Dual Axis, Low *g*, Fully Integrated Accelerometers

By Harvey Weinberg

The *ADXL202* is the newest low-*g* (±2 *g*), dual-axis, surface-micromachined accelerometer from Analog Devices. Building on experience gained in manufacturing millions of *i*MEMS® accelerometers in the past six years, the ADXL202 is the world's first commercial dual axis, surface micromachined accelerometer to combine low-*g* sensing with lowest power, lowest noise, and digital outputs—all on a single silicon chip.

Surface micromachining, first commercialized with the ADXL50, allows for integration of the acceleration sensor with all signal conditioning electronics—tight integration of the sensor and its signal conditioning is what has made this impressive performance possible.

Lower cost was a major driver in the ADXL202 design effort. Integrating two axes resulted in a significant cost reduction per axis. In addition, while the ADXL50, ADXL150, and ADXL250 can be thought of as "acceleration to volts" transducers, the ADXL202 adds a Pulse Width Modulated (PWM) digital output capability as well. Since most accelerometers will interface with a microcontroller, a PWM output obviates the need for an A to D converter, further driving down the user's total system cost.

Sensor Structure

As with all of our accelerometer products, the sensor element is a differential capacitor whose output is proportional to acceleration (basic sensor information can be seen in *Analog Dialogue* 27-2, 1993, and *Analog Dialogue* 30-4, 1996). Since device performance is so dependent on sensor design, a brief explanation of some of the key factors in beam design is appropriate.

The beam is made up of many interdigitated fingers. Each set of fingers can be visualized as shown in Figure 1. The differential capacitance of each finger is proportional to the overlapping area between the fixed outer plates and the moving finger, and the displacement of the moving finger. Clearly these are very small capacitors, and in order to reduce noise and increase resolution we need as large a differential capacitance as practical.

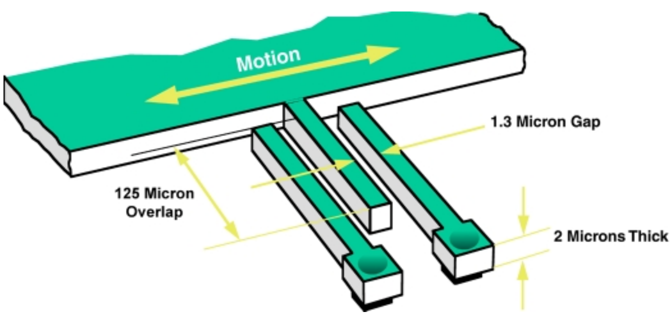

Figure 1. Beam Dimensions for a Single Finger.

The capacitor area is limited by the 2-micron height—fixed by process technology, while the (125-micron) overlap is adjustable to some extent. However longer fingers are not desirable for several reasons. Longer fingers are harder to manufacture and increased beam size translates to more expensive parts.

The movement of the beam is controlled by the polysilicon springs holding the beam. These springs and the beam's mass obey the same laws of physics we learned in high school. The force (F) on a mass (m) subject to acceleration (a), according to Newton's Second Law, is $F = m\,a$, and the deflection (x) of a restraining spring (obeying Hooke's Law) is proportional to the applied force, $F = k\,x$, and:

$$x = (m/k)\,a$$

The only two parameters under our control are the spring stiffness, or spring constant, (k), and mass (m). Reducing the spring constant seems like an easy way to improve beam sensitivity. But as usual, nothing comes for free. The resonant frequency of the beam is proportional to the spring constant, and the accelerometer must operate at frequencies below the resonant frequency. In addition, higher spring constants make for more rugged beams (higher shock survivability). So if we would like to keep the spring constant as high as possible the only parameter left to change is mass.

Adding mass normally implies a larger sensor area, resulting in more expensive parts, since the only way to add mass it to make the beam larger. In the ADXL202 a novel beam structure was invented, as shown in Figure 2. Rather than using two discrete beams placed orthogonally as in the ADXL250 (*Analog Dialogue* 30-4, 1996, page 5, Figure 5), the fingers that constitute the X and Y axis variable capacitors are integrated along the sides of a single square beam. This results in a reduction of the overall sensor area, yet the larger common beam mass enhances the resolution of the ADXL202. A spring suspension system, shown in Figure 3, situated in the corners of the beam, was designed to minimize cross-axis sensitivity (i.e., with acceleration along one axis, any tendency toward motion or outputs in the orthogonal direction is suppressed).

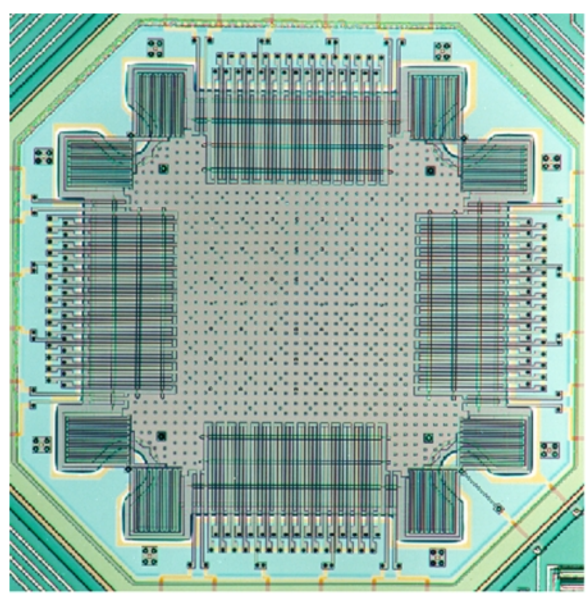

Figure 2. ADXL202 Beam Structure.

