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MEMS Focus on Cell Phone Camera Market

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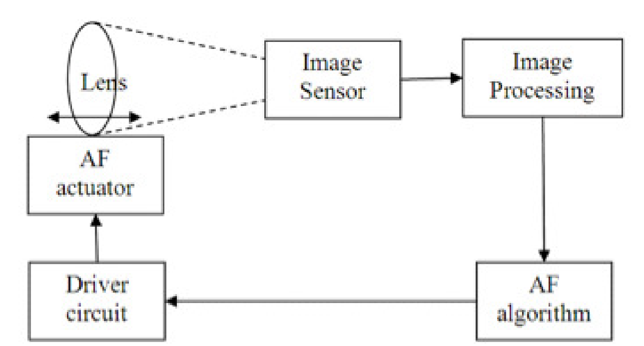
Auto focus (AF) is a common feature for **digital still cameras** (DSCs) to ensure that the object being photographed is in focus. However, AF has only recently been introduced into **high-end cell phone cameras** where the image quality, as well feature **size and low cost,** are critical requirements. The most common AF actuator for DSCs, **the stepper motor**, failed when applied to the cell phone market as it **could not be miniaturized** or stand up to the cell phone's more stringent reliability testing. As a result, a variety of **new technologies** have emerged to fill this need, with **MEMS technology** leading the pack.

Today, most cell phone AF cameras use voice coil motor (VCM) technology. When compared to MEMS technology, VCM experiences more severe limitations in size, performance and power consumption. As a result, of all the technologies being applied to the cell phone camera AF market, MEMS technology has the greatest potential for miniaturization and cost reduction because it integrates all of the actuator components on a single chip.

To understand the advantages and disadvantages of the various AF technologies, it is important to first examine how an AF system works. An AF system is composed of the image sensor, image processing, AF algorithm, driver circuit, an AF actuator and an imaging lens, as shown in the figure below.



Block diagram illustrating the system level operation of an auto focus (AF) system.

The image sensor captures an image, allowing the image processing to analyze the image to evaluate focus score and the AF algorithm commands the driver circuit to move or modify the lens to a next focus position. This cycle repeats until an optimum focus position is determined. The lens position or shape must then return to the same value it had when the best focus score was achieved. This requires the actuator to have good repeatability and low hysteresis. Furthermore, to avoid user frustration over the missed photo opportunities associated with latency, the actuator must respond quickly to the commands from the AF algorithm. Finally, in video mode, the AF algorithm is continuously active, so power consumption becomes an additional concern.

MEMS technology uses photolithography and etching of silicon wafers to enable tiny moving mechanical structures with less than one micron tolerance. This enables precise motion and a high quality picture when used in a cell phone camera. Key to reducing actuator size, MEMS enables the integration of mechanical and electrical components on a single chip. Furthermore, due to the low power consumption and silent operation of electrostatic actuation, MEMS AF actuators are uniquely capable of continuous AF for video. A photograph of a MEMS AF digital camera and the MEMS AF actuator that makes this type of camera possible are shown in the figure below. The size of a MEMS AF actuator chip is only 7 mm by 7 mm by 0.15 mm. With such a small actuator, the camera can be exactly the same size as a fixed focus camera (8.5 mm x 8.5 mm x 6 mm for a 5 megapixel camera).

Photograph of a MEMS digital camera for use in a cell phone (left) and a photograph of the MEMS stage used for AF (right).

A comparison of the MEMS AF actuator with competing technologies is shown in the figure below. These competing technologies can be classified into two groups: lens-motion-type AF and lens-modification-type AF. Lens-motion-type AF includes stepper motor (not included in the figure), voice coil and a piezo motor. In all these, as for the MEMS AF, precise alignment and motion control of the lens is important to maintain good image quality. Lens-modification-type AF includes liquid lens and liquid crystal devices. Changes in the lens shape and/or refractive index is key to implementing these types of AF.

