Module-IV

➢ **INTRODUCTION:-**

The word smart has been added as prefix to many things that are perceived to possess some form of intelligence. The term smart sensor was adopted in the mid-1980s in the sensor fields to differentiate this class of sensors from conventional sensors. A conventional sensor measures a physical, biological, or chemical parameters, such as displacement, acceleration, pressure, temperature, humidity, oxygen, or carbon monoxide content, and converts them into an electrical signal, either voltage or current. However, a smart sensor with some form of intelligence, provided by an additional microcontroller unit or microprocessor, can convert this raw signal into a level or form which makes it more convenient to use. This might include signal amplification, conditioning, processing, or conversion. In addition, over time, smart functions were not only built into sensors, but applied to actuators as well. Therefore, the term *smart transducers* as used in this chapter refers to smart sensors or smart actuators. Figure 4.1 illustrates the partitioning of a smart transducer s functions.

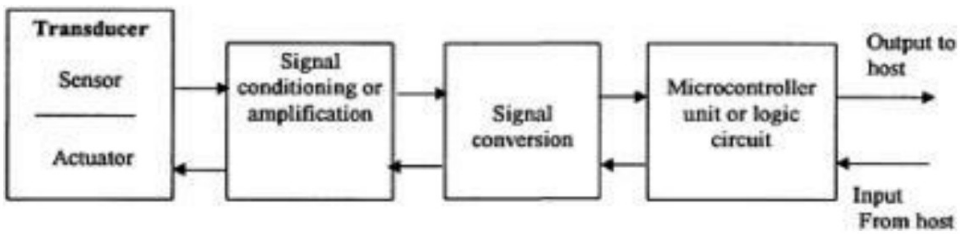


Fig. 4.1: A smart transducer

A smart transducer is either a sensor or an actuator that is instrumented or integrated with signal conditioning and conversion and a microcontroller or microprocessor to provide intelligent functions. Its output is migrating from an analog to a digital format for added capability to communicate with a host or a network.

As sensors and actuators become more complex they provide support for various modes of operation and interfacing. Some applications require additionally fault-tolerance and distributed computing. Such high-level functionality can be achieved by adding an embedded microcontroller to the classical sensor/actuator, which increases the ability to cope with complexity at a fair price.

In the machine vision field, a single compact unit which combines the imaging functions and the complete image processing functions is often called a smart sensor.

They are often made using CMOS, VLSI technology and may contain MEMS devices leading to lower cost. They may provide full digital outputs for easier interface or they may provide quasi-digital outputs like pulse width modulation.

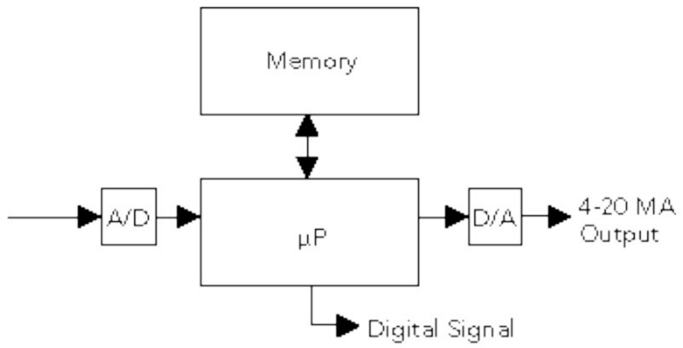
Advantages of smart transducers

1. Compact
2. Higher reliability
3. Lower cost

4. Can be done using existing cmos processes
5. Ease of use
6. electronic data storage
7. self diagnosis and remote calibration
8. self correction
9. auto display

➢ **SMART TRANSMITTER:-**

So far, the discussion has centered around electronic and pneumatic transmitters. The input and output of both of these types of transmitters is an analog signal -- either a mA current or air pressure, both of which are continuously variable. There is another kind of transmitter -- the "smart" transmitter.



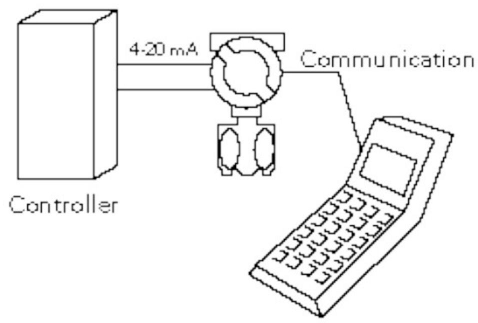


Fig. 4.2: Smart Transmitter Components and Function

The figure above illustrates functions of a smart transmitter. They can convert analog signals to digital signals (A/D), making communication swift and easy and can even send both analog and digital signals at the same time as denoted by D/A.

