MEMSIC SOLVES THE ACCELEROMETER PUZZLE

CASE STUDY

Mentor Graphics®

A M S   D E S I G N   &   V E R I F I C A T I O N

INTRODUCTION

Accelerometers play a valuable role in many markets. Your smart phone has them, as does your car. Medical applications for this device are growing by the day. Measuring the rate of change in velocity seems to have unlimited applications. So, it is no surprise that MEMS accelerometers shipped over 2 billion units in total last year, according to the Yole Développement "Status of the MEMS Industry report for 2015."

There are many design techniques available to create an accelerometer. A common technique is to fabricate a MEMS device with a proof mass suspended by springs (Figure 1). As acceleration takes place, the mass moves to close gaps between fixed and movable fingers, changing capacitance. Voltages are applied to the fingers and when the proof mass shifts, the movable fingers develop a voltage caused by the change in capacitance. This voltage is measured to determine acceleration. However, moving parts are subject to stiction (two surfaces in close proximity, like the fingers, adhere to each other), errors due to vibration, and actual fracture of the moving parts due to shock (g-forces).

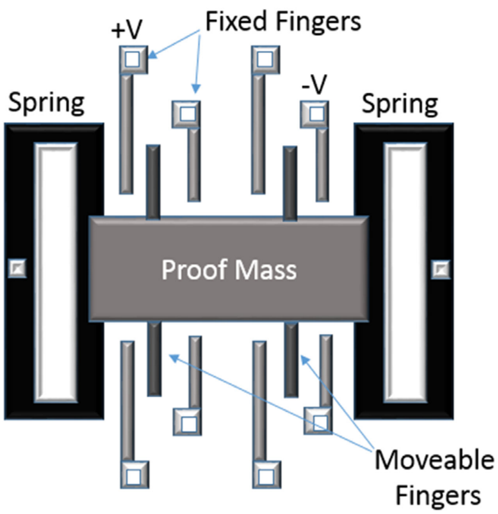

Figure 1: Proof mass MEMS accelerometer representation.

Enter MEMSIC® Inc. located in Andover, Massachusetts. MEMSIC developed a MEMS and CMOS IC technology with no moving parts. Using a unique thermal technology, acceleration is measured by using heated gas molecules. Thus, the MEMSIC accelerometer offers many advantages:

- No stiction
- Tolerates over 50,000g shock
- No measurable resonance (resulting in vibration immunity)
- Zero-g offset stability
- No detectable hysteresis

It's hard enough to design mixed-signal processing onto the same chip as a MEMS device, but MEMSIC has managed to integrate these technologies on the same silicon and sells millions of accelerometers in a variety of industries. The company has also overcome two other hurdles: keeping production costs low by sticking to a standard CMOS IC process, and standardizing development on a single set of tools from Tanner.

DETECTING ACCELERATION AND MOTION

Most accelerometers depend on moving mass to determine motion, but MEMSIC differentiates itself from its competitors through its use of a thermo-mechanical sensor in silicon (Figure 2).

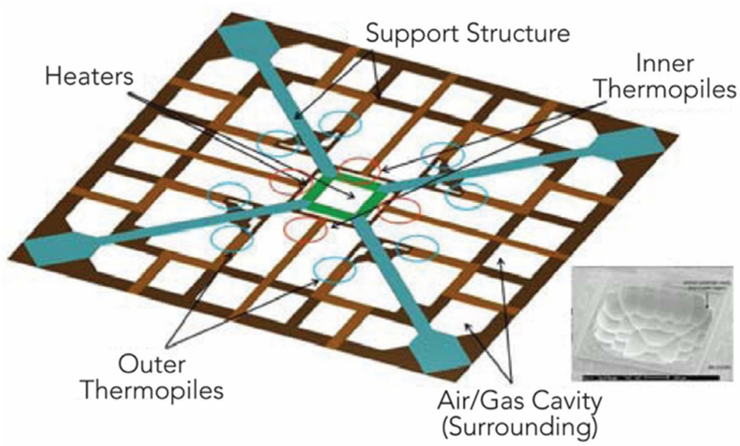

Figure 2: Basic MEMSIC accelerometer structure.

In the center of the 1mm-square sensor is a heater operating at 100°C above ambient temperature. Around the heater are symmetrically placed thermopiles for reporting temperature in different locations. A thermopile is a series of thermocouples, or temperature-sensing elements, connected in a series to boost voltage. The entire sensor is hermetically sealed in an air/gas cavity, outside of which is analog circuitry for amplification, control, analog-to-digital conversion and, in the 3-axis models, digital compensation/calibration circuitry.

In the absence of motion, the thermal profile is balanced among the thermopiles. But any motion or acceleration modifies the convection pattern around the heater, such that the thermopiles in the direction of the acceleration become hotter than the others. The analog circuitry interprets the resulting signal changes from the thermopiles as motion and acceleration.

With no moving parts, MEMSIC's accelerometers are longer-lasting, more reliable, and as much as 25 times more shock-resistant (greater than 50,000g) than their mechanical counterparts for measuring tilt, inclination, shock, and vibration. The chips appear in products that require the control or measurement of motion, such as car alarms, mobile electronics, global positioning systems, elevator controls, patient monitoring devices, and head-mounted displays for gaming.

