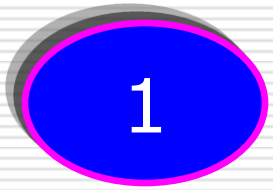

BASICS OF SMART SENSOR

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CONTENTS

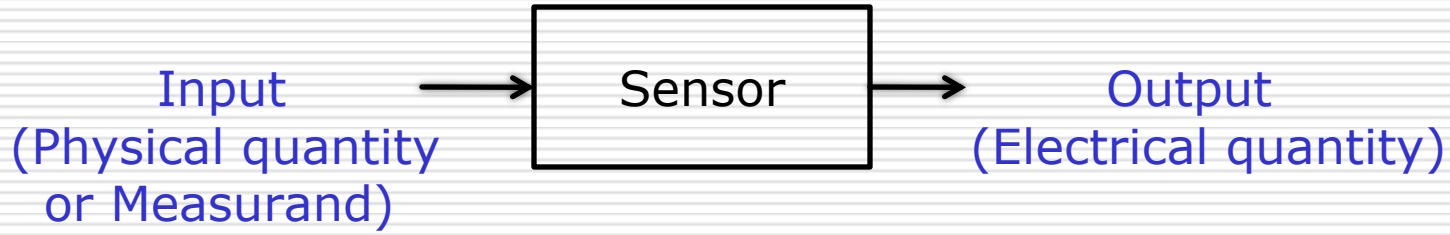
1.1

Basics of Sensors

- What is a Sensor?
- Sensor Input
- Sensor Output
- Operating Principles of Sensors
- Energy Source for Sensor
- Active or Generating Sensor
- Passive or Parametric Sensor

What is a Sensor?

- Device that senses a **physical quantity**
- This physical quantity becomes **input to the sensor**
- In the present context, the **output of the sensor** should be an **electrical quantity**
- Sensor output is a function of sensor input
- Input is called measured quantity or **"measurand"**



Sensor Input

- Input to the sensor is the *sensed or measured quantity, called as **measurand***
- Examples of the measurand are:
  - Temperature
  - Pressure and force
  - Torque
  - Displacement, velocity and acceleration
  - Strain
  - Flow, level and head
  - pH value
  - Humidity
  - Gas concentration
  - Voltage and current
  - Power and power factor
  - Frequency

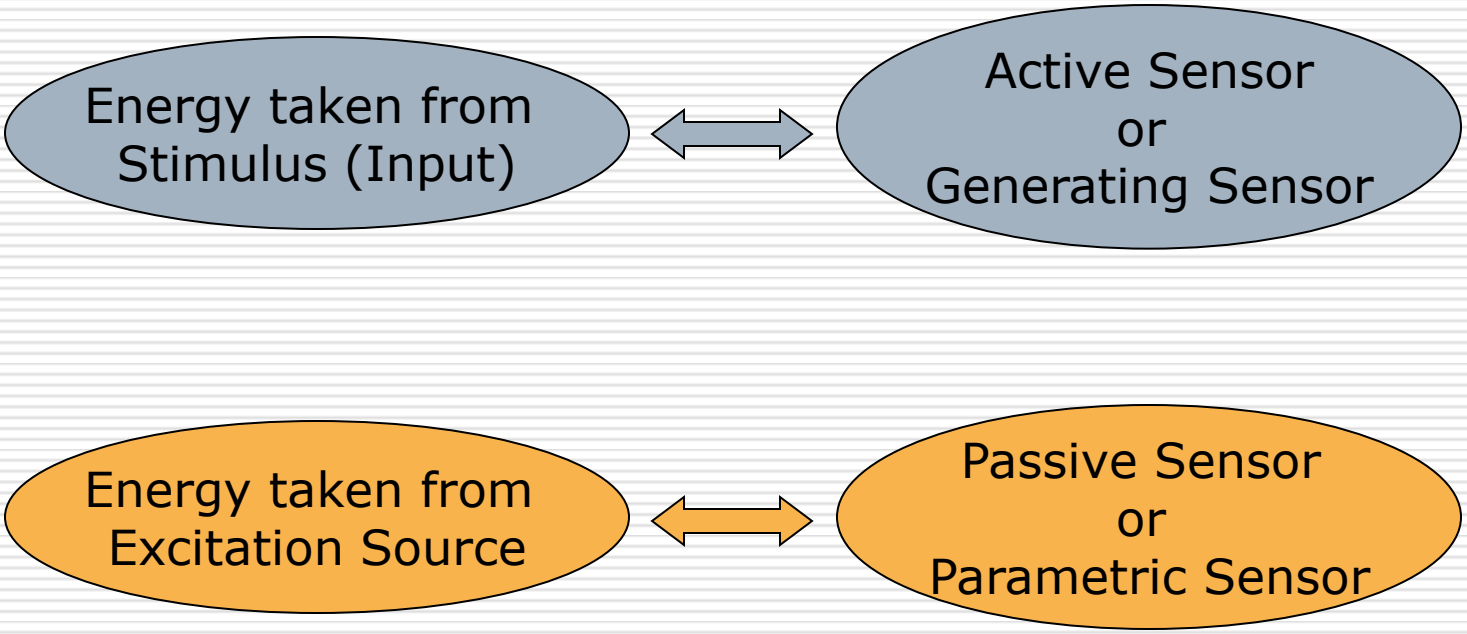
Sensor Output

- Generally speaking, the sensor output may be electrical, mechanical, hydraulic or even pneumatic
- But in the context of smart sensors, only those sensors that have an ***electrical output*** are relevant
- The electrical output of a sensor can be one of the two types:
  - Variation of an electrical parameter
  - An electrical signal
- Variation of electrical parameter means
  - Variation of resistance (delta R), or
  - Variation of inductance (delta L), or
  - Variation of capacitance (delta C)
- Electrical signal means
  - Voltage signal, or
  - Current signal

