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Motion sensing in the iPhone 4: MEMS accelerometer

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The power and attractiveness of **Apple's iPhone 4** lies in the sophisticated integration of **multiple sensing technologies**. Of specific note is the integration of a full **9 degrees-of-freedom (DoF)** motion sensing. The iPhone 4 is the first portable consumer device to incorporate a three-axis **accelerometer**, three-axis **gyroscope**, and three-axis **electronic compass**. The addition of these sensors allows for much better rotational **motion sensing**, gaming, image stabilization, **dead reckoning for GPS**, gesture recognition and other applications, than was possible with **only an accelerometer**.

The iPhone family of products has been evolving towards the goal of full 9DoF motion sensing. The original iPhone, which was launched in June 2007, incorporated only a STMicroelectronics LIS302DL accelerometer, while the iPhone 3G incorporated an STMicroelectronics LIS331DL accelerometer, both corresponding to 3DoF sensing. The iPhone 3GS incorporated an STMicroelectronics LIS331DL accelerometer and an AKM AK8973 electronic compass, thus providing 6DoF sensing. The iPhone 4, released on June 24, 2010, featured full 9DoF motion sensing, plus three microphones, two image sensors, ambient light and proximity sensors, and the archetypal touch screen sensor.

Chipworks has completed a full analysis, down to the silicon, of the three motion sensors found in the iPhone 4. In this three part series, we present some highlights from our analysis, with specific focus on the MEMS sensors, how they are made, and how they work. This article will review the results of our teardown of the iPhone 4 and will include a discussion of the three-axis accelerometer. The next article will provide the results of some of our analysis on the three-axis gyroscope used in the iPhone 4, while the third article will provide a review of the three-axis electronic compass technology.

iPhone 4 Teardown

Figure 1 below shows the top side of the main printed circuit board. The STMicroelectronics LIS331DLH accelerometer and the L3G4200D gyroscope devices are placed side-by-side, adjacent to the Apple designed but Samsung fabbed, A4 microprocessor. Although not labeled with ST part numbers, the devices were identified through comparison with devices previously analyzed by Chipworks. The AKM8975 electronic compass is found on the other side of the main board, adjacent to a Samsung flash memory chip, as seen in Figure 2. These three motion sensors appear to independently provide signals to the A4 microprocessor iOS operating system. These signals are then integrated in software by the apps.

Figure 1: iPhone 4 main board top side.

