A Multi-Element Smart Gas Sensor
with IEEE 1451 Protocol

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Presentation Topics

- Goals and Applications
- Review of gas sensor technologies
- Analog signal conditioners – various technologies
- Smart (digital) sensor configurations
- IEEE 1451 protocol
- Multi-element gas sensor module design
- Networking considerations
- Test data

Goals and Applications

- Measurement of gases for environmental monitoring, industrial safety and homeland security
- Design a sensor pad which allows interchange of sensors for various gases
- Convert gas sensor data to digital form (smart sensor)
- Interface to various networks
- Configure automatically (plug and play)
- Use commercial, off-the-shelf sensor elements

Gas Sensor Technologies

- Semiconductor – resistive*
- Semiconductor – voltage*
- Amperometric*
- Catalytic*
- Infrared
- Photo-ionization
- Fluorescent
- Surface acoustic wave (SAW) & vibrating beam
- Capacitive* and other

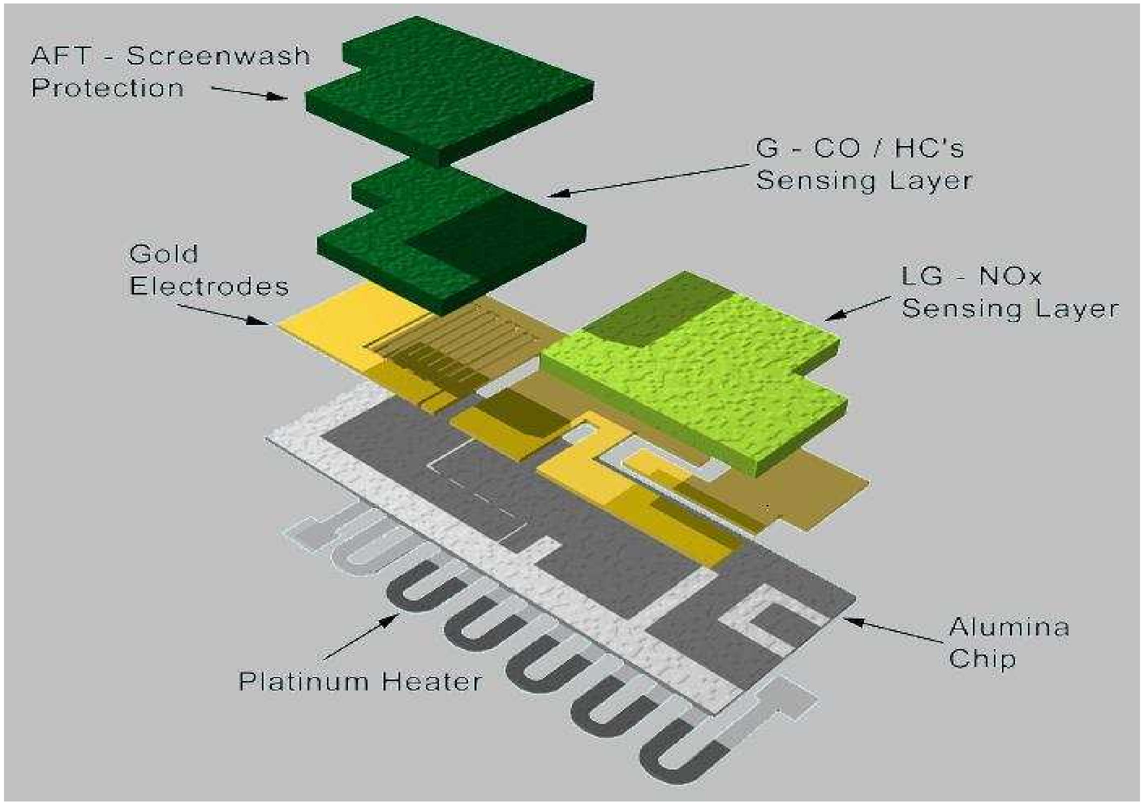
* Used in this multi-sensor

Solid State (Semiconductor, Resistive) Characteristics

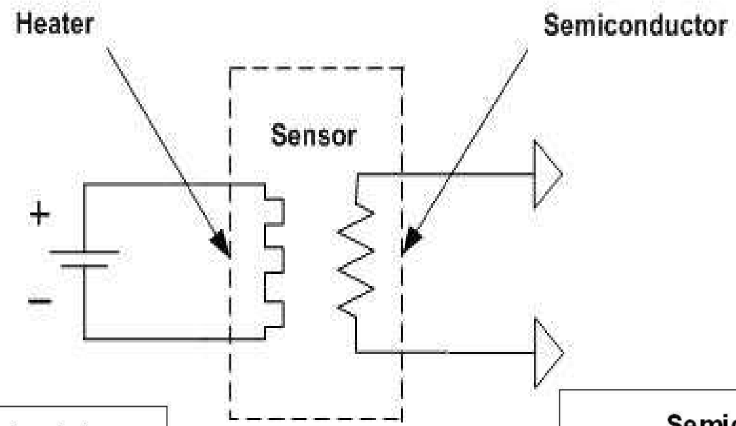
- Based on Tin Oxide (SnO_2) or similar metal oxide semiconductors
- Surface reaction with ambient gases when hot (350-500 ^{o}C)
- Heater (e.g. 4 v @ 100 mA) heats substrate
- Adsorbed gas reduces grain-boundary potential barrier and thus increases conductivity (decreases resistance)
- Delta-R is a function (approx. log or square root) of gas concentration (ppm)
- Resistance also decreases with temperature so temperature control needed for zero stability

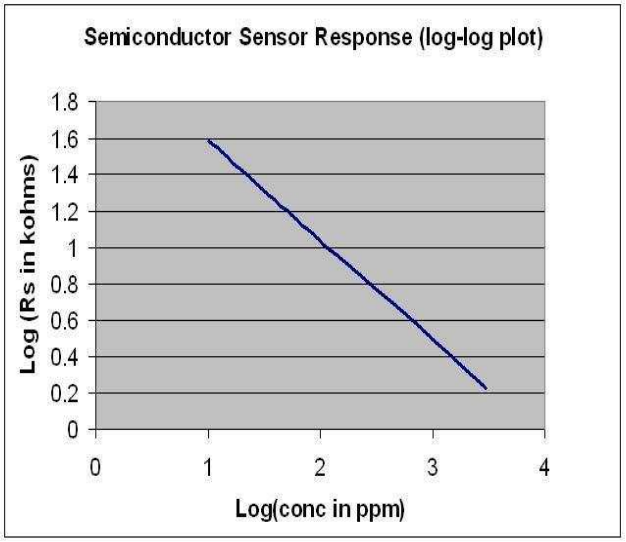
Solid state sensor construction

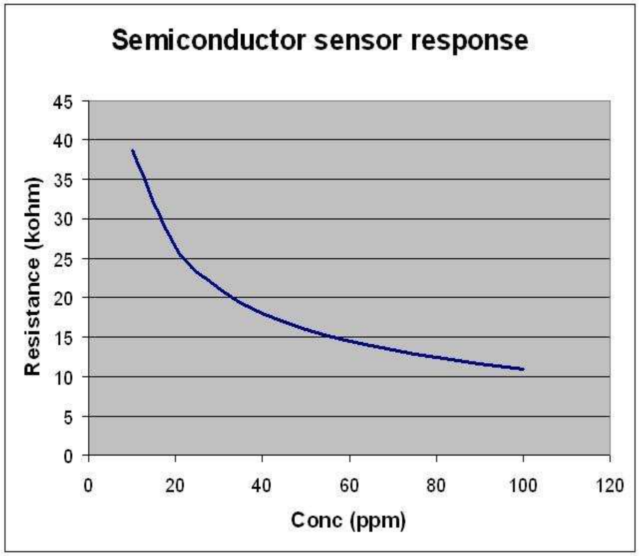
CityTech Ltd – Semiconductor Sensor



Solid State – Resistive Responses

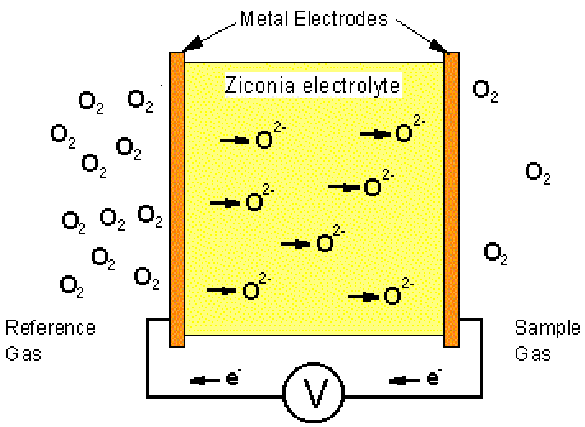






Solid Electrolyte Gas Sensor

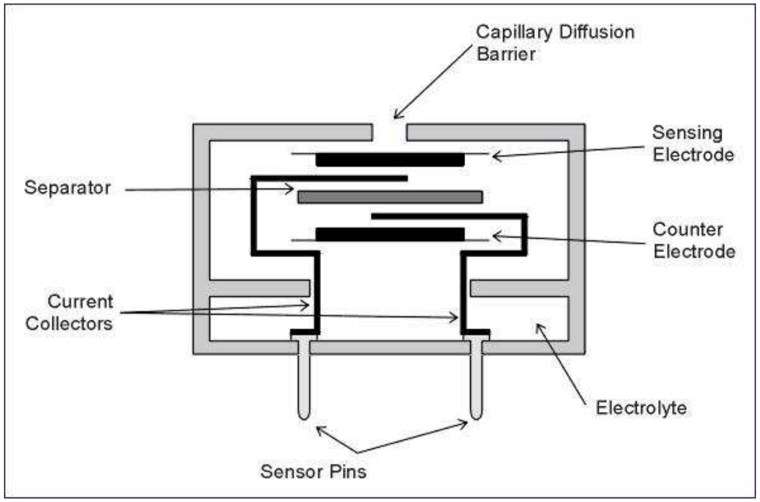
- Similar to semiconductor gas sensor but has voltage output
- Heater (5v @ 11.5 ohms)
- Has thermistor for temperature control
- Vsen increases 50 mv per factor of 10 change in gas conc
  (220 to 490 mv at 350 ppm)
- Requires hi-Z amplifier
- Examples: Figaro TGS4160 (CO_2)
  or Oxygen (zerconia)
- Periodic re-zeroing desirable



