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Biaxial MEMS Raster Scanner with Linear Ramp Drive

Hakan Urey, Randy Sprague*
KOÇ University, Istanbul, TURKEY
*Microvision Inc., Washington, USA
hurey@ku.edu.tr

ABSTRACT

A biaxial MEMS raster scanner is developed for laser scanning displays. We discuss microfabrication, packaging, and design aspects, and how to minimize power consumption and linearity error by optimizing the vertical scanner resonant frequency and drive waveform.

Introduction:

Integration of MEMS scanner and diode light sources (e.g. laser diodes, LEDs) provide a powerful combination for display and imaging applications. Scanner requirements depend on the system resolution, number of light sources used, and the raster scan architecture. A typical SVGA display system requires +/-6deg mechanical scan angle, and 60Hz and 20 KHz operation frequencies for the vertical and horizontal scanner. There are many additional stringent requirements on scan amplitude and frequency control, scanner linearity, dynamic mirror flatness, and scanner position control (with sub-pixel accuracy), etc.[1] Cross-coupling between scan frames and different oscillation modes makes it even more difficult to meet these requirements. Further, choice of the scanner resonant frequencies impact the scanner drive waveform and some scanner die within the acceptable range of resonant frequencies might produce large deviations from linear scan during operation. A design that meets all the requirements is presented here.

Microfabrication and Packaging:

A picture of the scanner die and two different packaged devices are illustrated in Figure 1.[2] Starting wafer is 300um double side polished Silicon wafer. The flexures that hold the inner horizontal-scan frame (scan mirror) and the outer vertical-scan frame are structured using DRIE with high precision for good resonant frequency control. The outer frame is thinned to reduce mass using KOH etch from the backside. For electrostatic actuation of the scan mirror, a capacitive drive electrode is attached to the die using glass frit bonding with 3µm gap tolerance. The electrodes are covered with dielectric material to prevent arcing. External magnets and copper coils are used for actuation of the vertical scan frame. A thick copper plating process with high fill-factor was developed to plate copper coils on top of the vertical frame. There are several coil and magnet architectures developed for electromagnetic actuation for different scanners.[3]

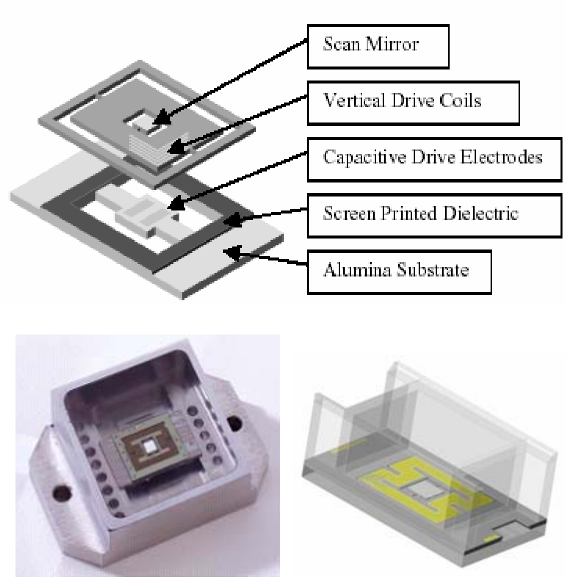

Figure 1: Top: Scanner die, Bottom Left: Vacuum-sealed scanner package; Bottom Right: Wafer-scale packaged die.

The figure at the bottom left shows the scanner package used in a MEMS display product. The can is made of Kovar for its good CTE match to silicon. The lid is sealed to the can in a vacuum, using a gold indium eutectic. The glass window placed on top is covered on both sides with anti-reflective coatings to reduce loss of light along the optical path and stray light in the optical path. NdBFe magnets are mounted in the can on either side of the scanner in order to actuate the magnetically driven vertical axis.

The figure at the bottom right shows the wafer scale packaged (WSP) die. Wafer scale packaging greatly reduces the cost of MEMS. A rigid frame is bonded on the surface of the scanner and a flat piece of glass is bonded on top of the rigid frame. A vacuum seal is achieved between the capacitive drive substrate, the scanner die, and the glass seal. Using bi-magnetic or comb-drive electrostatic actuators can lower the voltages and eliminate vacuum sealing. However, the performance of such actuators reported in the literature does not meet the performance requirements of scanning displays.

Design of the torsional horizontal resonant scanner is described in detail elsewhere.[4]

Vertical Scanner Design:

For the horizontal scanner, the operation frequency is set equal to the torsional resonant frequency of the horizontal scan mirror to take advantage of high Q. The vertical scanner is operated at the frame rate of the display (typically 60Hz) and the scan waveform is chosen as a linear ramp or a sawtooth waveform to produce uniform line spacing across the 2-D raster. Non-sinusoidal vertical scan waveform requires a careful choice of the resonant frequency as the choice has a strong impact on the power consumption. Minimizing power requirements is particularly important for mobile display applications.

