Piezo Motor for Ultra-Thin Auto Focus Cameras

David A. Henderson, Qin Xu, Daniele Piazza
New Scale Technologies, Inc., Victor, NY 14564, USA, www.newscaletech.com

In 2008, approximately 1.2 billion mobile phone handsets will be manufactured. Of these, more than 200 million will include cameras with a micro actuator for automatic focus (AF). More than 10 million will also incorporate optical zoom (OZ) combined with AF. To keep pace with shrinking camera dimensions and increasing mega pixels, the motors must become smaller and yet still achieve micrometer precision. New Scale developed the SQUIGGLE® motor in 2003, which meets the longer stroke requirements for AF and OZ cameras. This motor is 50 percent smaller than comparable piezo motors while achieving 10 times higher force and resolution. In 2007/2008 New Scale developed a new patent-pending ultrasonic piezo motor that meets the challenges of Ultra-Thin Auto Focus (UTAF) cameras. The UTAF motor saves space and height by combining the motor with the linear guide mechanism and enables overall camera thickness less than 5 millimetres.

Keywords: piezoelectric, ultrasonic, motor, phone camera, auto focus, optical zoom

Introduction

In 2008, approximately 1.2 billion mobile phone handsets will be manufactured and 900 million will include a tiny digital camera. Approximately 200 million of these cameras will use a micro actuator to move the lens to achieve automatic focus (AF) from 10 cm (macro) to infinity. In addition, more than 10 million phone cameras will incorporate 3X optical zoom (OZ) and AF, which requires two independently moving lens groups.

The market trend is clear – customers prefer thinner mobile phones. Handset thickness is the critical differentiating feature and design engineers around the world are "fighting for every millimetre" of size reduction. This relentless market pressure is driving phone cameras to become thinner, while at the same time, create better pictures. In 2004, the market expectation for an AF camera height was a 10 mm cube with a VGA or 1 mega pixel image sensor. In 2008, the size goal is height less than 5 mm while using a 5 mega pixel (MP) sensor. AF and OZ cameras are fundamentally larger than AF-only cameras, because more complex optics must be used, yet they still face the same pressure to reduce the height from 10 to 6.5 mm.

SQUIGGLE Motors

The patented[1] SQUIGGLE motor uses ultrasonic standing wave vibrations in a threaded nut to directly rotate a screw. This unique operating principle "wraps" the vibration motion of the nut around the screw threads to directly produce linear movement without requiring additional mechanical conversion. The threads multiply linear force and position resolution and reduce linear speed. The result is a tiny high-force motor capable of sub-micrometer stepping and velocity control. Additional features include precise off-power hold and a manual adjustment option by turning the screw.

Fig. 1: *SQUIGGLE Linear Motor*

This linear motor is a novel implementation of previous rotary motors using tube bending vibrations. The first wobbling ultrasonic rotary motor was conceived more than 60 years ago by Williams and Brown (1948)[2]. This motor uses an orbiting stator to engage a round shaft or gear where tangential contact produces rotation. In 1995 a rotary motor was demonstrated by Morita[3] which uses a thin walled piezoelectric cylinder. A miniaturized rotary motor, using two piezo plates and a hollow metal tube, was demonstrated by Koc, Catagay and Uchino[4] in 2002.

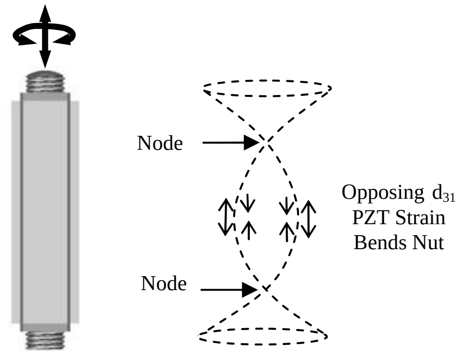

Fig. 2: *Motor Motion and Vibration Mode Shape*

The SQUIGGLE motor requires a small axial preload to maintain constant contact between the nut and screw threads. This preload creates the tangential friction force that rotates and translates the screw. Two orthogonal bending vibrations are combined to create the orbital motion in the nut. The two bending modes are created using orthogonal piezoelectric plates bonded to the outside of the metal nut.