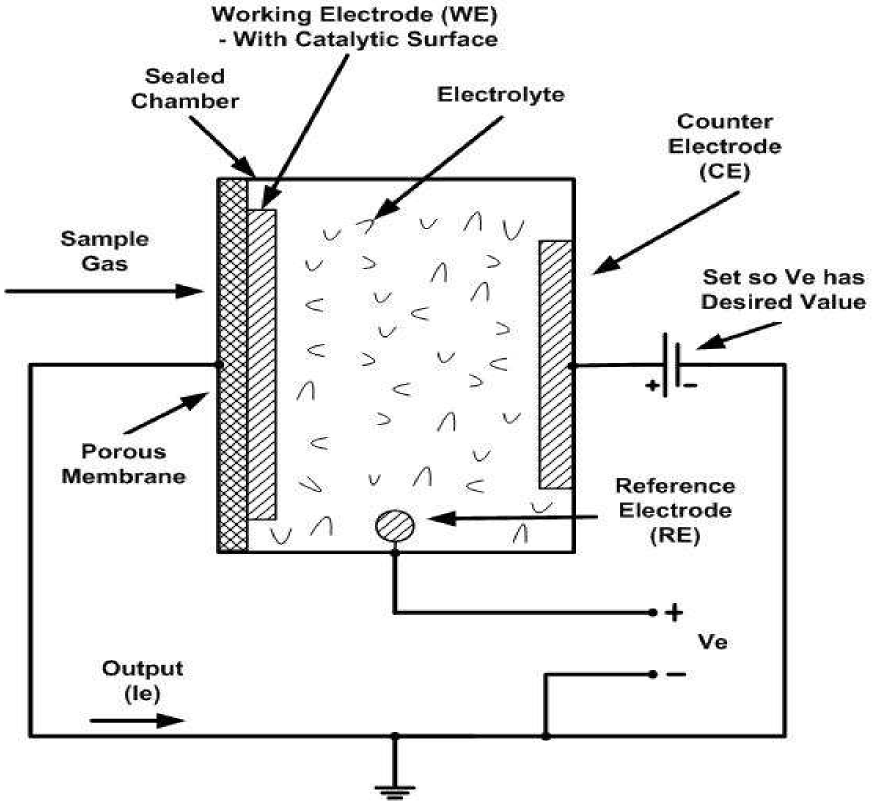
Amperometric Characteristics

- Chemical reaction involving gas releases electrons at electrode (electrolysis reaction)
- Example: $\frac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2 OH^-$
- Gas is dissolved in electrolyte (e.g. H_2O)
- Reaction is reversible so number of electrons released is proportional to gas concentration (gas conc in electrolyte is proportional to partial pressure of gas in air)
- Reaction occurs at specific applied voltage (e.g. 0.55 volts)
- Sensor current output is proportional to gas conc (ppm)

Amperometric Construction



City Tech Ltd – Toxic Gas Sensors

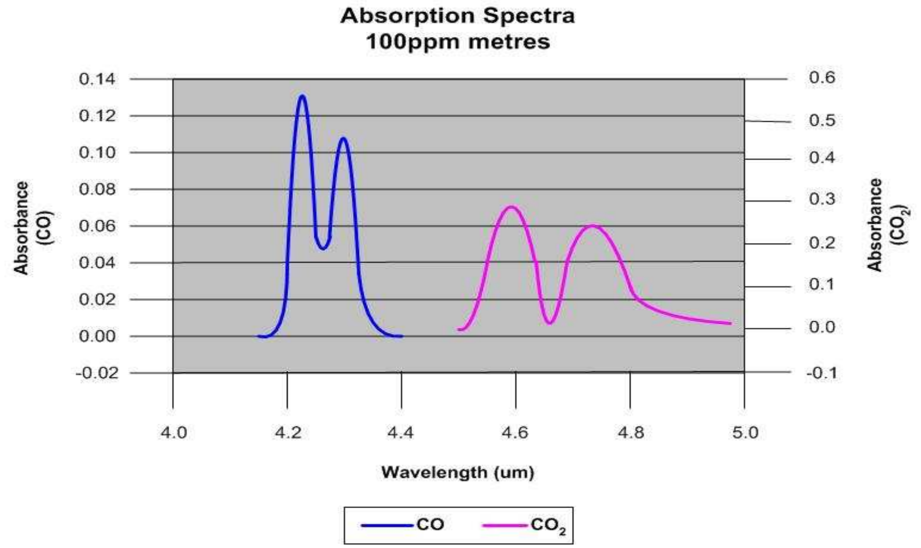


Infra-red Principle

- Some gases absorb light at particular IR wavelengths
- $I/Io = e^{-Ax}$

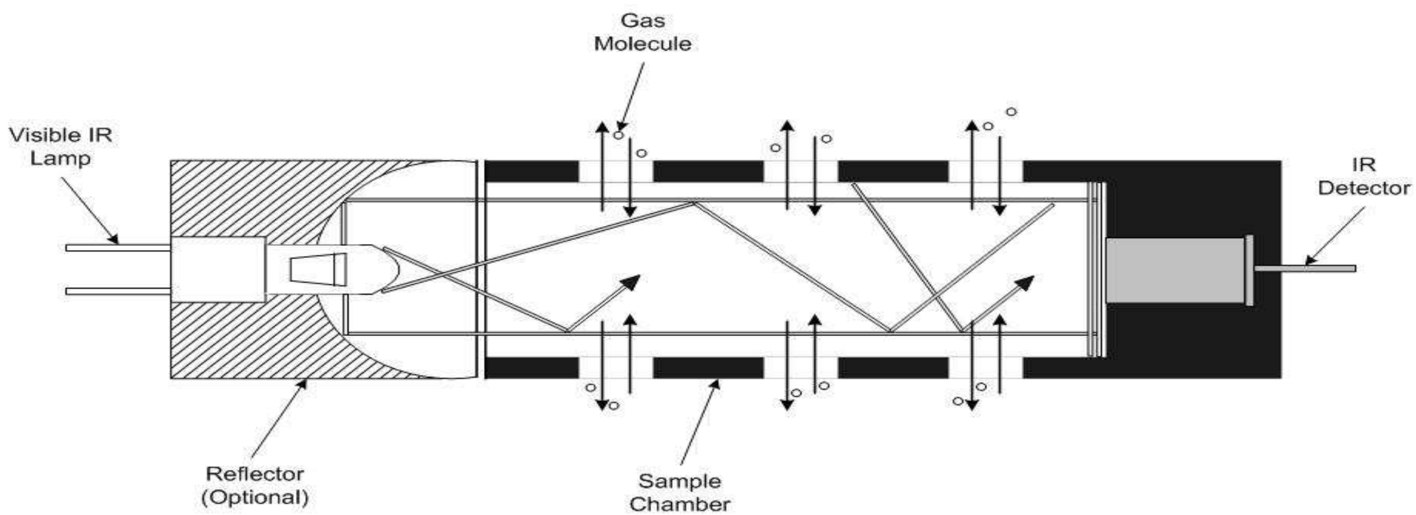
  where I/Io is light absorbed during transmission,

  x is path length and A is absorption coef. at specific wavelength
- Transmission filters select specific wavelength bands
- A is proportional to gas concentration
- IR sensors reproducible but not sensitive (need high conc or long paths)



Infra-red Construction

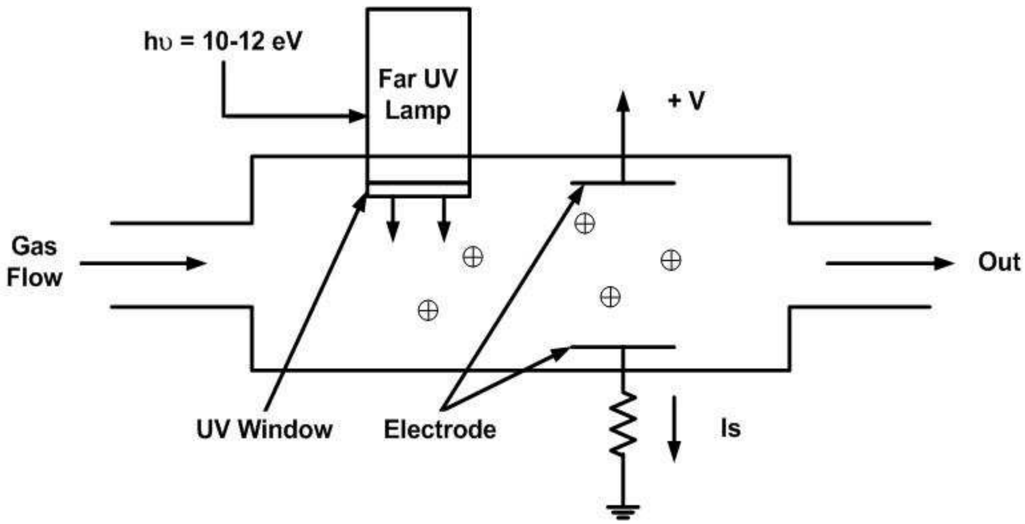
Gilway Visible/IR Lamps for NDIR Gas Sensors



Acoustical detection an attractive option

Photo-ionization

- High energy UV photons (> 3ev or <300 um) will ionize some gases (e. g. toluene, trichloroethyene) but not others (e.g. air, methane)
- Ions collected by e-field produce a current proportional to gas conc
- Sensitive (< 1 ppm) but not selective
- Special UV lamps costly and have limited life (also high power)

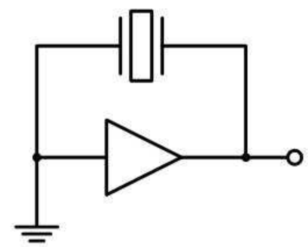


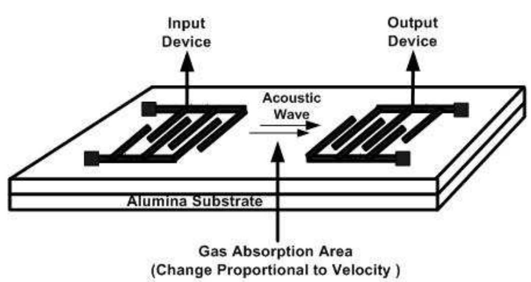
Fluorescent

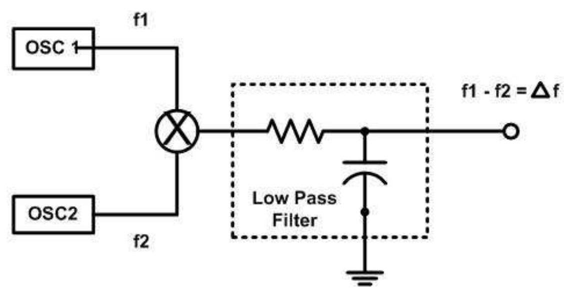
- UV light impinges on some organics produces a fluorescent light proportional to ambient gas concentration (e.g. oxygen)
- High sensitivity (because photo-detectors are sensitive)
- Applicable only to a few gases (but used with many biological materials where it can be sensitive and selective)
- Few commercial sensors using this technology are available.