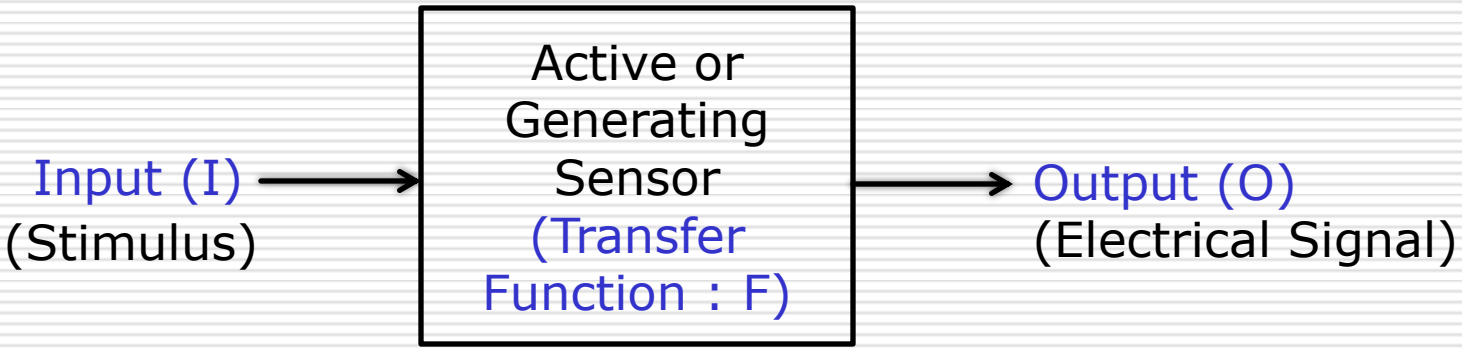
Operating Principles of Sensors

- Sensors work on various physical phenomena
- Almost all physical phenomena known to the scientists have been used in devising one or the other sensor
- Examples of simple sensors with phenomena used are:
  - Variation of metal resistance with temperature (RTD)
  - Variation of wire-resistance with physical dimensions (strain gauge)
  - Variation of inductance with reluctance (inductive displacement sensor)
  - Variation of capacitance with electrode dimensions and spacing (capacitive displacement transducers or sensors)
  - Variation of capacitance with dielectric constant (liquid level sensor)
  - Electro-magnetic induction (LVDT)
  - Thermo-electric effect (thermocouple)
  - Piezo-electric effect (piezo-electric pressure transducer)
- Examples of sensors based on other phenomena are:
  - Opto-electronic light sensor
  - Semiconductor-junction temperature sensor
  - Ultrasonic flow sensor
  - CCD imaging sensor
  - Biosensors

Energy Source for Sensor



Active or Generating Sensor

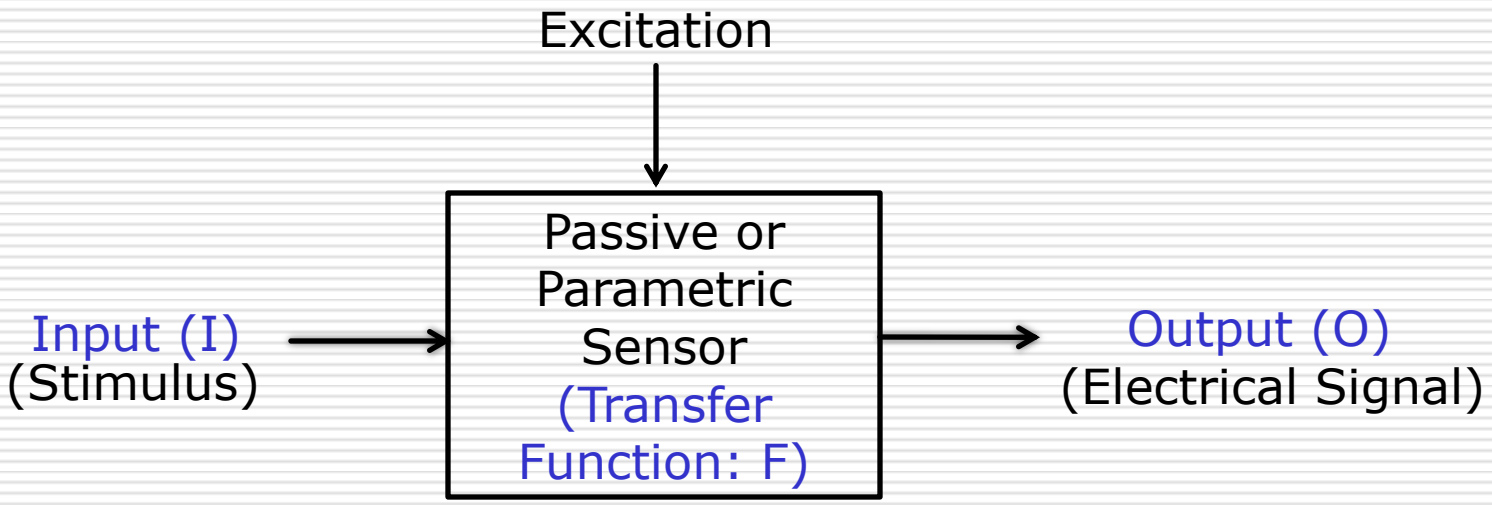


$O = F.I$

$O \ \alpha \ I$ is preferred by users

- The source of stimulus supplies energy to the sensor
- The sensor does not need an external excitation
- Output of the sensor is an electrical signal
- Examples: Thermocouple (temperature sensor)
  Piezoelectric pressure sensor

Passive or Parametric Sensor



O = F.I

O α I is preferred by users

- Excitation is usually a constant voltage and sometimes a constant current
- Output of the excited passive sensor is an electrical signal
- Excitation source supplies energy to the sensor
- Examples: Resistance temperature detector/ sensor
  Variable-gap capacitive displacement sensor

