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SMART SENSORS AND MEMS

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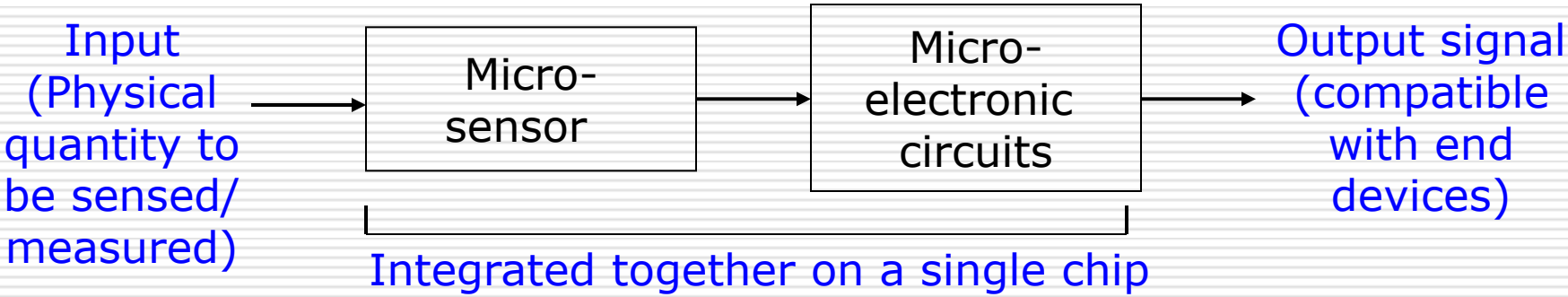
What is a Smart Sensor?



- A smart sensor comprises a micro-sensor and micro-electronic circuits integrated together on a single chip. Its output should be compatible with the end device/ device(s) intended to be used.
- There is no standard definition of smart sensor as yet, but a good definition is given below:
- *"Smart Sensor is a micro-sensor suitably integrated with appropriate micro-electronic circuits such that the output is fully or easily compatible with the intended end device or devices".*
- *The micro-electronic circuits include:*
  *(a) some **essential** analog signal processing circuits, and*
  *(b) any **optional** digital signal processing and other circuits.*

Levels of Integration in Smart Sensors

- The electrical signal after signal conditioning (or processing) can have one of the following forms:
  - Digital
  - Analog
  - Quasi-digital (pulse width or pulse frequency)

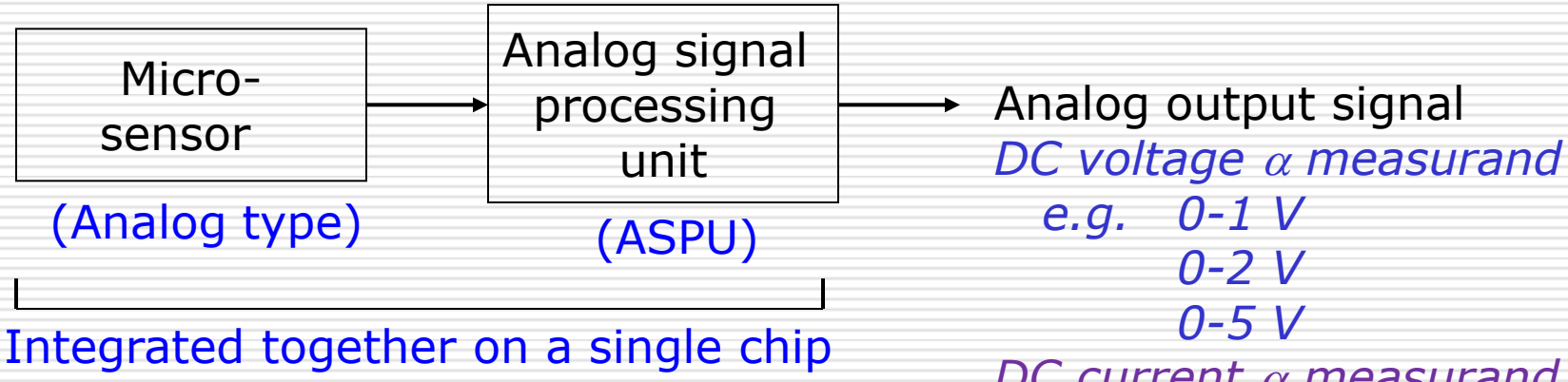
- The extent or level of integration of electronics with the micro-sensor can vary very widely as under:
  - Lowest Level: Smart sensor with analog output
  - Low Level: Smart sensor with quasi-digital output
  - High Level: Smart sensor with digital output
  - Higher Level: Smart intelligent sensor or (simply) intelligent sensor
  - Highest Level: Smart network sensor or (simply) network sensor

Smart Sensors with Analog/ Quasi-Digital/ Digital Output

- Smart sensor with analog output
- Smart sensors with quasi-digital output
  - Smart sensor with PWM output
  - Smart sensor with PFM output
- Smart sensor with digital output

