Lecture 02

MEMS DMD, Airbag and Pressure Sensor

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Outline

1. Digital Micromirror Device (DMD)
2. MEMS Airbag Sensor
3. MEMS Pressure sensor

Why DLP Projection System

Advantages of DLP

- High brightness
- High contrast
- Grey scale achieved by digital modulation (DMD)
- Compact, light weight, low power
- Particularly attractive for portable system

DMD features and requirements

Number of moving parts	0.5 to 1.2 million
Mechanical motion	Makes discrete contacts or landings
Lifetime requirement	450 billion contacts per moving part
Address voltage	Limited by 5 volt CMOS technology
Mechanical elements	Aluminum
Process	Low temp., sputter deposition, plasma etch
Sacrificial layer	Organic, dry-etched, wafer-level removal
Die separation	After removal of sacrificial spacer
Package	Optical, hermetic, thermal vias
Testing	High-speed electro-optical before die separation

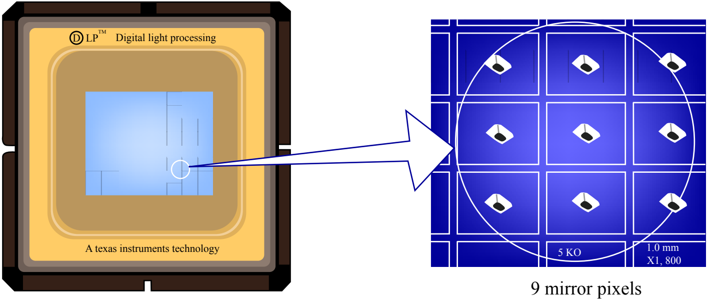
Digital Micromirror Device (DMD)

- The DLP micro-optical projection system developed by Texas Instruments in 1977
- Uses a matrix of micro-mirrors to selectively switch reflected light, to form a projected matrix of pixels
- Contains over a million tiny pixel-mirrors each measuring 16 μm by 16 μm and capable of rotating by $\pm 10^0$, over 1000 times a second
- Light from a projection source impinges on the pupil of the lens (or mirror) and is reflected brightly onto a projection screen
- Incident light from a collimated source is either reflected into the image direction, when the mirror is in one position, or deflected out of the image direction when the mirror is tipped to a different position
- Gray scale is achieved by time division, controlling the length of time within the frame interval that the mirror is tipped to reflect light in the image direction
- DMD's are used for displays for PC projectors, high definition televisions (HDTV) and digital cinemas

Digital Micromirror Device (DMD)

- The DMD is a reflective spatial light modulator (SLM) which consists of millions of digitally actuated micromirrors.
- Each micromirror is controlled by underlying complementary metal-oxide-semiconductor (CMOS) electronics.
- A DMD panel's micromirrors are mounted on tiny hinges that enable them to tilt either toward the light source (ON) or away from it (OFF) depending on the state of the static random access memory (SRAM) cell below each micromirror.
- The SRAM voltage is applied to the address electrodes, creating an electrostatic attraction to rotate the mirror to one side or the other.
- The DMD has a light modulator efficiency in the range of 65%, and enables the contrast ratio ranging from 1000:1 to 2000:1.

The Texas Instruments® DMD

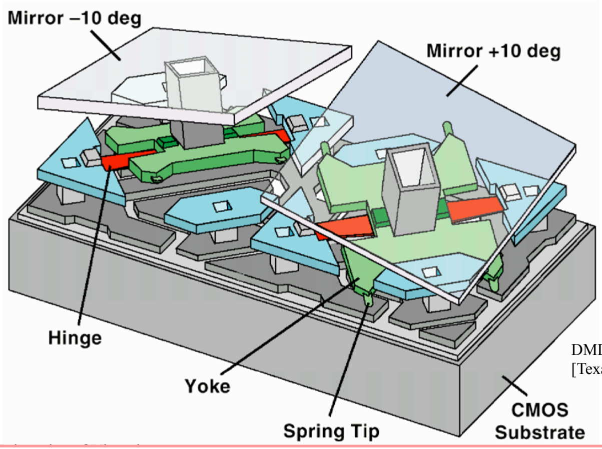


1,310,720 mirror pixels
(1280 x 1024)

9 mirror pixels

Large two-dimensional array of aluminum micro-mirrors is fabricated over a silicon integrated circuit that contains the drive electronics along with electrodes for electrostatically tipping the mirrors to various positions. Each mirror controls one pixel of the image.

