Smart Sensor Design and Networking Standards

Dr. Darold Wobschall

Associate Professor Emeritus (EE)

and

President, Esensors Inc.

Goals

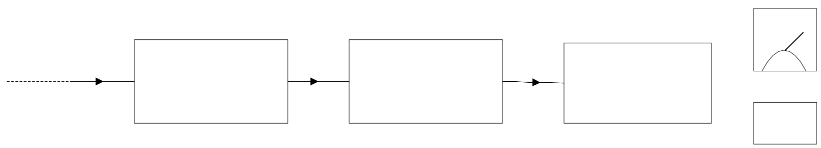
- Review electronic sensors and signal conditioners
- Describe smart sensor design
- Discuss sensor networks, both wired and wireless
- Promote the IEEE 1451 sensor network standard
- Comment on wireless sensor future

Sensor Development
past and future

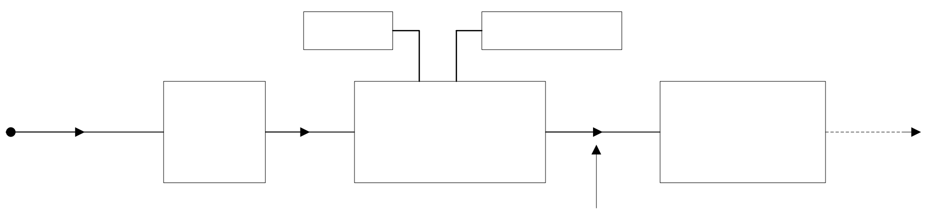
- Most sensor principles known (by physicists) for over 100 years
- Many sensors used industrially for over 60 years
- Computer controls and appetite for data have driven sensor uses, especially Machine-to-Machine (M2M).
- Continuing improvements in manufacturing methods (e.g. MEMS) have made sensors smaller & easier to use
- Advances in electronics (analog, a/d, microcomputers, communications) lower costs and add functionality.
- Smart, digital, networked sensors are the future trend

Sensor Classes

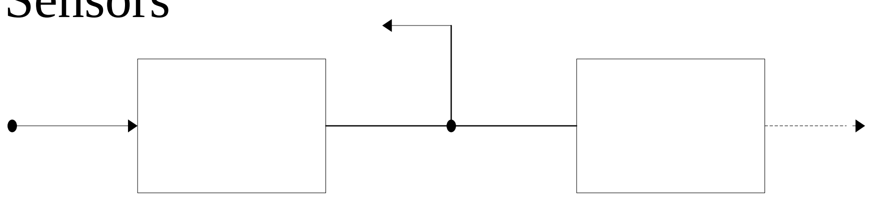
- Basic Sensors



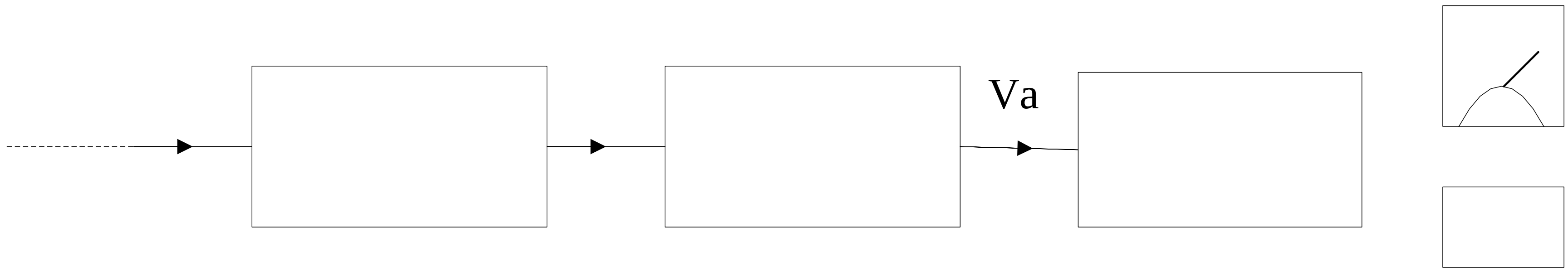
- Smart Sensors



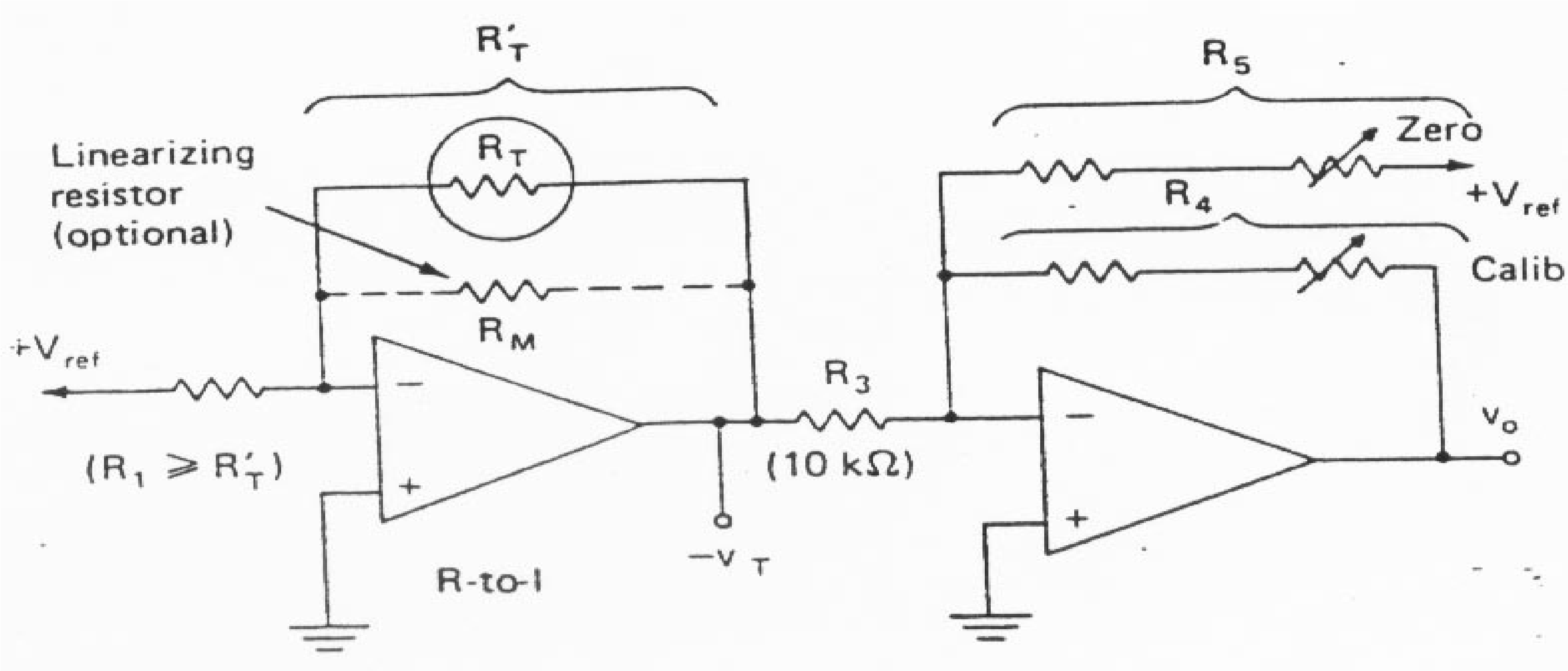
- Networked Sensors



Basic Sensor Block Diagram



Signal Conditioner Example (Thermistor)



$$-v_T = \left(\frac{V_{ref}}{R_1}\right) R_T$$

Partial List of

Measured Parameters and Sensor Technologies

- Acceleration/Vibration
- Level & Leak
- Acoustic/Ultrasound
- MachineVision
- Chemical/Gas
- Motion/Velocity/Displacement
- Electric/Magnetic
- Position/Presence/Proximity
- Flow
- Pressure
- Force/Strain/Load/Torque
- Temperature
- Humidity/Moisture