Smart Sensor with Analog Output

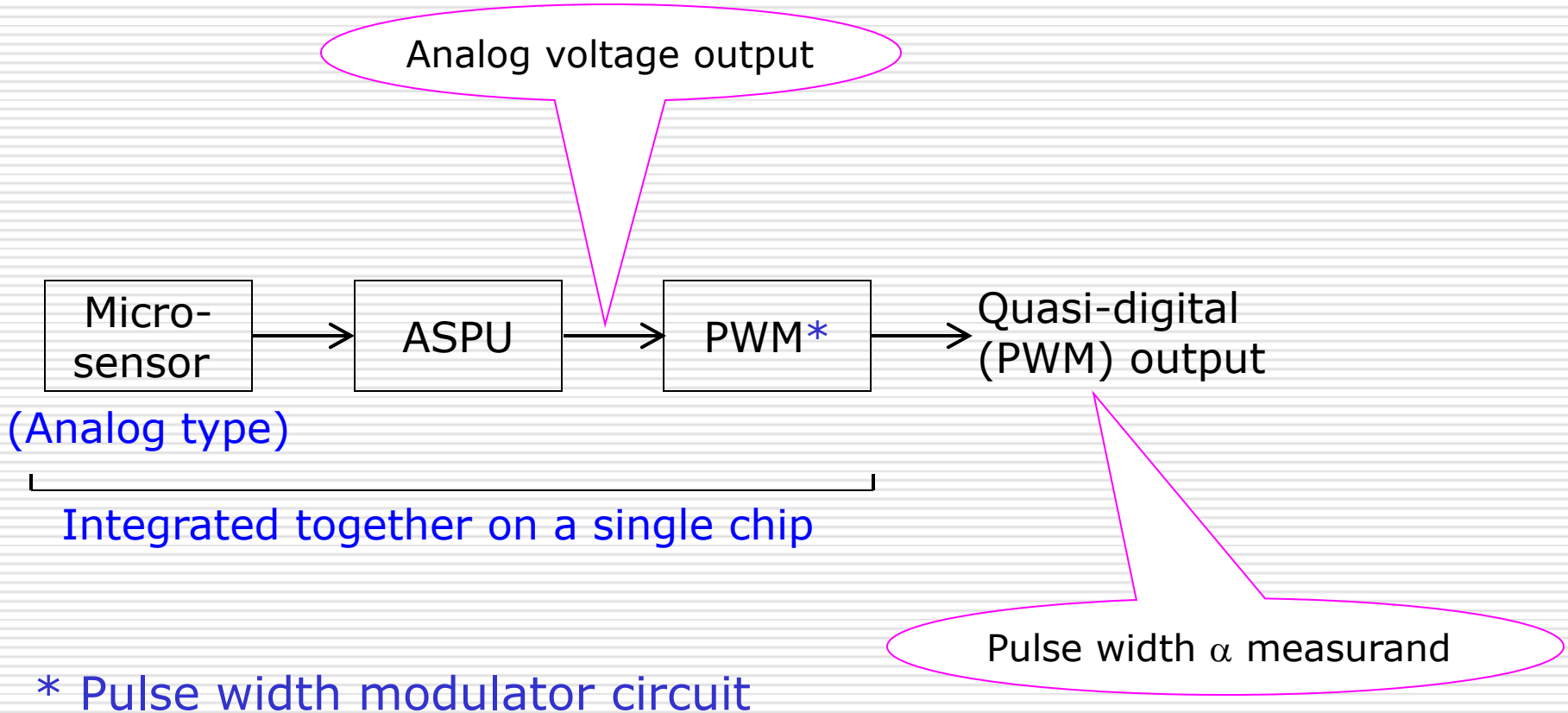
Schematic



(a) Passive micro-sensor: Excitation source and excitation circuit included as first two elements of ASPU

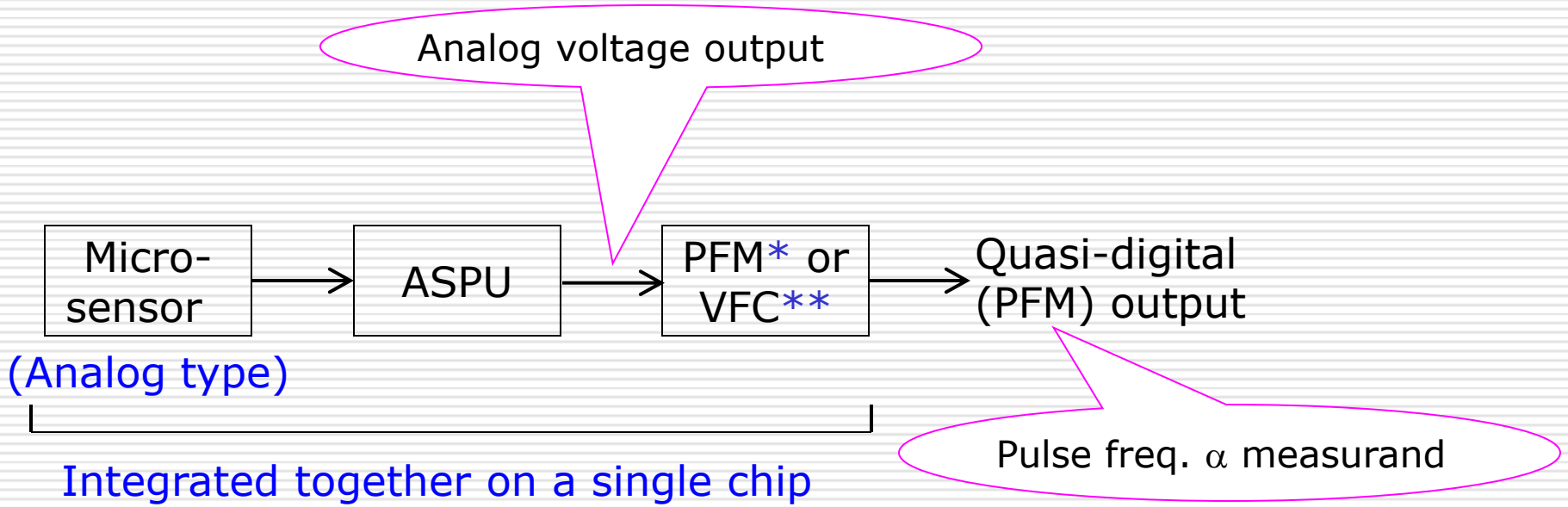
(b) Active micro-sensor: Excitation source and excitation circuit not required