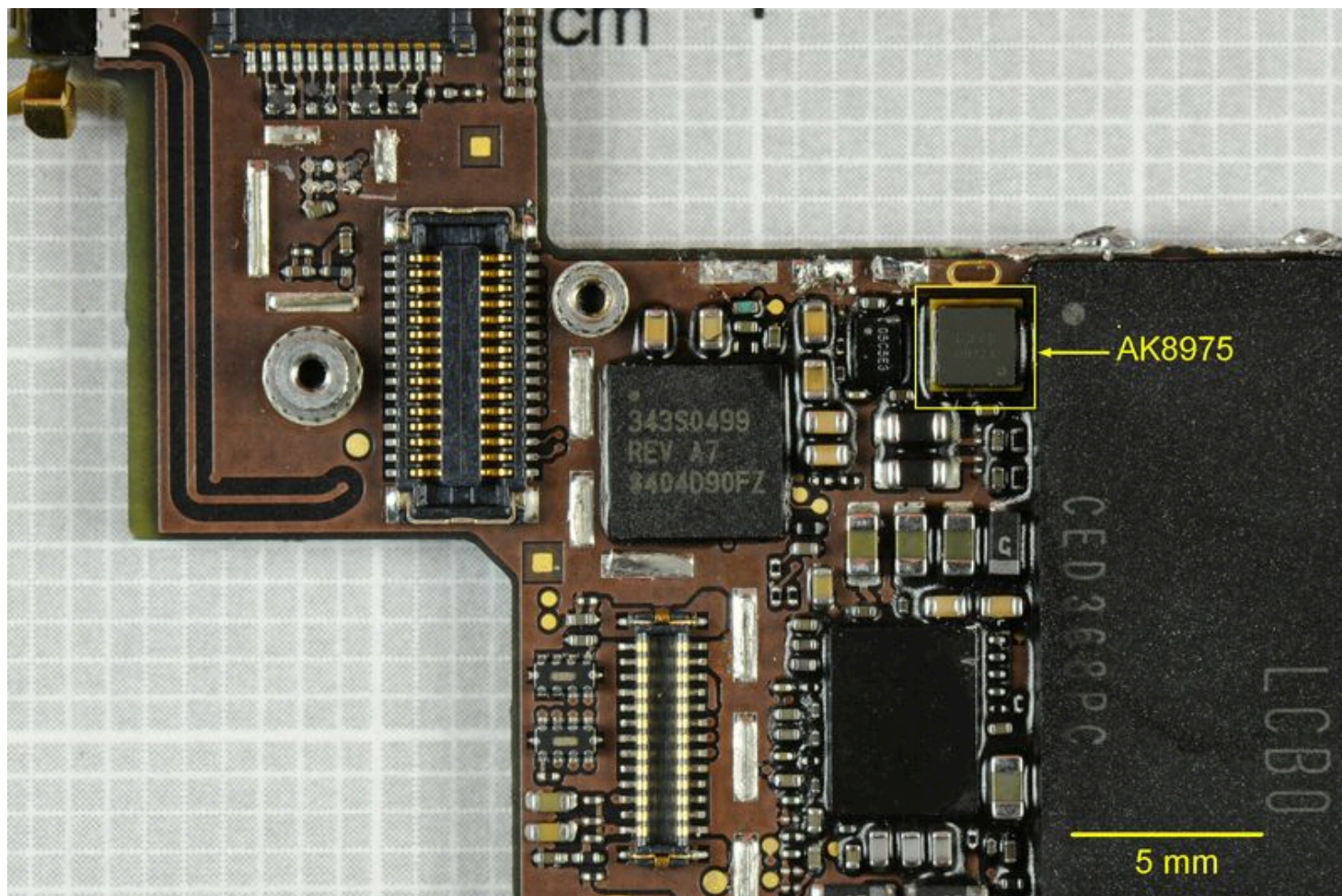


Figure 2: iPhone 4 main board bottom side.

iPhone 4 Three-Axis Accelerometer: STMicroelectronics LIS331DLH

The LIS331DLH device comes packaged in a 3 mm x 3 mm x 1 mm thick LGA type package. It contains two chips, an ASIC and a MEMS. The MEMS chip incorporates a cap, as can be seen in Figure 3, which sandwiches the micromachined layer in a cavity between the MEMS die and the cap die. A lead-doped frit glass seal is used to hermetically seal the cavity. The ASIC die lies on top of the MEMS cap, and is wire bonded to both the MEMS die and the package substrate, which provides interconnection to the outside world. The stacked, ASIC over MEMS, geometry has been used in all the ST inertial sensors analyzed by Chipworks. Other vendors use a side-by-side geometry, which makes thinning the package to below 1 mm easier, but makes shrinking the linear dimensions more challenging.