SAW and vibrating beam

- Surface acoustic wave (SAW) travel from transmitter to to receiver on substrate surface
- Velocity depends on surface mass which is effected by adsorbed gases
- Positive feedback produces oscillation at frequency which depends on sound velocity and thus gas concentration

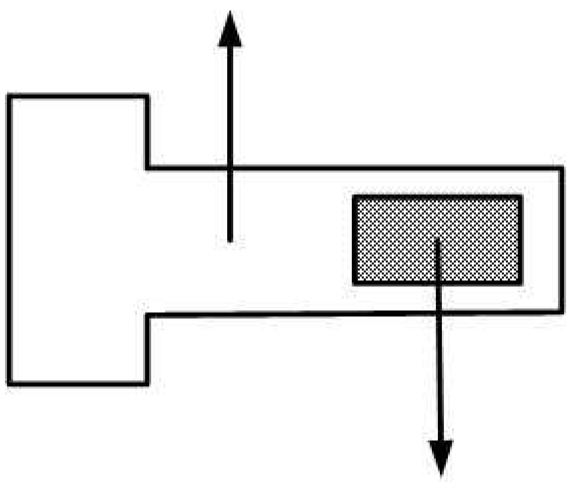






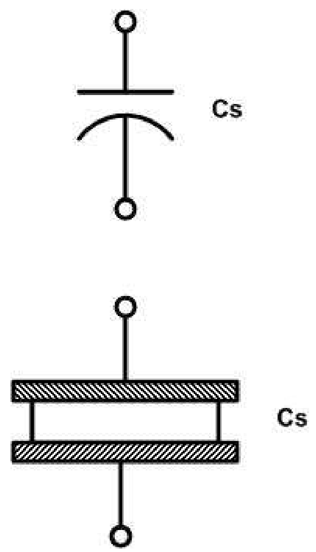
SAW and vibrating beam continued

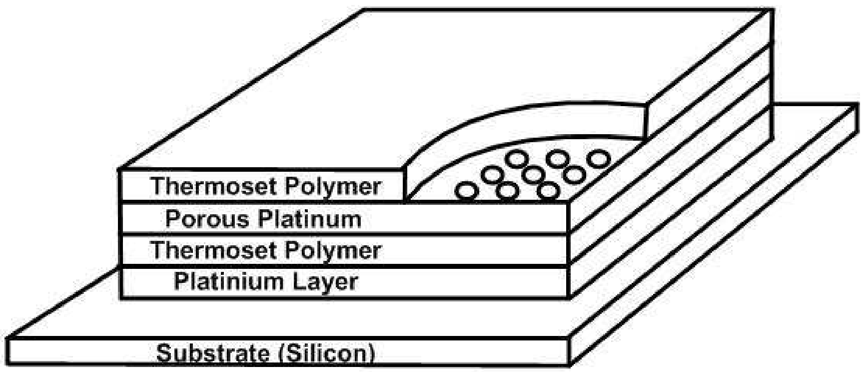
- Usually used in pairs (one not exposed to gas) and difference (beat frequency) measured
- Moderate sensitivity and selectivity
- Vibrating beam type (usually quartz) resonance frequency varies with mass loading and thus gas concentration.
- Can be small and low cost
- Few commercial products available.



Capacitive

- Dielectric constant of polymer increase with absorbed gas such as water vapor (K is 80 for water, 2-3 for polymer)
- Typically C increase by 10-30% as relative humidity (RH) varies from 0 to 100%.





Other Gas Sensor Technologies

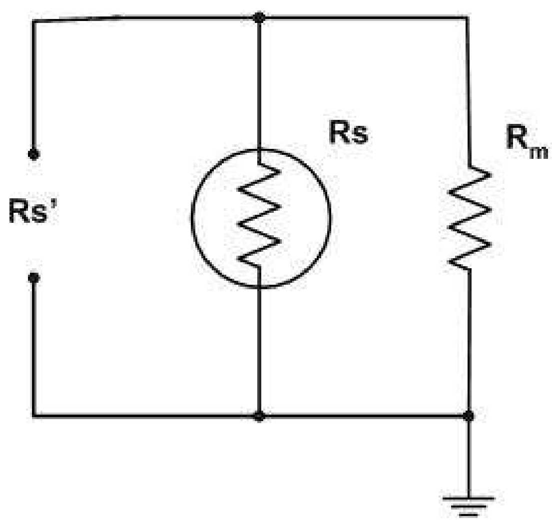
These techniques have few commercial product available

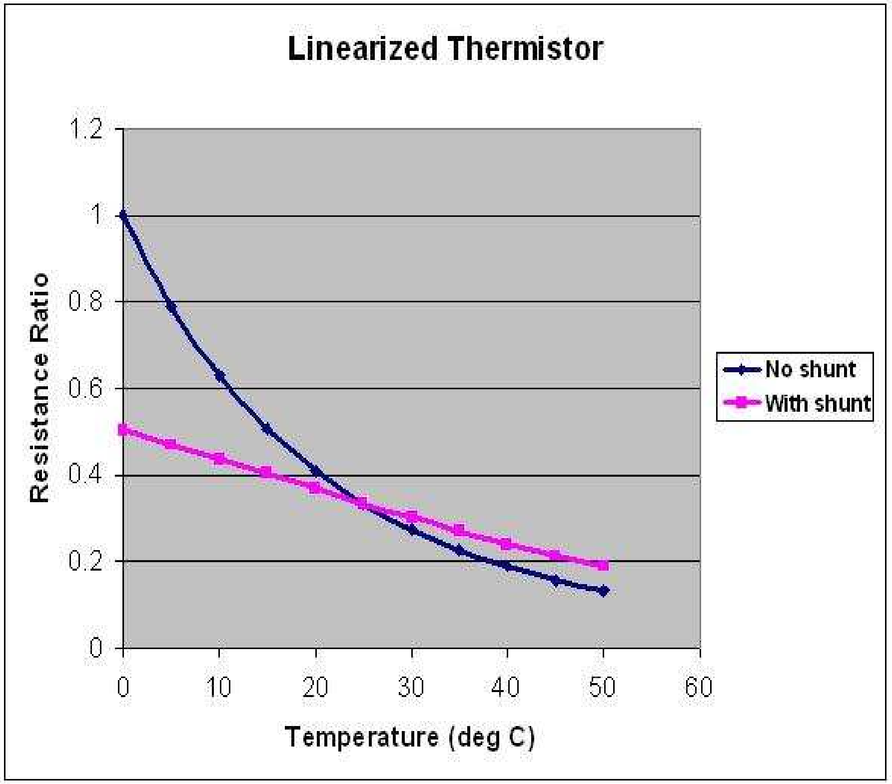
- Polymer resistance
- Fiber optic
- ChemFET
- Miniaturized versions of mass spectrometers

MEMS Sensors

- Micro Electronic Mechanical Systems (MEMS) type sensors are miniaturized versions of types already described
- Promise much smaller size, lower power and lower cost than conventional gas sensors
- Many under development but few commercially available.

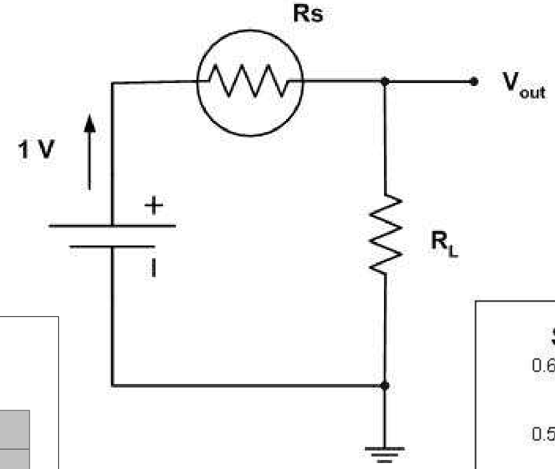
Linearization by shunt resistors

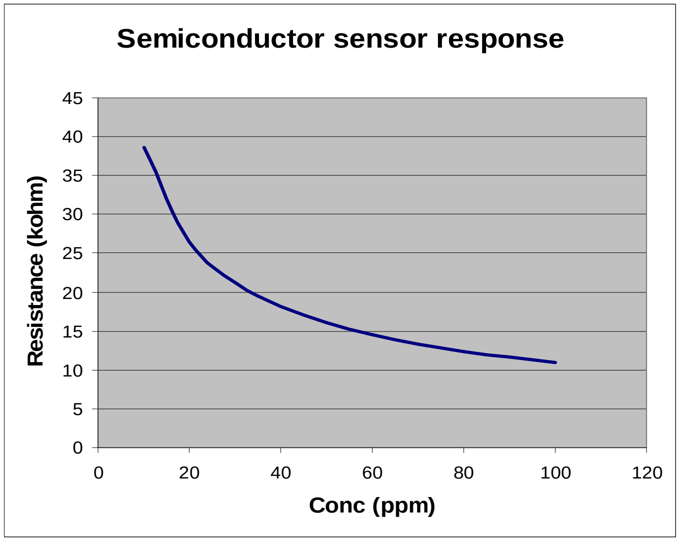


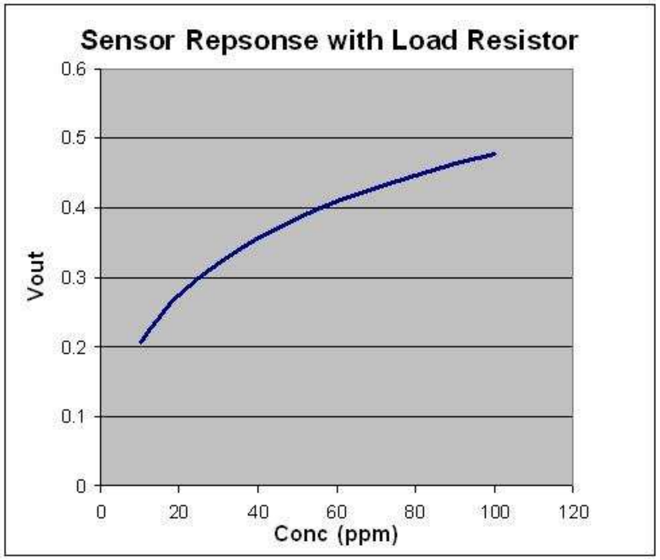


Rs has log response vs T (thermistor)