A smart transmitter has a number of other capabilities as well. For instance, inputs can be varied, as denoted by A/D. If a temperature transmitter is a smart transmitter, it will accept millivolt signals from thermocouples and resistance signals from resistance temperature devices (RTDs) and thermistors.

Components of the smart transmitter are illustrated in the lower figure. The transmitter is built into a housing about the size of a softball as seen on the lower left. The controller takes the output signal from the transmitter and sends it back to the final control element. The communicator is shown on the right.

The communicator is a hand-held interface device that allows digital "instructions" to be delivered to the smart transmitters. Testing, configuring , and supply or acquiring data are all accomplished through the communicator. The communicator has a display that lets the technician see the input or output information. The communicator can be connected directly to the smart transmitter, or in parallel any where on the loop.

- **SMART TRANSMITTER WITH HART COMMUNICATOR:-**

Modern field instruments, otherwise known as smart transmitters, are intelligent microprocessor-based field instruments that monitor process control variables (e.g., temperature, mass flow rate, and pressure). Such field devices are becoming more intelligent, as some processing capabilities are being distributed into the field domain from centralized control rooms. This has simultaneously increased the complexity of the smart transmitter signal chain and added additional challenges to the design of the end product. The incorporation of extra intelligence, functionality, and diagnostic capabilities, while developing a system which can operate effectively within the limited power available from the 4 mA to 20 mA loop, is the immediate challenge facing system designers. A sample solution developed by Analog Devices, Inc., and registered with the HART® Communication Foundation focuses on such a design.

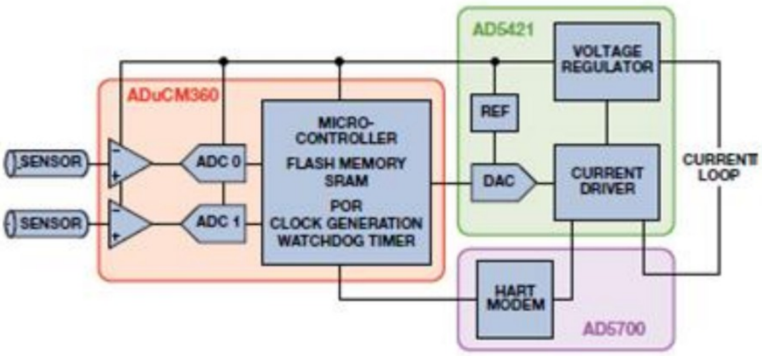


Fig. 4.3. Smart transmitter signal chain.

The two sensors shown in Figure 4.3 are common to smart transmitter designs, whereby the primary variable is dependent on a secondary variable (e.g., temperature compensation of a primary variable).

The ADuCM360 on-chip ADC 0 measures the field instrument primary sensor: in this case, it's a resistive bridge pressure sensor, while the ADC 1 is used to measure the secondary temperature sensor signal. This allows for temperature compensation of the primary sensor. As with the ADCs, both instrumentation amplifiers are also integrated onto the ADuCM360, along with excitation current sources, voltage reference, and other support analog circuitry. All the field instrument digital functions are provided by the low power 32-bit ARM Cortex™-M3 RISC processor. The microcontroller is, thus, a complex component, with the potential to require a lot of power, so the more processing that can be done per milliwatt, the better. Therefore, the clock frequency at which the controller is operated is adjusted to maintain the required operation and still operate within the low power budget. The same is true of the clock signal for any of the microcontroller peripherals/interfaces. Another crucial aspect for the ADuCM360 to stay within its allocated power budget is the ability to dynamically switch the power to the individual blocks. Such a power gating feature ensures that power is provided to each functional block, as and when it is required, but is switched off when that particular functional block is not in use. As well as processing the measurements, the ADuCM360 is used to control the DAC, which, in turn, controls the loop current.

This AD5421 is a complete, loop powered, digital-to-4 mA-to-20 mA converter that incorporates the reference, loop interface stage, and programmable voltage regulation circuitry necessary to extract a low power supply from the loop, to power both itself and the rest of the transmitter signal chain. The DAC also provides a number of on-chip diagnostic features, all of which can be configured and read by the microcontroller, but can also operate autonomously. As an example, if the communication between the microcontroller and the DAC fails, the on-chip watchdog timer will automatically set the DAC analog output to a 3.2 mA “alarm” current after a defined period. This indicates to the host that the field instrument failed to operate.

➢ HART PROTOCOL - AN OVERVIEW :-

HART is an acronym for "Highway Addressable Remote Transducer". The HART protocol makes use of the Bell 202 Frequency Shift Keying (FSK) standard to superimpose digital communication signals at a low level on top of the 4-2OmA. This enables two-way field communication to take place and makes it possible for additional information beyond just the normal process variable to be communicated to/from a smart field instrument.