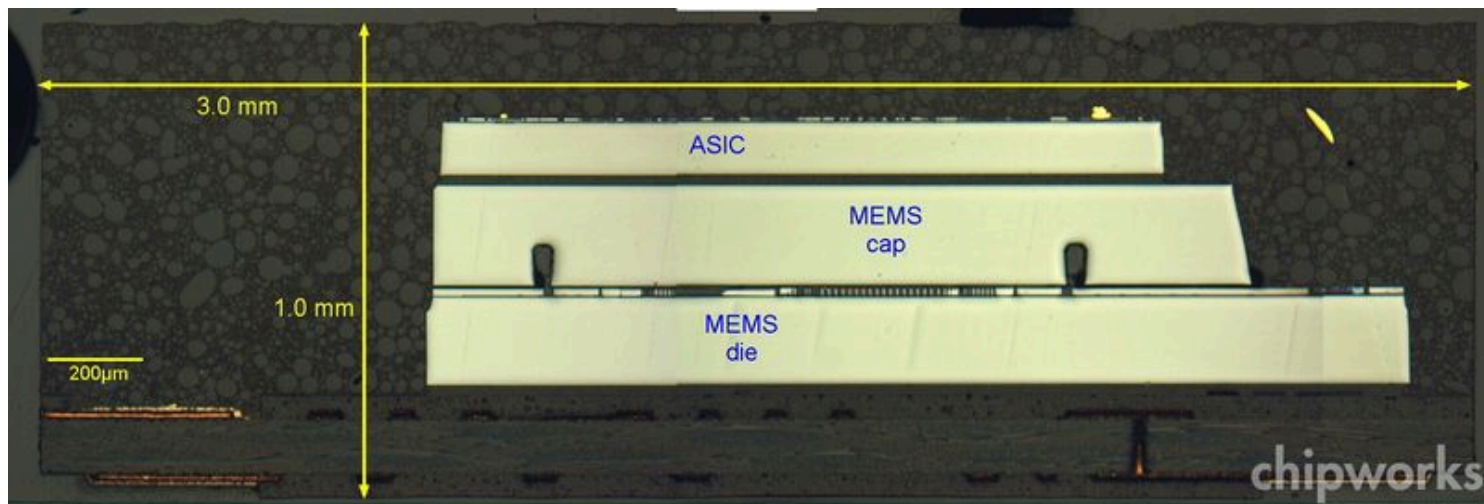


Figure 3: LIS331DLH package cross section.

Decapsulation of the LGA package, followed by removal of the cap, reveals the structure of the MEMS die, shown in Figure 4. The C5L12B MEMS die, which has 2008 mask marks, contains a separate sensor for XY and Z linear acceleration. The die was fabricated

with ST's thick epi-poly layer for micro-actuators and accelerometers (THELMA) process, which provides a 2 μm minimum feature size in a two polysilicon surface micromachined MEMS process.

The XY sensor consists of a polysilicon proof mass, which is anchored to the substrate via leaf springs that constrain the proof mass motion to the XY plane. Interdigitated, parallel-plate capacitors, mounted within the proof mass structure, capacitively sense inertial deflection of the proof mass in the X and Y directions. The Z-sensor is formed using a top polysilicon plate that is cantilevered on a torsion spring. Inertial deflection of this plate is sensed capacitively by a bottom polysilicon plate.