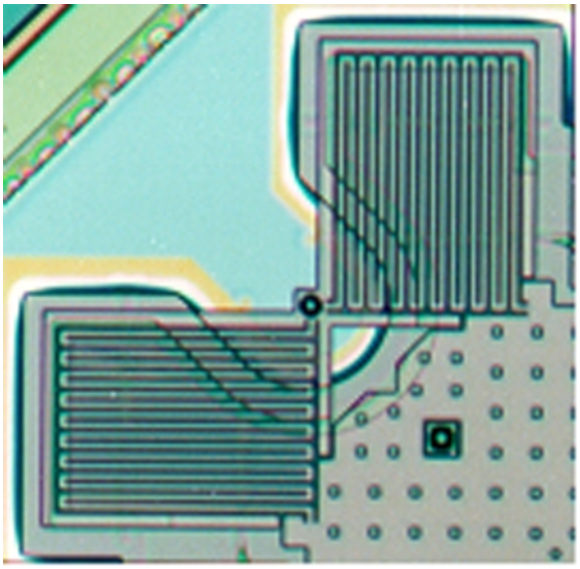

Figure 3. Detail of One Corner of the ADXL202 Beam showing springs.

Circuit Architecture

The circuit architecture (shown in Figure 4) of the ADXL202 is similar to the ADXL250 up to the demodulator. The fixed outer plates are driven with square waves that are 180 degrees out of phase. When the movable fingers (and hence the beam) are centered between the fixed outer plates, both sides of the differential capacitor have equal capacitance and the ac voltage on the beam is zero. However, if the beam is displaced due to an applied acceleration, the differential capacitance will be unbalanced and an ac voltage of amplitude proportional to the displacement of the beam will result.

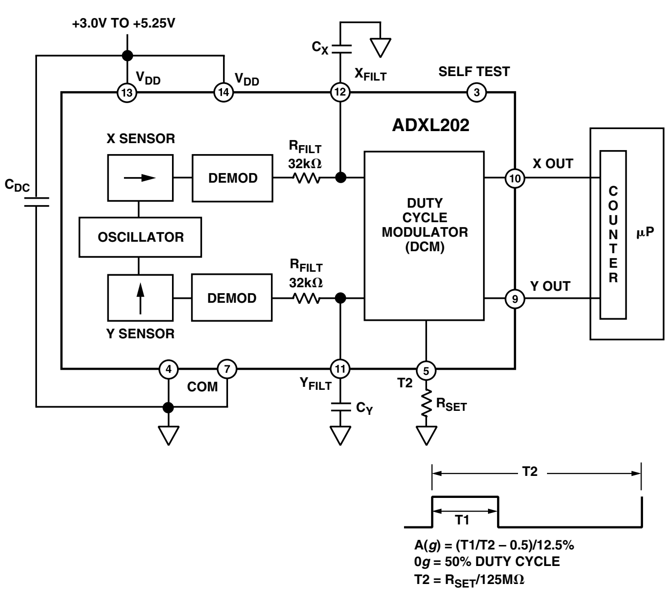

Figure 4. ADXL202 Circuit Architecture.

This ac voltage is amplified and then demodulated by a synchronous demodulator. The output of the demodulator drives the duty cycle modulator through a 32-kΩ resistor. Here a pin is available on each channel to allow the user to set the bandwidth by adding two external capacitors (one per channel) creating a simple first-order RC low pass filter. The low pass filtered signal is converted to a PWM signal by the duty cycle modulator. The period of the PWM output may be set from 0.5 to 10 ms, using a single resistor.

Performance and Applications

Just as it was impossible 25 years ago to predict where low-cost lasers would turn up, today it's difficult to imagine the large number of applications where low-cost accelerometers will be used. The ADXL202 breaks so many performance-vs.-cost barriers that most of its really successful applications are not classically "accelerometer" (literally "acceleration-measuring") applications. They are now being used in car alarms, machine health monitoring, joysticks, game pads, and other computer input devices.

As mentioned in the introduction, the ADXL202 is the lowest noise dual axis surface micromachined accelerometer in production today. With its typical noise density of 500 m*g*/$\sqrt{\text{Hz}}$, it is possible to resolve inclinations of better than ±1° of tilt at bandwidths of up to 50 Hz. The high-resolution (approximately 14-bit) duty-cycle modulator allows users to take advantage of the ADXL202's capabilities in low cost systems. These capabilities have opened the door to several other non-traditional applications, such as car alarms (where they are used to sense jacking-up or towing) and automatic machine leveling.

Support Tools

Extensive support tools are available for designers. The hardware tools available are a simple evaluation PCB with an ADXL202 in its minimum circuit configuration (part number ADXL202EB), and the ADXL202EB-232, a complete 2-axis data acquisition system that interfaces to a PC. Primarily targeted at designers who need to fully understand how acceleration measurement will enable their application or product, the ADXL202EB-232 includes software for viewing accelerometer signals and data logging.

The ADXL202 Interactive Designer is an Excel-based spreadsheet model that takes the user through the design process of selecting ADXL202 components and defining software parameters for microcontroller interface. The spreadsheet outputs component values and information about the resolution, bandwidth and acquisition rate of your design. It is available free at the Web site listed below.

Also available at that site are several hardware and software reference designs, highlighting different interface techniques and a variety of application notes. Each reference design includes flow charts and source code for various popular micro-controllers, as well as a description of where each data acquisition method is appropriate. These documents can be found at **http://www.analog.com/iMEMS/products/ADXL202_top.html.**

© Analog Devices, Inc., 1995–1999
All brand or product names mentioned are trademarks or registered trademarks of their respective holders.
*i*MEMS is a registered trademark of Analog Devices, Inc.: integrated MicroElectronic Machines