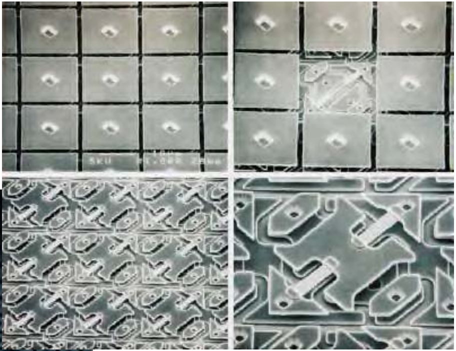
The Texas Instruments® DMD

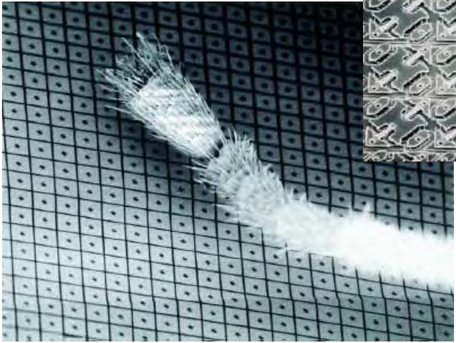


DMD Operation Schematic, [Texas Instruments]

Anatomy of DMD

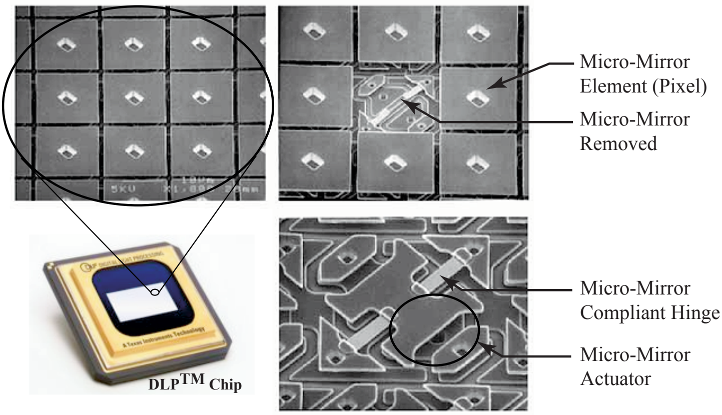
Anatomy of DLP/DMD





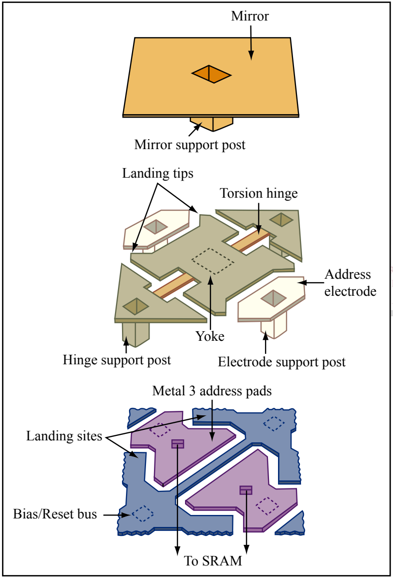
Ant's leg on the DMD array

Micro structure of DMD



DMD Operation [Texas Instruments]

Constituent Parts of the Digital Micro Mirror



e.

- One mechanical mirror per optical pixel
- 16 μm aluminum mirrors
- Pixels rotate 10 degrees in either direction
- Motion is limited by mechanical stops
- On: +10 degrees
- Off: -10 degrees

DMD Principle

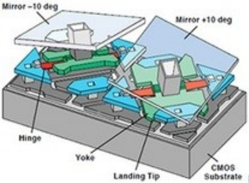


Figure 4. Two DMD pixels (mirrors are shown as transparent)

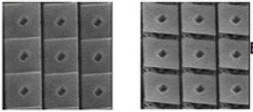


Figure 5. SEM video images of operating DMD

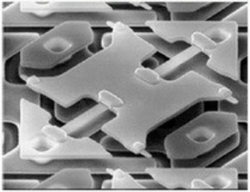


Figure 12. SEM photomicrograph of yoke and spring tips (mirror removed)