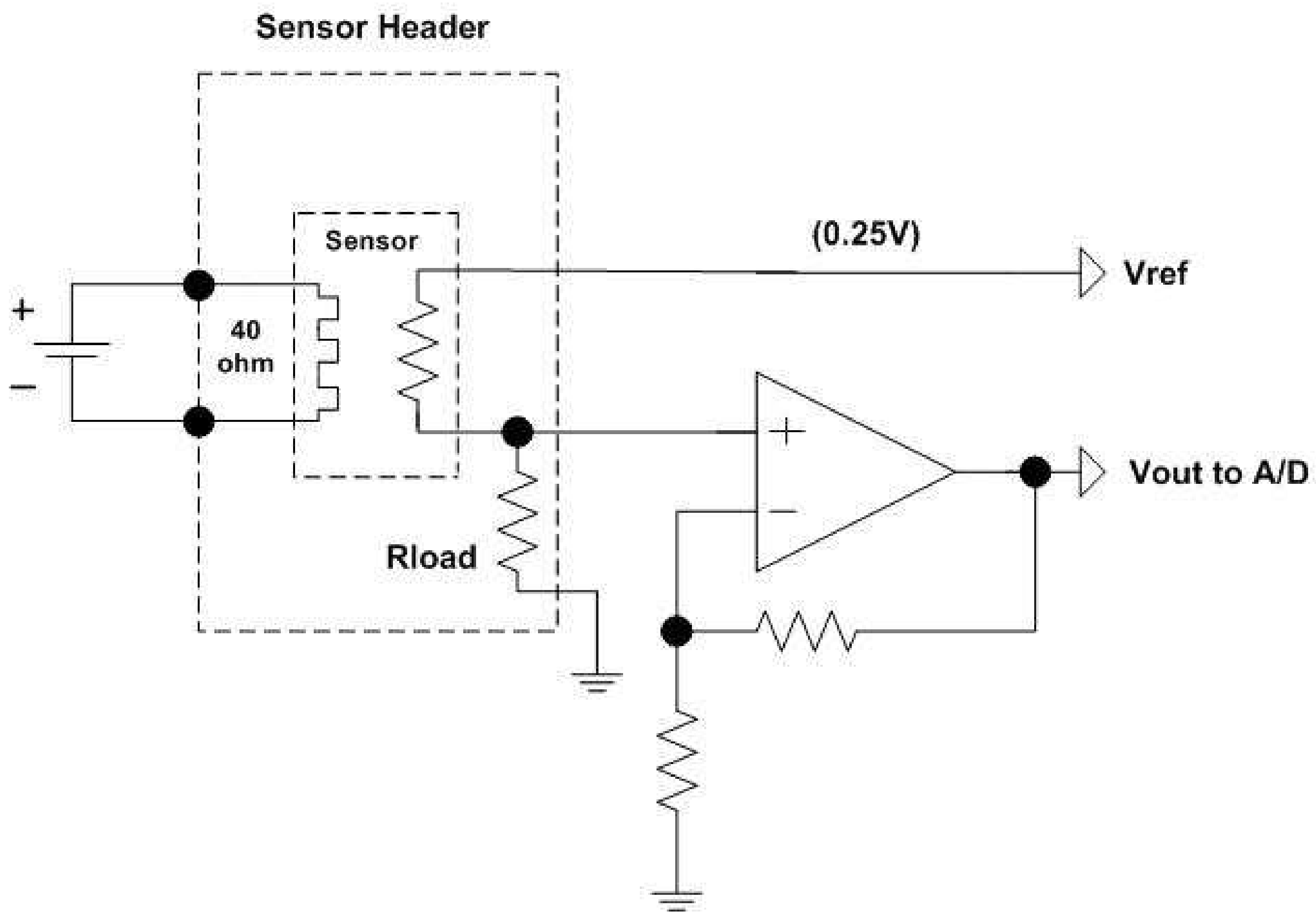
Linearization by load resistors



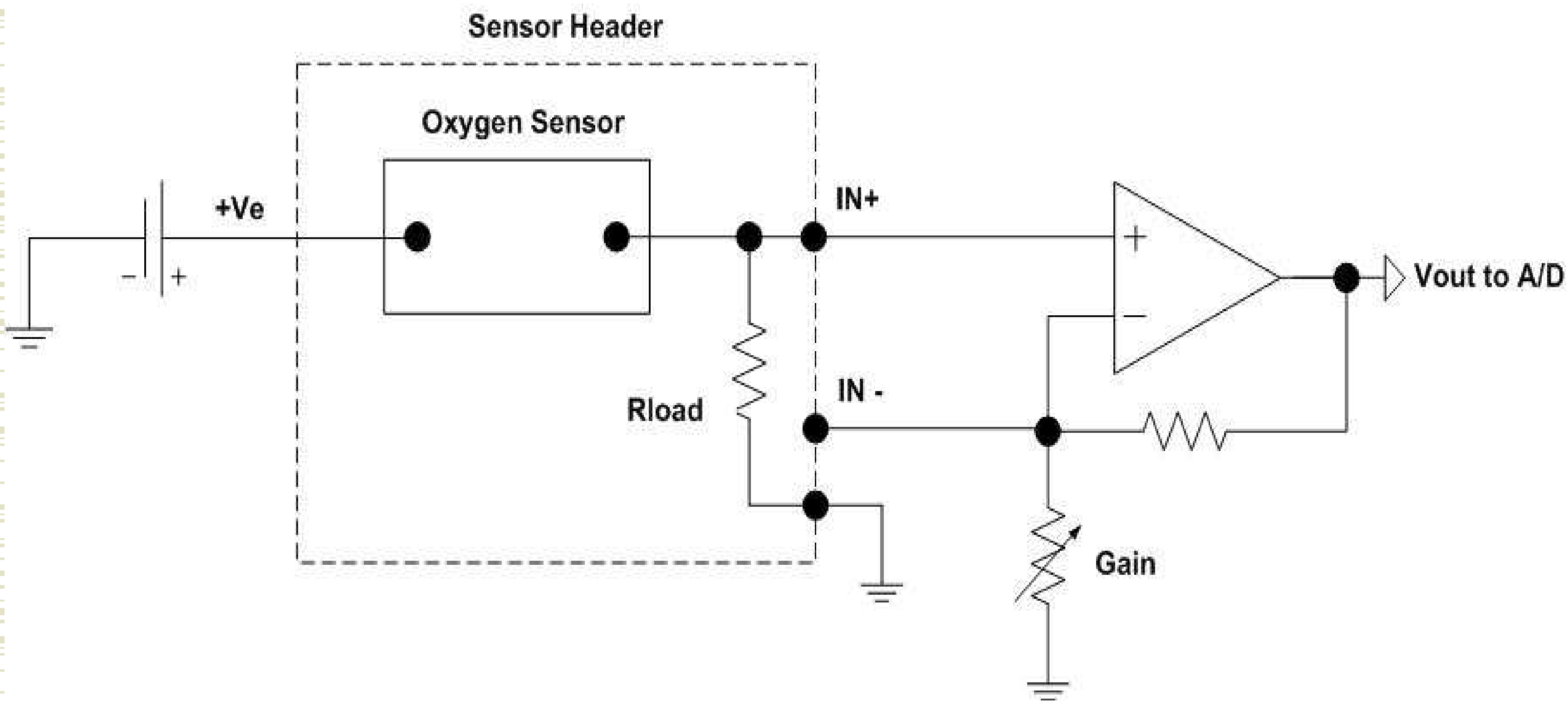




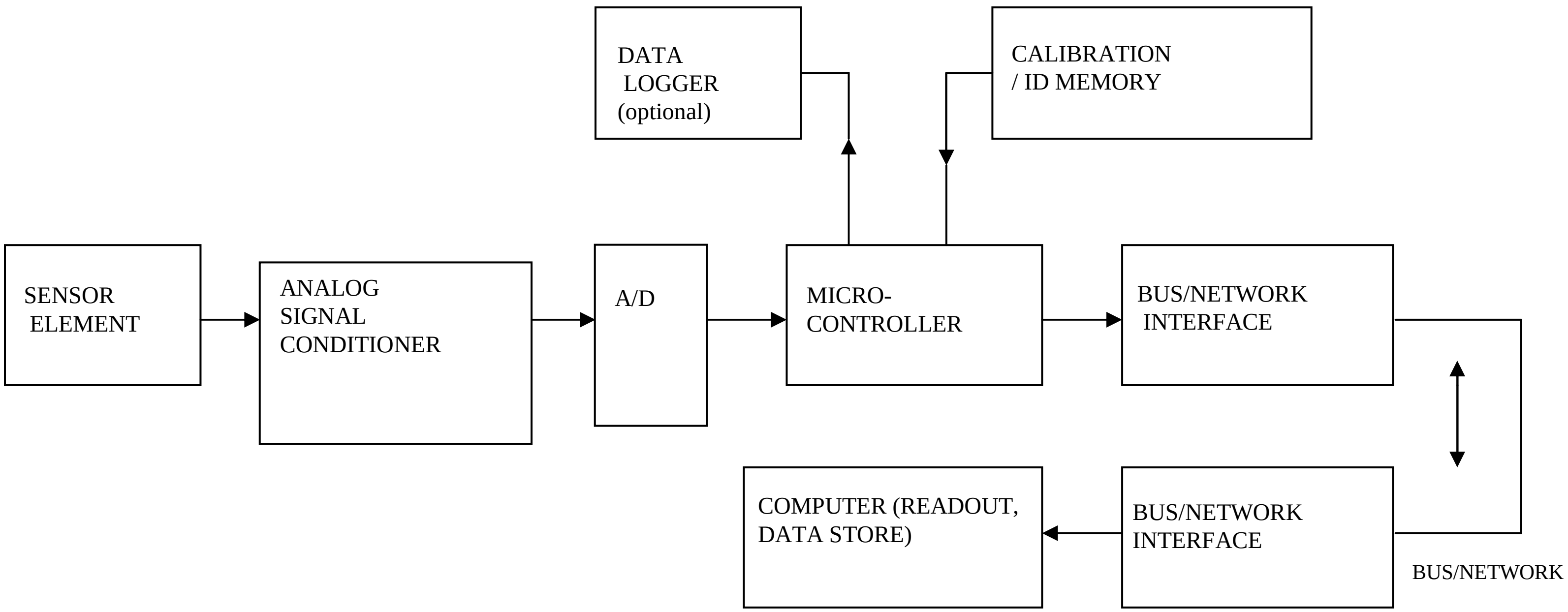
Signal Conditioner for Voltage Type Sensors



Signal Conditioner for Amperometric Type Sensors



Generic Smart Sensor Block Diagram



Need for Network Standards

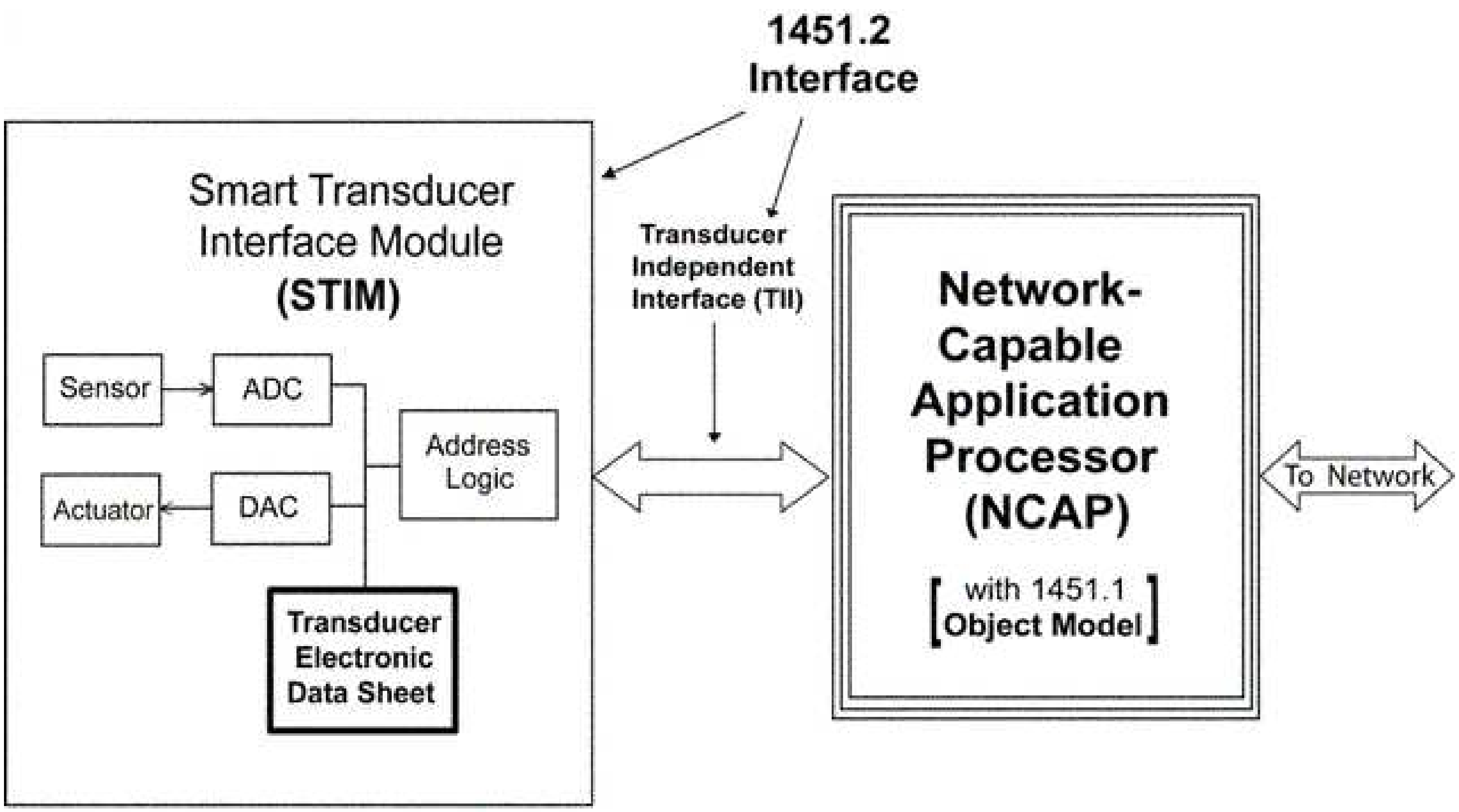
- Smart sensors require a digital network
- Over 50 sensor networks and busses in common use
- Users and manufactures would like one standard to reduce manufacturing/installation costs and for plug&play capability
- No single local network is likely to dominate in near future due to divergent needs
- The Internet via Ethernet will likely be one of the dominate networks (but cost and complexity are problems)
- The IEEE 1451 standard for sensor interfacing overcomes many of the complications of multiple networks