Smart Sensor with PWM Output
Schematic



* Pulse width modulator circuit

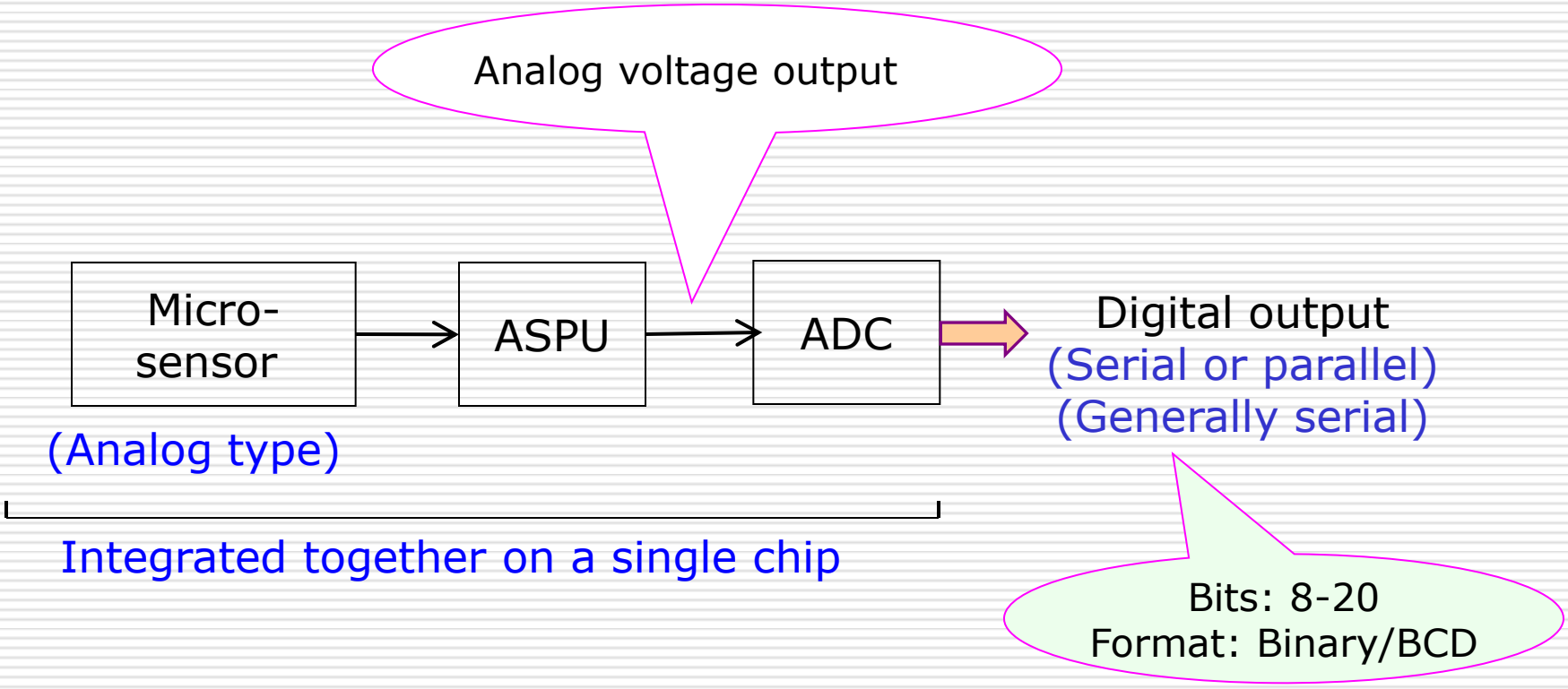
Smart Sensor with PFM Output
Schematic



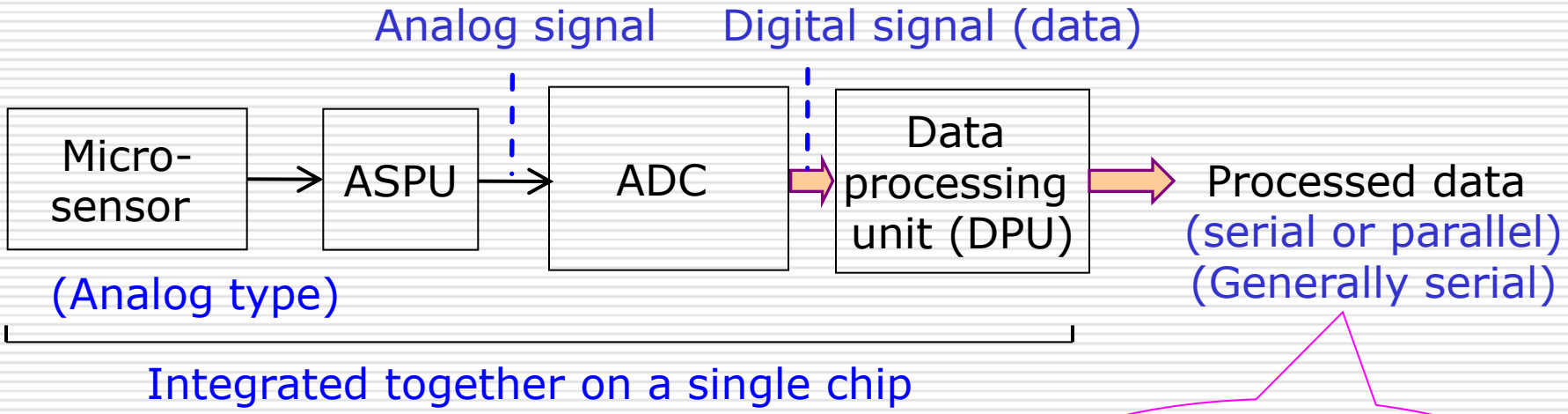
* Pulse frequency modulator circuit

**Voltage-to-frequency converter circuit

Smart Sensor with Digital Output
Schematic



Intelligent Sensor



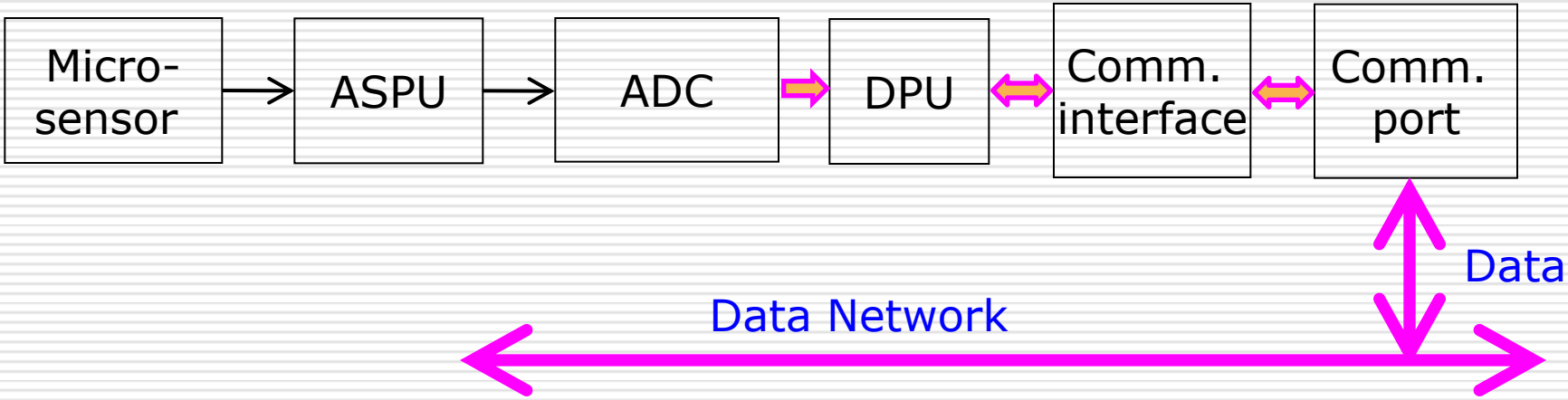
Can be readily connected to a host computer or any other digital system