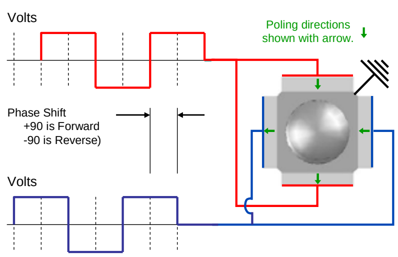

Fig. 3: *Two-Phase Motor Drive Signals*

The SQUIGGLE PZT plates are activated to achieve the required vibration using a two-phase square-wave electrical drive with a fixed frequency and + or - 90 degree phase shift. Positive 90 degree phase shift produces forward movement and negative 90 degrees produces reverse movement. The operating and performance parameters are shown in Table 1.

Motor Parameter	**Value**
Width (mm)	1.55 x 1.55
Length (mm)	6
Screw (mm)	M 0.9 X 0.125
Stroke (mm)	12
Force (grams)	20
Speed (mm/sec)	5
Resolution (µm)	0.50
Frequency (kHz)	~ 150
Voltage	20-40
Motor Power (Watts)	0.3
Lifetime	> 300,000 cycles

Table 1: *SQUIGGLE motor operating and performance parameters*

AF and OZ Cameras Using SQUIGGLE Motors

Tiny phone cameras require more then just small motors. All components must be optimized for size and performance. The starting point for a camera design is selecting the image sensor. Next the optics must be designed to minimize size. Finally, the motion system for moving the optics must be integrated. Table 2 shows some typical specifications for AF and OZ cameras in 2008 and the goals for 2009.

Zoom Camera Specifications	**2008 Announced**	**2009** *Predicted*
Size	**8.5**x15.3x28 mm (H x W x L)	**6.5**x11.5x20 mm (H x W x L)
Image Sensor	**5-8 MP**	**8-12 MP**
Format	1/3.2”	1/4”
Pixel Size	1.8 µm	1.4 µm
Optics	“Folded Path” *(figure 4)*	
Zoom	3X	
Motion		
Focus Stroke	2-4 mm	1-3 mm
Zoom Stroke	5–8 mm	4-6 mm
Precision	Better than 5 µm	
Acoustic Noise	< 32 dB	

Table 2: *Typical specifications for autofocus and optical zoom cameras*

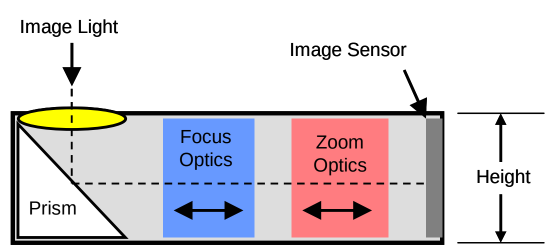

Fig. 4: *“Folded Optics” for AF and OZ fit best in mobile phone cameras*

New Scale’s SQUIGGLE motor is small enough to achieve the predicted specifications for AF and OZ cameras. Most difficult predicted requirement is reducing the height from 8.5 to 6.5 mm by 2009. Two SQUIGGLE motors can be mounted side by side within the 6.5 mm height to independently move the focus and zoom optical assemblies (Figure 5). The additional camera width required for the SQUIGGLE motors is only 2 mm. By comparison, stepper motors require two or three times more width. A 6.5 mm camera height can not be achieved using electromagnetic stepper motors which are used today.

Unlike stepper motors, SQUIGGLE motors are not self-encoded and do require a separate position sensor. New Scale recently introduced a new magnetic position sensor in collaboration with austriamicrosystems[5] (AMS). This sensor is a system-on-a-chip solution with repeatability of 2 µm and an integral zero reference capability. The sensor chip and magnet add less than 1.5 mm to the width of the camera. AMS and New Scale have also developed a miniature drive ASIC that is only 4 X 4 mm, including the voltage boost from 2.8 to 40 volts, and operates two SQUIGGLE motors.