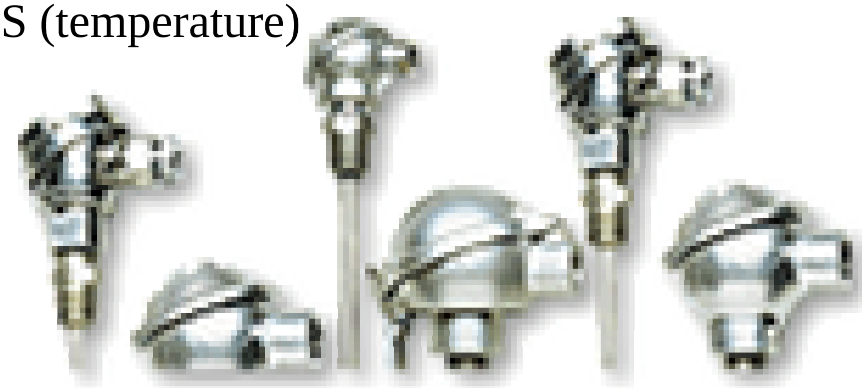
- Resistance
- Capacitance
- Inductance & magnetics
- Optical & fiber optic
- Voltage & piezoelectric
- Ultrasonic
- RF/microwave

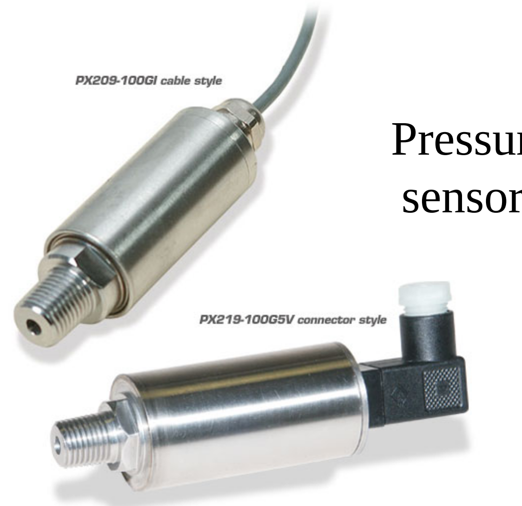
Sensors (and sensor industry) are subdivided (fragmented) by:

1. Parameter measured
2. Technology
3. Application area

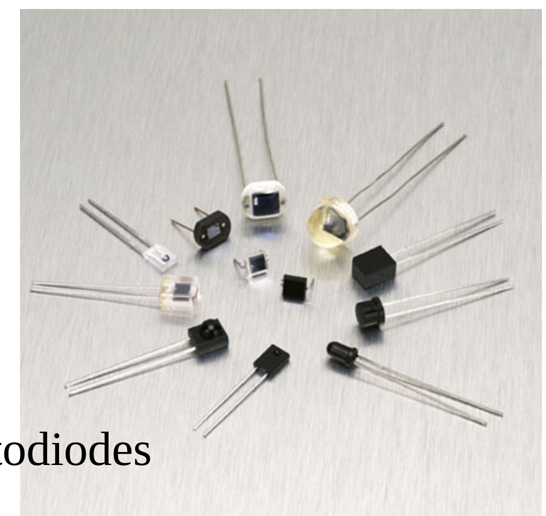
Some Sensor Elements

RTS (temperature)





Pressure sensors



Photodiodes

Force Sensor

PC Signal Acquisition Plug-in Method
(older, analog approach)

- A Star configuration: each sensor connected directly to DAQ.
- Results in many wires if multiple sensors
- Calibration done in software for each sensor
- Noise often causes errors

Isolated M Series Multifunction DAQ
16-Bit, 250 kS/s, ±10 V or ±20 mA Analog Inputs

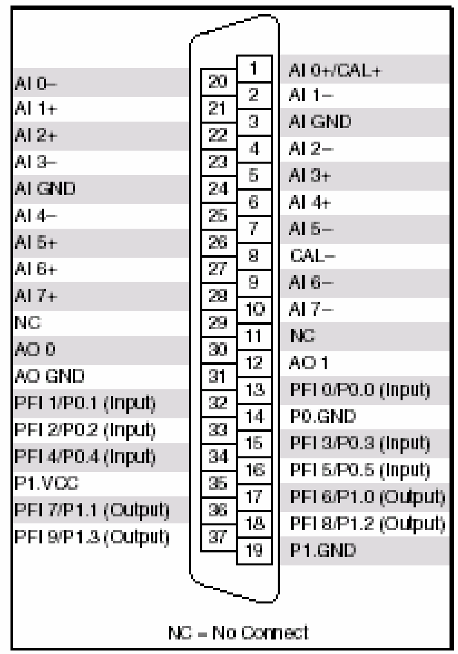
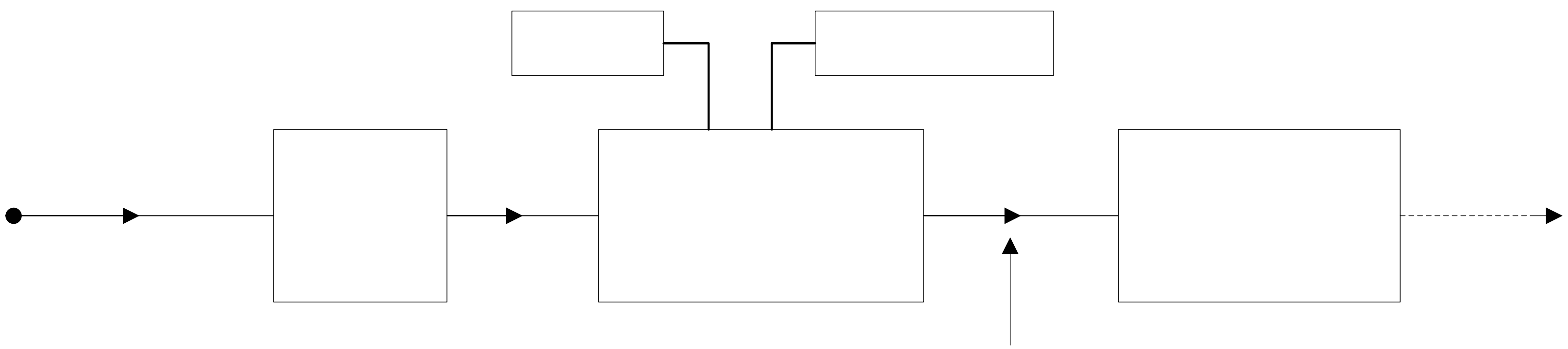


Figure 5. NI 6238 Pinout

Smart Sensor Block Diagram



Smart (Digital) Sensor Features

- Analog/Digital Converter

  Typically 10-14 bits, usually internal

- Microcontroller (embedded)

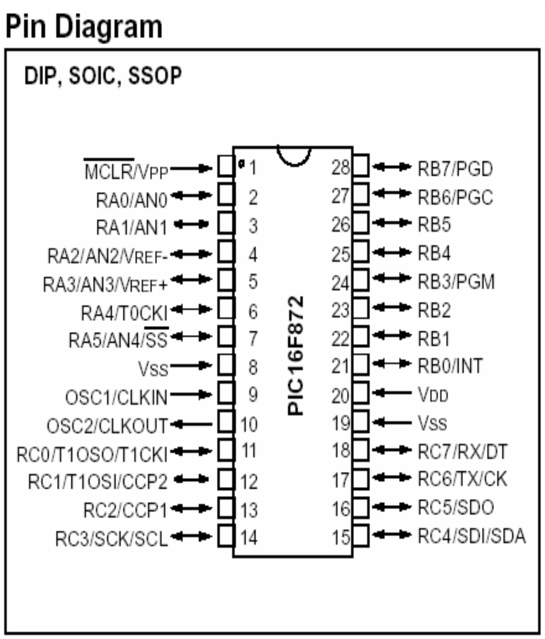
  PIC or similar 8-bit micro with appropriate features