The HART protocol communicates at 1200 bps without interrupting the 4-2OmA signal and allows a host application (master) to get two or more digital updates per second from a field device. As the digital FSK signal is phase continuous, there is no interference with the 4- 2OrnA signal.

HART is a master/slave protocol which means that a field (slave) device only speaks when spoken to by a master. Master devices include handheld terminals as well as PC-based work places, e.g. in the control room. HART slave devices, on the other hand, include sensors, transmitters and various actuators. The variety ranges from two-wire and four-wire devices to intrinsically safe versions for use in hazardous environments.

The HART data is superimposed on the 4 to 20 mA signal via a FSK modem. This enables the devices to communicate digitally using the HART protocol, while analog signal transmission takes place at the same time (see .Coding.on page 16ff and Lit./2/).Field devices and compact handheld terminals have an integrated FSK modem,whereas PC stations have a serial interface to connect the modem externally.

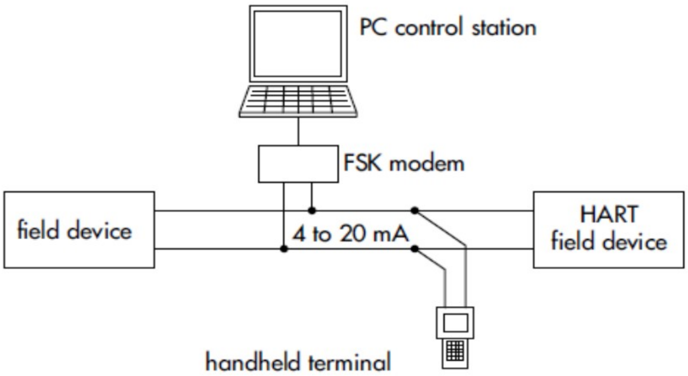


Fig. 4.4: Connection scheme of a HART host device and a HART field device

Figure 4.4 shows a typical connection scheme of a HART host device and a HART field device. HART communication is often used for such simple point-to-point connections.

The HART protocol can be used in various modes for communicating information to/from smart field in3truments and central control or monitor systems. HART provides for up to two masters (primary and secondary). This allows secondary masters such as handheld communicators to be used without interfering with communications to/from the primary master, i.e. control/monitoring system. The most commonly employed HART communication mode is master/slave communication of digital information simultaneous with transmission of the 4-2OmA signal. The HART protocol permits all digital communication with field devices in either point-to-point or multidrop network configuration.
There is an optional "burst" communication mode where single slave device can continuously broadcast a standard HART reply message.

HART COMMUNICATION LAYERS

OSI layers	HART layers
application	HART commands
presentation	
session	
transport	
network	
data link	HART protocol rules
physical layer	Bell 202

Fig. 4.5: HART communication layer

The HART protocol utilizes the OSI reference model. As is the case for most of the communication systems on the field level, the HART protocol implements only the Layers 1, 2 and 7 of the OSI model. The layers 3 to 6 remain empty since their services are either not required or provided by the application layer 7

MICRO-ELECTRO-MECHANICAL SYSTEMS

Micro-Electro-Mechanical Systems, or MEMS, is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of micro fabrication.
The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics.

The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move.
The term used to define MEMS varies in different parts of the world. In the United States they are predominantly called MEMS, while in some other parts of the world they are called "Microsystems Technology" or "micro machined devices".
While the functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics, the most notable (and perhaps most interesting) elements are the micro sensors and micro actuators.
Micro sensors and micro actuators are appropriately categorized as "transducers", which are defined as devices that convert energy from one form to another. In the case of micro sensors, the device typically converts a measured mechanical signal into an electrical signal.

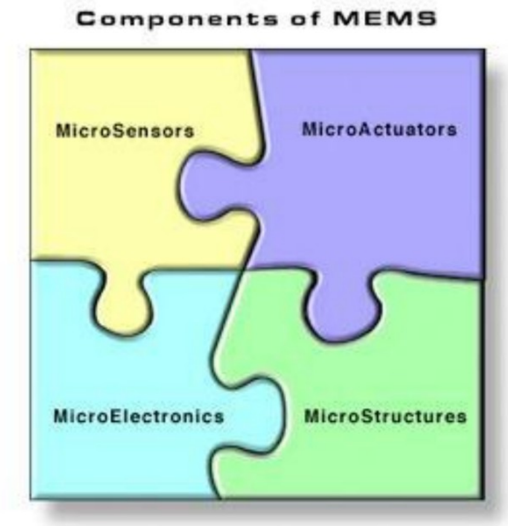


Fig. 4.6: Components of MEMS

Materials for MEMS manufacturing:
The fabrication of MEMS evolved from the process technology in semiconductor device
fabrication, i.e. the basic techniques are deposition of material layers, patterning by photolithography and etching to produce the required shapes.