ONE TOOLSET FOR ANALOG AND MEMS DESIGN

"Back in the 1990s our design center used Tanner Tools, so we adopted them and have used them ever since," explains MEMSIC's Director of Technology Partnership and Development, Yongyao Cai. "Our accelerometers combine MEMS IP and analog circuitry IP, and the Tanner tools are flexible enough for both our circuitry and the sensor. We model the sensor as a resistor, and we can also model it as a polarized resistor because the thermopile has polarity."

"Tanner tools have been 100% reliable for us ever since we started using them in 1999. We can work in Tanner tools on MEMS design one minute and analog design the next minute. Plus, we've never had a tapeout error due to verification." - Yongyao Cai

For the design of accelerometers, MEMSIC engineers use MEMS Pro, an application from SoftMEMS® built on top of Tanner's L-Edit™ for designing and analyzing MEMS. In fact, early MEMSIC products were even simpler and did not require full mechanical simulation, so the MEMS engineers worked directly in L-Edit.

The engineers at MEMSIC use MEMS Pro to create a 3D model directly from the layout for finite element analysis. They use L-Edit to modify the details of the sensor and for layout (Figure 3). After layout, they use L-Edit LVS and L-Edit Standard DRC. Finally, they export from L-Edit to a GDS layout file and send the tapeout to TSMC® for fabrication.

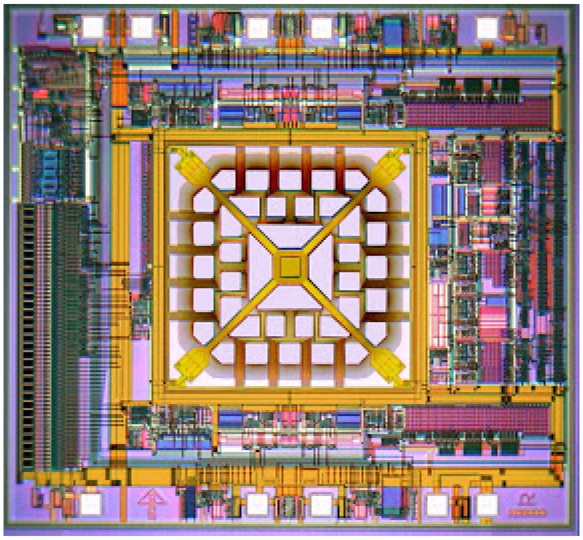

Figure 3: Accelerometer layout using L-Edit.

MEMS DESIGNS AND CMOS FABRICATION

To take advantage of lower fabrication costs, MEMSIC designs its sensors almost exclusively with standard CMOS layers. For example, the heater is gate polysilicon and the first layer of the thermopile is metal and polysilicon.

"We have a tremendous advantage over our competitors," continues Yongyao. "Our process is almost independent of the fabrication foundry because our design is 95-99% CMOS. We can easily change the process and foundry to take advantage of better production pricing. Our competitors, on the other hand, use proprietary MEMS processes, fabricating either by themselves or through a specialized foundry, and that is always more expensive than working with a traditional CMOS foundry."

MEMSIC also enjoys an advantage when changing geometry. Most of its competitors are still employing older-generation process technology and changing to a newer technology in MEMS will result in a completely different process and a costly conversion. MEMSIC employs newer technology and its standard CMOS IC process allows it to ramp up volume and production quickly after a change in geometry.

92,000 ACCELEROMETERS IN BEIJING

The most public application of MEMSIC's technology was for the electronic "Waving Torch" distributed to all attendees of the opening ceremonies at the "Bird's Nest" Stadium for the 2008 Olympics in Beijing, China (Figure 4).

Figure 4: The Waving Torch.

The torch resembles a 20-30cm wand, with a linear array of LEDs. Shaken from side to side, the torch tricks the human eye into seeing iconic Olympic images – symbols for major sports, the Olympic logo, Chinese greetings, and the five Olympic mascots – displayed in mid-air as the LEDs switch on and off. The core technology in the torch includes a MEMSIC algorithm and accelerometer (designed with Tanner tools) to detect the user's back-and-forth hand movement and to fire each LED as needed for the image.

"We worked on this project for half a year as an Olympic promotional tool," says Yongyao. "The user waves the torch through the air and the LEDs display the pattern according to the motion. It's a good example of how much information an accelerometer can provide on position, orientation, and speed."

CONCLUSION

To keep costs low and performance high, MEMSIC needs to design MEMS-based accelerometers for production in a standard CMOS IC process. Since 1999, the company has relied on the flexibility of Tanner tools to design 2-axis and 3-axis MEMS accelerometers and the associated circuitry.

To learn more about the Tanner solution, view the whitepaper "Creating a MEMS Device: How to Get Started?" at http://go.mentor.com/4kk6p

ABOUT MEMSIC, INC.

MEMSIC Powerful Sensing Solutions

MEMSIC (MEMS + IC) Inc. provides a wide portfolio of sensing solutions. The company develops breakthrough MEMS sensor components and system integration technologies for a broad set of markets, including consumer, automotive, aviation, and marine.

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