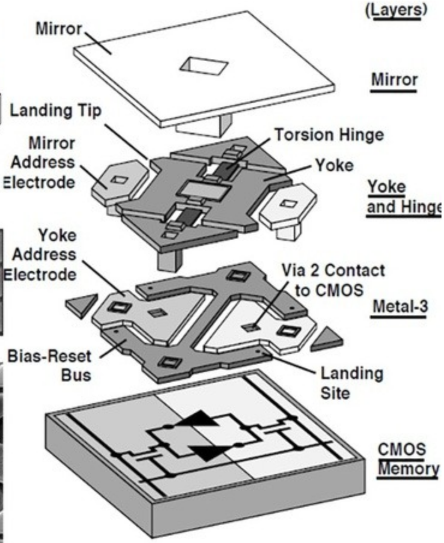
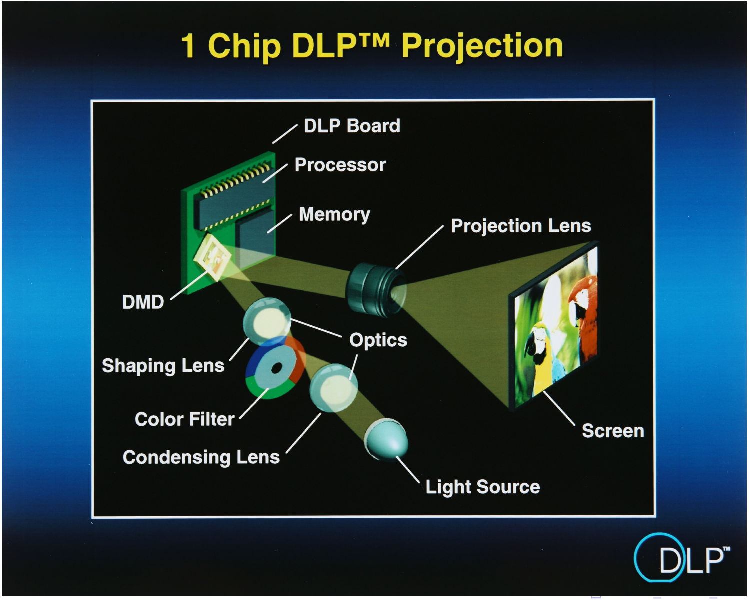


Figure 8. DMD pixel exploded view

Digital Light Processing (DLP) Projection System



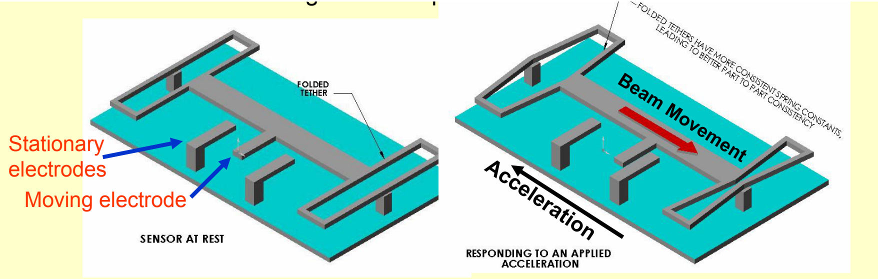
Digital Light Processing (DLP) Projection System

- To create the complete projection system, the DMD is used with a light source, optics, a color filter and a projection lens.
- The DMD chip is mounted on a circuit board that contains the circuitry needed to convert a digital representation of an incoming image into the appropriate sequence of control signals to actuate the mirror array.
- Incident light from a collimated source is either reflected into the image direction, when the mirror is in one position, or deflected out of the image direction when the mirror is tipped to a different position.
- Gray scale is achieved by time division, controlling the length of time within the frame interval that the mirror is tipped to reflect light in the image direction.
- Color obtained by rotating color wheel
- Color alternative: use three chips

Airbag sensor

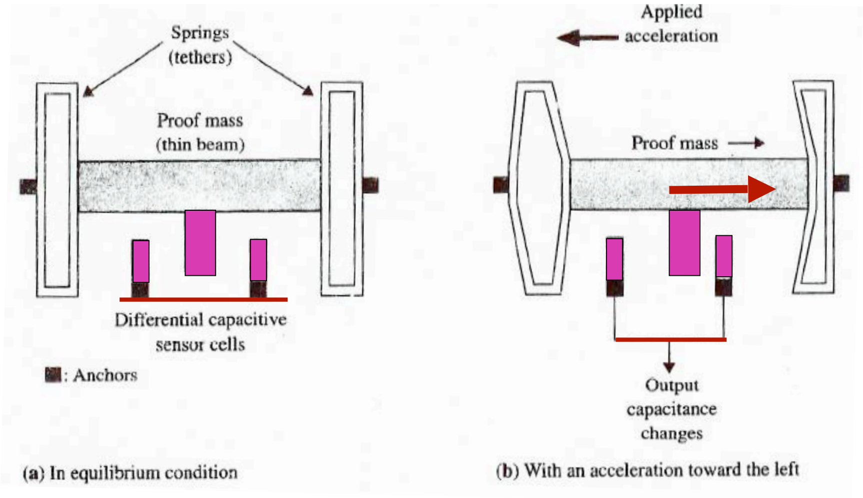
- One of the first commercial devices using MEMS and in widespread use today in the form of a single chip containing a smart sensor, or accelerometer
- Accelerometer measures the rapid deceleration of a vehicle on hitting an object. The deceleration is sensed by a change in voltage.
- An electronic control unit subsequently sends a signal to trigger and explosively fill the airbag.
- MEMS airbag sensors replaced the conventional mechanical "ball and tube" type devices which were relatively complex, weighed several pounds and cost several hundred dollars.