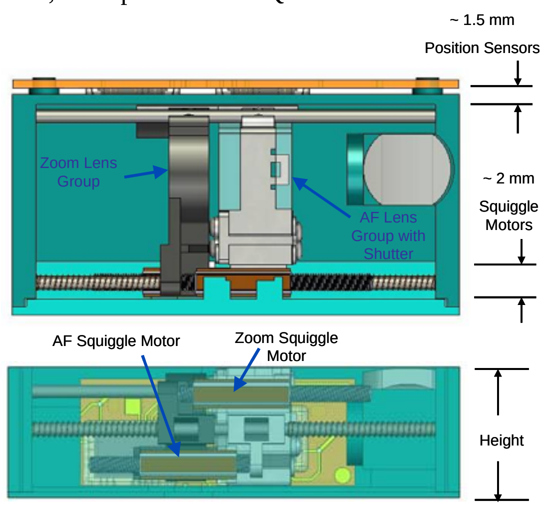

Fig. 5: *SQUIGGLE AF and OZ Camera Reference Design*

Ultra-Thin Auto Focus (UTAF)

The race to miniaturize AF cameras is even more urgent than zoom cameras. AF cameras have a single lens assembly that requires a small movement to change the camera focus from macro to infinity. The required lens motion is about 300 micrometers with 10 micrometer precision when supporting 0.2 grams. Other critical camera specifications include:

- height less than 5 mm
- length and width less than 8.5 mm
- lens diameter of 6.5 mm
- operation at 2.8 volts
- power less than 100 mW
- operation from -30C to +70C
- 2500 G shock resistance.

Table 3 shows the trends of the critical AF camera specifications.

AF Camera Specifications	2005	2008	2009 *Predicted*
Size	**10**x10x10 mm (HxWxL)	**6.5**x8.5x8.5 mm (HxWxL)	<**5**x6.5x6.5 mm (HxWxL)
Image Sensor	VGA	5 MP	8 MP
Motion			
Stroke	300 µm (Macro to Infinity)		
Precision	Better than 10 µm		
Lifetime	>1 million cycles		

Table 3: *Trends in critical autofocus specifications*

The 5 mm height restriction can not be reached with SQUIGGLE motors, so in 2007/2008 New Scale developed the patent-pending UTAF motor (figure 6). UTAF is a significant improvement over the voice coil motor (VCM) and meets the most demanding specifications for ultra thin auto focus cameras.

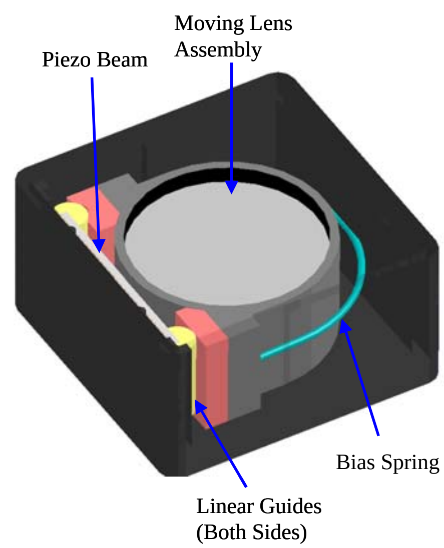

Fig. 6: *UTAF motor in ultra-thin auto focus camera*

VCMs are the dominant micro motor for auto focus cameras today. This simple actuator produces force in proportion to current at a low voltage. An electric coil wraps around the lens assembly and is integrated with a permanent magnet and closed magnetic flux path. Applying current to the coil generates a Lorentz force in the direction parallel to the optical axis (axial direction) with a magnitude proportional to the current. The lens is supported by a flexure guide mechanism that axially deflects in response to the Lorentz force to produce the desired lens position. Constant current and power are needed to maintain a specific position. The VCM has fundamental scaling limits on smaller size, force, power, precision and shock sensitivity and struggles to meet the requirements for 5 and 8 mega pixel cameras.