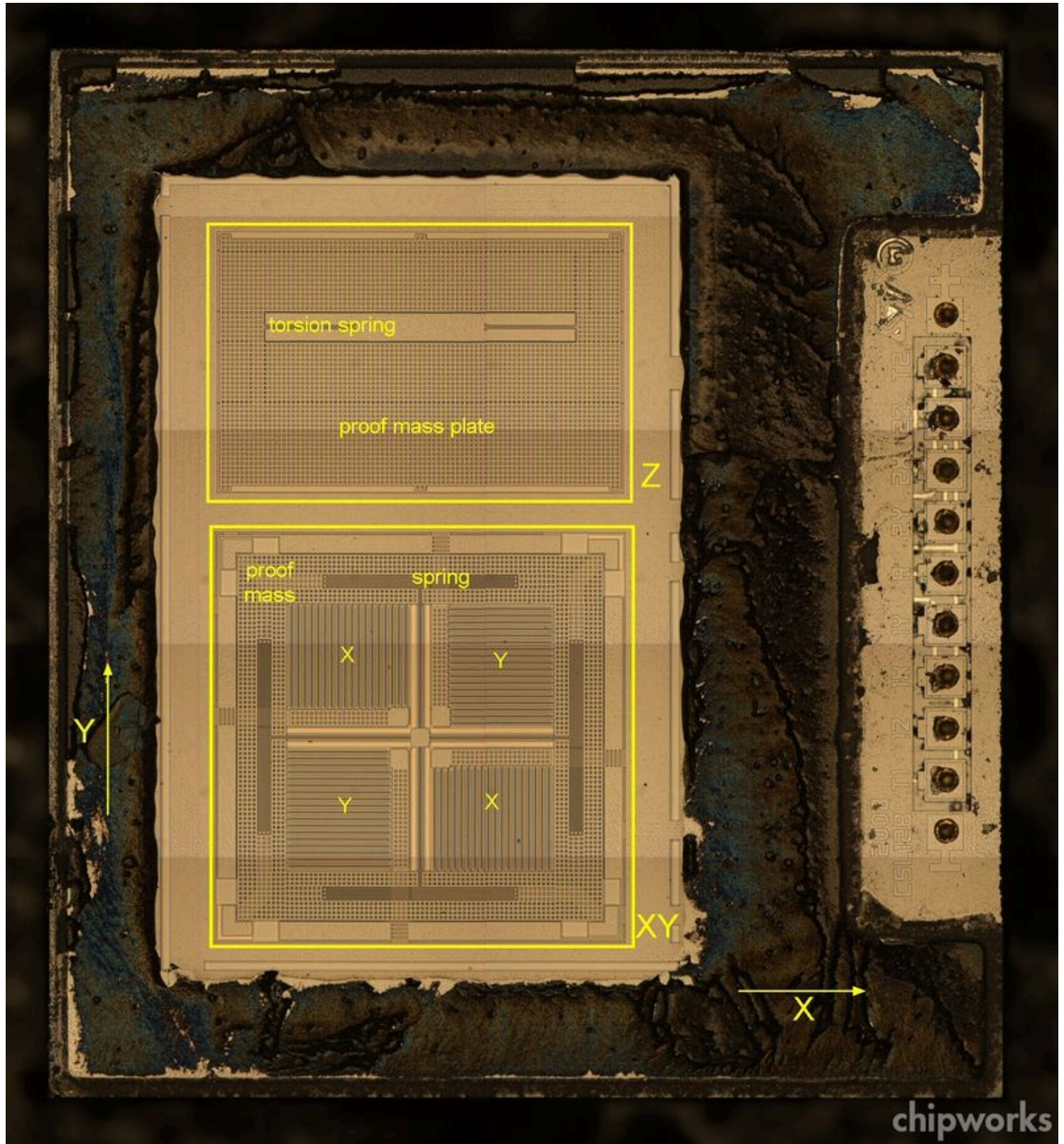


Figure 4: LIS331DLH C4L12B three-axis accelerometer MEMS die.

A detailed view of the XY sensor, showing a portion of the proof mass supported by the leaf spring, is given in Figure 5. The interdigitated capacitor plates are attached alternately to the proof mass and to fixed anchors to the substrate.

