this sensor. Place a finger on the capacitive sensor, and the capacitance increases. Remove the finger and the capacitance decreases. Add circuitry to measure the change in capacitance and it is possible to determine the presence or absence of a finger.

Figure 1: Basic Capacitive Sensor



Construction

All that is needed to make a capacitive sensor is a trace, a space, and another trace. These traces can be made part of a circuit board with an insulated overlay placed directly over them. They can be built onto windows using the glass printed circuit technology used for rear window defoggers. They can also be screened on the back of an insolating decal and made to conform to curved surfaces, making them applicable to almost every application in a vehicle.

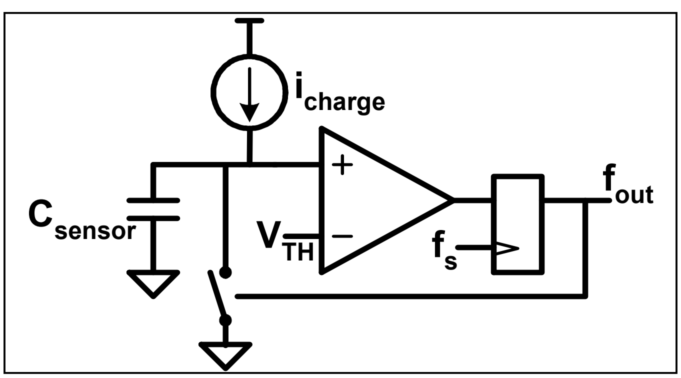
To construct a capacitive switch requires:

- A capacitor
- Capacitance measuring circuitry
- Local intelligence to translate capacitance values to a switch state.

A typical capacitive sensor has a value of 10 to 30pF. Typical finger coupling capacitance to the sensor through 1mm of insulating overlay is in the range of 1 to 2pF. For thicker overlays the coupling capacitance decreases. To sense the presence or absence of a finger, it is necessary to implement capacitance-sensing circuitry that can resolve better than 1 part in a 100 capacitance change.

A relaxation oscillator is an effective and simple circuit for measuring capacitance. A typical topology is shown in Figure 2.

Figure 2: Typical Relaxation Oscillator Topology



This circuit consists of four components:

- A synchronous comparator
- A current source

- A discharge switch
- A capacitive sensor

Initially, the discharge switch is open. With this switch open, all the current goes into the sensor, causing its voltage to linearly slew. This charging continues until the sensor voltage reaches the threshold level of the comparator. The comparator then transitions from low to high, causing the discharge switch to engage. The capacitive sensor quickly discharges through this low impedance path to ground. The output of the comparator transitions from high to low, and the cycle repeats. As shown by the following equation, the output frequency (f_{out}) is directly proportional to the charging current and inversely proportional to the threshold voltage and sensor capacitance. Measure this frequency to determine the sensor capacitance:

$$f_{out} = \frac{i_{charge}}{C_{sensor} \cdot V_{TH}}$$

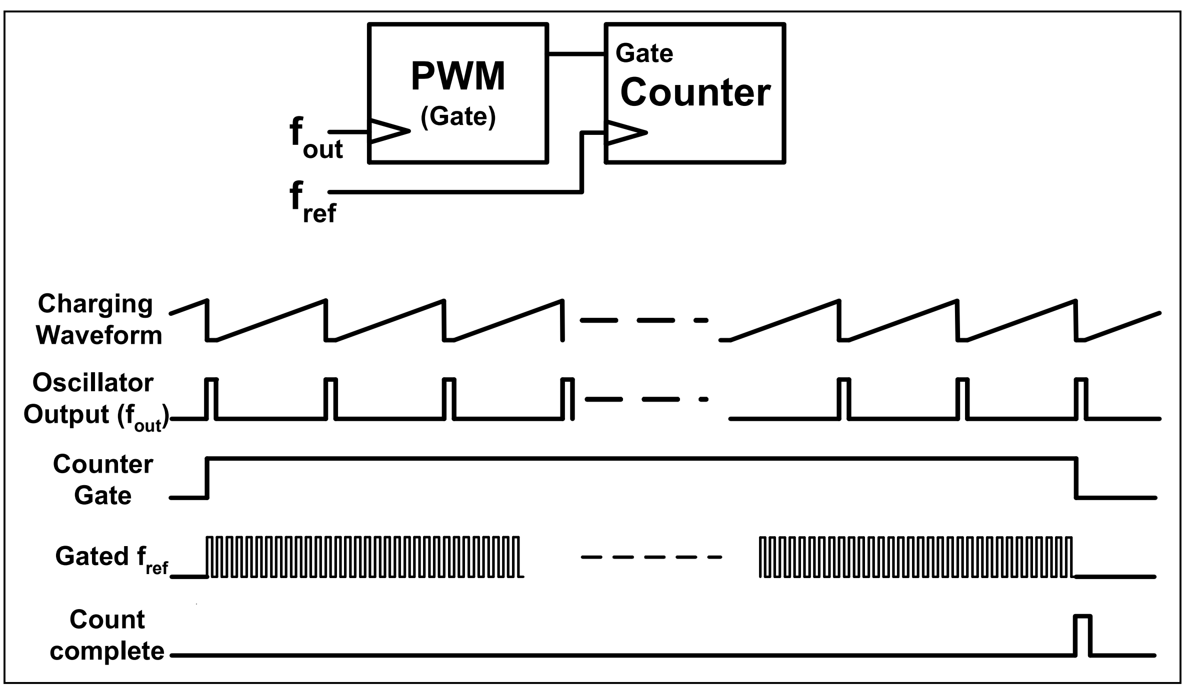
With a charging current of 5uA, a comparator threshold of 1.3V, and a sensor capacitance of 30pf, the output frequency is 128kHz. The more time spent measuring the output frequency, the more resolution that can be obtained. Better frequency resolution results in better sensitivity of the capacitance measurement. Increasing measurement time increases the measured capacitance resolution. Measurement time change can be adapted, application-by-application, to different sensor sizes and overlay thicknesses.