The UTAF motor saves space and height by combining the motor with the linear guide mechanism. An ultrasonically vibrating beam is oriented perpendicular to the optical axis and is only 2.5 mm high, which is thinner than the lens assembly (~ 3 mm). The height of the camera is determined by the CMOS image sensor and optical design - not the motor. The vibrating beam contacts the lens at two points to maximize stability and driving force. The lens and UTAF motor are held together by a flexure spring that maintains a constant bias force as the lens moves.

Comparison	**VCM**	**UTAF**
Range	250 µm	500 µm
Force	< 0.5 gram	2 grams *(moving)* 4 grams *(holding)*
Displacement Sensitivity	5 µm	0.5 µm
Operating Power	200 mW *Continuous to hold position.*	~100 mW *When moving. Zero power to hold position.*
Shock Resistance	Low	High

Table 4: *Comparison of voice coil to UTAF*

The UTAF motor provides a smaller, lower power and more precise solution. At the same time this motor achieves very high resolution (< 0.5 µm) by creating a unique vibration mode that optimizes resolution and speed for the auto focus function. Using multi-layer co-fired ceramic processing, the vibrating beam is manufactured as a single part that operates directly from the phone battery voltage of 2.8 volts. MEMS fabrication processes are being evaluated to further reduce size.

This is the performance of the UTAF (Figure 7):

Driving Force	2 grams
Operating Frequency	40 kHz
Holding Force	4 grams
Drive Voltage	2.8 volts *(multi-layer piezo)*
Resolution	< 0.5 µm
Range	500 µm
Speed	5 mm/second

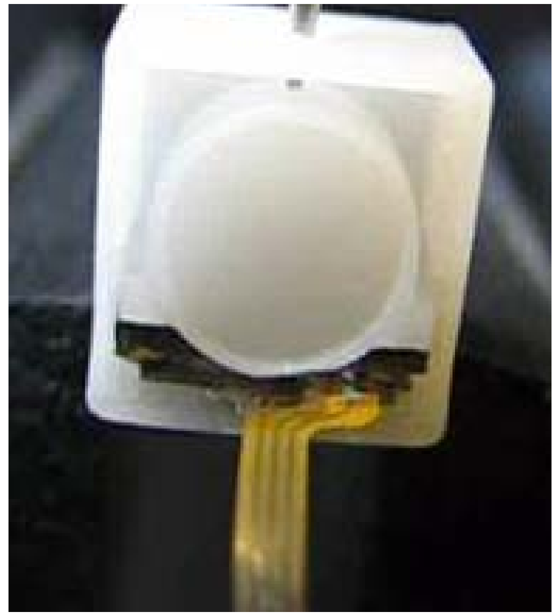

Fig. 7: *UTAF motor Prototype*

Conclusion

The rapid adoption of cameras in mobile phones is a global reality. This industry is “fighting for every millimeter” as design engineers focus on reducing camera height while at the same time making the pictures better. AF and OZ are established solutions for improving image quality which are creating a new market for more than one billion tiny motors per year. The fundamental keys to winning market share are rapid and continuous reduction of size, power and cost. SQUIGGLE and UTAF motors meet these simultaneous goals of extreme miniaturization, greater performance and lower cost.

References

[1] US Patents 6,940,209, 7,170,214, 7,309,943 and 7,339,306.

[2] W. Williams and W.J. Brown, “Piezoelectric Motor”, US Patent, 2439499, April 1948.

[3] T. Morita et al: “An Ultrasonic Micro Motor using a bending transducer based on PZT thin film”, Sensors and Actuators A, Vol. 50, pp. 75-80, 1995.

[4] Koc, B., Cagatay, S., Uchino, K., “A piezoelectric motor using two orthogonal bending modes of a hollow cylinder”, IEEE Trans. Ultrasonic Ferroelectric Freq. Cont. 49, 495 -500, 2002.

[5] See www.austriamicrosystems.com .