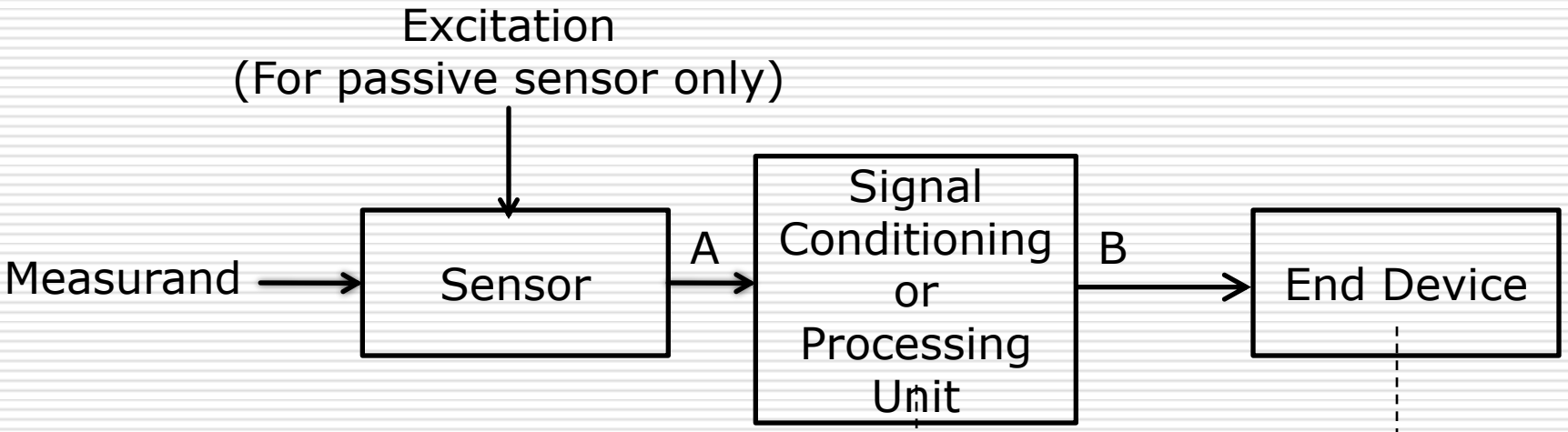
Electrical Excitation Circuits for Passive Sensors

- Voltage applied across sensor
- Current driven through sensor
- Potential divider circuit
- Wheatstone bridge circuit
  - Quarter sensor-bridge
  - Half sensor-bridge
  - Full sensor-bridge

1.2 Signal Conditioning or Processing

- Sensor used in Measurement System
- Signal Conditioning or Processing Circuits
  - Analog electronic circuits
  - Converter circuits
- Sensor used for feedback in Closed-Loop Control System

Sensor used in Measurement System



- Incompatible magnitude and/or form of electrical signal A
- This unit conditions or processes electrical signal A into signal B to make it compatible with the End Device

- Indicating device
- Display device
- Storage device
- Communication device
- Data processor

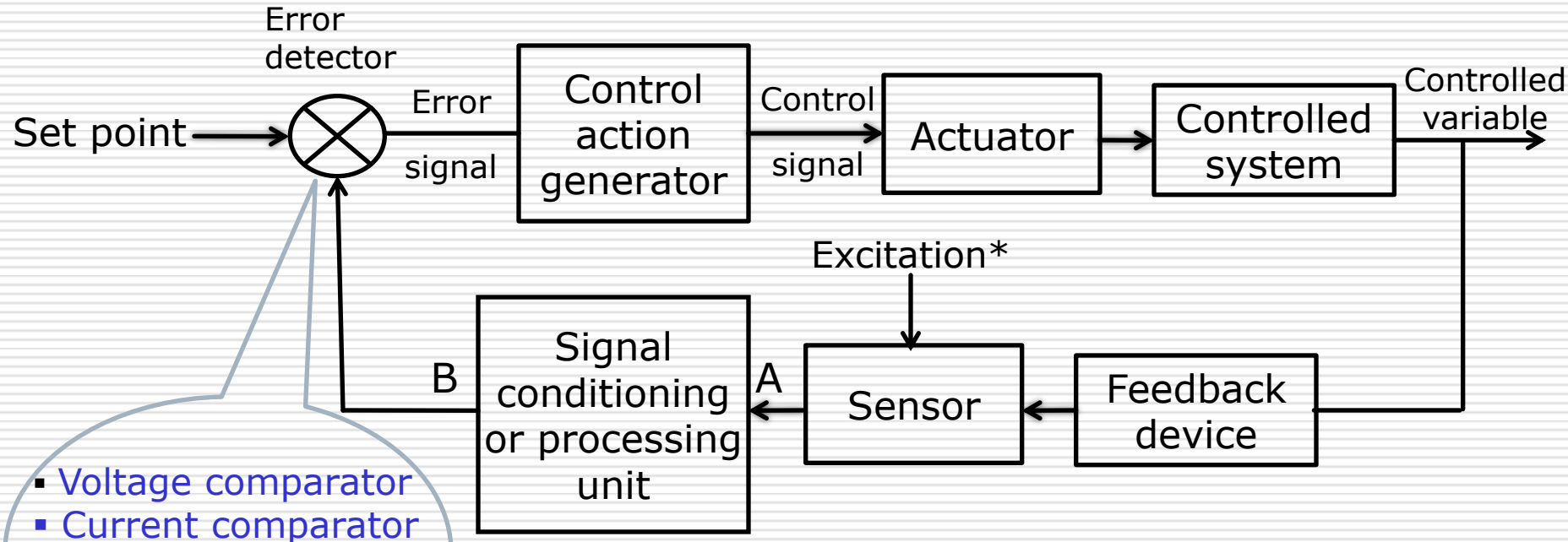
Analog Electronic Circuits used for Signal Conditioning

- Amplifiers
  - D.C. coupled
  - A.C. coupled
  - Differential
  - Instrumentation
- Operational circuits
  - Adder
  - Subtractor
  - Multiplier
  - Divider
  - Integrator
  - Differentiator
- Active filters
  - Low pass
  - High pass
  - Band pass
  - Band reject (notch)
- Modulators/Demodulators
  - Pulse width modulator (PWM)
  - Amplitude detector (demodulator)
  - Phase sensitive amplitude detector

Converter Circuits used for Signal Conditioning

- Analog to Digital Converter (ADC)
  - Integrating ADC (Slow)
  - Instantaneous ADC (Fast)
  - Incremental ADC (Faster)
  - Flash ADC (Fastest)
- Output of ADC
  - Binary-output
  - BCD-output
- Voltage to Frequency Converter (VFC)

Signal Conditioning in Feedback Control System



1.3 Sensor versus Transducer

- Sensor: Senses a physical input quantity and converts into an electrical output signal.
- Transducer: Converts one form of energy into another form of energy for measurement or control.
- Input transducer $\Leftrightarrow$ Sensor
- Output transducer $\Leftrightarrow$ Actuator

1.4 What is a Smart Sensor?

- No standard definition so far.