Power in an electromagnetic actuator can be calculated by multiplying the square of the current drive waveform with the coil resistance. The current drive signal can be computed by first starting with an ideal ramp signal and filtering with an FIR low pass filter to limit the retrace time and dividing with the mechanical response of the scanner, which can be modeled as a 2nd order linear system. We tried several different windowing functions to test the linearity of the scanner drive waveform and found that best results are obtained using a *Kaiser*-type window function (using MATLAB by MathWorks Inc.). The width of the window is adjusted until the retrace time and linearity of the scan waveform was acceptable. As shown in Figure 2, the Kaiser-type window gives a ripple-free error function, which is important for good image quality.

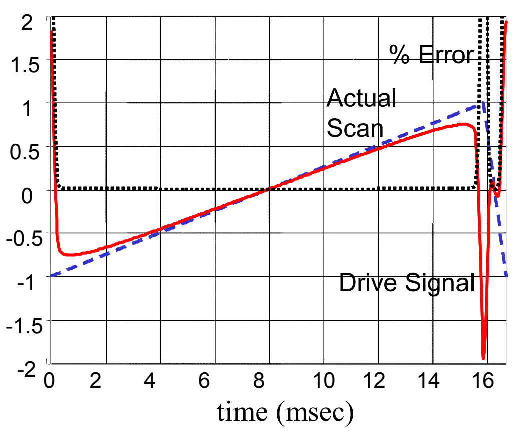

Figure 2: One period of the ideal ramp, scanner drive waveform, resultant vertical scan waveform, and the percentage error between the ideal and actual waveforms assuming f_{res}=310Hz.

Figure 3 and Figure 4 illustrate the tradeoff in power consumption and the scan linearity error (normalized to full-scan amplitude). For error sensitivity analysis, we assumed a ±1% shift in the scanner resonant frequency during operation due to environmental effects. If the resonant frequency is set too low or too close to 60Hz or its harmonics, the scan waveform sensitivity to small variations in frequency is large. If it is set too high, the large power consumption due to large torsional stiffness and the cross coupling with horizontal scanner oscillation modes, which start at several KHz, becomes a problem.

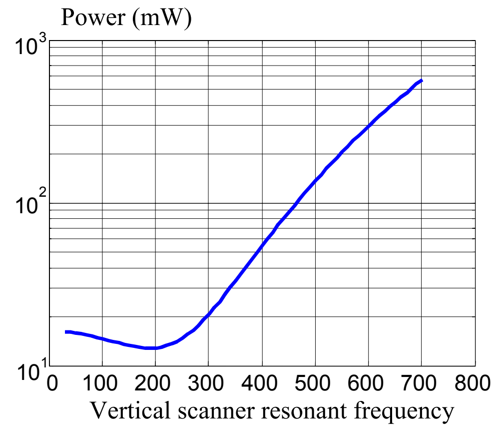

Figure 3: Power required for linear ramp drive waveform as a function of scanner resonant frequency.

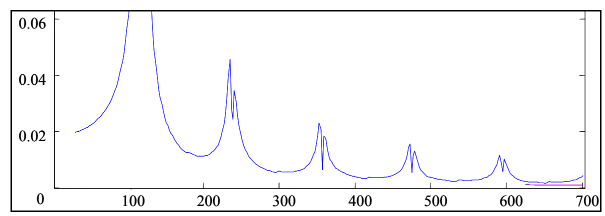

Figure 4: Maximum error normalized to full-scan angle as a function of scanner resonant frequency for 60Hz operation frequency.

Conclusions:

A scanner that meets all the requirements of an SVGA display system has been fabricated and productized. Good design points for the vertical scanner resonant frequency are 310Hz and 470Hz. The corresponding linearity errors are less than 0.1% across the scan area. A 1% shift in resonant frequency during operation causes the linearity error to be as large as 0.6% and 0.4%, respectively. The corresponding vertical scanner power consumptions to achieve full SVGA resolution are about 20mW and 100mW, respectively.

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[1] H. Urey, D. Wine, T. Osborn, "Optical performance requirements for MEMS-scanner based microdisplays," in *MOEMS and Miniaturized Systems*, SPIE Vol. 4178, pp. 176-185, Santa Clara, California (2000)

[2] M. Helsel, J. D. Barger, D. W. Wine, T. D. Osborn, "Wafer scale packaging for a MEMS video scanner," Proc. SPIE Vol. 4407, p. 29-35, Edinburgh, Scotland (2001)

[3] H. Urey, F. A. DeWitt IV, P. A. Lopez, and J. Tauscher, "MEMS Sinusoidal raster correction scanner for SXGA displays," in *MOEMS Display and Imaging Systems*, SPIE Proc. Vol. 4985, pp.106-114, San Jose, California (2003)

[4] H. Urey, D. W. Wine, and J. R. Lewis, "Scanner design and resolution tradeoffs for miniature scanning displays," Flat Panel Displays, Proc. SPIE vol. 3636, San Jose, California, January 1999