- Sensor Identification (serial # etc)
- Calibration information

  Compensates for sensor variations; conversion to engineering units

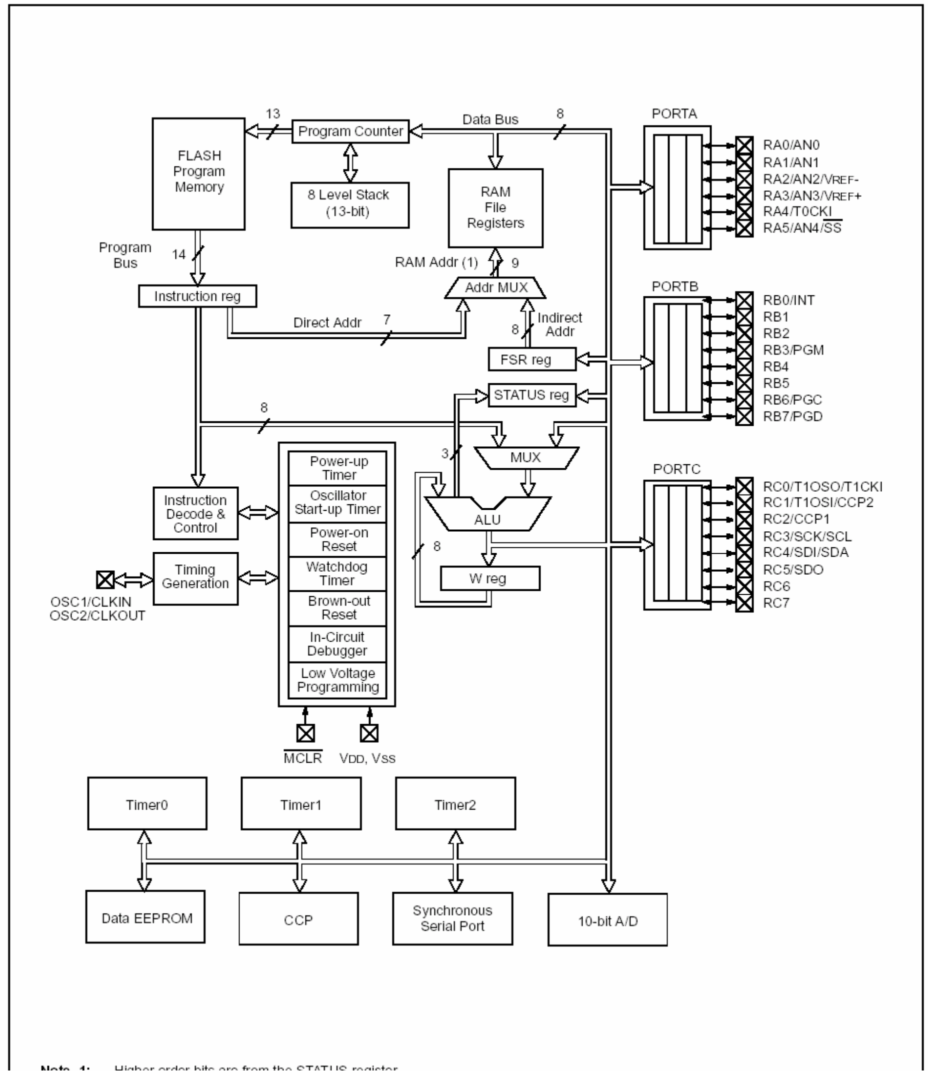
- Data logging and real-time clock (optional)

Microcontroller Example



Ne

FIGURE 1-1: PIC16F872 BLOCK DIAGRAM



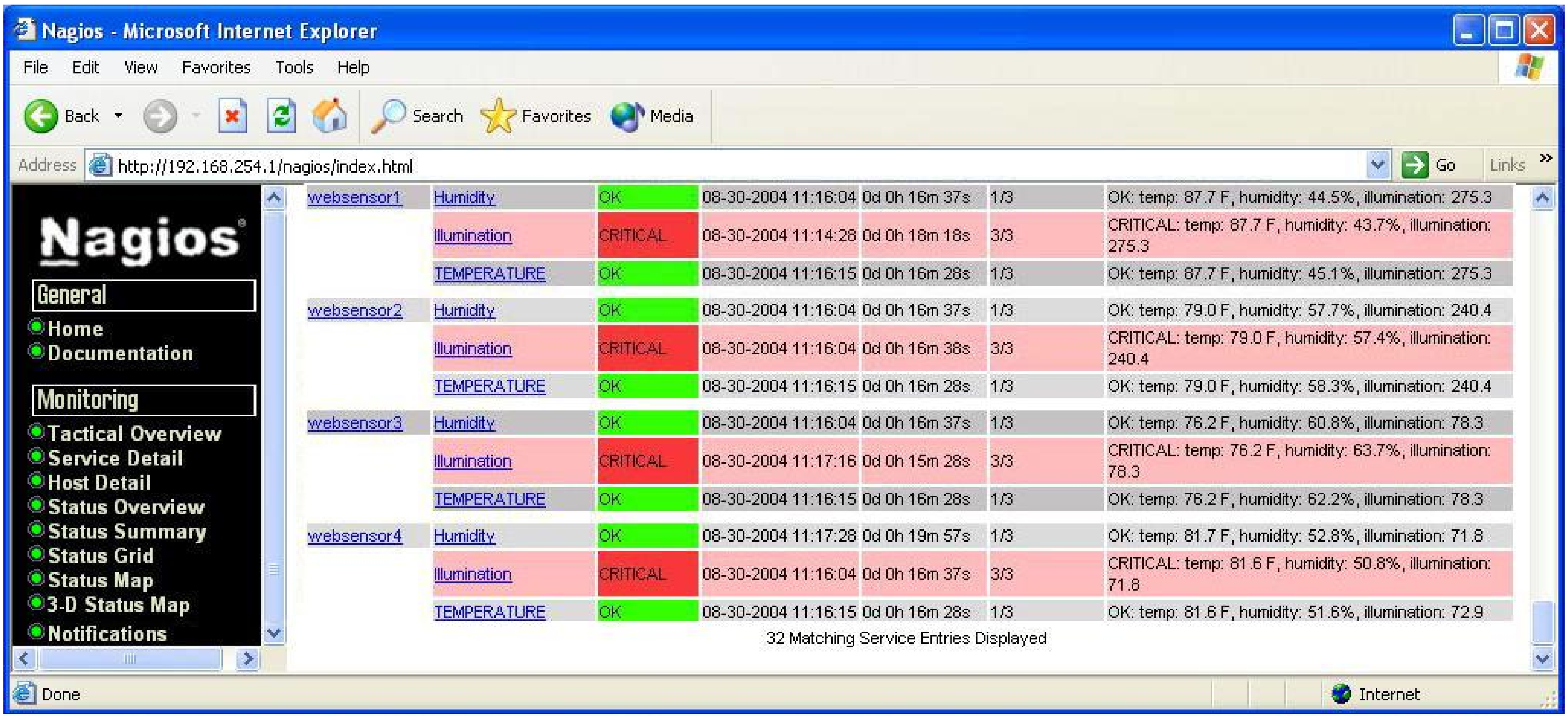
Connection of Non-networked Smart Sensors to Computers

- USB (best for PCs) or RS232 (best for Instruments) Serial Data Lines
- One line and port per sensor (a problem with large systems)
- Data protocol not standardized