1 Silicon:
Silicon is the material used to create most integrated circuits used in consumer electronics in the modern world. The economies of scale, ready availability of cheap high-quality materials and ability to incorporate electronic functionality make silicon attractive for a wide variety of MEMS applications.
Silicon also has significant advantages engendered through its material properties. In single crystal form, silicon is an almost perfect Hookean material, meaning that when it is flexed there is virtually no hysteresis and hence almost no energy dissipation. As well
as making for highly repeatable motion, this also makes silicon very reliable as it suffers very little fatigue and can have service lifetimes in the range of billions to trillions of cycles without breaking.

2 Polymers
Polymers on the other hand can be produced in huge volumes, with a great variety of material characteristics. MEMS devices can be made from polymers by processes such as injection molding, embossing or stereo lithography and are especially well suited to micro fluidic applications such as disposable blood testing cartridges.

4.3 Metals
Metals can also be used to create MEMS elements. While metals do not have some of the advantages displayed by silicon in terms of mechanical properties, when used within their limitations, metals can exhibit very high degrees of reliability.
Metals can be deposited by electroplating, evaporation, and sputtering processes. Commonly used metals include gold, nickel, aluminum, copper, chromium, titanium, tungsten, platinum, and silver.

Actuation

On-chip actuation of microsystems has been a particularly challenging aspect of MEMS development. Common macro-level actuation approaches, such as hydraulics, pneumatics, electric motors, internal combustion engines and turbines, are either too difficult to fabricate at the micro level or do not work well at that scale. Electrostatic attraction is one approach that has been widely used for actuation of microsystems. While electrostatic actuation is suitable for many applications, some systems require either lower voltages or higher output forces. Electrostatic and thermal actuation approaches are described in more detail.

Electrostatic Actuation

According to Coulomb's law, the electrostatic force acting between two charges is inversely proportional to the distance between the charges. For macro-scale objects, this force is normally negligible. However, micro-scale devices may have very small gaps, making electrostatic attraction an important source of mechanical motion. This actuation technology is especially attractive because it uses very little power. On the other hand, large voltages (typically tens to hundreds of volts) are required.

The simplest type of electrostatic actuator consists of a movable plate or beam which is pulled toward a parallel electrode under the application of a voltage difference. This type of actuator is illustrated schematically in Figure 5. The movable electrode is suspended by a mechanical spring, which is often simply a micromachined beam. When voltage is placed across the electrodes, opposite charges on each one attract each other. However, unless they touch, the electrodes only draw sufficient current to charge the actuator's effective capacitance, resulting in low power requirements. The attractive force is larger when the movable electrode is closer to the fixed electrode, with the force proportional to the reciprocal of the square of the gap.

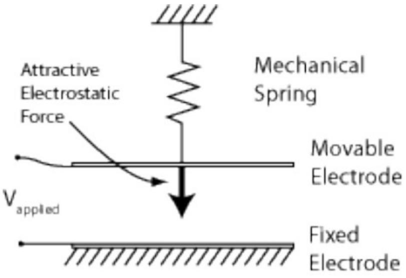


Fig. 4.7: A parallel-plate actuator consists of two parallel electrodes.

Because of this inverse relationship, these parallel-plate actuators suffer from instability for voltages beyond a threshold known as the "pull-in" voltage. For voltages beyond the pull-in voltage, the electrostatic attraction grows more quickly than the mechanical restoring force, causing the electrodes to crash into each other. Unless the electrodes are protected with a dielectric coating or mechanical stops to prevent contact, this normally results in catastrophic melting or vaporization of the actuator due to sudden current flow between the electrodes. For systems with a linear spring, the pull-in voltage is the voltage which causes the movable electrode to deflect one third of the gap. Hence, these actuators cannot be stably operated for deflections larger than this. However, many types of mechanical springs, including fixed-fixed beams, exhibit nonlinear deflection characteristics, leading to a larger usable deflection range.

Comb drive electrostatic actuators avoid the pull-in instability and remove the dependence of the force on the deflection. As with parallel-plate actuators, comb drives consist of one fixed and one movable electrode. The electrodes are shaped like interdigitated combs, however, as shown in Figure 4.7. Using straight combs, like those shown in the figure, results in an attractive force that is nearly constant over a wide range of deflection of the movable comb. The attractive force falls rapidly when the combs disengage and rises rapidly when the combs approach full engagement, but most comb drives are designed to operate entirely in the constant-force region.

