

Using an Analog Devices AD774X Capacitance-to-Digital Converter for Differential Button Sensor Operation

Eric Otte
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Executive Summary:

Capacitive sensors are increasingly being utilized in human-interface applications for their cost-effectiveness and accuracy. This application note describes how to select and best use capacitance-to-digital converter circuits from Analog Devices in a variety of common applications, and provides details on how to implement a differential button sensor using an AD7745 capacitance-to-digital converter.

Keywords:

AD7745, AD4476, AD7747, Master, Slave, Traces, Host Processor

Introduction:

Capacitive sensors are commonly used in touch-pads for mobile devices such as MP3 players, but the technology is not limited to only touch-based applications. Capacitive sensors can be used to precisely determine the presence of conductive or dielectric objects, and can also determine the thickness, movement, acceleration, distance, and other similar properties of such objects. All capacitive sensors function by establishing an electric field from a small sensor area and creating a base capacitance value in the process.

Conductive or dielectric objects interfering with the electric field will then change the capacitance value of the sensor; a change which can be accurately measured and processed.

The Analog Devices' AD774X series of capacitance-to-digital converters (CtDs) offer precision measurements down to one femto-Farad of change in capacitance. The AD774X series outputs digital data from one to two sensor inputs with 24-bit resolution over an I2C serial interface to a host processor, typically a microcontroller, which can then process the data and perform functions based on results.

The AD774X series offers low costs of less than \$10 per chip, and industry-leading accuracy and linearity, making it an excellent choice for capacitive-sensing applications when only one or two sensor inputs are required. For applications requiring many sensor inputs, such as touch-pads, the AD714X series should be used, which is not covered in this document.

Objective:

The goal of this application note is to describe the advantages of the AD774X series of CtDs, provide examples of typical applications involving the AD774X series, and describe how to effectively implement a differential button sensor using an AD7745 CtD.

When to Use the AD774X Series:

The Analog Devices AD774X series includes the AD7745, AD7746, and AD7747 capacitance-to-digital converters. In the Analog Devices family of CtDs, the AD774X series is similar to the AD715X series in that it only offers capacitive measurements on one to two channels, meaning it can only measure one to two sensors. For multiple-sensor applications, such as a touch-pad or scroll-wheel, the AD714X series allows for up to 14 channels of operation. The AD774X series described here provides the highest level of accuracy at a resolution down to one femto-Farad (fF) and a digital output resolution of 24 bits. Comparatively, the AD715X series offers only 12 bits of output resolution, but is less expensive and consumes less power.

Given this knowledge, the AD714X series should be used when the application involves an array of multiple sensors, such as a touch-pad. The AD715X series is ideal for applications requiring only one or two channels, and where low-power consumption is a priority, or the increased accuracy of the more expensive models is not necessary. For example, to simply determine the presence of a finger touching a

button, the high resolution of the AD774X series is not necessary and the AD715X series may be used. The AD774X series should be used in applications where very high accuracy is crucial, for example in precision thickness or positioning measurements.

The AD774X Series:

The AD7745, AD7746, and AD7747 CtDs are based around a 24-bit Sigma-Delta modulator, which directly converts the capacitance value of the sensor into a 24-bit digital output. They can be interfaced with a capacitive sensor layout with a base capacitance value of up to 17 pF, which can be nulled to 0 using the on-chip CAPDAC's. The CtDs can then report changes from 0 to +/- 4 pF and output it as a 24-bit digital signal over the I2C interface to a host processor, such as a microcontroller, giving a resolution down to 4 femto-Farads. The AD7745 and AD7746 are designed for floating capacitive sensors, meaning neither trace on the capacitive sensor input pins is grounded. Of these, the AD7745 allows for one channel of conversion, while the AD7746 allows for two (identical otherwise). Either channel can be setup as a single-ended or differential input channel. The AD7747 is designed for grounded capacitive sensors, where one trace on the capacitive sensor input pins is grounded, and supports one channel.

In most cases, designers should look to utilize the AD7745/6 instead of the AD7747, as the AD7747 is much more prone to parasitics.

Since one of the traces is grounded in the AD7747 setup, any extraneous capacitance to ground, such as from cables used to carry the signal data, is seen as an increase in the base capacitance of the system. These parasitic capacitances can easily grow to be larger in magnitude than the capacitance of the sensor traces themselves, and can extend beyond the range of the CAPDAC's, preventing proper operation. For this reason, a "shield" pin is provided, which is essentially an identical output waveform to the excitation pin, which can be connected to the grounded shield of a cable or wire to prevent parasitic buildup. Due to the added complexity of such a setup, the AD7747 should only be used in cases where one trace of the sensor *must* be grounded. The AD7745/6 are highly resistant to parasitic capacitances to ground as both traces are floating, and only capacitance formed between the two traces, and parallel wires carrying the signal data, will contribute to the system base capacitance.