Solving the previous equation for capacitance results in the following equation:

$$C_{sensor} = \frac{i_{charge}}{V_{TH}} \cdot \left(\frac{1}{f_{out}} \right)$$

It is apparent that it is actually desirable to measure the period of the output frequency. Figure 3 shows the block diagram and waveforms for making a period measurement.

Figure 3: Period Measurement Block Diagram

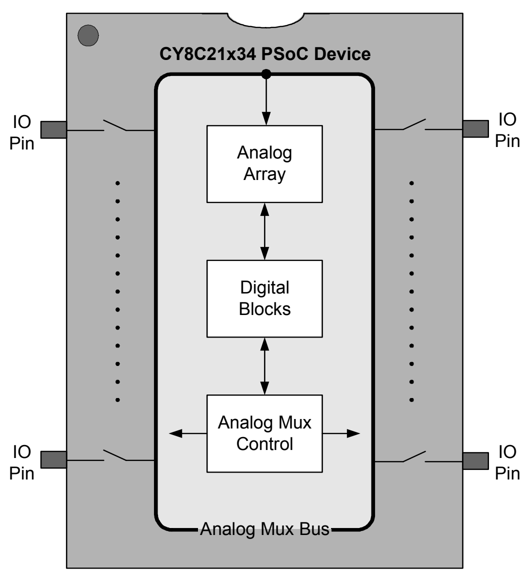


The output frequency is used to clock a pulse width modulator PWM. The PWM output is a waveform that is some number of low periods followed by some number of high periods. The actual values are determined by each application. This signal serves as the gate for the counter. A high gate allows the counter to increment at a rate of $\mathbf{f_{ref}}$. On the falling edge of this gate signal, an interrupt is generated, allowing the counter to be read and reset. As stated earlier, a charging current of 5uA, a comparator threshold of 1.3V, and a sensor capacitance of 30pf, generates a 128kHz output frequency. With a reference clock of 6MHz, the counter value accumulated for one period would be 46 counts. A gate of two periods results in a count value of 93 counts. For 10 periods, the counter value is 468 counts. Clearly the larger the accumulated count value, the greater resolution, or sensitivity, becomes. A larger accumulated value can be achieved by:

- Increasing reference frequency
- Decreasing the oscillator frequency
- Increasing the number of periods for the gate signal.

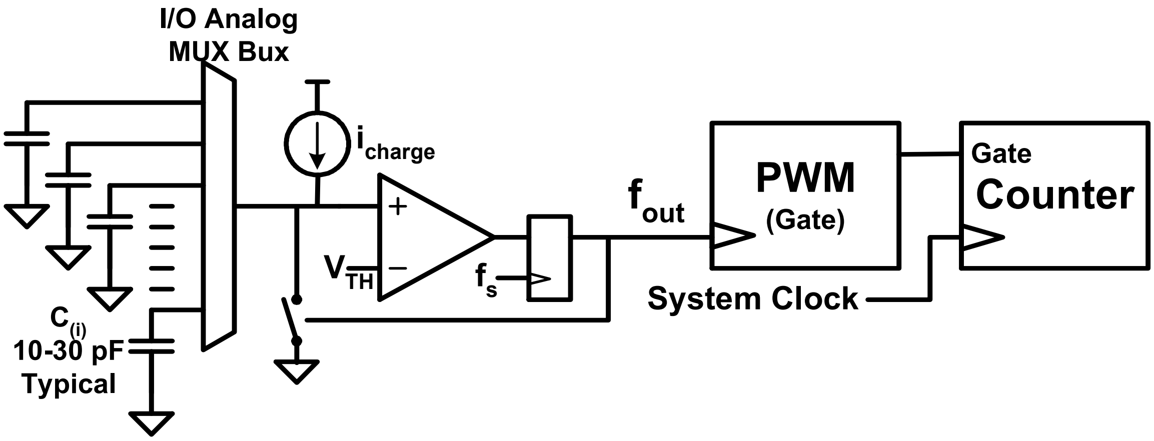
A configurable mixed signal array provides a cost-effective means for implementing a capacitance switch sensor. A block diagram is shown below in figure 4.