DPU : μP + memory + I/O interface

OR

Microcontroller

Network Sensor



- *Output data of a network sensor is available on an integrated communication port in an appropriate format, which allows networking of such sensors **without requiring** any further interface circuitry or data formatting.*
- *Communication is bidirectional.*

Advantages of Smart Sensors

I General advantages of Smart Sensors

II Additional advantages of Intelligent Sensor

III Additional advantages of Network Sensor

General Advantages of Smart Sensors

1. User's Convenience because of:
   - No wiring
   - Compact size
   - No need to design or select SC
   - Fast to use
2. Superior Performance because:
   - Externally-induced noise is absent, resulting in high SNR
   - Built-in sensor-specific SC circuit performs better than general purpose SC circuits
   - Built-in compensating circuits reduce sensitivity to temperature/ excitation changes
3. Higher Reliability because of:
   - Reduced component count
   - Absence of wiring
4. Lower Cost because of:
   - Use of mass production techniques
   - Single production-line for μ-electronics and μ-sensor

Additional Advantages of Intelligent Sensor

- No wiring as no external ADC or μ-Processor is needed
- No interfacing issues as ADC and μ-Processor are already integrated on the chip
- Cheaper than adding external DPU
- Higher flexibility as the critical functions are performed in software (changes in these functions are possible without changing hardware)
- Internal data logging using on-chip memory

Additional Advantages of Network Sensor

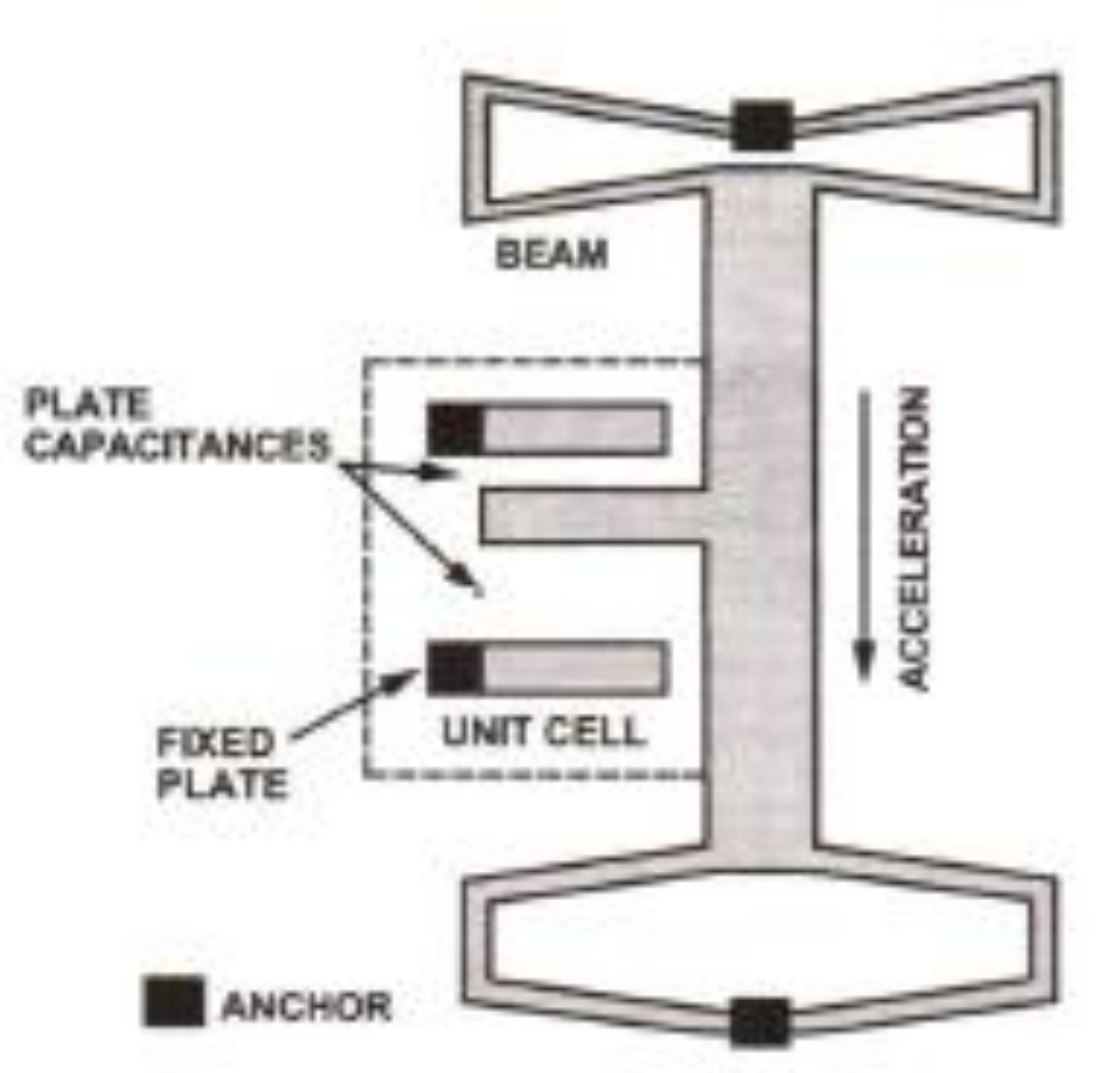
- No wiring as no external communication circuits are needed
- No issues of interfacing with communication network
- Cheaper than adding external communication circuits

What is MEMS?

- MEMS is an acronym for "Micro-Electro-Mechanical System"
- Definition : "MEMS is a system, containing some electrical and some mechanical components, on a miniature device"
- The miniature device has micro-metric dimensions
- Overall dimensions generally do not exceed 10 mm
- Dimensions of any internal feature range from less than 1 μm up to 100 μm
- Functionally, MEMS is a transducer in one the following forms:
  - MEMS Sensor: **Input**: Mechanical quantity to be measured
    Output: Electrical signal
  - MEMS Actuator: **Input**: Electrical control signal
    Output: Mechanical action