	MEMS	VCM	Piezo-motor	Liquid Lens	Liquid crystal
Actuator size (mm)	7.0x7.0x0.15	8.5x8.5x5	8.5x8.5x5	7.75 (circle) x2	4.5x4.5x0.5
Module Size (mm)	8.5x8.5x6 with shutter	8.5x8.5x6 without shutter 10x10x8.5 with shutter	8.5x8.5x6 without shutter 10x10x8.5 with shutter	8.5x8.5x8 without shutter 10x10x10 with shutter	8.5x8.5x7 Without shutter 10x10x9 with shutter
Supports 1/3" optical format	Yes	Yes	Yes	Yes	No
Imager resolution	8 MP	8 MP	8 MP	3 MP	3 MP
Driver size (# of pins)	7	7	18	10	15
Peak Power	0.5 mW	250 mW	80 mW	8 mW	100 mW
Repeatability	1 um	10 um	Needs position sensor	N/A	N/A
Hysteresis	3 um	20 um	Needs position sensor	Yes	Yes
Speed	5 ms	30 ms	30 ms	200 ms	500 ms
Reliability cycles	10 million	1 million	100 thousand	1 million	1 million
Reflow compatible	Yes	No	No	No	No
Reliability environmental	No degradation	Image degradation and hysteresis	Motion control degradation	Oil and water separation	Requires temperature control
Acoustic noise	No	No	Yes	No	No

Comparison of the leading AF technologies for cell phone cameras.

Lens-motion-type AF has two key requirements. First, the motion must be controlled with optical precision. Second, the actuator must use low power and occupy small space. For example, although stepper motors were used in DSCs in the first autofocus cameras, they cannot be used for cell phone cameras due to size and power consumption.

As mentioned earlier, VCM is the dominant solution for AF in the cell phone market due to high volume availability. Similar to the actuator on a speaker, a VCM uses magnets and coils to generate a force. However, the motion control requirements for a camera are much more stringent than for a speaker, and the VCM lack of precision degrades image quality. In addition, the VCM's high power consumption is an issue particularly for video. As the size of the cell phone camera continues to shrink, these problems of the VCM are accentuated. As a result, cell phone OEMs are actively searching for replacements for the VCM.

Another approach that has seen limited success in the cell phone market is the piezo motor. Some examples are the piezoelectric actuators from Limited 1 and Konica Minolta. The Limited 1 actuator is unique in that it achieves mechanical motion amplification by making a coil of piezoelectric material, but it has been plagued by severe environmental reliability issues. The piezo motor from Konica Minolta is more representative of most piezoelectric actuators and achieves large motion through thousands of small steps. The main disadvantage of piezoelectric actuators is that they require position sensing due to their large hysteresis and poor positioning repeatability. The position sensor requirement combined with the limited strength of piezo materials

translate into disadvantages in size. Furthermore, the sound generated by some of these piezo actuators is an issue for video sound recording.
Lens-modification-type AF has not been successful in entering the cell phone camera market to date. This is likely because the image quality degradation limits their application to low end cameras where AF is not an affordable feature. For example, the liquid lens from Varioptic changes the radius of curvature of the surface by joining two liquids with a different index of refraction to change optical properties. Because the optical surface created by these two liquids is spherical, as opposed to aspheric, spherical aberration limits its application to 3 megapixel (MP) resolution cameras.

Finally, there are also non-optical solutions which use image processing techniques, like extended depth of focus (EDOF), which have secured a space in the low-end camera market to enhance the performance of fixed focus cameras. However, these solutions do not directly compete in the high-end camera market. Tessera, a leader in both MEMS AF actuator and EDOF, is looking at ways to combine these two technologies in the future to further enhance high-end cell phone camera performance. As the introduction of AF into the top cell phone cameras proceeds, MEMS technology is building up capacity to meet the demand for high image quality, convenient feature size and affordability.

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After 10 years at NASA's Jet Propulsion Laboratory working on high precision laser metrology systems and MEMS based sensors, Roman Gutierrez founded SiWave (aka Siimpel) in 2000 to develop MEMS optical switches for fiberoptic telecommunications. Following the collapse of the telecom market in 2001, Roman developed the MEMS-based digital camera and helped to refocus the company on the high growth cell phone camera market. The company was acquired by Tessera in 2010 and Roman continues as CTO/VP Engineering for the MEMS division. Roman is a pioneer in the application of MEMS and optics to new product development and has authored 56 issued patents and has over 30 patents pending. He received his BS in Applied Physics from the California Institute of Technology and his MS in Electrical Engineering from the University of California Santa Barbara.

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