The following notes are written directly for the AD7745/6, but can also be applied to the AD7747 with the knowledge that slight modifications may need to be made to deal with the added problem of parasitics to ground, such as using the SHIELD pin.

Interfacing an AD7745 to a Differential Button Sensor

Button sensors are one of the most common and easiest to implement applications for capacitive sensor technology. Capacitive buttons are now replacing mechanical ones in many modern appliances due to their sleek profile, long operating life and “high-tech” appeal. One feature often desired for an array of buttons is that no two buttons should be able to be pressed at the same time. This can be implemented using a differential button sensor.

While the AD7745 can certainly handle button sensors, it only offers one channel of input, implying only one differential input can be operated per chip. Given that only two differential buttons are to be implemented, the design is straightforward. A differential setup operates by only comparing the *difference* in capacitance between two traces/buttons, as opposed to the *absolute* change in capacitance of each button. When only one button is pressed in a differential pair of buttons, there will be a capacitance change on that sensor input, but not on the other. Thus the difference in capacitance between the two will be large and a “touch” will be registered on the pressed button. However, if both buttons are pressed at the same time, both sensors will experience an approximately equal change in capacitance and thus the difference between the two will be small, so no “touch” will be registered. This differential mode of operation thus prohibits two buttons from being pressed at the same time.

To implement this differential button sensor, the AD7745 must first be connected to a differential pair of button trace layouts. Capacitive sensor buttons are typically laid out as copper traces on a standard FR4 or Flex PCB. An example of a button sensor can be seen in Figure 1. It is far easier to implement this application if the two button sensor layouts used in the differential pair are identical. For more details on sensor trace design, see Reference 1. Figure 2 displays the pin layout of the AD7745. General details on all the pin functions are provided in the datasheet (see Reference 2), but the necessary connections for this application will be described here.

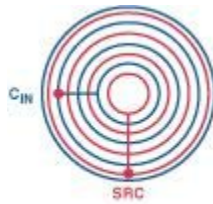


Figure 1: Typical button sensor trace layout

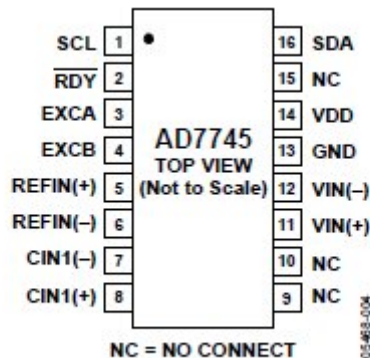


Figure 2: AD7745 pin layout

- **SCL:** I2C interface clock line. One directional, received from I2C master device.
- **SDA:** I2C interface data line. Bidirectional, transfers data bit-by-bit to and from the I2C master device.
- **EXCA:** Source excitation signal to be routed to one trace of sensor layout, configurable 32 kHz square wave.
- **EXCB:** Additional, identical excitation signal source.
- **CIN1(+):** In differential operation mode, one of the two capacitive channel inputs. Connects to a sensor trace.
- **CIN1(-):** In differential operation mode, the other capacitive channel input. Connects to a separate sensor trace.
- **VDD:** DC voltage input for the AD7745. Requires at least 2.7 V, though 3.3 V or 5 V is preferred.
- **GND:** Ground input.

Each button sensor should have two separate traces forming the pattern. The AD7745 should be connected as follows: the EXCA and EXCB should each be routed to one of the traces on each button; the CIN1(+) and CIN1(-) should be connected to the other trace on each button. VDD should logically be connected to a steady DC voltage source, and bypass capacitors of 0.47 uF are recommended near the inputs to the AD7745. GND should understandably be connected to a common ground node.

These connections may be implemented on a custom PCB, a proto-board, or on an AD7745/6 development board. The development board includes PC software to allow rapid prototyping of various

sensor trace designs, and is recommended for those new to capacitive sensors. See Reference 3 for more details.

The SCL and SDA I2C interface pins should be routed to the host processor in the system. It should be noted that the AD7745 and most CtDs are not stand-alone devices; they require a host processor to configure them and process the data they can produce. For those unaware, the I2C communication system is a common two-wire system involving a uni-directional clock line (SCL) and a bi-directional data line (SDA). The controlling processor in a system is known as the I2C Master, and the devices under control, such as DACs or CtDs, are known as the I2C Slaves. The Master is responsible for producing the clock signal (SCL) that synchronizes the Master and Slave devices, and for initiating all data communications between the two devices using standardized procedures. The Master writes to and reads from the Slaves over the SDA line, while the Slave devices can only read from the Master. The Master (host processor) is commonly a microprocessor, although any processor that supports I2C Master Mode will work. For more details on the I2C interface, see Reference 4.