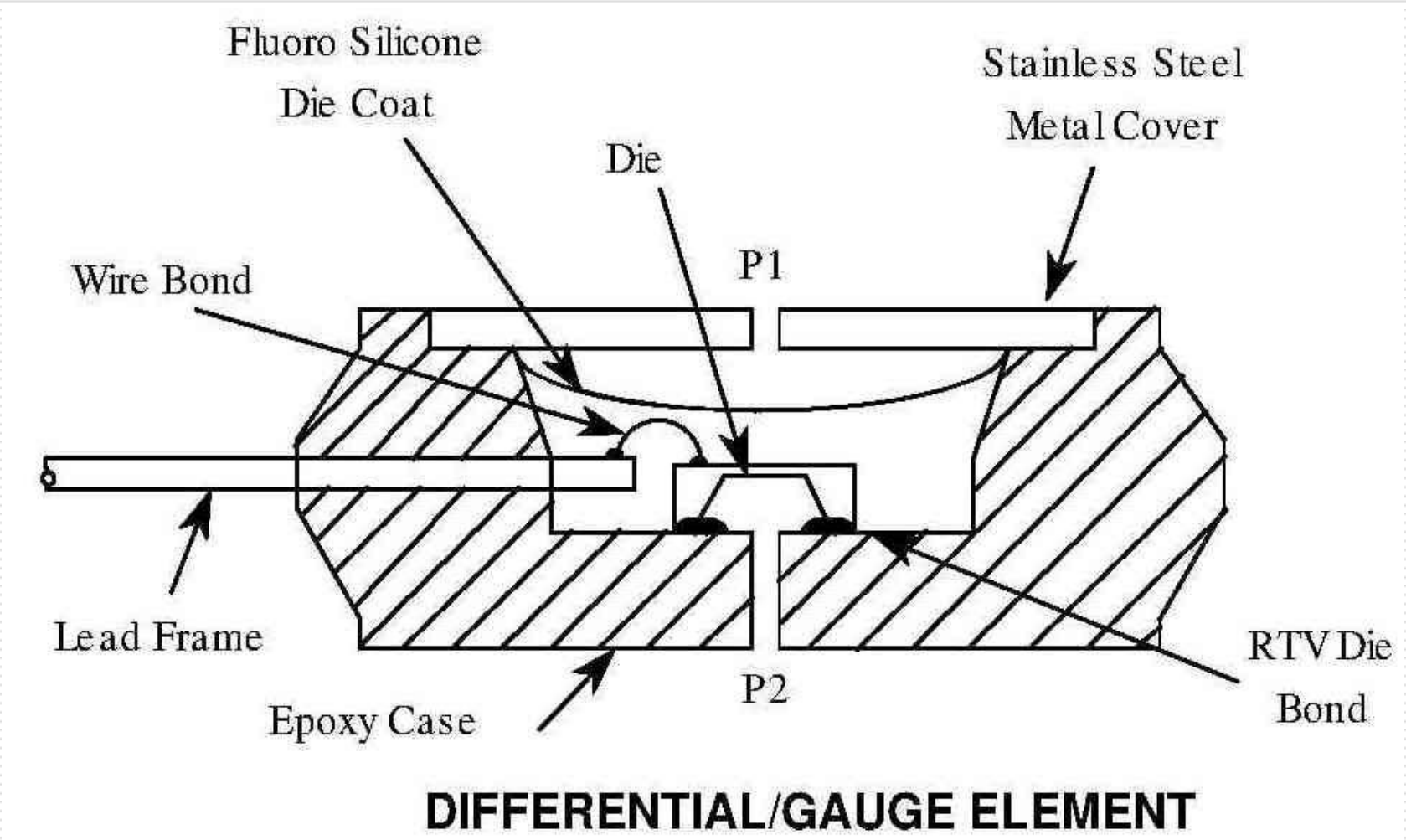
[Some examples are given in next few slides]