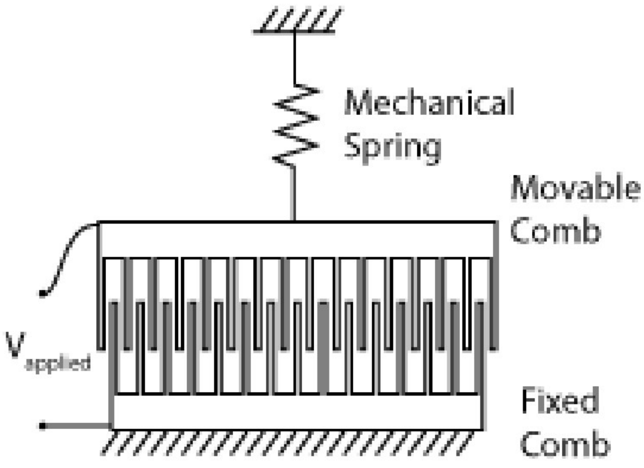


Fig. 4.7: A comb-drive actuator

Comb drives also suffer from instability when the applied voltage is too high, but this instability is not directly related to the deflection of the movable comb. As long as each comb finger is perfectly centered between two opposing comb fingers, the net transverse force acting on that finger will be zero. However, it is common for the fingers to become slightly off-center during motion. If the resulting transverse force is large enough, it will either cause bending of the fingers or it will pull the entire comb in the transverse direction. Hence, for sufficiently large applied voltage, the fingers on opposing combs can touch, which is frequently catastrophic due to melting or vaporization of the fingers.

Thermal Actuation

A change in temperature causes an object to undergo a change in length, where the change is proportional to the material's coefficient of thermal expansion. This length change is usually too small to be useful in most actuation purposes. Therefore, a method of amplifying the displacement is an essential part of thermal actuators. Figures 4.8 a to 4.8 d illustrate four examples for achieving amplification of thermal expansion in microactuators.

Bimetallic devices use two materials with different coefficients of thermal expansion that are fused together. As the temperature increases, one material expands more than the other and the actuator bends to accommodate the different deflections. An example is demonstrated in Figure 4.8a Challenges associated with bimetallic actuators include somewhat complicated fabrication and the potential for delamination of the layers.

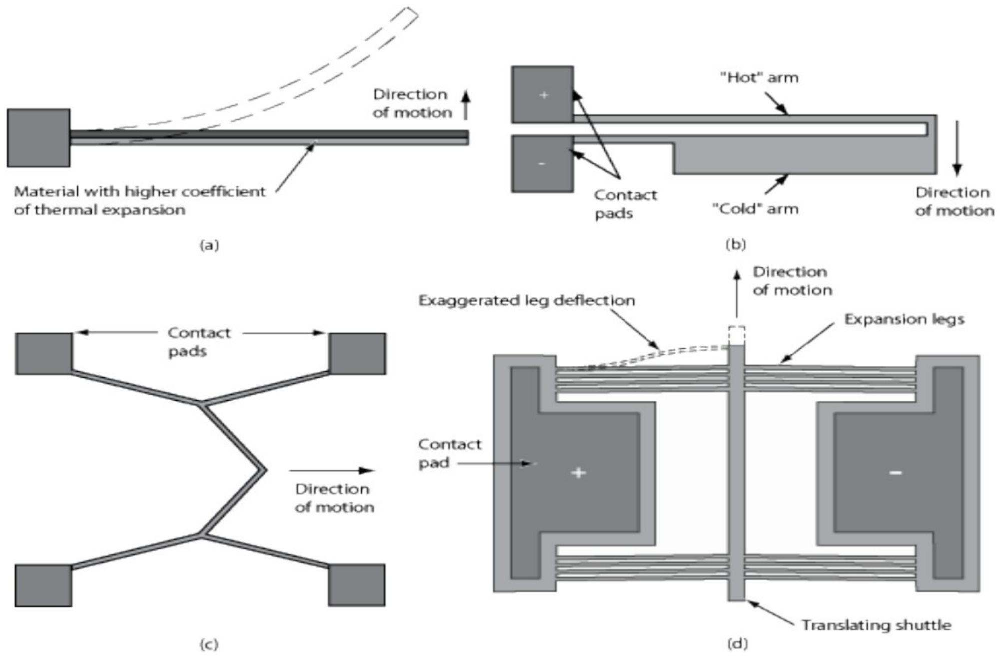


Fig. 4.8: Example thermal amplification approaches, including (a) bimetallic, (b) pseudo-bimorph, (c) geometry-based amplification, and (d) a thermomechanical in-plane microactuator (TIM).