With all pins on the AD7745 connected, and assuming functional button sensors and an established I2C interface with a host microprocessor, the next step to implementing a differential button sensor application is to modify the AD7745 registers. While the AD7745 contains 19 total registers, this application note will only

discuss registers vital to this design. Each register contains 8 bits of data, and can be read by the Master as a single byte.

- **Status (R/O):** Provides details on the current status of the AD7745 to the Master.
- **Cap Data High/Med/Low (R/O):** Three separate registers containing the current capacitive data from the sensors. For proper operation, the three registers should be read sequentially, giving the proper 24 bits of capacitive data information.
- **Cap Setup (R/W):** Allows configuration of the capacitive input channels.
- **Excitation (R/W):** Allows configuration of the excitation signals.
- **Configuration (R/W):** Allows configuration of the mode of operation of the AD7745.
- **Cap DAC A (R/W):** Stores the capacitance data used to null out the base capacitance of one of the buttons, from 0 – 17 pF.
- **Cap DAC B (R/W):** Stores the capacitance data used to null out the base capacitance of the other button, from 0 – 17 pF.

The Master can write to the R/W registers by first issuing a “Start Bit” command on the I2C SDA line to alert the slave devices (see Reference 4). The Master will then output a hexadecimal “address” of the device it wishes to write to. In the case of the AD7745, the device address is “0x90” for a write and “0x91” for a read. Once this address command is received and acknowledged by the AD7745 (done automatically), the Master will then output the “Register Pointer” address. The Register Pointer determines the register of the AD7745

that the Master would like to write to. For example, the AD7745 Status Register is register 0, so the Master would write a “0x00” command. Once this byte is sent and acknowledged by the AD7745, the Master can then complete the data transfer sequence by writing the value it wants to place in the indicated register. An example sequence is shown below in Figure 3.

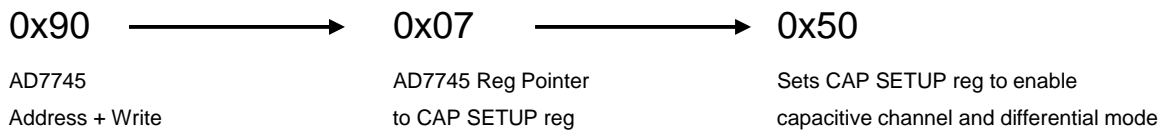


Figure 3: Example of Master output sequence to write to an AD7745 register

While the operator of the Master or a software program can go about setting the AD7745 registers in a number of different ways to configure the system for differential use, a recommended sequence is given below.

1. **EXC Register (0x09):** Enable both EXC outputs, enable max voltage on outputs – set to 0x2B
2. **CAP Setup Register (0x07):** Enable capacitive channel for conversion, enable differential mode – set to 0x50
3. **CAP DAC A Register (0x0B):** Enable DACA and set to a value to null out button A base capacitance – set to 0xXX
4. **CAP DAC B Register (0x0C):** Enable DACB and set to a value to null out button B base capacitance – set to 0xXX
5. **Configuration Register (0x0A):** Enable capacitive continuous conversion mode at 62 ms update rate – set to 0xA1

Upon completion of this setup sequence, the AD7745 will be running in continuous capacitive conversion, differential mode. The two CAPDACs will be used to null out the base capacitance of both of the button sensors (data found through testing). The base capacitance should be nulled as close to 0 pF as possible for best performance. At this point, the AD7745 will produce capacitive conversion data approximately every 62 ms (adjustable through Configuration Register). The conversion data is stored in three 8-bit registers, located at Register Pointer addresses 0x01, 0x02, and 0x03, forming a 24-bit capacitive data value. The registers need to be read sequentially, using the auto-increment feature of the I2C interface, for accurate operation (see Reference 4). The range of this capacitive channel is from -4.096 pF to 4.096 pF. The base value of 0 pF is thus represented by a reading of 0x800000 on the capacitive data registers, negative full-scale is 0x000000, and positive full-scale is 0xFFFFF. The host processor can then convert this data to a capacitive reading in pico-Farads for display purposes.

To complete the design, threshold settings for a touch need to be determined through testing, and programmed into the host processor. Due to the differential operation, a touch on button A will produce a positive capacitance reading of a certain amount, while a touch on button B will produce a negative capacitance reading of a certain amount (ideally very close to the amount for button A). A press of both buttons should produce a very small change in the capacitance reading. General thresholds can be determined through testing to find

the typical capacitive response for each button, and these threshold values can be programmed into the host controller. A touch will then be identified on button A when the reading falls into the positive threshold value, and on button B when the reading falls into the negative threshold value. Care must be taken to include all protective and dielectric materials that will be placed over the buttons when performing threshold testing, as these will cause changes in the capacitive readings when added or removed. Finally, the host processor can initiate commands based on the touch input of the user.

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