MEMS-Based Acceleration Sensor



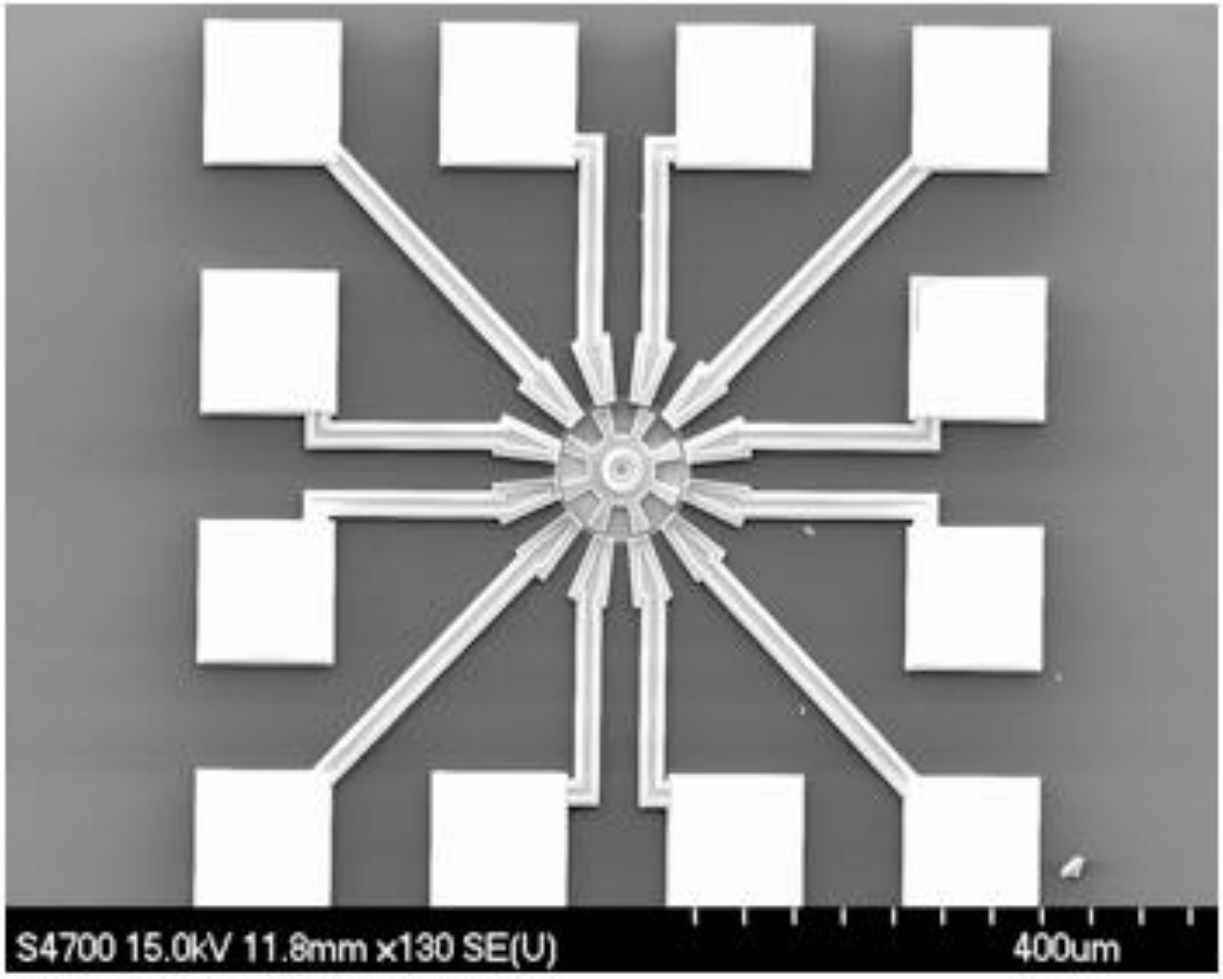
Source:
Data sheets of ADXL-150

MEMS-Based Pressure Sensor



Source: Data sheet of MPX5700

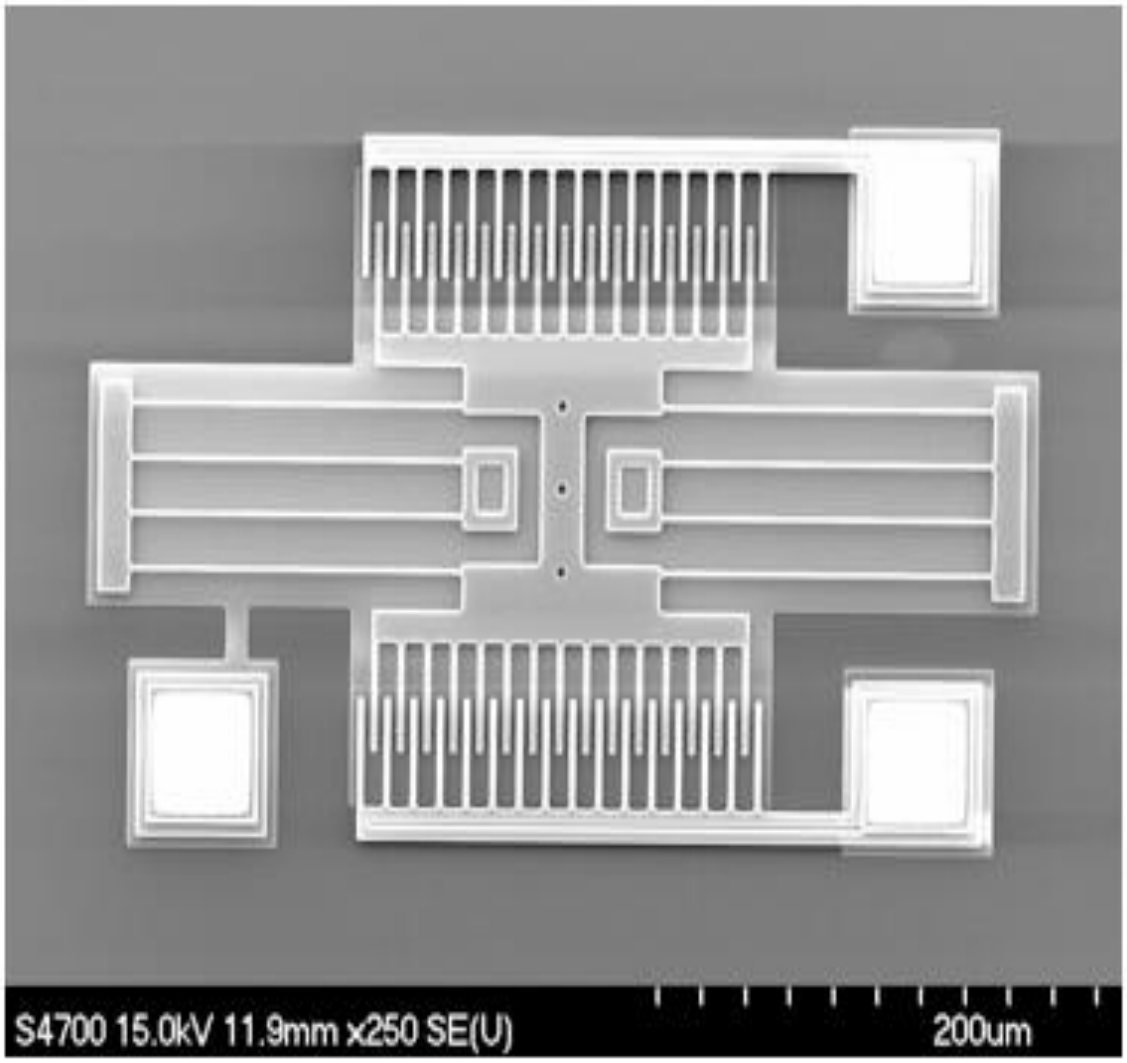
MEMS-Based Micro-Motor (Actuator)



Electro-statically actuated micro-motor fabricated by the MNX

Source: www.mems-exchange.org

MEMS-Based Resonator (Sensor/Actuator)



Resonator fabricated by the MNX (Can be used both as a micro-sensor and as a micro-actuator)