Websensor – sensor with Internet Address

- Uses Ethernet as the Network
- Microcontroller has TCP/IP (mini-website) as protocol
- Data can be read anywhere on Internet
- Polling/logging/display by NAGIOS (Lynix) freeware
- A smart sensor but does not have standard interface

Websensor data readout
(typical of digital sensor displays)

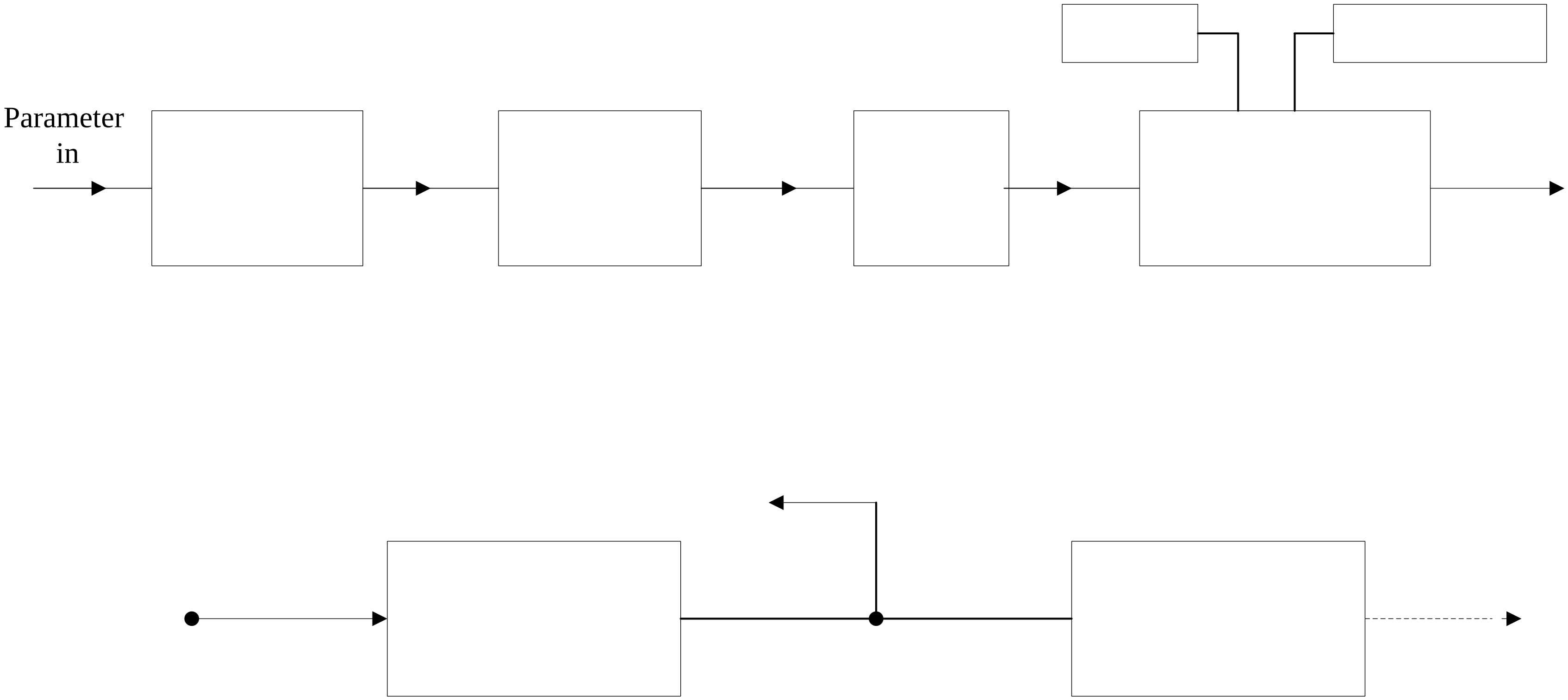


Sensor/Transducer Networks

- A network connects more than one addressed sensor (or actuator) to a digital wired or wireless network
- Both network and sensor digital data protocols are needed
- Standard data networks can be used but are far from optimum
- Numerous (>100) incompatible sensor networks are currently in use – each speaking a different language

The Tower of Babel

Networked Sensor Block Diagram

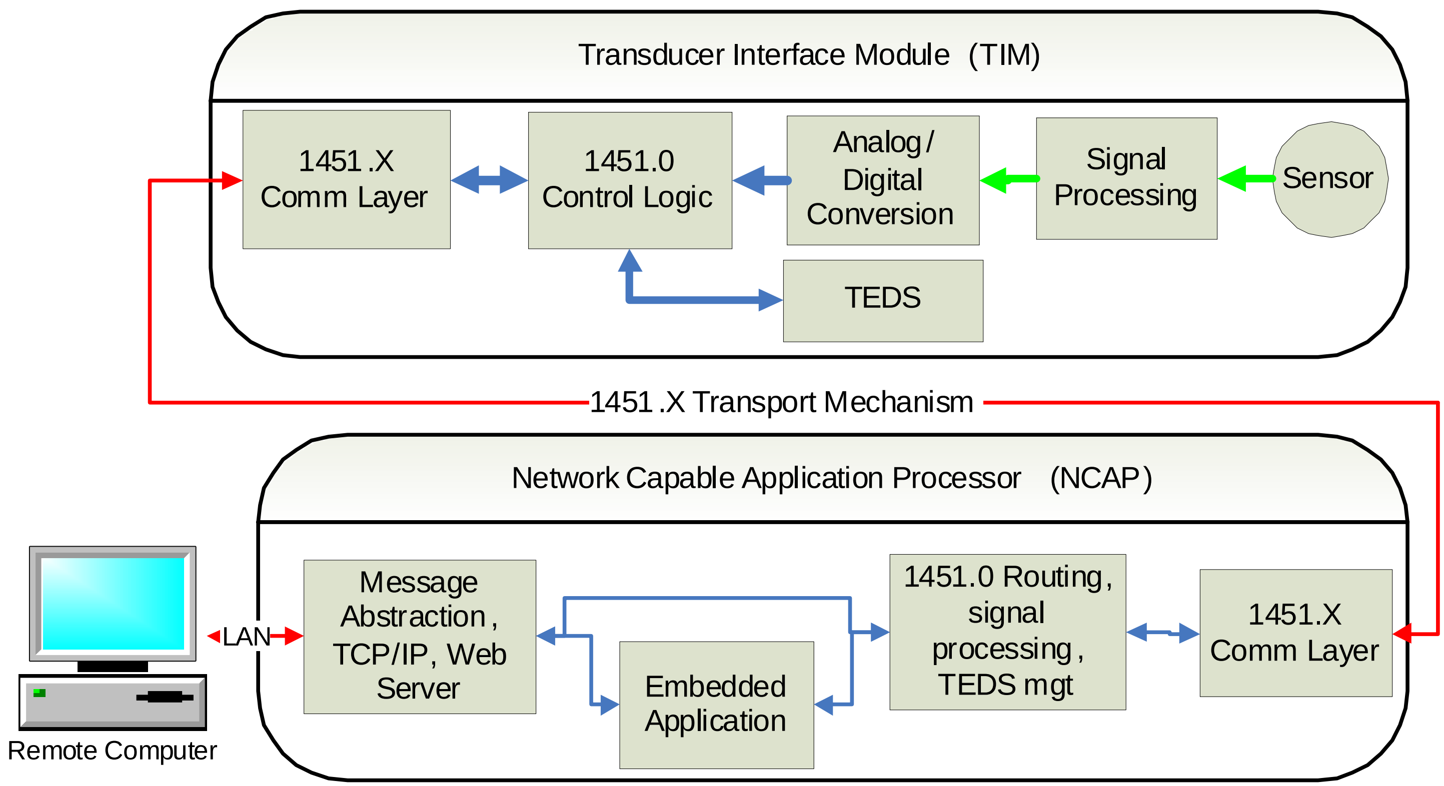


IEEE 1451 – the Universal Transducer Language

- Too many network protocols in common use
- Narrow solutions and borrowed protocols have not worked
- Sensor engineers in the fragmented sensor industry need a simple method of implementation
- How can it be done?
- We need something like USB, except for sensors
- The IEEE 1451 Smart Transducer Protocol standard is the best universal solution
- Supported by NIST, IEEE and many Federal agencies