- Most of the sensors labelled today as Smart Sensors by their manufacturers and recognized as Smart Sensors by the wide spectrum of users would fit into the following definition.

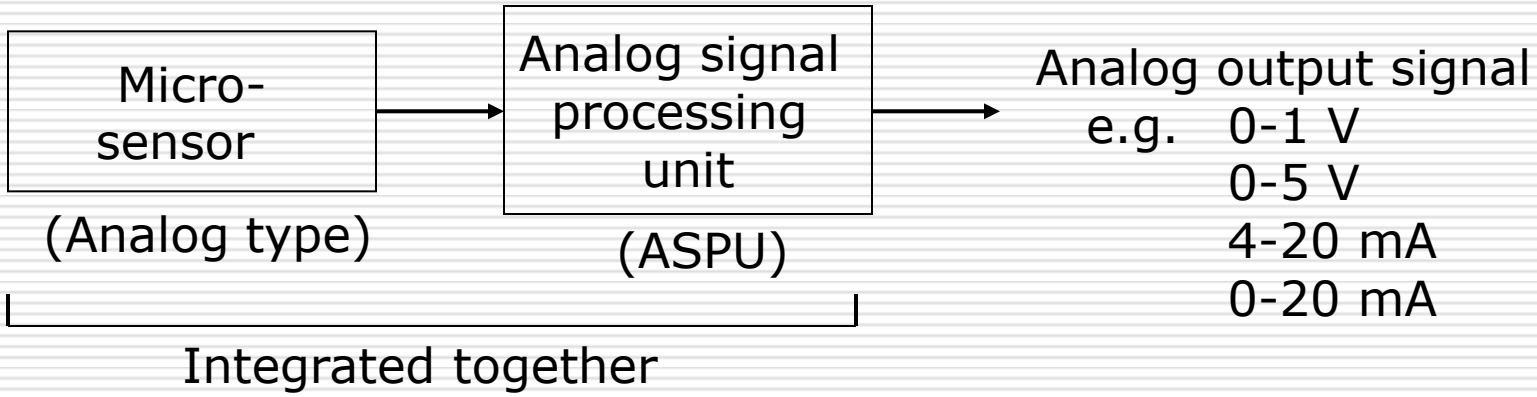
- *"Smart Sensor is a micro-sensor suitably integrated with appropriate micro-electronics (comprising an **essential** analog signal processing unit along with **optional** digital signal processing and other circuits), such that the output is fully or easily compatible with the intended end device or devices".*

1.5

Levels of Integration

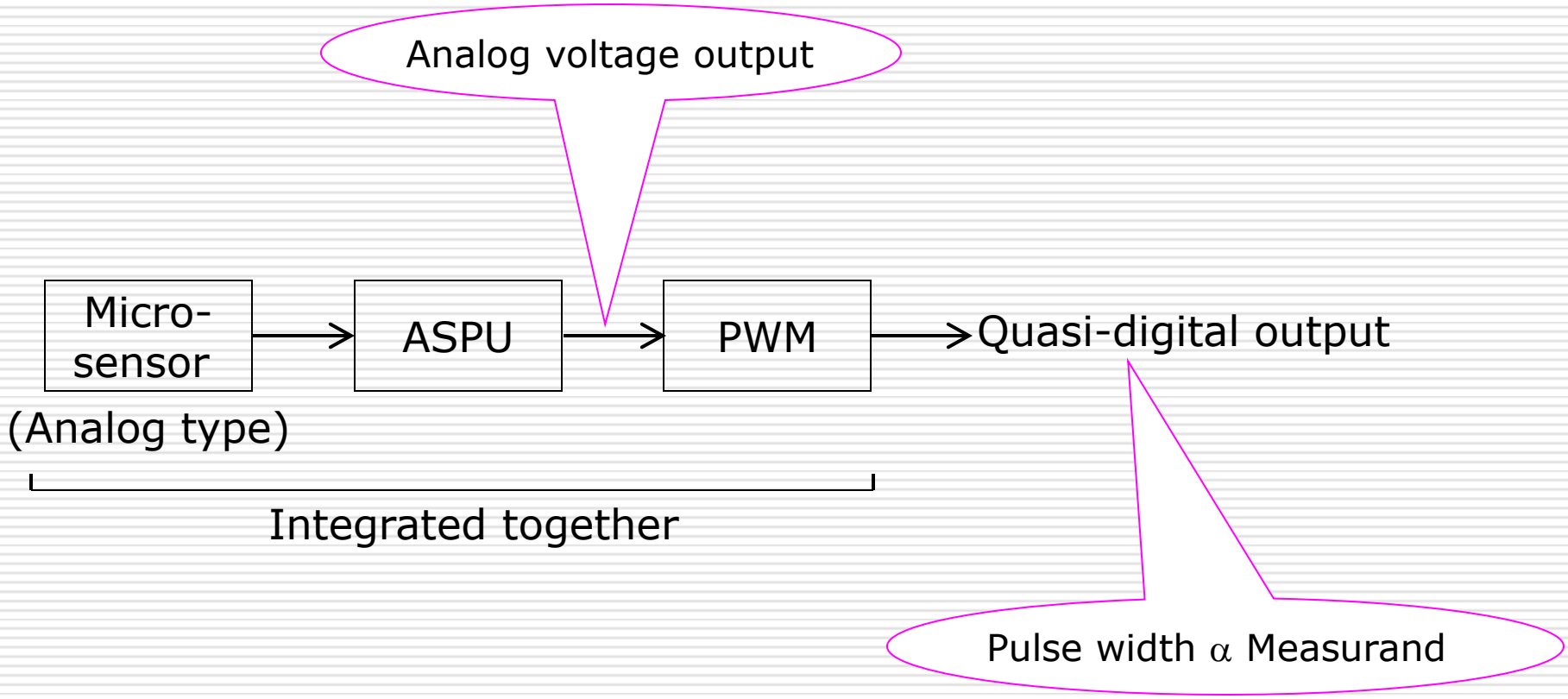
- The electrical signal after signal conditioning (or processing) can have one of the following forms:
  - Digital
  - Analog
  - Quasi-digital (pulse width or pulse frequency)
- The extent or level of integration of electronics with the micro-sensor can vary very widely as under:
  - Lowest Level: Smart sensor with analog output
  - Low Level: Smart sensor with quasi-digital output
    - Smart sensor with PWM output
    - Smart sensor with pulse-frequency 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 Sensor with Analog Output