IEEE 1451 Parts

- IEEE 1451.0 Protocols/formats (approval process underway)
- IEEE 1451.1 Object model (approved 1999)
- IEEE 1451.2 Interface (approved 1997)*
- IEEE 1451.3 Local network (approved 2003)
- IEEE 1451.4 Analog & TEDS (just approved)
- IEEE 1451.5 Wireless (early approval process)
- IEEE 1451.6 Canbus (just started)

* Enhancement /revision working group in process

Present (1997) IEEE 1451.2 System Block Diagram



Dot2

IEEE p1451.2 TEDS Blocks
--Transducer Electronic Data Sheet --

Machine Readable

- Meta-TEDS (mandatory)
- Channel TEDS (mandatory)
- Calibration
- Physical Layer Meta (proposed)
- Physical Layer Channel (proposed)

Note: One TEDS per channel for Channel and Calibration

Human Readable

- Meta-ID TEDS
- Channel-ID TEDS
- Calibration-ID TEDS

- Application Specific

  End Users' Application-Specific TEDS
- Future Extensions

  Industry Extension TEDS

New Tuples format TEDS approved by Dot 2 working group

Dot2

Advantages of the IEEE 1451 Standard

- Continuing network interface and microcontroller cost reductions have made interface more attractive.
- The sensor industry is closer to recognizing the necessity for a sensor network standard.
- The general concept of the IEEE 1451 approach, especially TEDS, is supported by many.
- Working groups are addressing the dot2 problems and expanding the standard via dot3, dot4, and dot5.

TEDS Memory Types

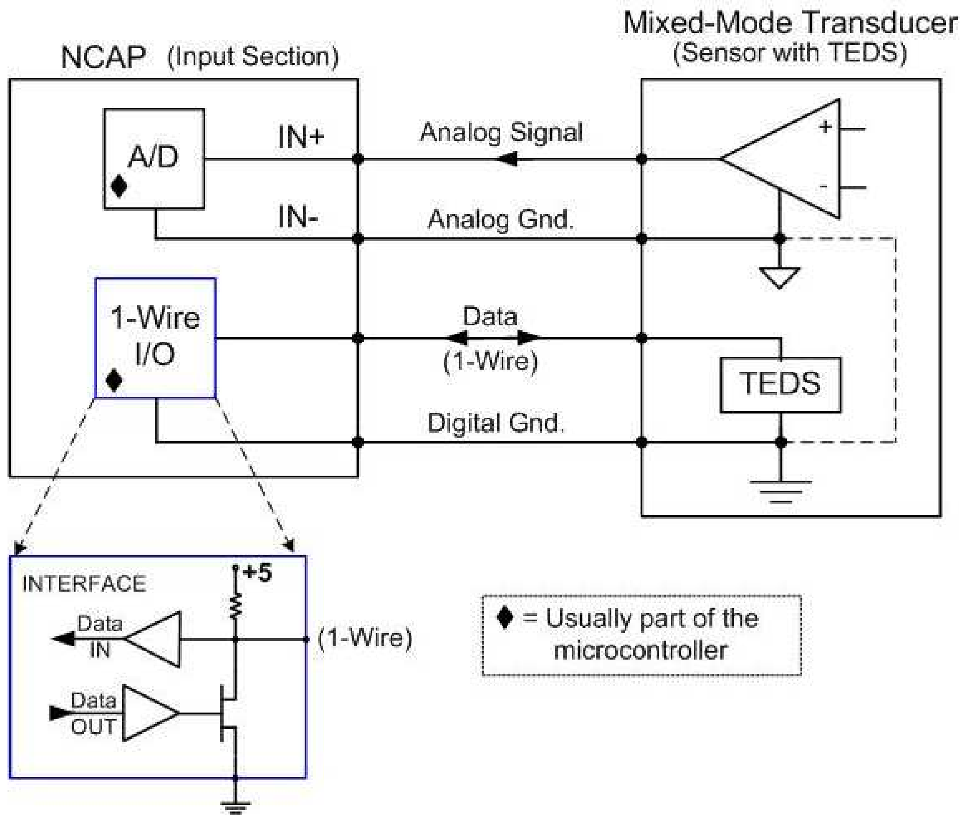
- Option #1 – Standard dot2 TEDS
  - * Meta-TEDS (binary/machine readable)
    - [Meta is all channel]
  - * Meta-ID-TEDS (ASCII)
  - * Channel-TEDS (binary)

Option #2 – Modified dot4

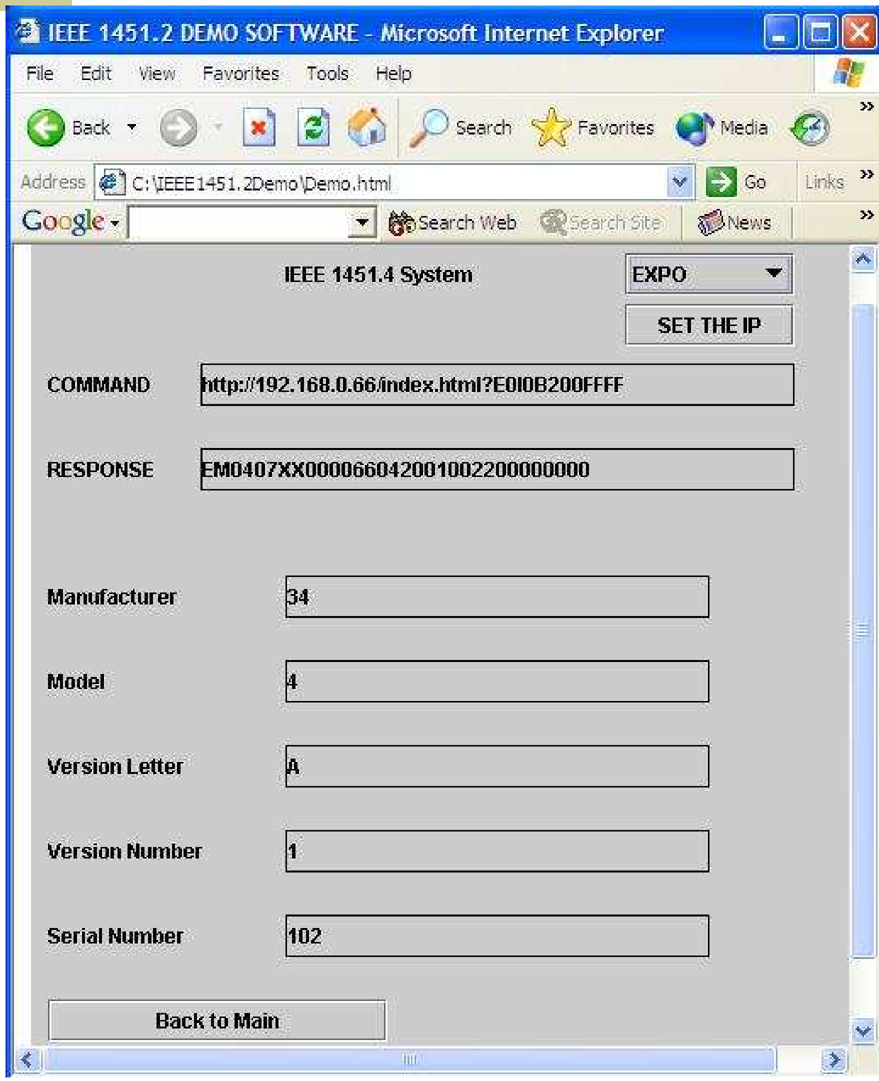
- * Basic TEDS (8 bytes, binary)
- * ID TEDS (user provided 24 bytes ASCII)
- * Standard templates available but special used here

Dot2

IEEE 1451.4 (Dot4) Interface



Basic TEDS



Basic TEDS (8 bytes)

- Manufacturer ID (14 bits)
- Model Number (15 bits)
- Version Letter (5 bits, A-Z)
- Version Number (6 bits)
- Serial Number (24 bits)