A review of the

IEEE 1451 Smart Transducer Concept

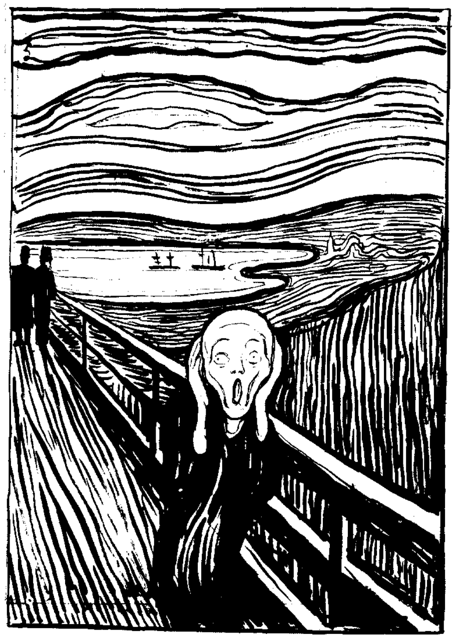


IEEE 1451 Advantages

- Comprehensive enough to cover nearly all sensors and actuators in use today (not 20/80% approach)
- Many operating modes
  (buffered, no-buffer, grouped sensors, timestamps, timed data, streaming …)
- Extensive units, linearization and calibration options
- Multiple timing and data block size constraints handled.
- Compatible with most wired and wireless sensor buses and networks (point-to-point, mesh, TIM-to-TIM, mixed networks).
- Efficient binary protocol (especially suitable for wireless)
- Standard is 400+ pages for basic part, over 1500 page total

But the Complexity!

- A comprehensive standard is necessarily complex
- There was little adoption of the original IEEE 1451.2 (TII) standard because of its perceived complexity
- Manual preparation of the TEDS is not practical
- A TEDS compiler is needed
- A compliance test procedure is also desirable to prove that the design is correct



Munch –The scream

IEEE 1451.0 (Dot 0) TEDS Format

- Required TEDS [Memory block with defined format]
  - MetaTEDS
  - Channel TEDS
  - Calibration TEDS (unless SI units)
  - Xdr-name TEDS
  - Phy TEDS
  - Also optional TEDS
- Data Transmission [specific octet format]
  - TEDS/Status requests
  - Triggering and configuration
  - Sensor read commands and data return
  - Actuator write commands and data sending

TEDS Format

- General format for each TEDS section:

Field	Description	Data Type	Number of Bytes
-------	TEDS Length	UInt32	4 bytes
1 to N	Data Block	Variable	Variable
-------	Checksum	Uint16	2 bytes

- Binary TEDS Tuple format for each data block:

  Type-Length-value (TLV)

  Example: 01 02 A3 04

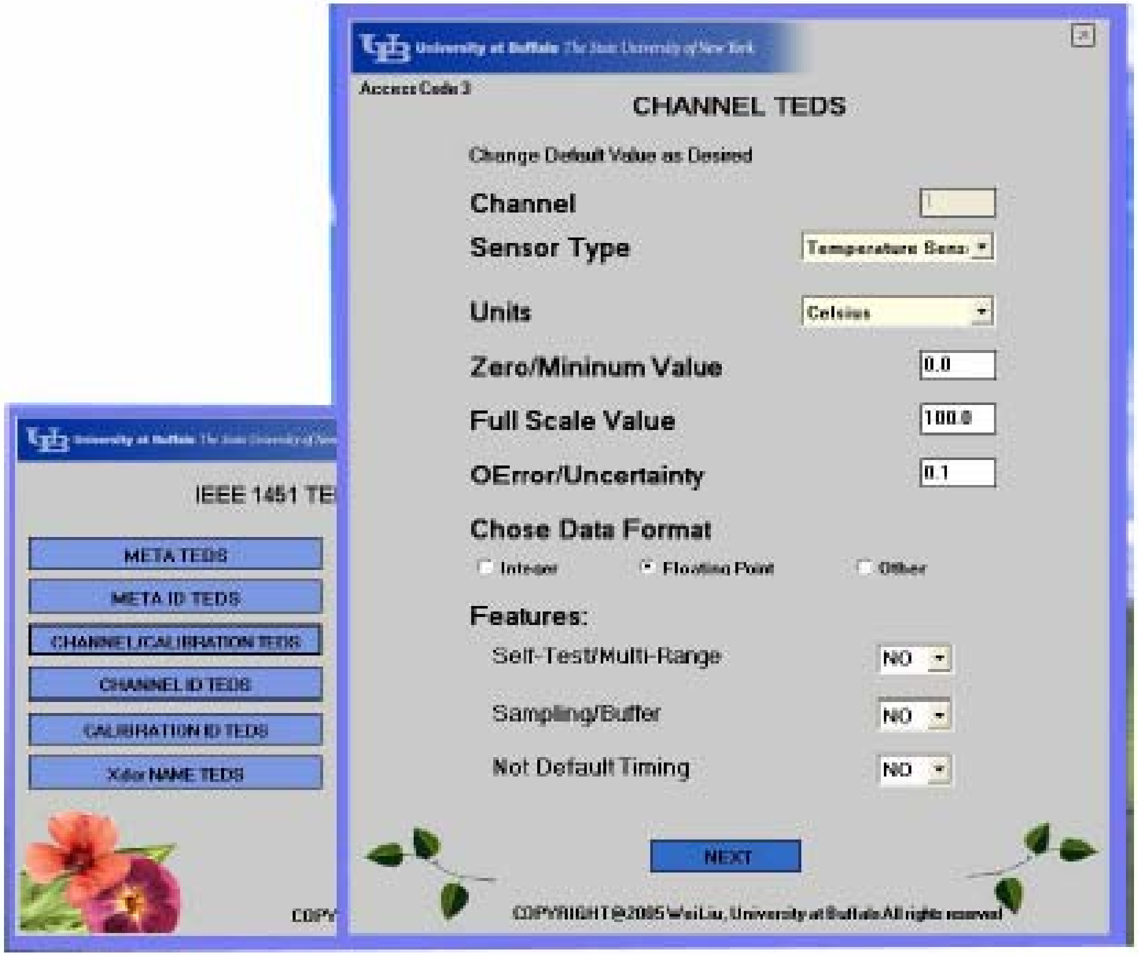
  Field type is 1, Length is 2 bytes, field value is "A304" hex

- Field example: Meta-TEDS (TEDS # 1)

  13: Number of Implemented Transducer Channels (default=1)

TEDS Compiler

- Part of Ph. D. thesis of Wai Liu (Univ. at Buffalo)



TEDS Sections Implemented

- Meta TEDS
- Meta ID TEDS
- Transducer Channel TEDS
- Transducer Channel ID TEDS
- Calibration TEDS
- Calibration ID TEDS
- XdrcName TEDS

Referenced by TEDS section/access code (e.g. #1 for Meta-TEDS)

Standard Transducer Units
(binary format)

SI Based Units

Base Quantity	Name	Unit Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Field	Description	Data Type	Number of octets
1	Physical units interpretation	UInt8	1
2	(2 * <exponent of radians>) + 128	UInt8	1
3	(2 * <exponent of steradians>) + 128	UInt8	1
4	(2 * <exponent of meters>) + 128	UInt8	1
5	(2 * <exponent of kilograms>) + 128	UInt8	1
6	(2 * <exponent of seconds>) + 128	UInt8	1
7	(2 * <exponent of amperes>) + 128	UInt8	1
8	(2 * <exponent of kelvins>) + 128	UInt8	1
9	(2 * <exponent of moles>) + 128	UInt8	1
10	(2 * <exponent of candelas>) + 128	UInt8	1