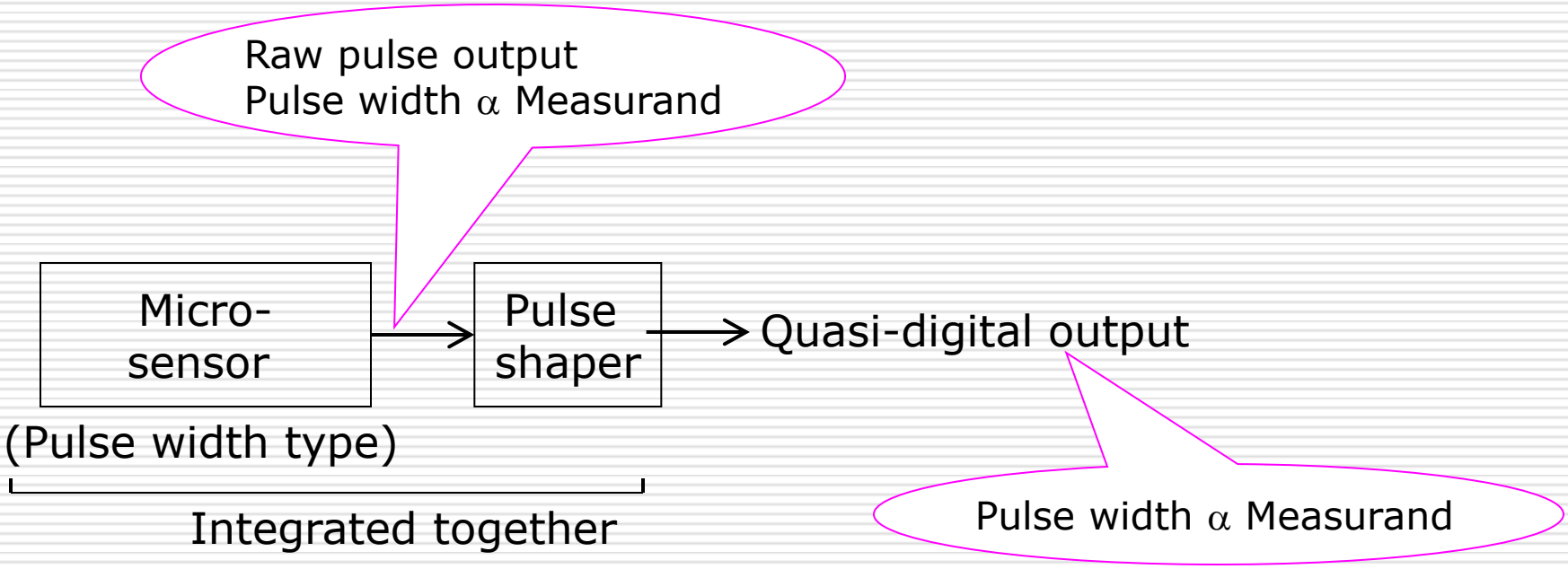


(a) Passive micro-sensor: External excitation essential
(b) Active micro-sensor: External excitation not required

