APPLICATION NOTE

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Using the TEGAM Model 2350 as Part of a MEMS Optical Profiling System

Introduction

This application note describes how a customer used the TEGAM Model 2350 Dual Channel, High-Voltage amplifier to make a MEMS optical profiling system more effective, and how he applied the system to test and study the reliability of MEMS devices.

Figure 1

Figure 1 – TEGAM's Model 2350 dual channel amplifier offers up to 400 Vp-p output voltages at high bandwidths. It features customizable gains, very low noise, short circuit protection, and unmatched stability. The Model 2350 is preferred in MEMS applications.

Application Summary

Micro Electro Mechanical Systems, commonly known as MEMS, are increasingly becoming widely used for micro-miniature actuators and sensors that detect electrical, mechanical, chemical, and physical phenomena in numerous measurement applications around the world. Their extremely small dimensions are their most outstanding quality, and with features measured in units of micrometers, semiconductor-processing techniques must be used to manufacture them.

To date, three basic types are made: One with solid-state features, and two with moving parts (rotating or flexing structures). The solid-state sensors are the most reliable, contain signal-conditioning circuitry, and are designed for detecting chemicals, temperature, humidity, electric and magnetic fields, and similar phenomena. The types fabricated with flexing features, such as cantilever beams are widely used in accelerometers. Finally, the third type contains miniature parts that physically move, such as wheels and gears. However, this class of device describes more than just sensors; they are also micro-mechanisms. Although the modulus of silicon is about 165 GPa, comparable to that of some steel, the moving parts tend to rub, wear out, and have a relatively short operating life. Consequently, they are still largely under development.

Initial Development Difficulties

Scientists have been studying several different methods of manufacturing MEMS devices recently -- particularly the last type -- to substantially reduce the coefficient of friction between moving parts and extend their life. However, the sensors' extremely small size makes handling them difficult for the investigators. In spite of these obvious difficulties, scientists at Sandia National Laboratories in New Mexico designed and fabricated a special test bed, called an optical profiler that contains a high-power interferometer microscope to monitor the MEMS operation and measure the sensors' wear resistance. A computer generates low-frequency signals by means of a custom program and sends them to an amplifier, which actuates the devices. The amplified signals reach the device through miniature probes located between the microscopes' objective lens and the surface of the MEMS device.

Unfortunately, these early optical profilers came with some serious limitations. For one, the space between the MEMS device and the microscope's objective lens, known as the working distance, was insufficient to allow most types of probes to be used. In an attempt to accommodate a variety of probes, several methods had been devised to increase the

10 TEGAM WAY • GENEVA, OHIO 44041
440-466-6100 • FAX 440-466-6110
www.tegam.com • e-mail:-sales@tegam.com

working distance. But, the majority of these techniques reduced the optical resolution, which tended to compromise the test results.
Another problem relates to the MEMS's drive signals. Typically, MEMS devices depend on a relatively high voltage to generate sufficient electrostatic forces to operate the devices' movable structures, such as miniature mirrors used in optical projectors. The zero to 10-V, low-level drive signals themselves are not difficult to generate within the computer, but the amplifiers that are needed to boost that output from 150 to 200 Volts require special operating parameters.

Solving the Working Distance Problem

One firm, E. M. Optomechanical, Inc., Albuquerque, New Mexico, recently licensed the Sandia National Laboratory patents for the optical profiler and has begun manufacturing a version that substantially increases the working distance to more conveniently accommodate the probes. Called the OPTOPro, the profiler has a long working distance of 38 mm, far more than the standard profilers that cover only 10 to 12 mm.

Tom Swann, owner of E. M. Optomechanical, made some major improvements to the mechanical features of the profiler, but retained the original MEMScript tm software developed at Sandia. The software does basically two things: First, it controls the computer's output voltage, which drives the high-voltage amplifier, and second, it monitors and measures the motion of the devices with phase-shift interferometry. This is a technique that is accurate to within just a few angstroms.

Basically, the OPTOPro contains a Michelson interferometer reference mirror on piezoelectric material. As the computer-based controller shifts through four increments of lambda (wavelengths), the complete phase image of an interference pattern appears. The computer's numerical algorithm then computes the height of each feature at every point. With this method, researchers can measure the size and shape of a cantilever beam structure, for instance, to within 5 nanometers. The unit also contains a high-resolution monochrome CCD camera to observe the MEMS's features and moving parts in three dimensions.

The first customer to receive the productionized OPTOPro profiler was the Chemical Engineering Department of Auburn University, Auburn, Alabama. Robert Ashurst, Assistant Professor of Chemical Engineering and principal MEMS researcher, uses the optical profiler to study tribological performance and reliability of certain types of MEMS devices. "I want to find out how many times we can operate a device before its performance begins to suffer," says Ashurst. "Another aspect under study is how we can chemically engineer surfaces so that failure modes that cause their performance to degrade are reduced."
For example, one common problem in MEMS devices that move and touch is a phenomenon called stiction. "We are learning how to chemically treat its surfaces so that stiction does not occur," says Ashurst. "And in order to evaluate the processes used to treat the surfaces, we measure forces and test the devices in order to quantify the stiction, coefficient of friction, and wear. Its one thing to make a MEMS device at the research level and show that it works, but its quite another thing to make it into a commercial product when you have to prove that its going to work. And the probe station is most useful for the quantification of these device properties."