Dot 0 Command/Response Structure

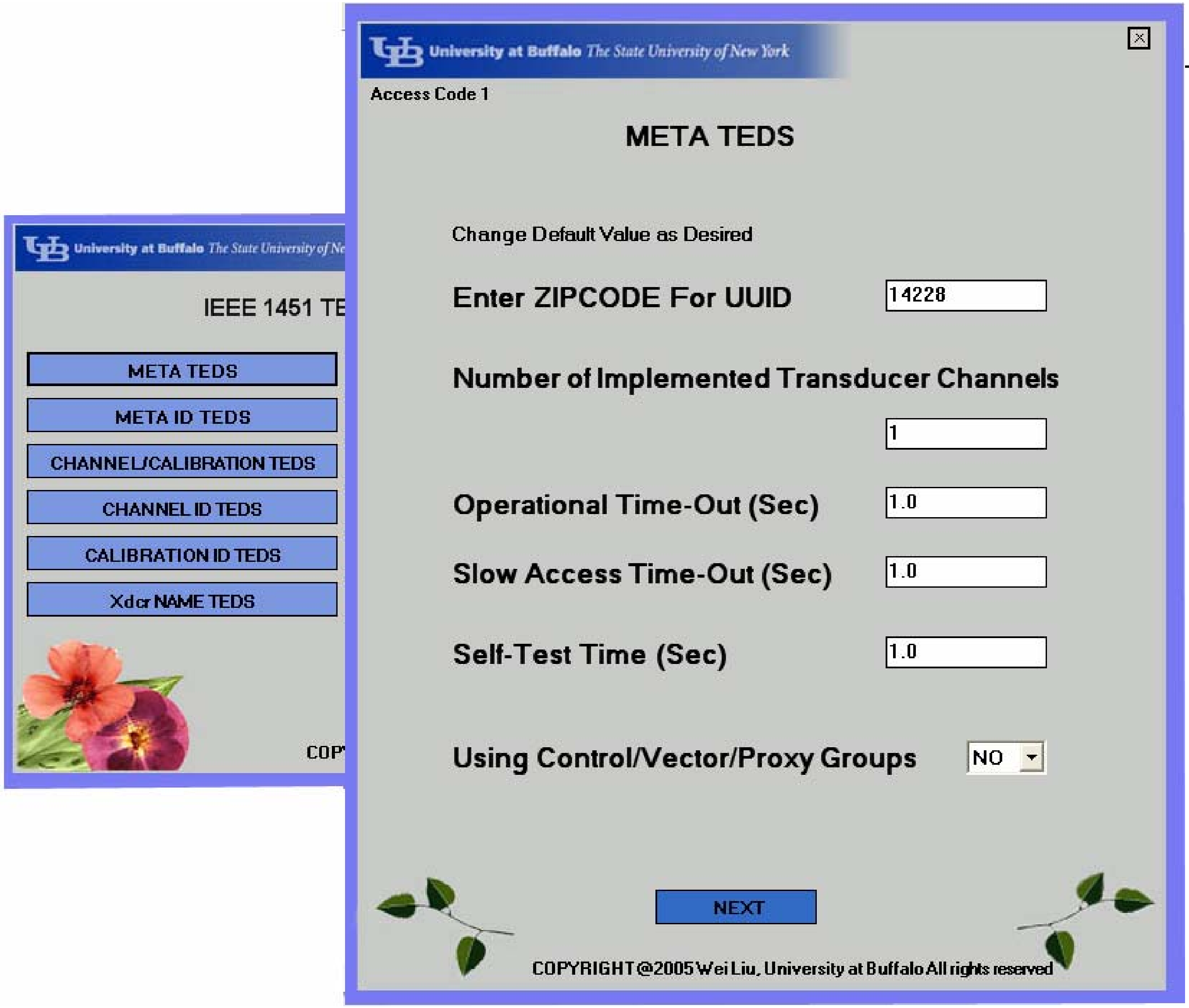
Byte Number	Description
1	Destination Transducer Channel Number (Most significant byte)
2	Destination Transducer Channel Number (Least significant byte)
3	Command Class
4	Command Function
5	Length (Most significant byte)
6	Length (Least significant byte)
7-N	Command dependent bytes

NCAP Command Message Structure

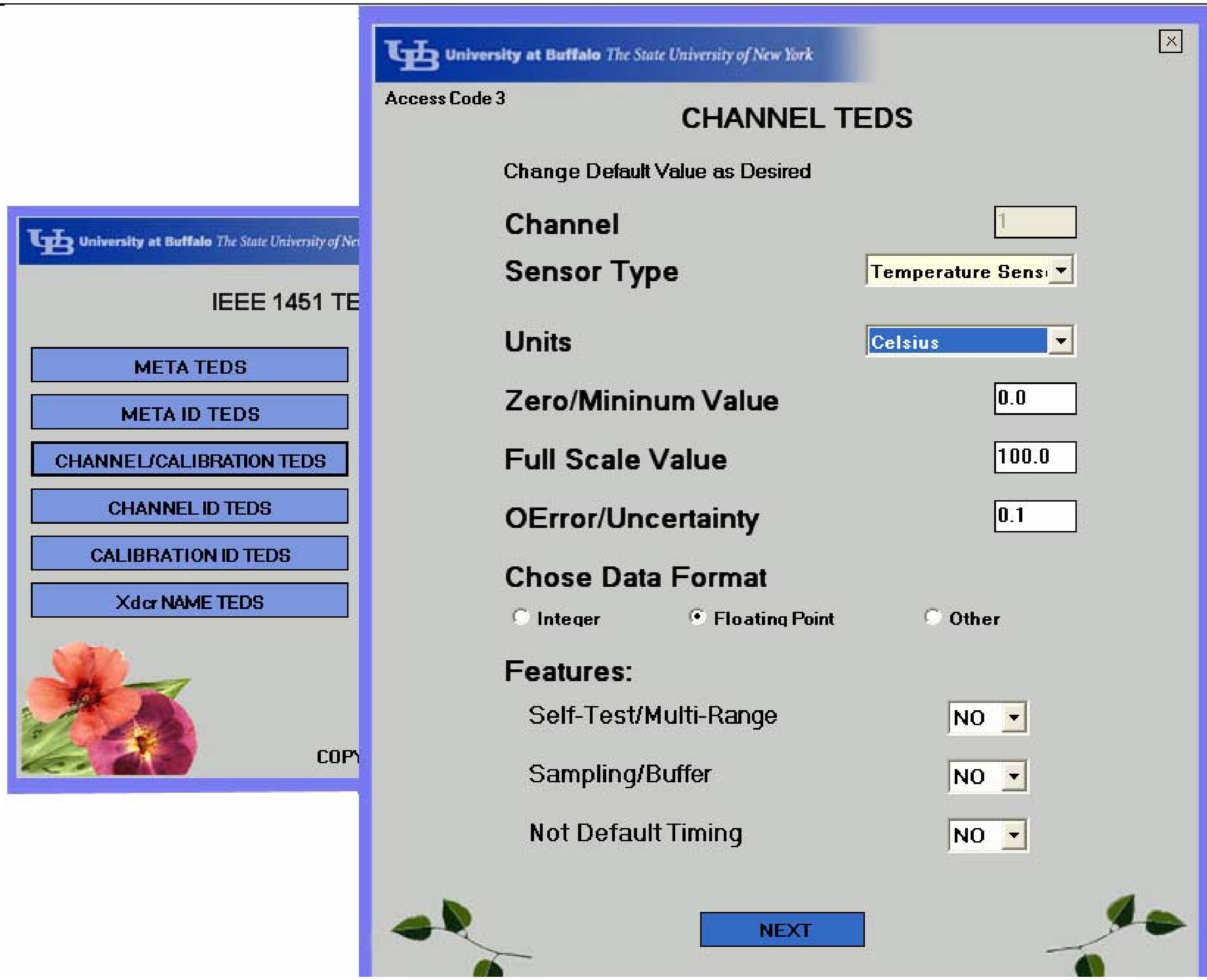
Byte Number	Description
1	Success/Fail Flag
2	Length (Most significant byte)
3	Length (Least significant byte)
4-N	Reply dependent bytes