Dot4

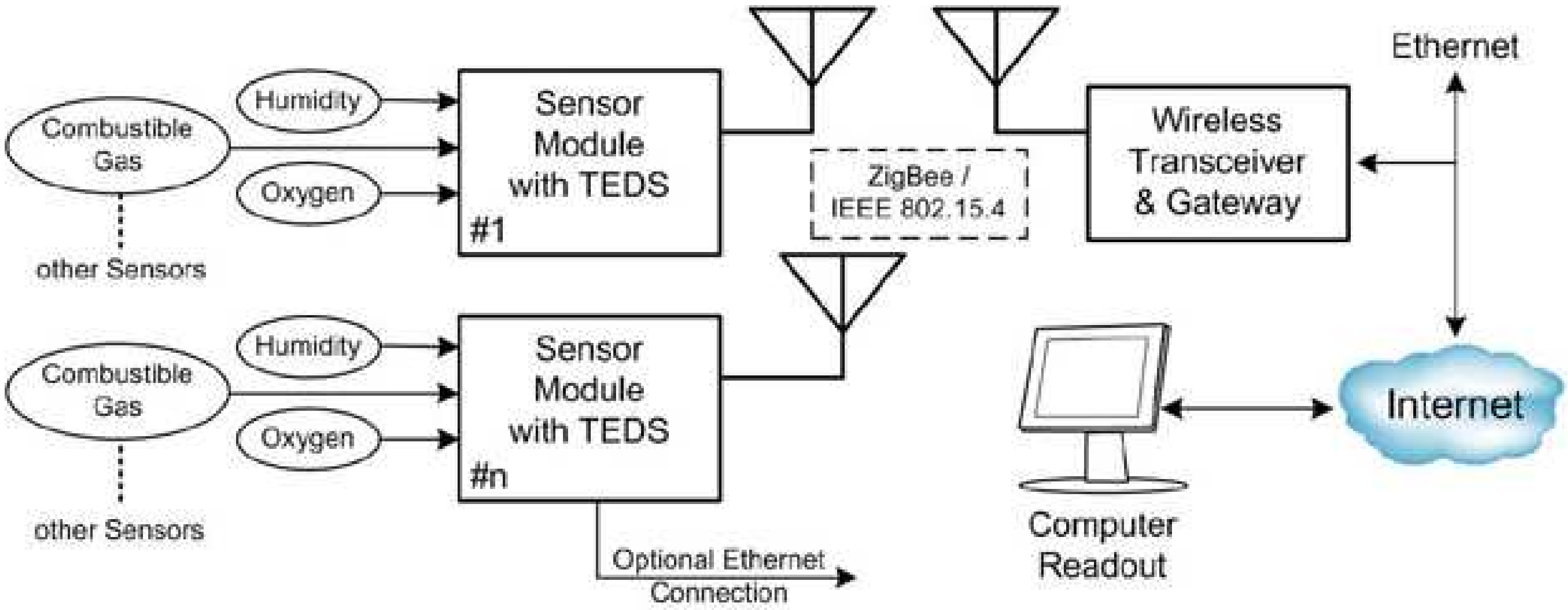
Dot 2 to Dot 4 TEDS Conversion

- Dot4 TEDS read over 1-wire (specific sensor head)
- Contains standard TEDS and special (manufacturer specific) TEDS
- Special head configuration data used for signal conditioner setup
- A/D data read in and converted to floating point (Dot2 option)
- Calibration data from Dot4 TEDS used to convert to engineering units
- Data from Dot4 standard TEDS used to prepare tuples style Dot2 (Dot0) TEDS (Meta, Channel, Meta-ID, and Channel ID)
- Parameters (fields) not in Dot4 TEDS inserted into Dot2 TEDS
- UUID or Universal Unique Identification (10 bytes) consists of 6-byte Dot4 TEDS as the least significant + 4 bytes (FFFF0000h), which will not occur using the specified Dot2 formula

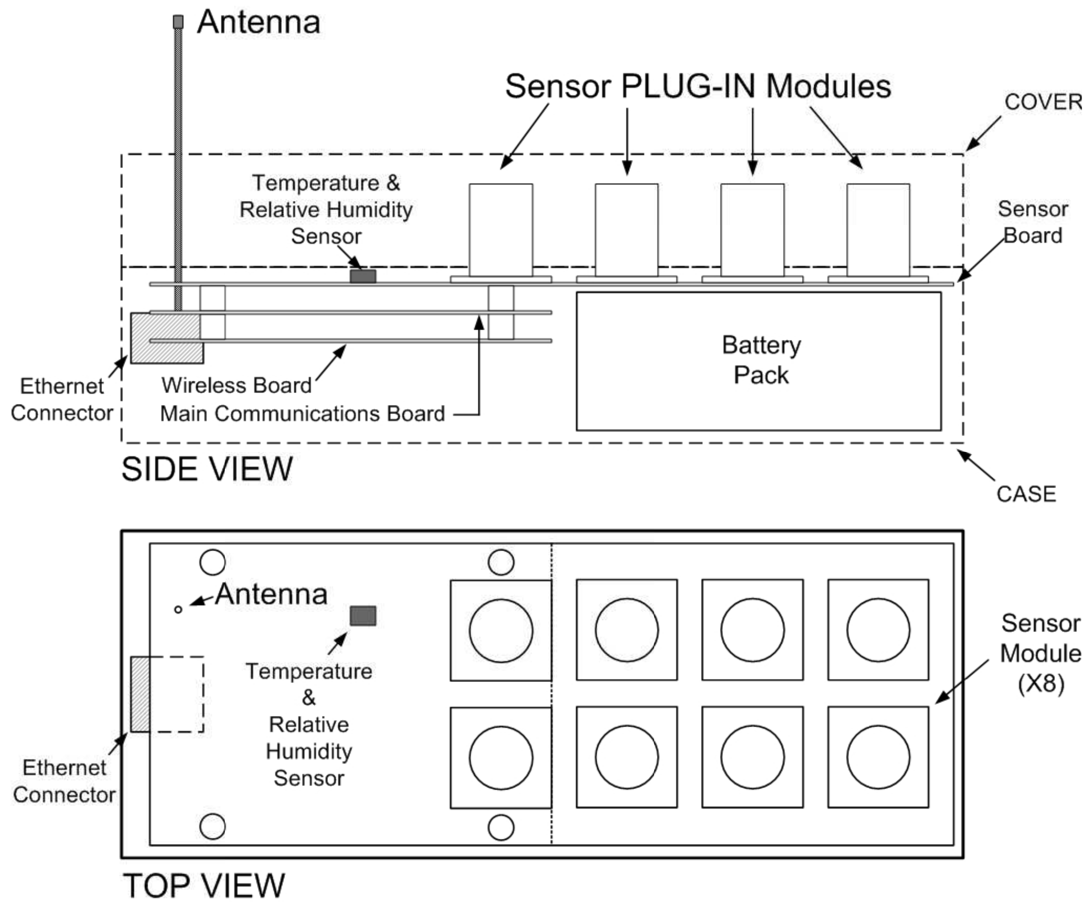
Multi-Element Gas Sensor Design Challenges

- Sensor elements for different gasses use different technologies, and thus signal conditioners, making sensor head/element interchange difficult.
- Many reliable off-the-shelf sensor elements require large amounts of power (heaters) thus reducing battery life.
- Multiple communications channels (Wireless, Internet via Ethernet) may be needed
- Auto configuration (plug and play)
- Should be easy to use
- Moderate cost desirable