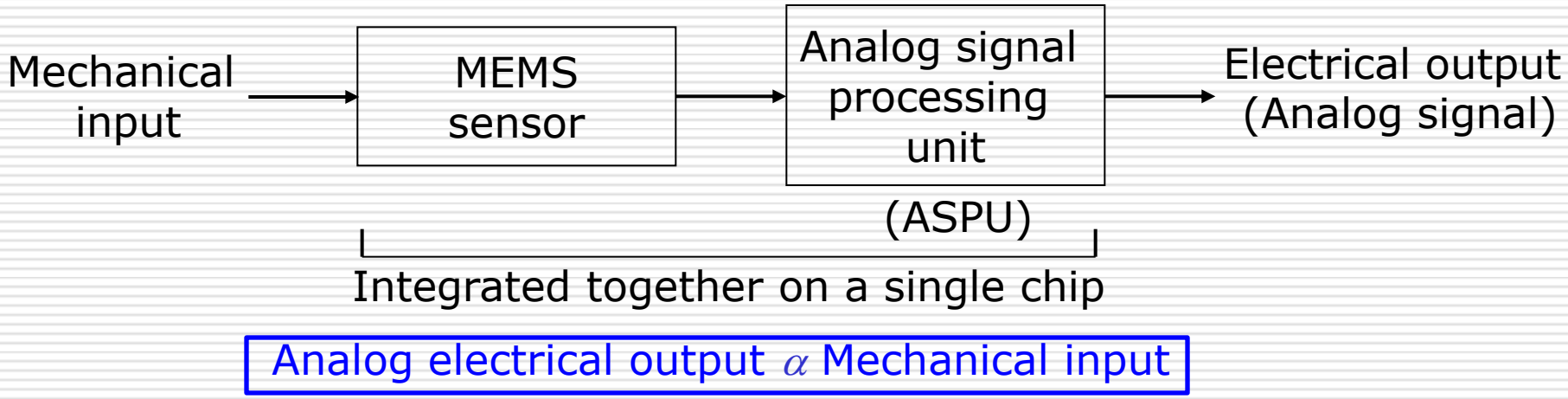
Source: www.mems-exchange.org

Smart MEMS Devices

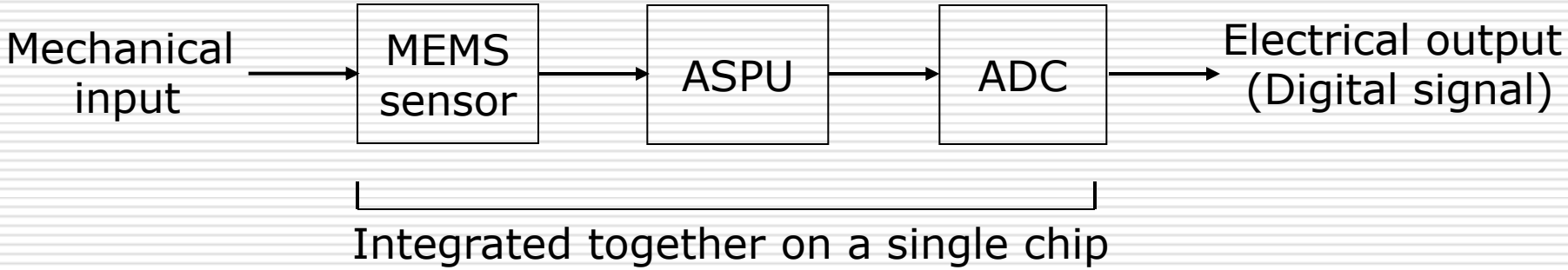
- MEMS sensors and actuators are usually integrated with micro-electronics on a single chip to achieve their real potential
- The micro-electronic circuit is fabricated on a chip using IC techniques, while MEMS is fabricated on the same chip using compatible micro-machining techniques.
- The integrated device is a Smart MEMS device.
- Smart MEMS devices are designed for one of the following functions:
  - Smart MEMS Sensor
  - Smart MEMS Actuator
- Smart MEMS sensor is a special case of smart sensors, in which the micro-sensor is a MEMS and input is a mechanical quantity.
- Most of the smart actuators are smart MEMS actuators, which give a mechanical output.
- Some smart MEMS devices can function both as a sensor and an actuator.

Smart MEMS Sensors with Analog/Digital Output

Schematics



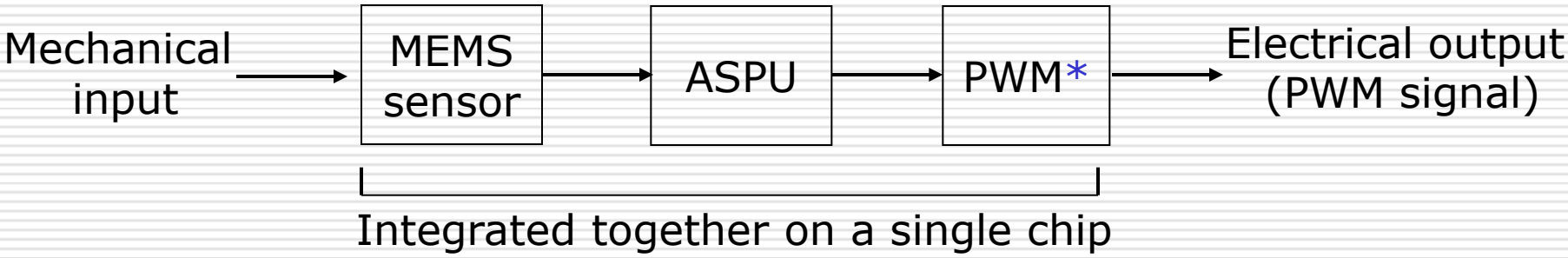
Analog electrical output α Mechanical input



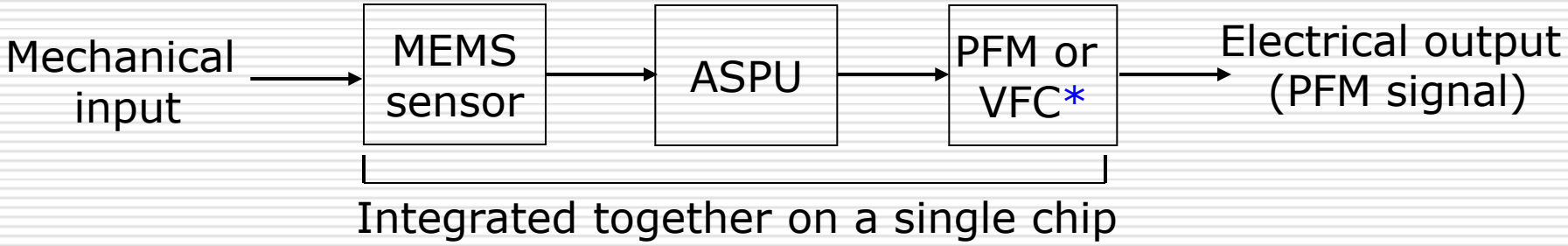
Digital electrical output α Mechanical input

Smart MEMS Sensors with Quasi-Digital Output

Schematics



* Pulse width modulator circuit



* Pulse frequency modulator circuit
or Voltage-to-frequency converter circuit

Smart Sensors with Analog Output
Examples

1. AD590 / AD592 : Analog Devices
 - Smart temperature sensor with analog current output
 - Output = 1 μA /K
2. LM34 / LM35 : National Semiconductor Corporation
 - Smart temperature sensor with analog voltage output
 - Output = 10 mV per ˚F / 10 mV per ˚C
3. HIH4000 Series : Honeywell
 - Smart humidity sensor with analog voltage output
 - Output = 0 – 4 V
4. ADXL311 : Analog Devices
 - Dual-axis smart MEMS acceleration sensor with analog voltage output
 - Output = 174 mV/g
5. MPX5700 Series : Freescale Semiconductor Inc.
 - Smart MEMS pressure sensor with analog voltage output
 - Output = 6.4 mV/kPa
6. LPY503AL: STMicroelectronics
 - Two-axis Smart MEMS Gyro Sensor with analog voltage output
- Output : 0-2 V (8.3 mV/^{o}/s for ±120 ^{0}/s range)
 (33.3 mV/^{o}/s for ±30 ^{0}/s range)