TIM Reply Message Structure

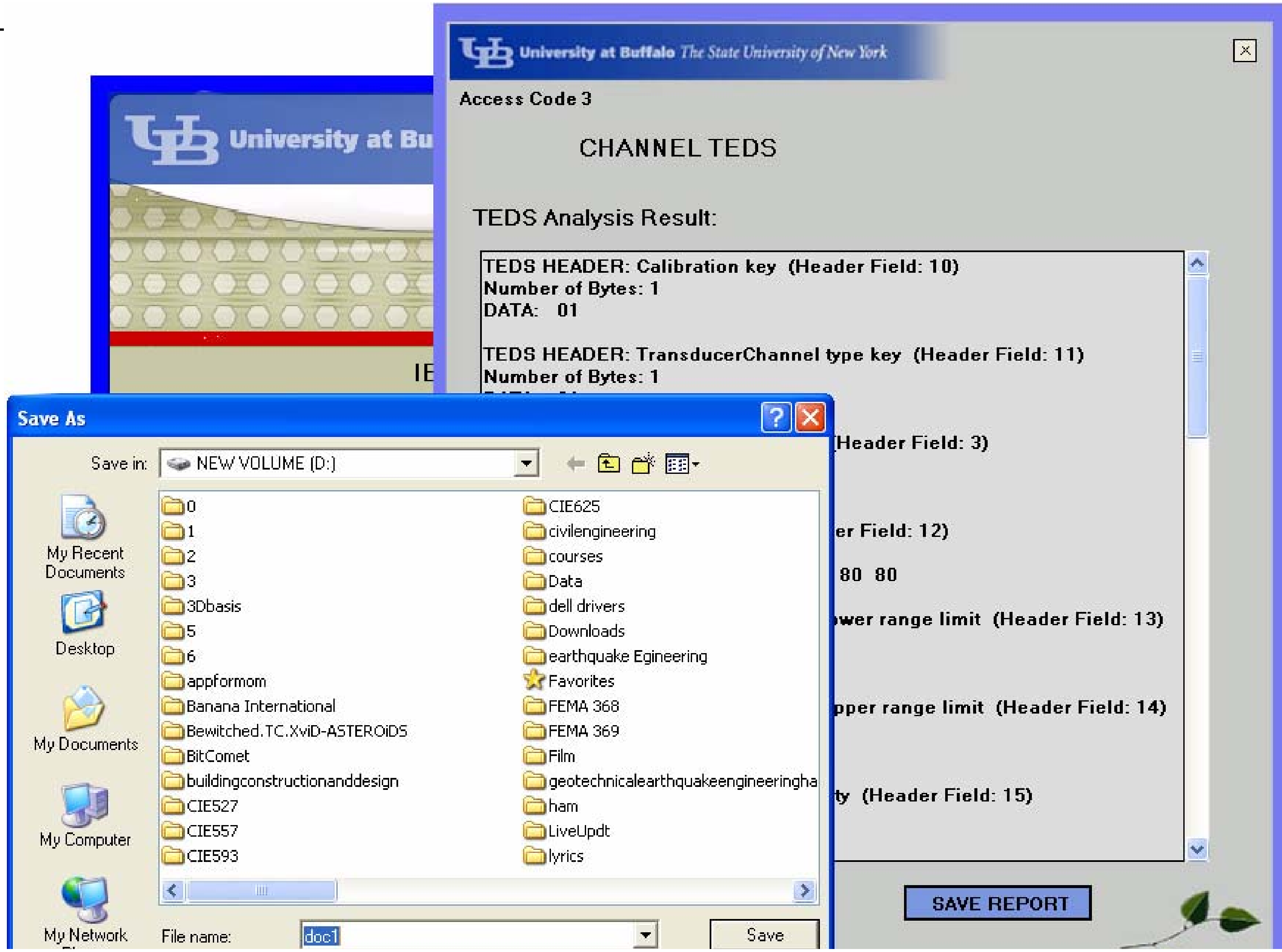
Meta-TEDS Writer Screen



Channel/Calibration TEDS (for linear sensors)



TEDS Reader


University at Buffalo The State University of New York
Access Code 3
CHANNEL TEDS
TEDS Analysis Result:
TEDS HEADER: Calibration key (Header Field: 10)
Number of Bytes: 1
DATA: 01
TEDS HEADER: TransducerChannel type key (Header Field: 11)
Number of Bytes: 1
(Header Field: 3)
er Field: 12)
80 80
wer range limit (Header Field: 13)
pper range limit (Header Field: 14)
ty (Header Field: 15)
SAVE REPORT
Save As
Save in:
NEW VOLUME (D:)
My Recent Documents
Desktop
My Documents
My Computer
My Network
0
1
2
3
3Dbasis
5
6
appformom
Banana International
Bewitched.TC.XviD-ASTEROiDS
BitComet
buildingconstructionanddesign
CIE527
CIE557
CIE593
CIE625
civilengineering
courses
Data
dell drivers
Downloads
earthquake Egineering
Favorites
FEMA 368
FEMA 369
Film
geotechnicalearthquakeengineeringha
ham
LiveUpdt
lyrics
File name:
doc1
Save

IEEE 451 TIM Compliance Tester

- TIM (Transducer Interface Module) is most complex and done by sensor design engineers

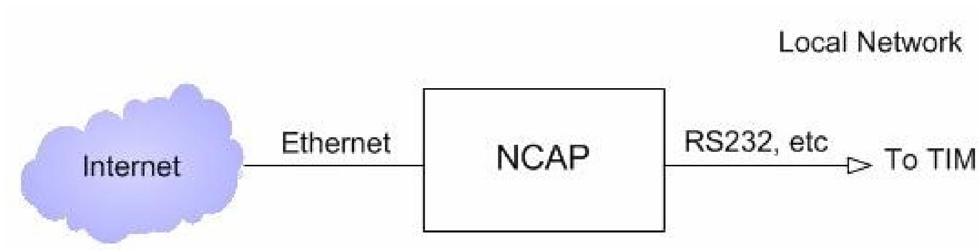
  (TIM tester can be used by the few NCAP designers)
- Tester verifies compliance of a TIM to IEEE 1451.0 (Dot 0) protocol
- Focus is on TEDS checking and data transfer format
- Physical device compliance not checked (part of other standards, e.g. RS485, Bluetooth)
- Tester uses serial bus (RS232)
- Testing may be done by Internet

Standard TIM/NCAP Configurations

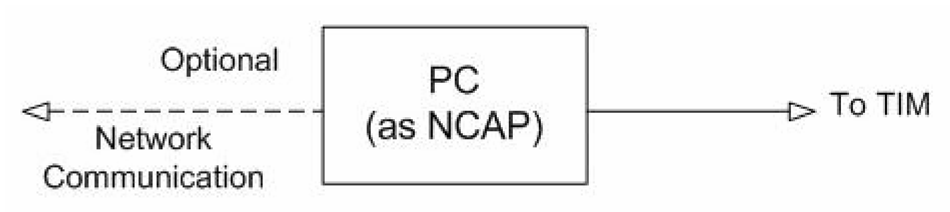
The following 3 slides describe TIM and NCAP configurations for which the TIM tester can be used