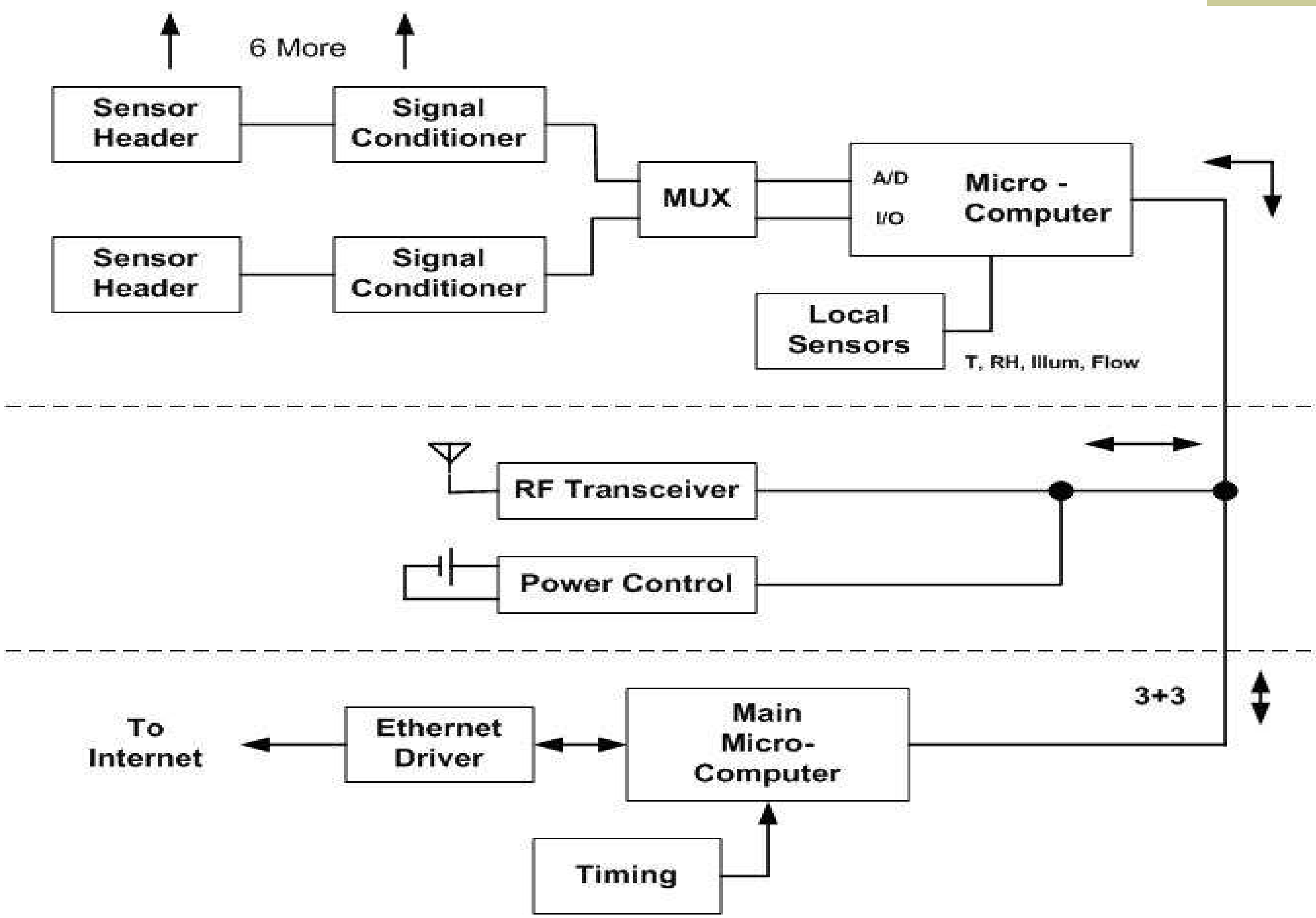
System Block Diagram



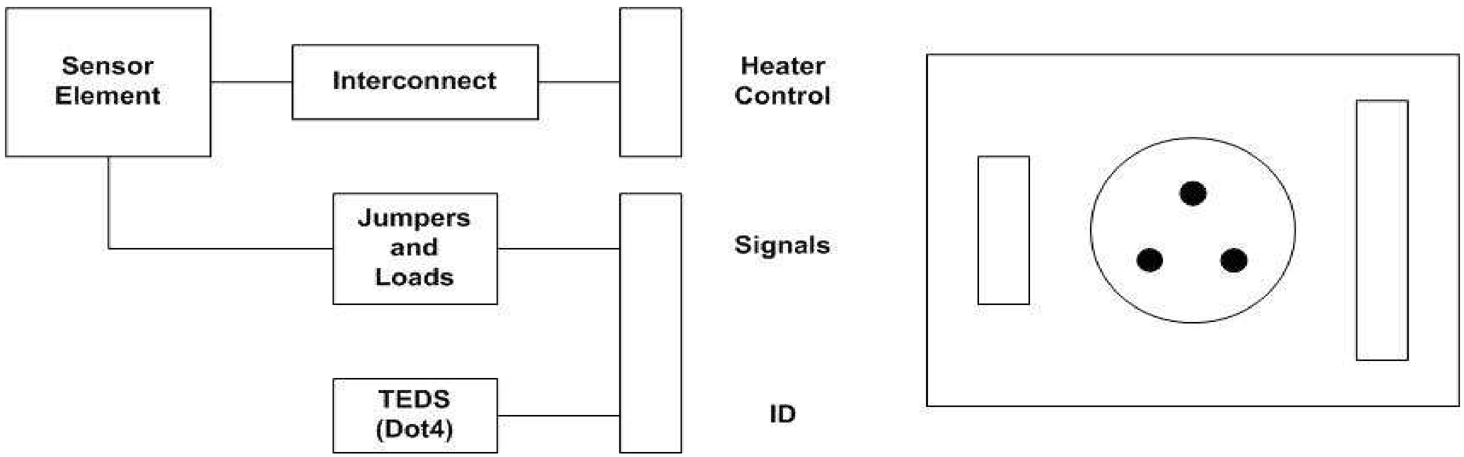
Sensor Pod Board Organization



Sensor Pod Block Diagram



Sensor Head Block Diagram



* Technologies Accommodated

Semiconductor with Heater (e.g. CO) – 3 Types

Amperometric (e.g. O_2) – 2 Types

Catalytic (e.g. Methane) – 2 Types

Gas Sensor List

HVAC/Environmental

- Carbon dioxide
- Humidity /Temperature
- Smoke

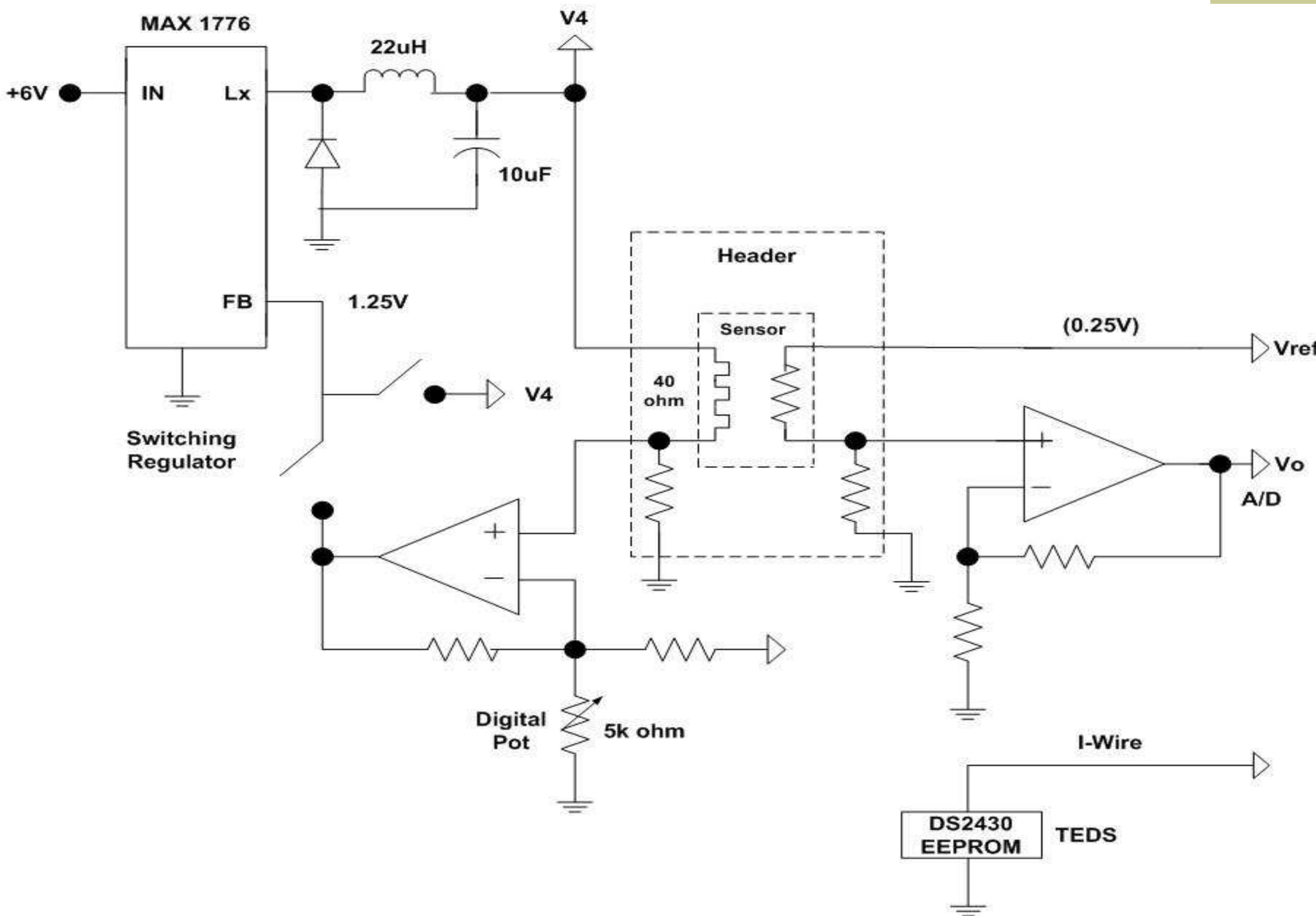
Decontamination/Industrial gases

- VOC/Methyl bromide
- Ozone
- Hydrogen peroxide
- Oxygen
- Combustible gases
- Carbon monoxide

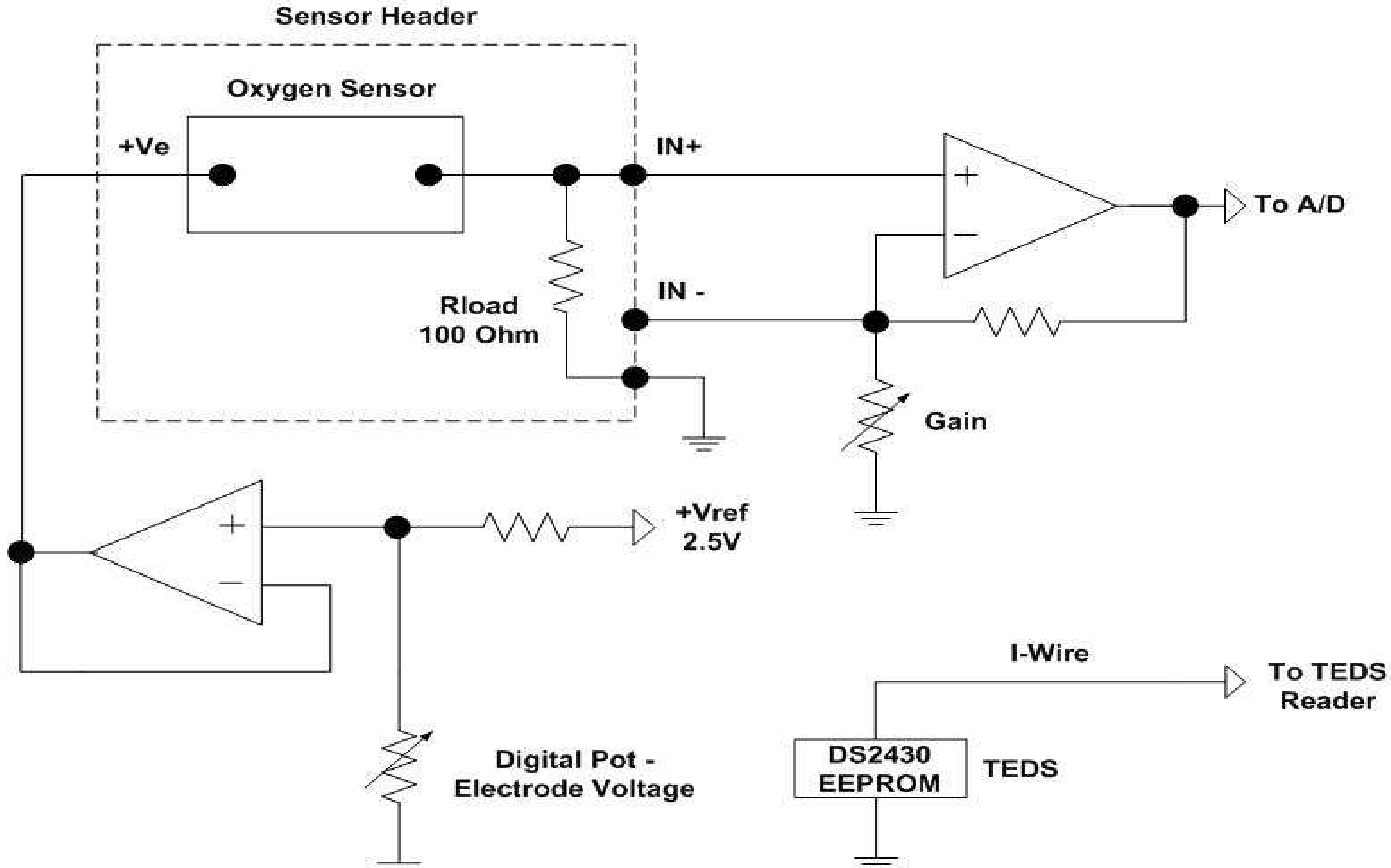
Toxic gas sensors

- Hydrogen sulfide
- Sulfur dioxide
- Chlorine (chlorine dioxide)
- Hydrogen cyanide
- Nitric oxide
- Nitrogen dioxide
- Hydrogen chloride

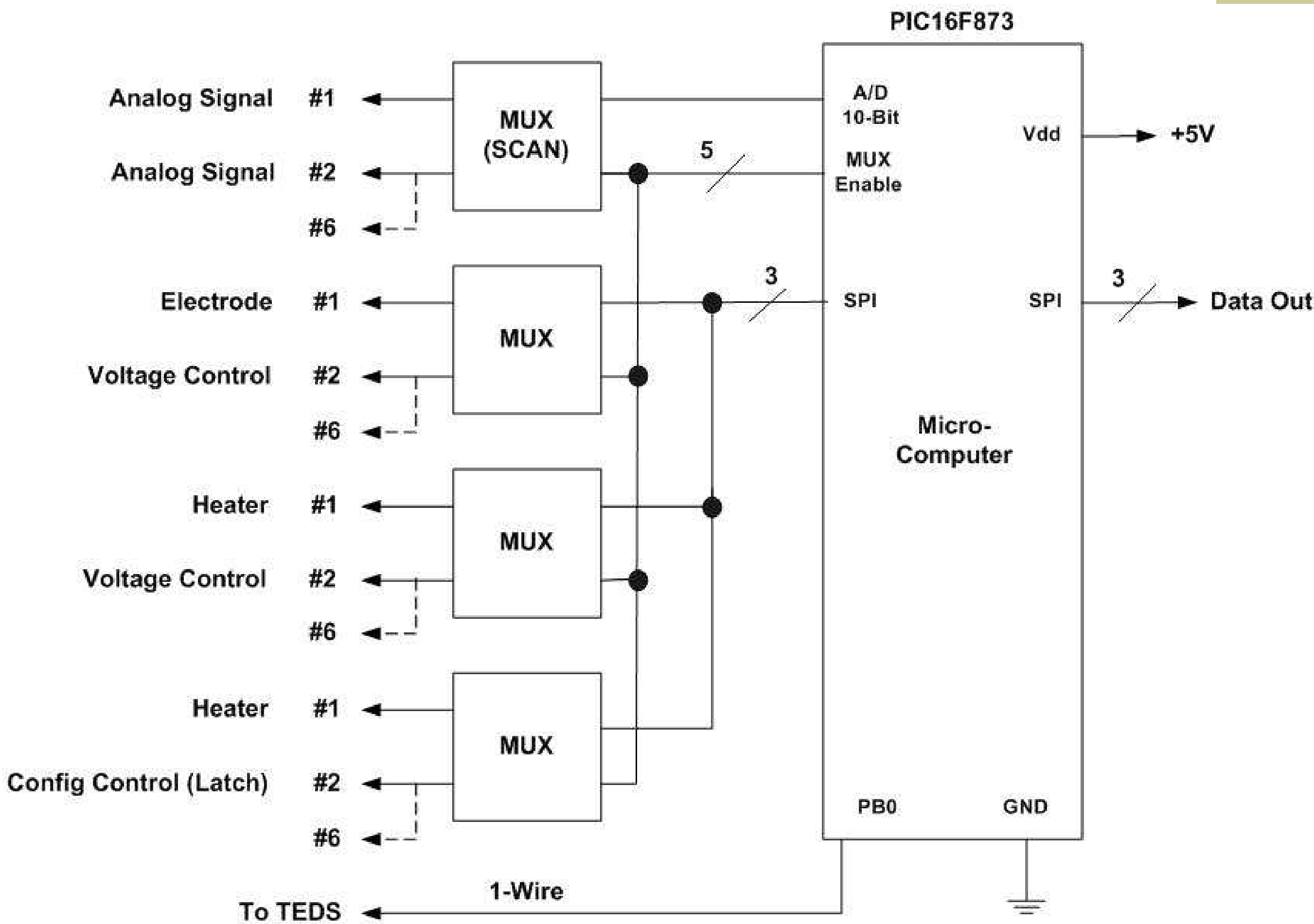
Sensor Signal Conditioner
- Semiconductor type -