While bimetallic actuators heat both materials to the same temperature but exploit their differences in coefficients of thermal expansion, pseudo bimorphs use a single material with a uniform coefficient of thermal expansion, but with different parts experiencing different temperature changes. This approach makes it possible to construct an actuator from a single layer of the same material. An example is the device shown in Figure 4.8 b which has one leg thinner than the other. An electric current runs through the legs, but the thin leg will have a higher electrical resistance and will heat up more than the wide leg. As the hot leg expands it will cause the actuator to rotate in the direction shown.

Another approach for amplifying the thermal expansion is to use geometric constraints that force the actuator to move in the desired direction. An example of this type of amplification is the "bent beam" actuator, illustrated in Figure 4.8c . As the thin legs heat up, the expansion causes an amplified deflection in the direction shown.

The Thermomechanical In-plane Microactuator (TIM) also exploits geometric constraints , as illustrated in Figure 4.8d. It consists of thin legs connecting both sides of a center shuttle. The leg ends not connected to the shuttle are anchored to bond pads on the substrate and are fabricated at a slight angle to bias motion in the desired direction. As voltage is applied across the bond pads, electric current flows through the thin legs. The legs have a small cross sectional area and thus have a high electrical resistance, which causes the legs to heat up as the current passes through them. The shuttle moves forward to accommodate the resulting thermal expansion. Advantages of this device include its ability to obtain high deflections and large forces, as well as its ability to provide a wide range of output forces by changing the number of legs in the design.

➢ Applications:-

Digital Micromirrors

One of the most visible commercially available microelectromechanical systems is Texas Instruments' Digital Micromirror Device (DMDTM) which is used in applications such as portable projectors, rear-projection televisions, and cinema projectors. The DMD is a rectangular array of moving micromirrors that is combined with a light source, optics, and electronics to project high quality color images [14].

Figure 4.9 shows the architecture of a single DMD pixel. A 16 micrometer square aluminum mirror is rigidly attached to a platform (the "yoke"). Flexible torsion hinges are used to connect the yoke to rigid posts. An applied voltage creates an electrostatic force that causes the mirror to rotate about the torsion hinges. The electronics and structure are designed to allow the mirror to be rotated by 10 degrees in either of two directions (the "on" and "off" positions). When tilted in the on position, the mirror directs light from the light source to the projection optics and the pixel appears bright. When the mirror is tilted in the off position, the light is directed away from the projection optics and the pixel appears dark.

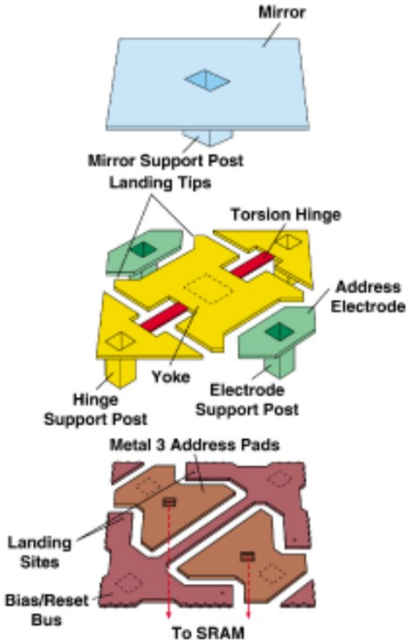


Fig. 4.9: Architecture of the Texas Instruments Digital Micromirror Device (DMD). (Illustration courtesy of Texas Instruments.)

The micromirrors can be combined in an array on a chip, and each micromirror is associated with the pixel of a projected image

The DMD architecture nicely illustrates several MEMS concepts - a few of these are:

- Multi-layer MEMS fabrication was used to make the DMD structure and electronics in layers below the mirror to create a high fill factor.
- The torsion hinges use compliance to obtain motion while avoiding rubbing parts that cause friction and wear.
- The small mass of the micromirrors allows them to move very quickly.
- Electrostatic forces were used to actuate mechanical devices, resulting in low power requirements.

MEMS in Optical Circuits

A wide variety of optical components may also be implemented in MEMS. For example, the Digital Mirror Device discussed above uses micromachined mirrors to redirect light. MEMS mirrors have also been used for optical switching applications, allowing optical communication to be routed without requiring conversion to electrical signals. Adaptive optics systems using MEMS mirrors have been built to correct distortions due to air refraction or lens anomalies.

MEMS optical waveguides are often used to route optical signals within a MEMS optical chip. These waveguides consist of a core with low loss at optical wavelengths. Using micromachining, the waveguides can be patterned on the same chip as other optical components. Both mechanically suspended and fixed waveguides have been demonstrated. Suspended waveguides can also be designed to deflect mechanically. Hence, they can also switch or attenuate a signal when the waveguide is moved in and out of alignment with other components.