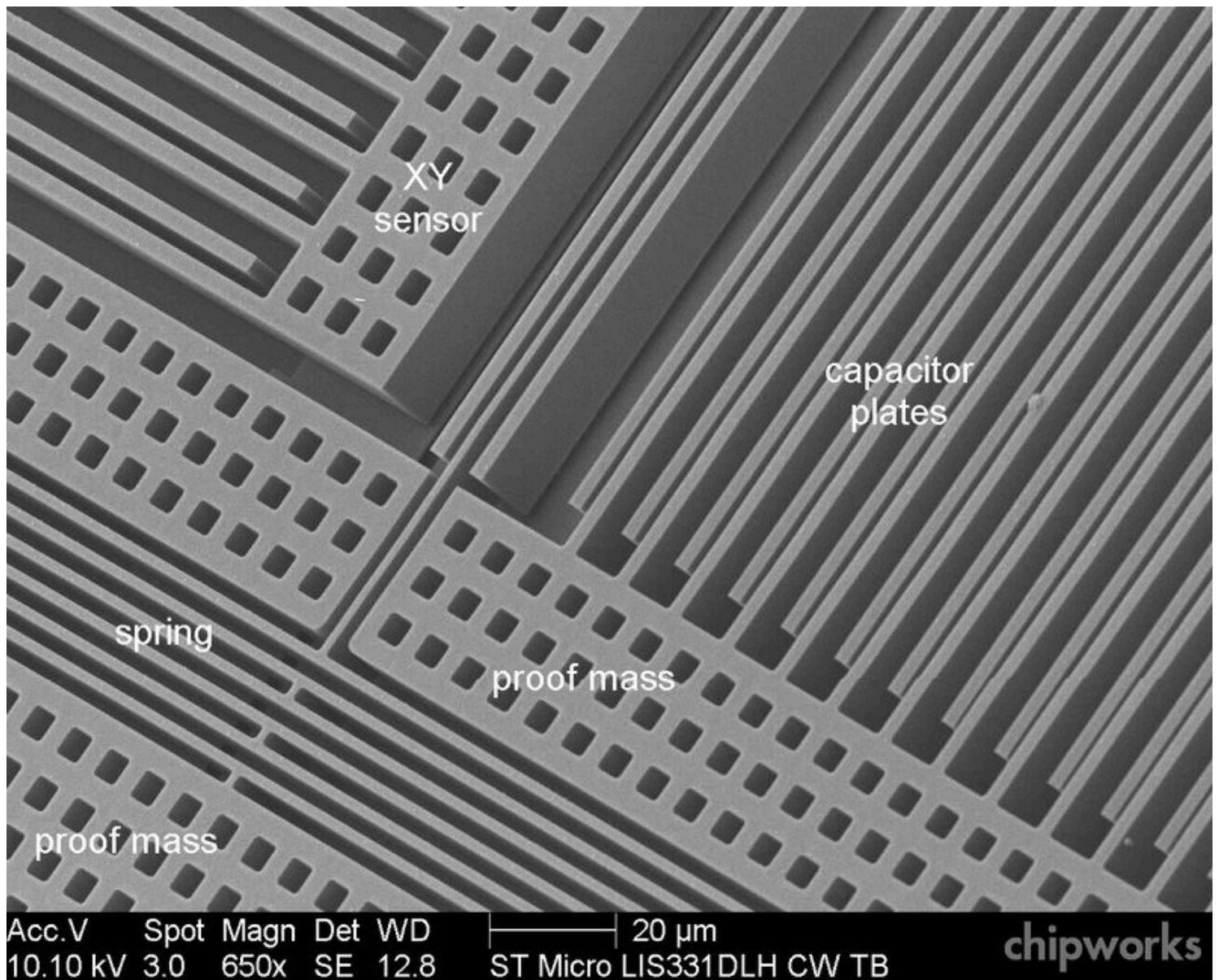


Figure 5: LIS331DLH XY sensor detail.

The ASIC controller processes signals from the MEMS structure. It is likely that the ASIC actually uses capacitive feedback to maintain a DC bias on the plates, such that the capacitance (plate spacing) remains constant. This DC bias would be the output signal. The ASIC delivers a digital I2C/SPI serial interface standard output to the A4 processor.

The next article in this series will review the STMicroelectronics L3G4200D three-axis gyroscope that is used in the iPhone 4.

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Comments



Thank you Dr. Dixon Warren

so from the above explanation we understand the accelerometer that has been used in iPhone 4 is a MEMS capacitive accelerometer!

Posted by: Amir | [March 05, 2011 at 02:45 PM](#)



Nice article. To find out more about Motion Sensors Used in iPhones, Please See here

Posted by: [Motion Sensors Used in iPhones](#) | [April 21, 2011 at 02:41 PM](#)

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