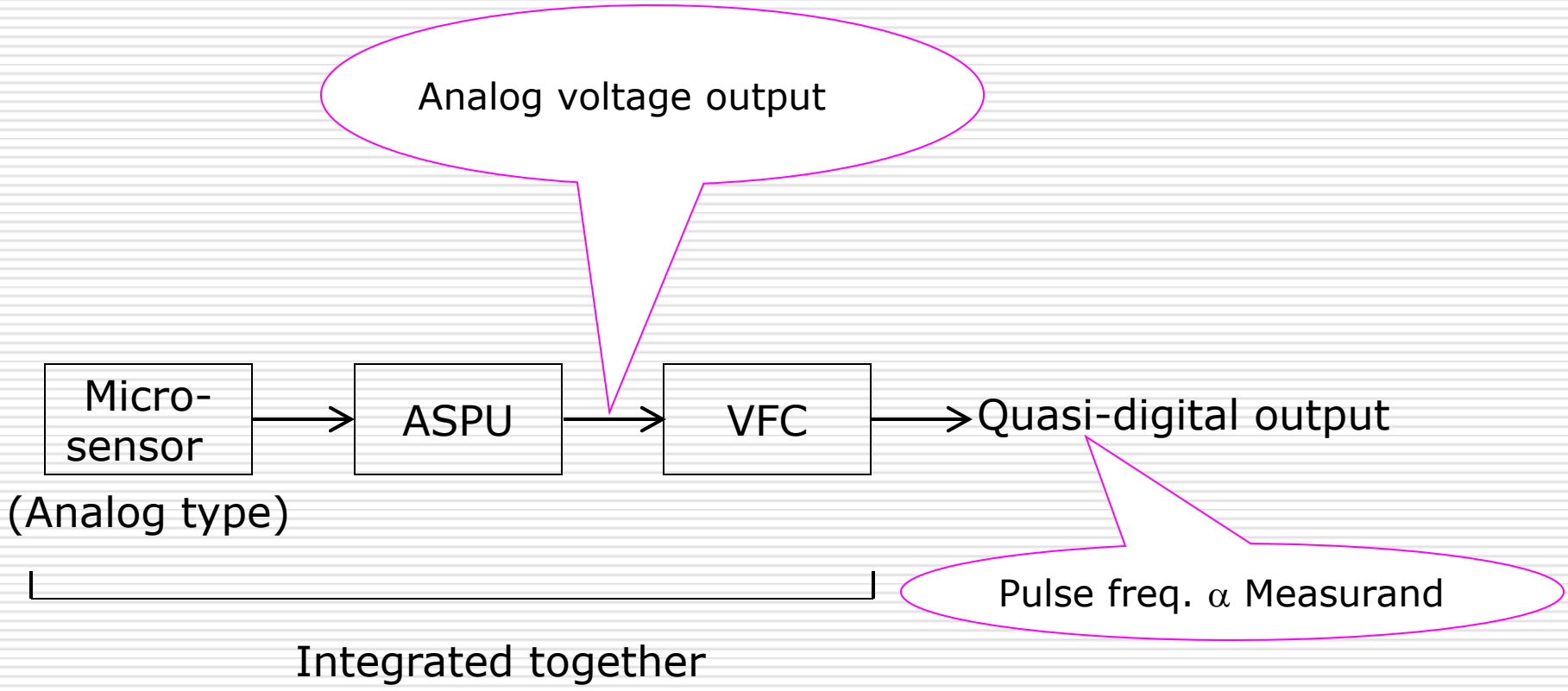
Smart Sensor with PWM Output
Common Approach



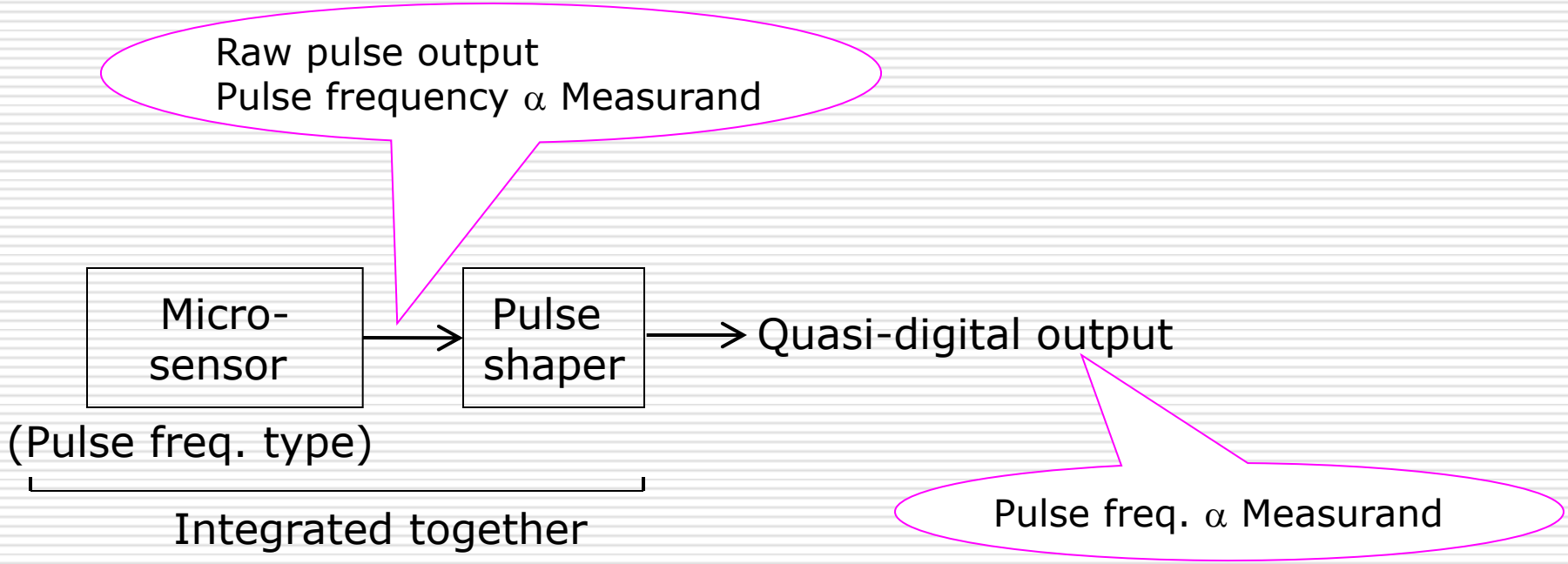
Smart Sensor with PWM Output
Alternative Approach



