Tactile feedback solutions using piezoelectric actuators (Part 2 of 2)

Tim Blankenship, Product Definer, Touch Interface Products, Maxim Integrated Products Inc. - November 22, 2010

Abstract
Implementing tactile (haptic) feedback in consumer-electronic devices enhances the user’s experience. It provides a sense of touch in a user-interface design and is the newest major interface on smartphones and other portable consumer-electronic devices. Several haptic technologies are available now, including but not limited to vibration motor actuation, piezoelectric actuation, and electro-active polymer actuation. This article explains the basics of piezoelectric-based actuation and how it offers a fast response time, thin profile, and low power, all of which are important in handheld applications.

Part 1 of this article discussed piezo characteristics, basics of operation, and modeling; you can read it here.

Design decisions
A single-layer or multilayer configuration?
The information from Table 1 suggests using single-layer piezo actuators. They are more available and already in production volumes; multilayer piezos, while in production, are less available. Also, a single-layer piezo costs much less, a factor that becomes more important in solutions with more than one piezo. For example, several smartphones on the market have multiple single-layer discs mounted behind the display. A similar multilayer piezo solution would cost considerably more.

Discrete components or a single-chip solution?
One of the drawbacks of piezo-based haptics has traditionally been the complexity of the solution. Typical piezo-based solutions have used discrete components to implement the complete tactile feedback system; the extra discrete components included a microcontroller, flyback boost or charge-pump integrated circuit, flyback transformer or inductor, miscellaneous resistors, capacitors, diodes, and transistors. Compare that with DC-motor-based haptics which require few or no external components.

A single-chip monolithic haptic solution such as the MAX11835 has several advantages over the older, discrete designs: smaller printed circuit board (PCB) footprint, lower power, lower bill-of-materials (BOM) cost, and simple software support. Couple this with the low profile afforded by piezos, and the MAX11835 becomes an attractive solution for portable handheld devices.

Figure 7 presents the block diagram of a monolithic high-voltage haptic actuator controller.

Figure 7: Circuit diagram for a tactile feedback solution using piezo actuators.
The MAX11835 monolithic solution is optimized to provide:

- Single-layer and multilayer piezo actuator support
- User-definable on-chip waveform storage (through the serial interface)
- On-chip waveform generator
- Built-in DC-DC boost controller
- Supply range that supports typical cell-phone battery voltages
- Small form factor to minimize PCB footprint
- Low-power operation

**The importance of power management**

Piezo actuators by themselves require very little power compared to, for example, DC motor actuators. Nonetheless, there are other power factors to consider:

- The power taken from the main supply for each haptic event
- The waveform type for each haptic event
- The number of events per second
- The power consumed by the high-voltage boost circuit

Power-consumption measurements were performed on various piezo actuators and high-voltage capacitors using the MAX11835 haptic actuator controller. The MAX11835 plays back a stored waveform using a software-controlled fly-back boost converter in a feedback loop. The test waveforms include a 100Hz sine wave and 20Hz ramp.

**Figures 8, 9a and 9b** show the output of the MAX11835 driving a 175V, 100Hz sine wave. The transformer’s primary current is also plotted.

- **Figure 8:** Output wave shape and boost power-supply current waveform from the MAX11835
- **Figure 9a:** Power vs. load for a 100Hz continuous sine wave.
- **Figure 9b:** Peak boost power-supply current vs. load. Test conditions: frequency = 100Hz sine wave; boost power-supply voltage = 4.2V; boost supply decoupling = 10μF; 6:1 transformer.

A button press is a common feature. The waveform in **Figure 10** uses a 40ms charge, 10ms discharge. The slow charge is imperceptible to the touch, and the rapid discharge feels like a mechanical button being depressed.
In Figure 11 the waveform is continuously running. The power scales down linearly as the duty cycle is reduced. There was no obvious difference in the piezo data between a mechanically loaded (at half-blocking force) and an unloaded piezo actuator.

Figure 11: Power vs. piezo voltage plot. Emulated button press using single and multiple disc piezos. The rapid increase in power above 180V is caused when the primary clamp in the MAX11835 turns on. (Click on image to enlarge)

Figure 12 presents the efficiency of the MAX11835’s boost process, measured as energy delivered to the load and the energy drawn from the boost power supply (VBST).

Figure 12: Energy transfer efficiency: energy stored on load and energy drain in VBST. The rapid increase in efficiency above 180V is caused when the primary clamp in the MAX11835 turns on. (Click on image to enlarge)

In Figure 12, note that the efficiency increases as the load capacitance increases. This is due to the quiescent power required by the boost circuit.

MAX11835 power vs. motor actuator power
Power consumed by the MAX11835 compares favorably with motor-based actuators, including eccentric rotating mass (ERM), linear resonant actuator (LRA), and voice-coil types.

Motor-based actuators typically require low voltages (1.8V to 3V), but the currents can be fairly large. Also, the turn-on and turn-off characteristics of motors, especially ERM types, are less than ideal for the crisp haptic response necessary for emulated buttons and textures.

Comparative measurements were made on the actuators shown in Table 2 and Figure 13. Two types of measurements were collected, continuous operation and pulsed operation. Continuous operation is generally not a realistic case since many haptic responses are short lived, even for textured surface emulation.

Table 2: Power consumption for motor-based actuators (With ∼3V across the motor, the time to reach 50% of maximum RPM; *Approximately one half the resonant frequency at 2V_{RMS}.) (Click on Table to enlarge)
Figure 13: The actuators that were compared and yielded data for Table 2; top to bottom: ERM Coin, ERM Bar, LRA, and voice coil.

Figure 14 shows power dissipation for continuous operation. In this graph, the piezos are driven with a continuous 100Hz sine wave at 180V amplitude. The other actuators are driven with either 3VDC or 2VRMS (LRA and voice-coil).

Figure 14: Continuous operation for the several actuators. (Click on image to enlarge)

Figure 15 shows power dissipation for pulsed operation. For this graph the actuators were driven with a 50ms pulse that emulated a button press. The piezos actuators were driven to 180V amplitude and the other actuators were driven with either 3VDC or 2VRMS (LRA and voice-coil).

Figure 15: Pulsed operation for the several actuators. (Click on image to enlarge)

Conclusions
Several conclusions can be drawn from the prior discussion. Clearly, single-layer--not multilayer--piezo actuators are a more attractive design solution at present for several reasons:

- Lowest cost
- Available from many sources
- In mass production
- Custom designs available
- Can be mounted behind or next to the LCD

Data show that power should be calculated for the haptic feedback circuit from the power supply. The waveform amplitude, type, and duration affect the resulting power usage and haptic response.

The number of events per second also affects the power usage. Consider scrolling or texture events vs. tapping or slow typing. Finally, normalizing the measurements to one event per second makes comparisons simple.
References

1. Information Display, October 2009, pages 18-21
2. Maxim Integrated Products, Datasheet for MAX11835

About the author

Tim Blankenship joined Maxim in 2005 and is currently a Product Definer for Touch Interface Products. Prior to joining Maxim he spent 13 years working in the LCD area for several companies in Austin, Texas and, before moving to Texas, spent 12 years working in various design roles, including memory, telecom, and CMOS mixed-signal systems at Harris Semiconductor in Palm Bay, Florida. He earned an MSEM degree from the Florida Institute of Technology in 1990 and a BSEE degree from the University of Florida in 1980, and can be reached at tim.blankenship@maxim-ic.com.

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