Micromachined lens arrays have also been demonstrated for optical applications. Figure 4.10 shows an example of three types of micromachined lens arrays. Similarly, diffractive gratings can be made using the fine dimensional control available from micromachining. These lens arrays and gratings have been used in optical filters and switches.

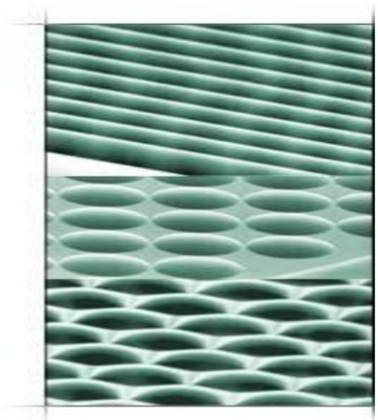


Fig. 4.10: Three types of MEMS lens arrays: cylindrical (top), circular lenses, square packed (middle), and hexagonal lense, hex packed (bottom).

Sensors

A sensor is a device that responds to a physical input (such as motion, radiation, heat, pressure, magnetic field), and transmits a resulting signal that is usually used for detection, measurement, or control. A transducer (often used as a synonym for sensor) is a device that is actuated by power from one system and converts it to a different form to another system. Advantages of MEMS sensors are their size and their ability to be more closely integrated with their associated electronics.

Piezoresistive and capacitive sensing methods are among the most commonly employed sensing methods in MEMS. Piezoresistance is the change in resistivity caused by mechanical stresses applied to a material. Materials with high piezoresistivity (such as some semiconductors which have more than an order of magnitude higher piezoresistivity than metals) are useful for transducing mechanical deformation to electrical signals. This is particularly useful in applications such as pressure sensors and accelerometers.

Capacitive sensors rely on the physical input being sensed to cause a change in capacitance. This capacitance change can be caused by changing the distance between the capacitor plates (e.g. pressure pushing two plates closer together) or by changing the dielectric (such as relative humidity sensor using a dielecric with a permittivity that changes with moisture content). The resulting change in capacitance can be very small and specialized electronics are required to detect the changes and convert them into a usable output signal.

An example of MEMS sensors include bulk micromachined pressure sensors, which have been commercially available since the 1970's. A typical design is illustrated in Figure 4.11. A cavity is etched to create a thin diaphragm which deflects under pressure. A backside port is etched in another substrate and bonded to the first. Piezoresistive pressure sensors have piezoresistive elements on the diaphragm that change resistance as the pressure increases. Another approach is to use the diaphragm as a plate in a capacitor and to detect the capacitance change as the diaphragm deflects under pressure.

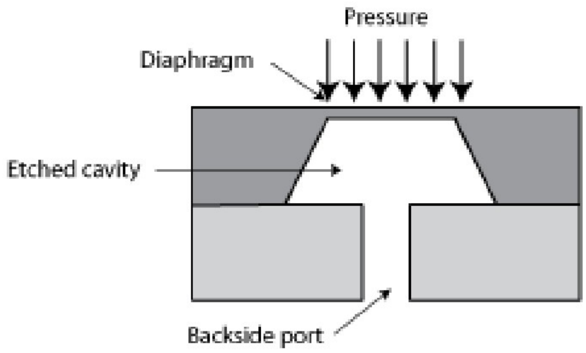


Fig. 4.11: An example of a MEMS pressure sensor.

Accelerometers are another example of commercially successful MEMS sensors. Applications include automotive airbag safety systems, mobile electronics, hard drive protection, and others. These have been successful enough that Analog Devices, a leader in MEMS sensors, had shipped over 200 million MEMS inertial sensors by April 2005. Figure 4.12 illustrates an example of a surface micromachined capacitive accelerometer. An acceleration causes a displacement of the inertial mass and the capacitance change between the comb fingers is detected.

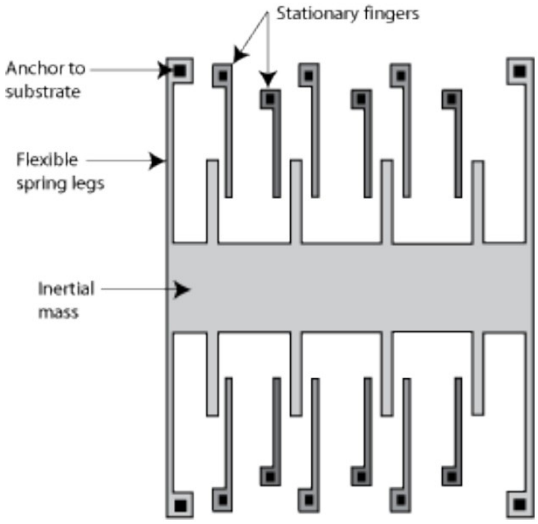


Fig. 4.12: A sketch of a capacitive MEMS accelerometer.