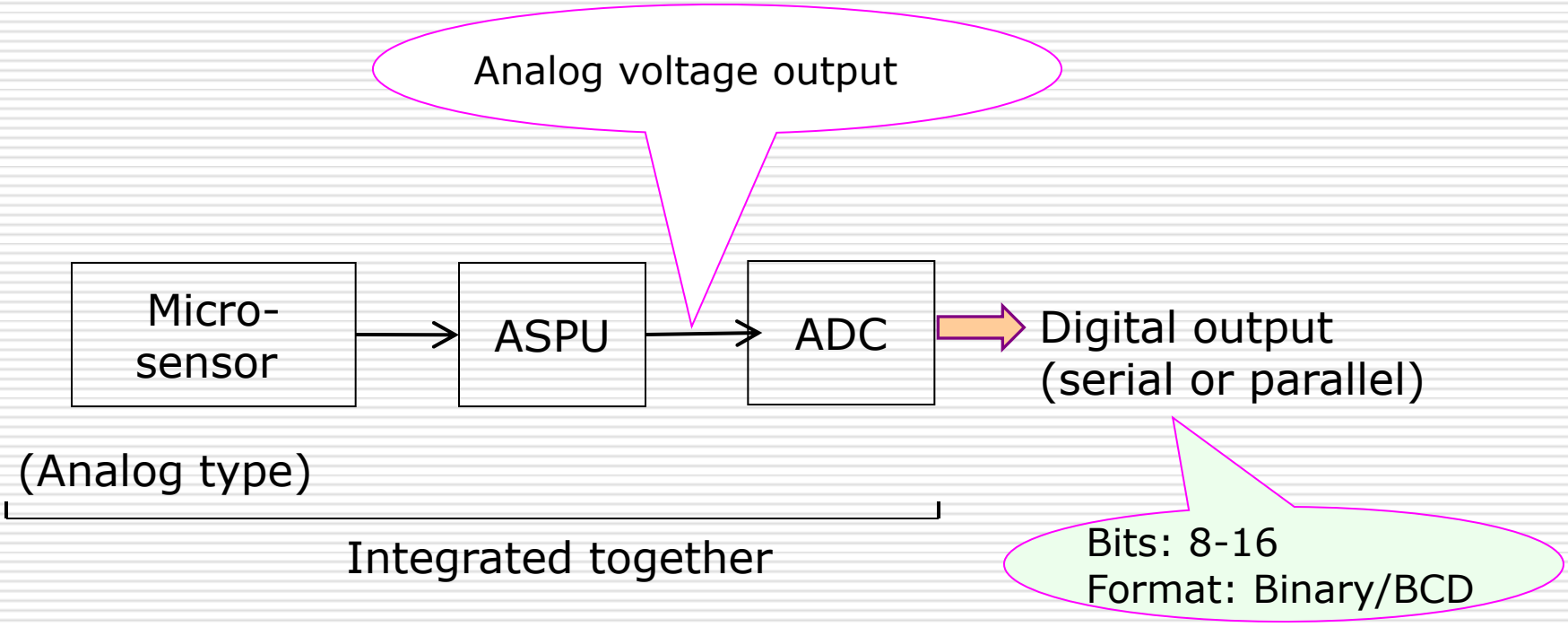
Smart Sensor with Pulse-Frequency Output
Common Approach



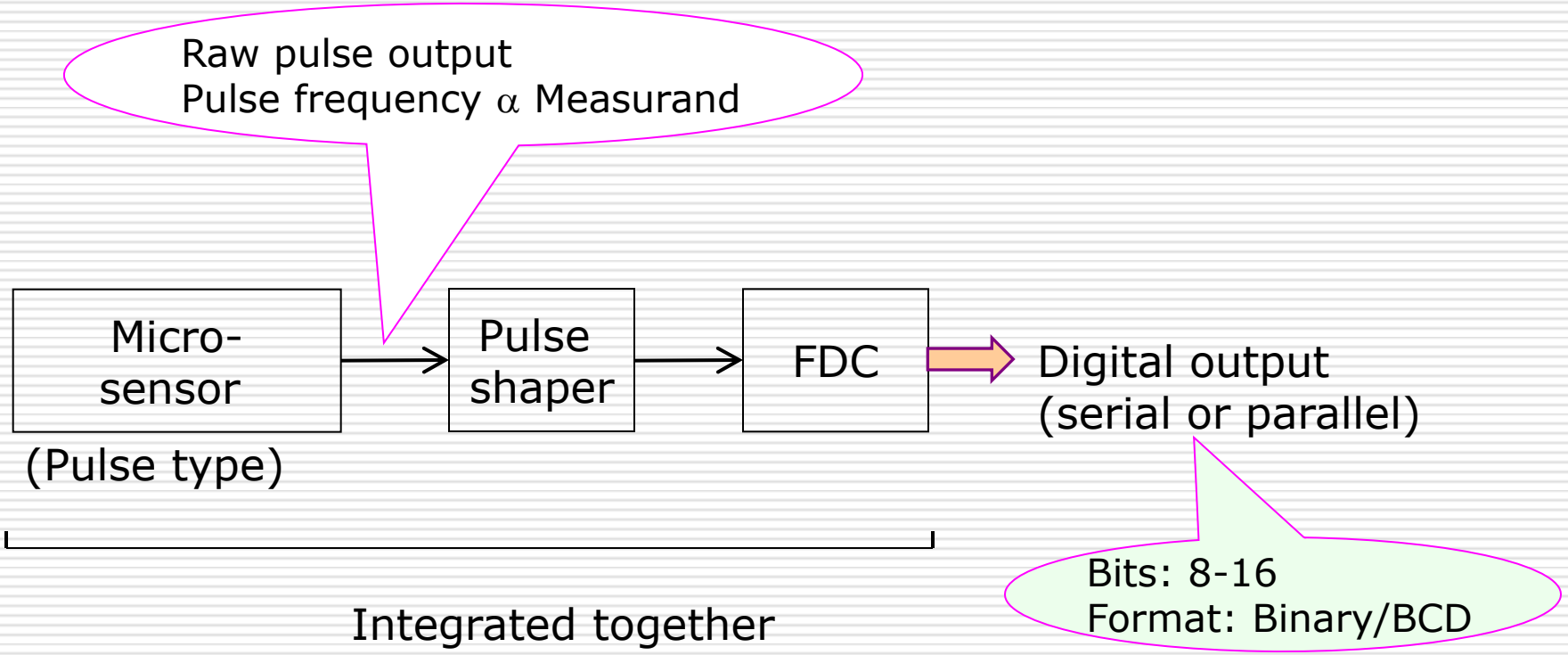
Smart Sensor with Pulse-Frequency Output
Alternative Approach