Smart Sensors with Digital/Quasi-Digital Output Examples

1. SHT7x / SHT1x Series : Sensirion Corpporation
   - Smart humidity and temperature sensor with serial digital output
   - Serial Interface = Similar to I^2C
2. BMP100 : Bosch Sensortec, Germany
   - Smart MEMS pressure sensor with serial digital output
   - Serial Interface = I^2C (Inter-Integrated Circuit)
3. ADXL345 : Analog Devices
   - Three-axis Smart MEMS Acceleration Sensor with digital serial output
   - Serial Interface : SPI and I^2C
4. ITG-3200 : InvenSense Inc.
   - Three-axis Smart MEMS Gyro Sensor with digital serial output
   - Serial Interface : Fast mode I^2C (400 kbps)
5. ADXL210 : Analog Devices
   - Dual-axis smart MEMS acceleration sensor with quasi-digital output
   - Output : PWM

Applications of Smart MEMS Pressure Sensors Examples

1. Barometric pressure measurement.
2. Wind pressure measurement over surfaces of aero-dynamic models and building models in wind-tunnel studies.
3. Blood pressure and respiration monitors.
4. Disposable intra-venous blood pressure monitor.
5. Implanted wireless pressure transmitter.

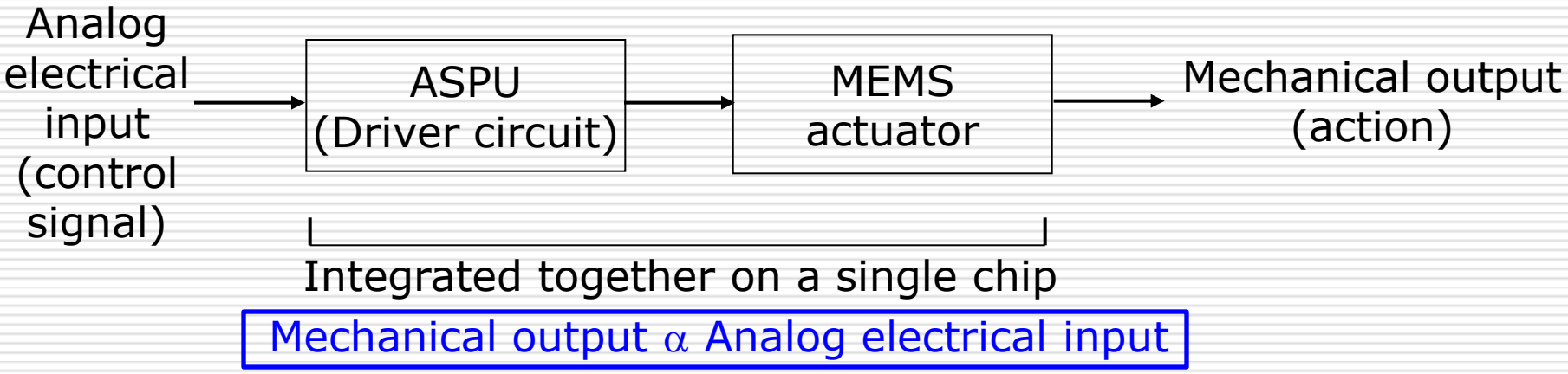
Applications of Smart MEMS Acceleration Sensors
Examples

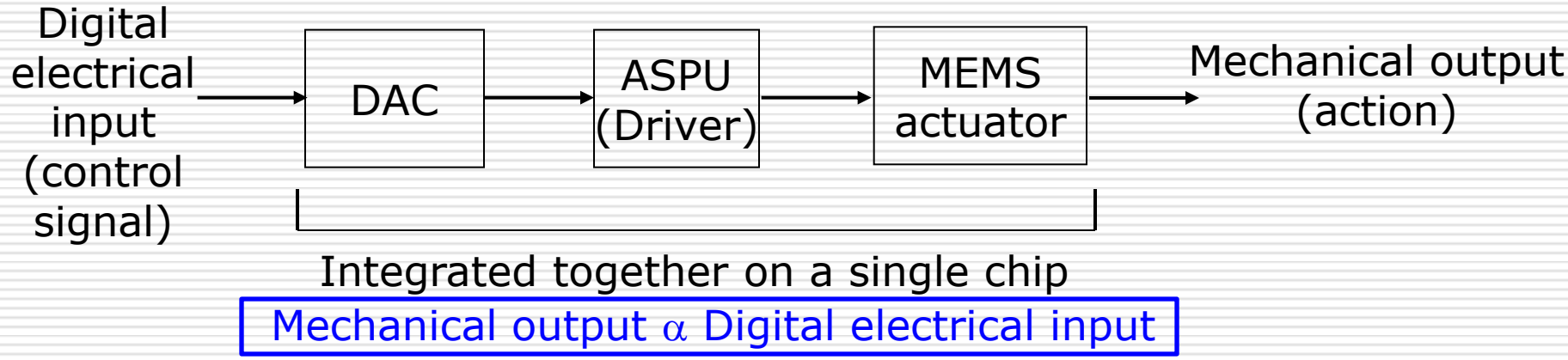
1. Measurement of acceleration, velocity and displacement, in general.
2. Used for accurate 3-axis positioning of aircraft.
3. Used in smart phones, for sensing motion along horizontal and vertical directions for changing screen orientation.
4. Used in smart phones and pedometers, for step counting and distance measurement.

Applications of Smart MEMS Gyro Sensors Examples

1. Measurement of angular velocity and displacement, in general.
2. Rollover detection in cars for electronic stability control to prevent roll over.
3. Used in airbag control system in cars and aircraft.
4. Used in flight controllers of drones for electronic stabilization.
5. Used in smart phones for rotation sensing and angle of rotation measurement.
6. Used in video and still cameras for image stabilization.

Smart MEMS Actuators with Analog/Digital Input Schematics





Applications of Smart MEMS Actuators
Examples

1. *Micro-valves* for control of gas and liquid flows.
2. *Micro-pumps* to develop positive fluid pressure
3. *Micro-flaps* to modulate air-stream on aero-foils
4. *Micro-resonators* for tactile reading by blind people
5. *Optical switches and mirrors* to redirect or modulate light beams