Actuation Signals

Ashurst was eager to get his program under way as soon as possible, but the original high-voltage amplifier manufacturer couldn't meet the delivery schedule. In addition, Ashurst had some serious doubts about the rated performance of the amplifier. "So at that point," says Ashurst, "I evaluated a number of other high-voltage amplifier manufacturers and discovered TEGAM, located in Geneva, Ohio. The TEGAM amplifier proved to have a number of advantages over the original." For example, the original amplifier could deliver only 150 V, compared to the TEGAM amplifier's output of 200 V. "Stepping up to 200 V makes a tremendous difference, because in electrostatic actuation, the force output scales as the voltage squares," says Ashurst.

"We measured and benchmarked the original amplifier and the TEGAM with an oscilloscope, and the TEGAM outperformed the competitor," says Ashurst. Although the slew rate of the TEGAM was rated at 250 V/microsecond and the competitor's was rated at 1000 V/microsecond, the measured deficiency appears to be due to parasitic losses, capacitive losses, and signal processing delays inside the competitor's amplifier. So, the actual, measured slew rate in the TEGAM is significantly better, as is its bandwidth, voltage and noise level. Says Ashurst, "We applied a square wave to the TEGAM and the other amplifier, subtracted each one's output from the source on a different scale, and found that the noise level of the TEGAM was superior."

Ashurst also needed relatively high bandwidth. Each channel can operate at one Msample/s, so a 10-point waveform can run at 100 kHz. Similarly, a 100-point waveform could run at 10 kHz. "In order to get waveforms other than square waves, a sufficient number of points is needed, usually more than 5, which corresponds to 200 kHz – the TEGAM's full power bandwidth," observes Ashurst.

Input and Output Impedance and Stability

On special order, TEGAM changed two model 2350 amplifiers from a standard gain of 50X with an input impedance of 50 Ohms to a gain of 20X with input impedance of 2k Ohms. Says Ashurst, "The computer interface only outputs a maximum of 10 mA, so a 50-Ohm input impedance does not allow the output to reach 10 V when it is current limited to 10 mA."

"One of the features that I like about the TEGAM is that it has no adjustments," says Ashurst. "I just turn it on and it works. Some of the other units I looked at had various modes of operation and performed differently for each mode. Moreover, these electrostatic devices run with virtually no current draw." Another important feature is its short-circuit protection. The TEGAM has a built-in 40-mA current limiter. "This current limit is quite sufficient for electrostatic actuation (which generally requires only enough current to charge a very small (few picofarad capacitor) but low enough that in case of catastrophic device failure the rest of the setup (such as probe tips) is undamaged.

Figure 2

Figure 2 – Under license from Sandia National Laboratories, Tom Swann, founder of E. M. Optomechanical, Inc., transformed a laboratory optical profiler configuration into a production style instrument that can be used more readily in a quality-control, factory setting. The re-engineered OPTOPro is more reliable, easier to use, and also more suitable for a university lab since it contains a fixed-gain TEGAM amplifier and only those controls and adjustments that are necessary for MEMS researchers and quality assurance technicians to carry out their jobs.

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Figure 3

Figure 3 – One major improvement that makes the OPTOPro ideal for MEMS development and characterization is its longer working distance, which allows researchers to more easily attach a variety of different probes. Another is the new TEGAM amplifier that delivers up to 200 V, the highest voltage currently available for MEMS research, to actuate the electrostatic features of the MEMS devices.

Figure 4

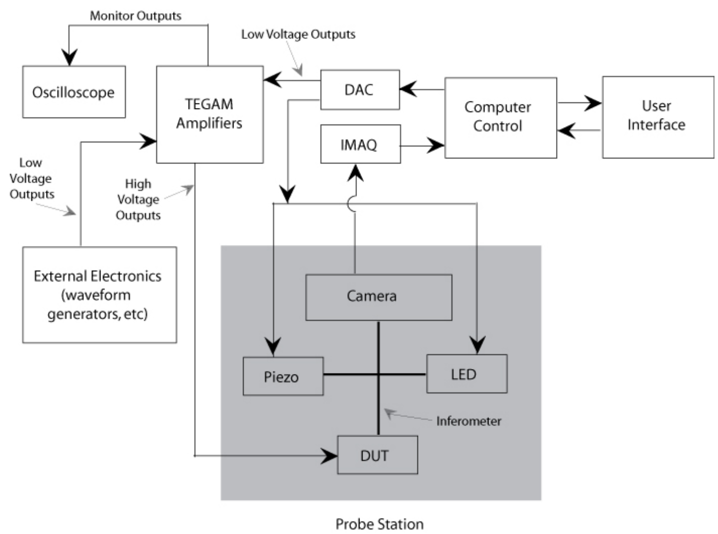

Figure 4 – Professor Ashurst, Auburn University, uses a desktop computer containing a National Instruments DAC card to feed signals to the TEGAM amplifier and the OPTOPro controls. The profiler’s flexibility lets researchers use different external generators, monitors, and data acquisition systems as needed for their unique studies.

Acknowledgements

TEGAM extends special thanks to Tom Swann of E.M. Optomechanical, Inc. and W.R. Ashurst of the Samuel Ginn College of Engineering at Auburn University, for their contributions to this article.

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440-466-6100 • FAX 440-466-6110
www.tegam.com • e-mail:-sales@tegam.com