Figure 4. Cypress CY8C21x34 Configurable Mixed Signal Array



It contains configurable analog blocks that allow the construction of a relaxation oscillator and digital blocks that implement the period measuring hardware. More important is the addition of an I/O analog multiplexer. Each pin has a switch that can connect it to an analog bus. An I/O analog multiplexer is a large cross-switch that allows any pin to be connected to a control system's analog array. Also connected to this bus are a programmable current source and a discharge switch. This combination of features allows any of the 28 I/O pins to be used as a capacitive senor input. A complete capacitor sense system is shown below in figure 5.

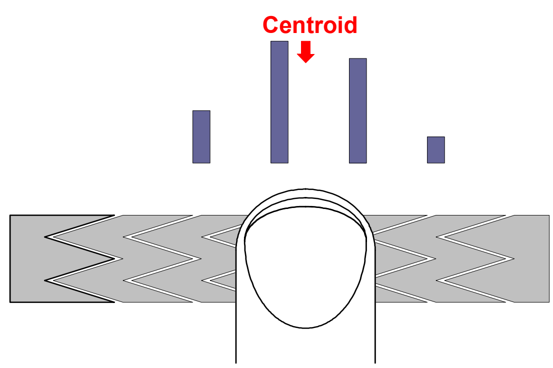
Figure 5. CY8C21x34 Configurable Mixed Signal Array



When two capacitor sensors are placed close to each other, it is possible for both to sense the presence of a finger pressed between them. This effect can be exploited to produce analog-like finger position sensing.

A slider is a set of contiguous sensors made in such a way that a finger will affect several sensors. The capacitive change for all affected sensors can be used to calculate a center of mass, or centroid. This value accurately places the finger position. Figure 6 shows how such a slider could be built.

Figure 6. Slider built from Contiguous Sensors



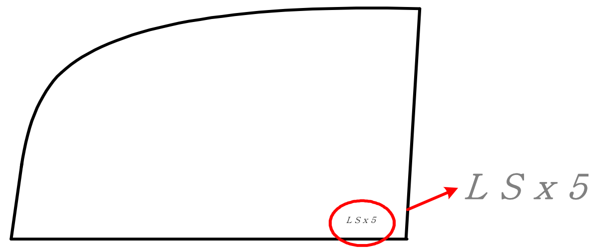
With sliders it is important to choose a sensor shape that easily allows the finger to affect multiple sensors.

A possible application for sliders is for cruise control. Imagine a series of transparent sensors placed over the speed values of the speedometer. Setting the cruise speed to 57 mph could easily be done be tapping the display about halfway between 55 and 60. Both light dimming and/or volume control are also candidates for cap sense sliders. Capacitive switches sensors can be added to the front of any gauge.

As auto control panels get more complex, it becomes harder to place all the controls in the limited available space. One area traditionally ignored is the surface of the steering wheel. For good reason, in many cars this is where the driver's airbag is mounted and no one wants a bunch of mechanical switches to rapidly disassemble into their face and chest upon airbag deployment. Capacitive sensors have no mechanical parts. They are just traces plated on the back of the steering wheel's airbag cover. If plating is not desirable, a thin flex circuit can be mounted just behind the cover.

Another area for control not exploited is the window area. How about placing the window defogger control on the window itself? Maybe the windshield wiper controls are now on the windshield. Imagine digital door locks that are on the window just above the door handle. The owner touches the sensors to enter the correct combination. The sensors can be made from glass printed circuit technology or from clear decals. These sensors can be shaped to look like a conventional keypad. But why be conventional? They can be made pieces of the car's brand or model name as shown in figure 7 below.

Figure 7. Digital Lock on Glass with Model Specific Keys



Warning! When you suggest such a feature to your management there will be one guy, most likely from marketing, that will express concern that people will not be able to unlock their car when the window is down.

Conclusion

Cap Sense switches are not limited to the car interior. An ideal example is a door handle sensor. For this application, the metal handle is used as the sensor. This sensor is made extremely sensitive to serve as a proximity detector. As the presence of a hand approaching the door is detected, power can be applied to security hardware requiring much higher power. As part of the car's alarm system this effect could be logged and the owner notified that someone is repeatedly trying the door handle of the car. (Maybe even call the owner's cell phone.)

With no mechanical parts and easily conformity to curved surfaces, touch sense capacitor switches can be an ideal technology for today's automotive applications. They are cost-effective replacements for conventional switches that also enable designers to implement new and innovative customer interface features.

References

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