Balanced force micro accelerometer



The accelerometer is essentially a capacitive or piezoresistive device consisting of a suspended pendulum proof mass/plate assembly.
As acceleration acts on the proof mass, micromachined capacitive or piezoresistive plates sense a change in acceleration from deflection of the plates.

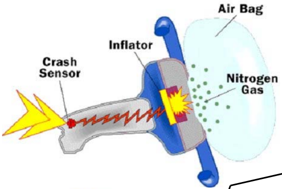
Airbag accelerometer

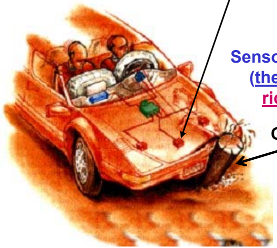


Operation of the airbag System

- A central Airbag control unit (ACU) monitors a number of related sensors within the vehicle, including accelerometers, impact sensors, side (door) pressure sensors, wheel speed sensors, gyroscopes, brake pressure sensors, and seat occupancy sensors.
- The bag itself and its inflation mechanism is concealed within the steering wheel boss (for the driver), or the dashboard (for the front passenger), behind plastic flaps or doors which are designed to "tear open" under the force of the bag inflating.
- Once the requisite 'threshold' has been reached or exceeded, the airbag control unit will trigger the ignition of a gas generator propellant to rapidly inflate a fabric bag.
- As the vehicle occupant collides with and squeezes the bag, the gas escapes in a controlled manner through small vent holes.
- The airbag's volume and the size of the vents in the bag are tailored to each vehicle type, to spread out the deceleration of (and thus force experienced by) the occupant over time and over the occupant's body, compared to a seat belt alone.

Inertia Sensor for Automobile Air Bag Deployment System





Micro inertia sensor (accelerometer) in place:

Sensor-on-a-chip: (the size of a rice grain)

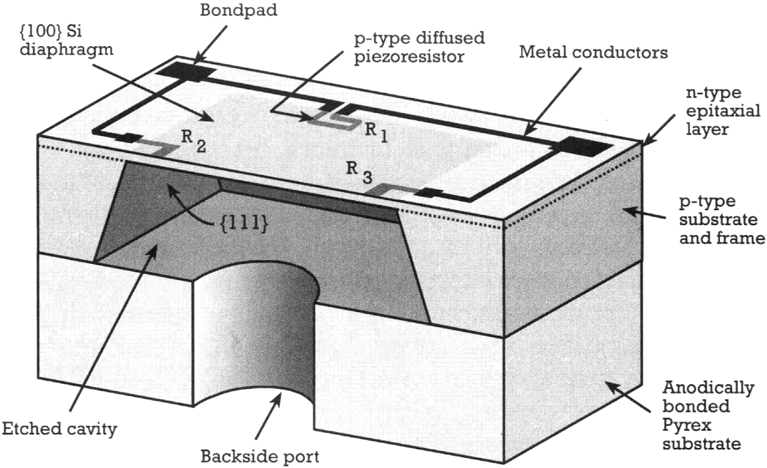
Collision

(Courtesy of Analog Devices, Inc)

MEMS Pressure sensor

- Pressure sensors are required in all walks of life, irrespective of civil- ian, defense, aerospace, biomedical, automobile, Oceanography or domestic applications.
- Designed to measure absolute or differential pressure.
- Two types of pressure sensor:
  - Piezoresistive sensing
  - Capacitive sensing
- The first high-volume production of a pressure sensor began in 1974 at National Semiconductor Corporation
- Pressure sensors are categorized as absolute, gauge and differential pressure sensors based on the reference pressure with respect to which the measurement is carried out.

Piezoresistive Pressure Sensors



Wheatstone Bridge configuration

Piezoresistive Pressure Sensors

- Consists of four sense elements in a Wheatstone bridge configuration that measure stress within a thin crystalline silicon membrane
- The stress is a direct consequence of the membrane deflecting in response to an applied pressure differential across the front and back sides of the sensor.
- The stress is, to a first order approximation, linearly proportional to the applied pressure differential.
- The membrane deflection is typically less than one micrometer.
- The output at full-scale applied pressure is a few millivolts per volt of bridge excitation
- The output normalized to input applied pressure is known as sensitivity [(mV/V)/Pa] and is directly related to the piezoresistive coefficients.
- The thickness and geometrical dimensions of the membrane affect the sensitivity and, consequently, the pressure range of the sensor.
- Devices rated for very low pressures (¡10 kPa) usually incorporate complex membrane structures, such as central bosses, to concentrate the stresses near the piezoresistive sensors and improve both sensitivity and linearity.