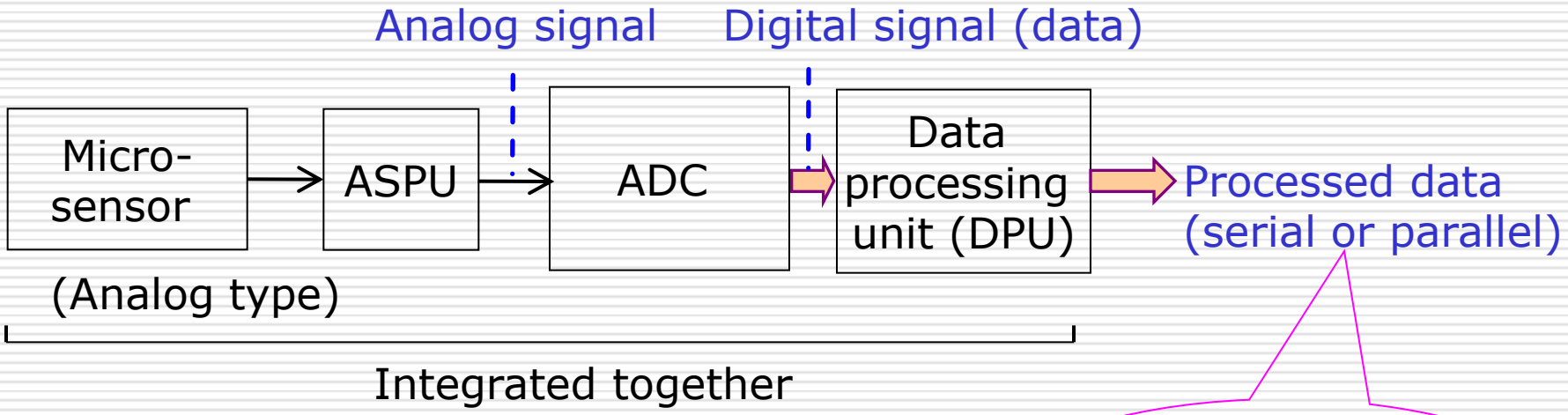
Smart Sensor with Digital Output
Common Approach



Smart Sensor with Digital Output
Alternative Approach



Intelligent Sensor



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

DPU = Microcontroller

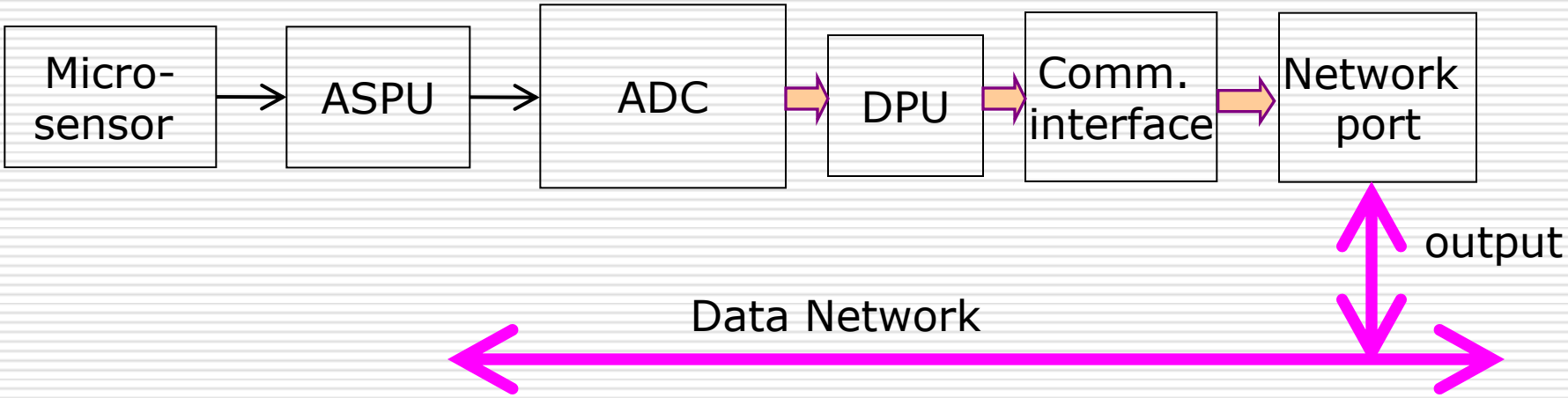
OR

μP + memory + I/O interface

OR

DSP +memory + I/O interface

Network Sensor



Output of a network sensor is the processed data available on an integrated network port, which allows networking of such smart sensors without requiring any further interface circuitry or data manipulation.

1.6 Advantages of Smart Sensors

I Advantages of integrating the ASPU with micro-sensor

II Additional advantages of integrating the ADC

III Additional advantages of integrating the DPU

IV Additional advantages of integrating the Network Port

Advantages of Integrating ASPU

1. User's Convenience because of:
   - No wiring
   - Compact size
   - No headache of selecting SC
   - No headache of designing SC
2. Superior Performance because:
   - Externally-induced noise is absent, resulting in high SNR
   - Built-in sensor-specific SC circuits perform better
   - Built-in negative feedback reduces nonlinearity
   - Built-in compensating circuits reduce sensitivity to temperature/ excitation changes
3. High Reliability because of:
   - Reduced component count
   - Reduced wiring
4. Cost Reduction because of:
   - Concurrent production of electronics and sensor
   - Mass production

Additional Advantages of Integrating ADC

- Ready compatibility with digital systems because of:
  - Digital output
- Cost Reduction because:
  - On-chip ADC is cheaper than external ADC

Additional Advantages of Integrating DPU

- Performance Improvement because of:
  - Linearization of response using software
  - Reduction of cross-sensitivity using software
  - Automatic self calibration
  - Self diagnostics
- Simpler Interfacing because:
  - Data formatting can be done conveniently as per need
  - DPU can talk easily with external computer
- Internal Data Logging
  - On-chip EEPROM or flash-RAM
  - Storage of field-measurement data
- Reduced external data processing
- Higher flexibility (as more functions are performed in software)

Additional Advantages of Integrating Network Port

- Ease of networking
- Reduced cost of networking
- Reduced time for setting-up a sensor network