Sensor Signal Conditioner
- Amperometric type -

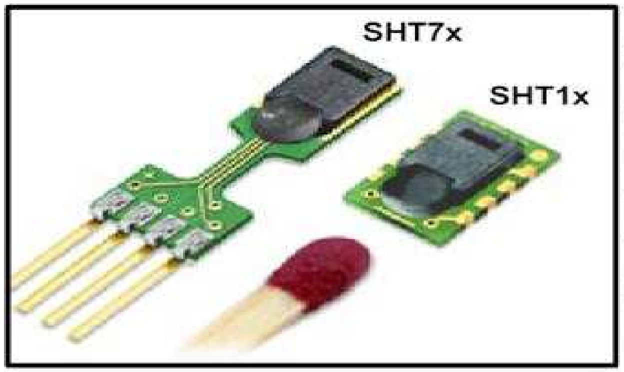


Sensor Signal Conditioner
- Microcomputer section -

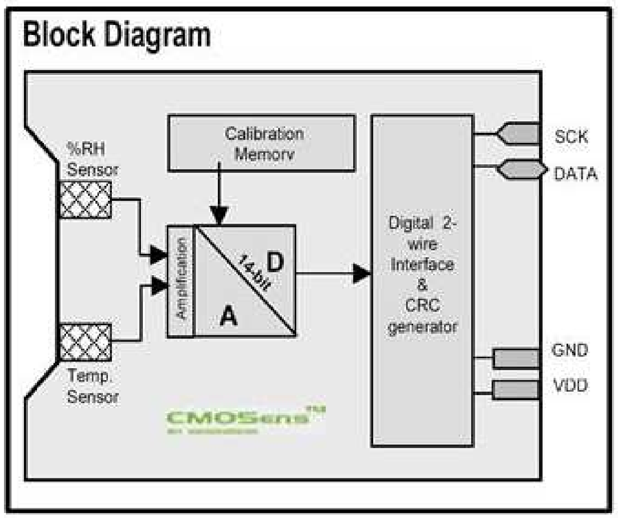


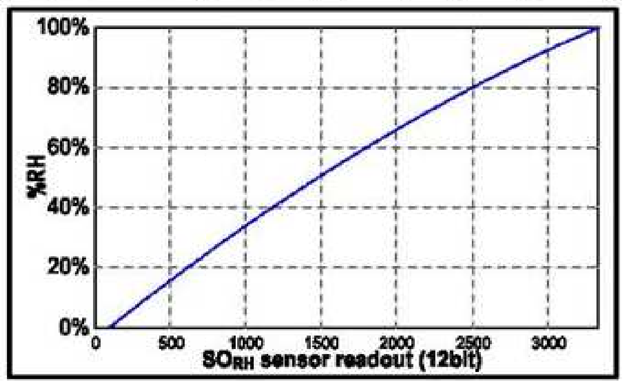
Humidity/Temperature Sensor
with digital output

SHT1x / SHT7x
Humidity & Temperature Sensor



Parameter	Conditions	Min.	Typ.	Max.	Units
Humidity					
Resolution (2)		0.5	0.03	0.03	%RH
		8	12	12	bit
Repeatability			±0.1		%RH
Nonlinearity	raw data		±3		%RH
	linearized		<<1		%RH
Range		0		100	%RH
Response time	1/e (63%) slowly moving air		4		s
Hysteresis			±1		%RH
Long term stability	typical		< 1		%RH/yr
Temperature					
Resolution (2)		0.04	0.01	0.01	°C
		0.07	0.02	0.02	°F
		12	14	14	bit
Repeatability			±0.1		°C
			±0.2		°F
Range		-40		123.8	°C
		-40		254.9	°F
Response Time	1/e (63%)	5		30	s





Communication Options

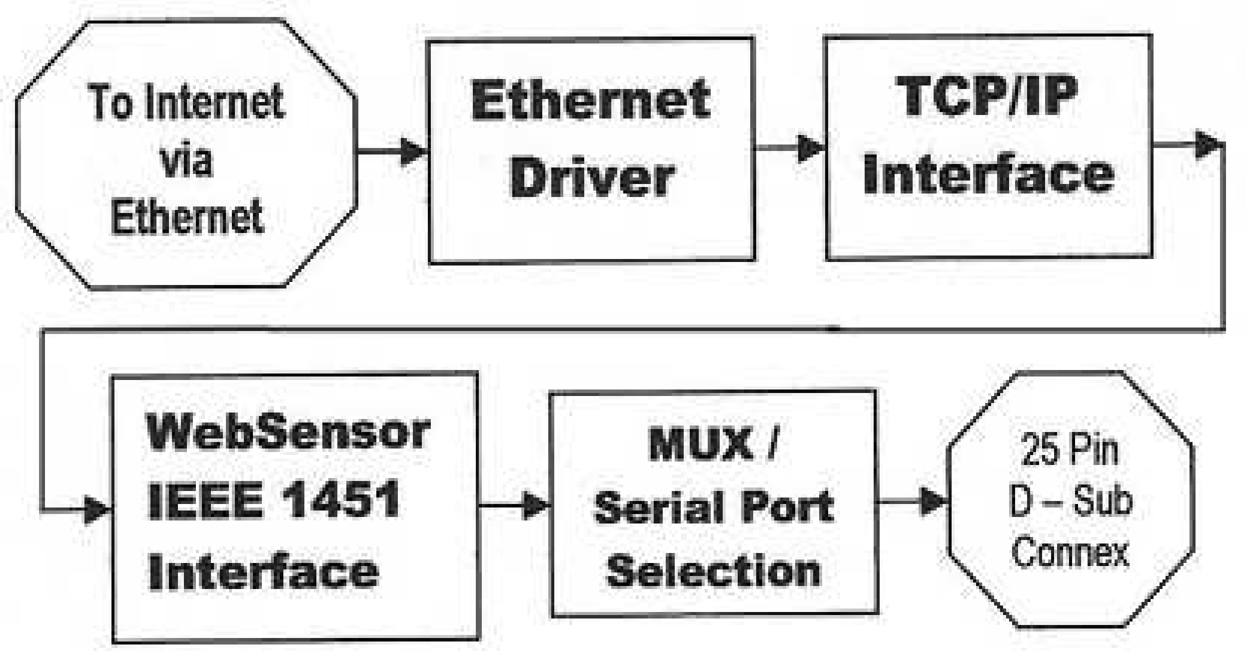
- Internet via Ethernet

  TCP/IP protocol similar to websensor
- RF Point-to-point – initial wireless version

  900 MHz spread spectrum (Chipcom)
- Full-feature wireless network (IEEE 802.15.4/Zigbee)

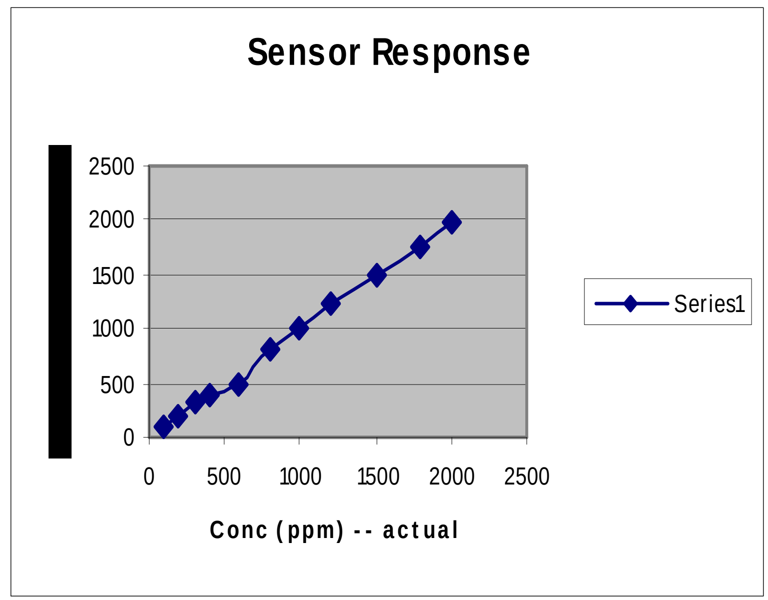
  Scheduled transmissions for power reduction, node-to-node hopping, collision recovery, error handling

NCAP Block Diagram



Test data

- VOC response to ethanol measured (100 to 3000 ppm)
- Method: small volume solvent injections into closed container
- Solid state VOC sensor resistance change converted to ppm and transmitted digitally
- Date from computer plotted



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Not final data

References

- R. Johnson, et al "A Standard Smart Transducer Interface" http://ieee1451.nist.gov/Workshop_04Oct01/1451_overview.pdf
- Philip N. Bartlett & Julian W. Gardner "Electronic Noses: Principles and Applications", Oxford Univ. Pr; (March 1999)
- R. Frank "Understanding Smart Sensors", 2nd edition, Artech House (2000)
- D. Wobschall "IEEE 1451 Prototype Dot 2 and Dot 4 NCAPs with Internet Access", Proc. Sensors Expo (Sept 2003)
- www.eesensors.com/IEEE1451

Experimental Dot2 TIM and NCAP demo at IEEE 1451 booth

Summary

- Interchangeable gas sensor elements/heads of varied technology requires adaptable signal conditioners
- A microcomputer-based smart sensor with the required signal conditioners was developed for this purpose.
- Transmission of sensor data over a network was demonstrated
- IEEE p1451 protocol was used for simplified signal readout and plug and play capability.

Further information: designer@eesensors.com