Other MEMS sensors include rate sensors, gyroscopes, radiation sensors, gas sensors, microphones, and mass flow sensors, to name a few.

Applications:-

RF MEMS Components

Several types of MEMS components have been designed to operate in radio-frequency communications circuits. Low-power MEMS filters, variable capacitors, and switches have all been identified as promising MEMS components of RF communications systems. MEMS filters use mechanical vibrations to filter RF signals. They have demonstrated extremely low-power operation. MEMS variable capacitors are used in tuning circuits and oscillators.

MEMS switches are especially attractive because they exhibit "nearly ideal" switch behavior . When on, their insertion loss is typically about 0.2 dB or less, and off-state isolation is normally 20 dB or better even at high frequency (20-40 GHz). In addition, MEMS switches are normally electrostatically actuated, so that they consume very little cycling power.

Two types of MEMS switches have been used. The simplest type opens and closes a contact between micromachined metal electrodes.

Capacitive switches do not suffer from this limitation. Capacitive RF switches also consist of a suspended electrode which is pulled toward a second electrode; however, a dielectric layer separates the two electrodes to prevent the flow of electrons between them. Instead, a capacitive switch works by changing the capacitance between the two electrodes. The ratio of on-state to off-state capacitance can be as high as 200. Because DC current does not flow between the electrodes, capacitive switches can often carry more power than metal contact switches. However, because capacitive impedance is a function of signal frequency, they operate in a more narrow frequency band than metal contact switches.

Inkjet Printing

In 1984, Hewlett-Packard introduced the Thinkjet printer, the one of the first desktop printers to use inkjet technology. The technology was based on micromachined inkjet print heads used to expel drops of ink onto paper in well-defined patterns.

Inkjet printing depends on ink drops being ejected through micromachined orifices to create the desired pattern. Many different techniques have been used to eject the ink drops. Fig. 4.13 illustrates a micromachined print-head that uses one method, called thermal inkjet printing by Hewlett Packard, where it was developed. In this method, a thin-film heater inside an ink-filled cavity heats a thin layer of ink. A bubble forms as the ink layer is superheated. The bubble rises out of the cavity through the micromachined orifice, carrying with it a drop of ink, which is expelled toward the paper. The size of the ink drop can be controlled by designing and fabricating an appropriately-sized cavity and orifice. Other methods for ejecting ink drops rely on mechanical pumping motions, often using piezoelectric materials. This application of micromachining has become extremely wide-spread in the printing industry; in addition, it is starting to be expanded to other industries, including automotive fuel injection, drug delivery, and other areas where precise control of fluid volume is required.

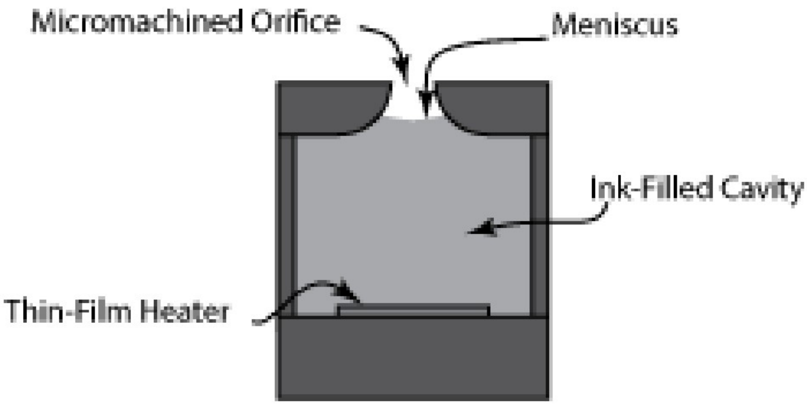


Fig. 4.13. A micromachined inkjet printhead.

Compliant Mechanisms

Achieving motion at the micro level presents some interesting challenges. Because bearings are not feasible and lubrication is problematic, friction and wear present major difficulties. Assembly of parts at this scale is difficult. The constraints introduced by the planar nature of MEMS fabrication also introduce a number of unique challenges in constructing mechanical devices.

The advantages of compliant mechanisms at the micro level include the following :

- Can be fabricated in a plane

- Require no assembly
- Require less space and are less complex
- Have less need for lubrication
- Have reduced friction and wear
- Have less clearance due to pin joints, resulting in higher precision
- Integrate energy storage elements (springs) with the other components