Network side (NCAP) options (wired)

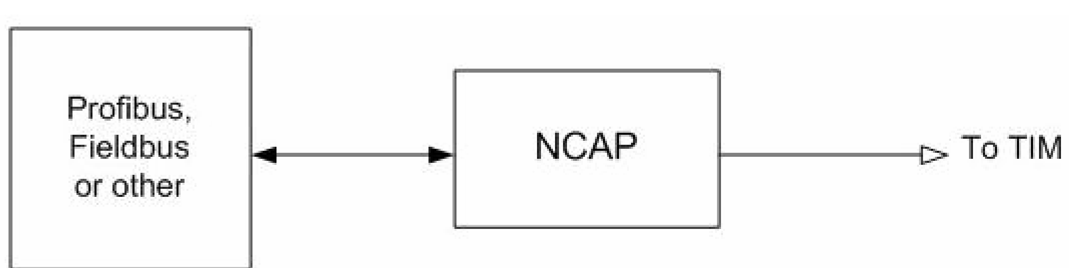
- Internet/Ethernet



- PC Readout



- Industrial network

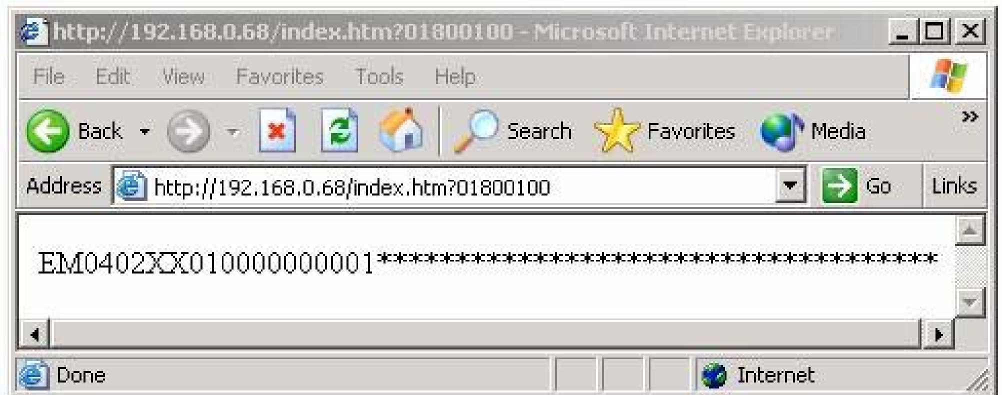


All use Dot 0 protocol

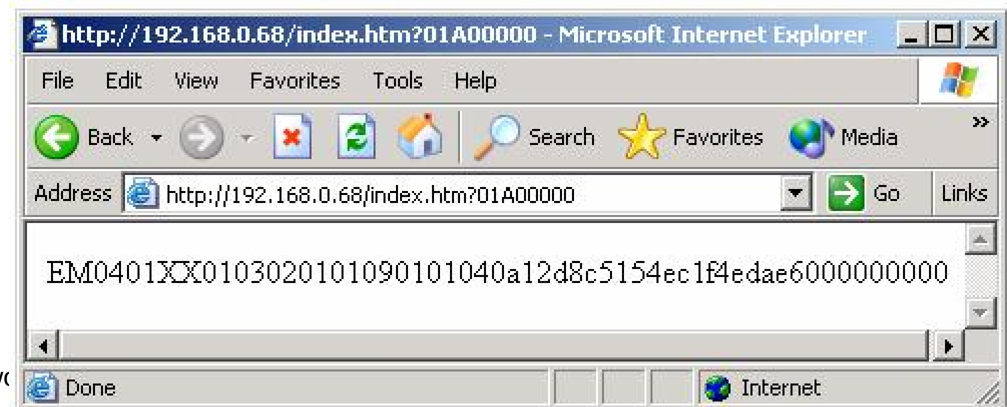
Data Readout Examples

(via Internet)

- Sensor data converted to ASCII for display

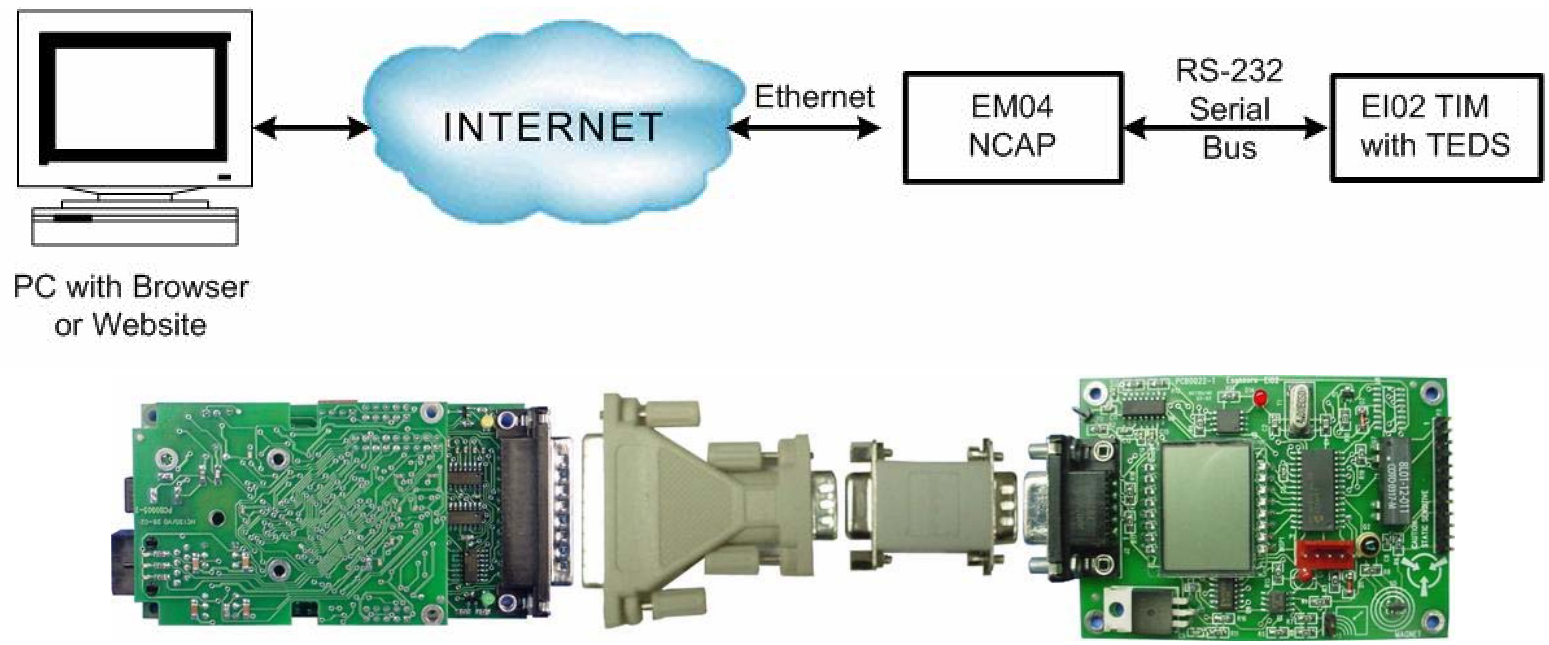


- TEDS data is displayed in hexadecimal form



Prototype TIM and NCAP

- NCAP interfaces to Internet via Ethernet



TIM Tester – Data retrieval

Serial Bus Format
and Relation to other Networks

- Tester uses RS232 serial bus only but…
- Interfaces to other physical devices (USB, RS485, Bluetooth, Zigbee, ….) available.
- TEDS retrieval is one feature
- Sensor data read (protocol check) for each channel:

  Idle mode – full scale value of sensor reading

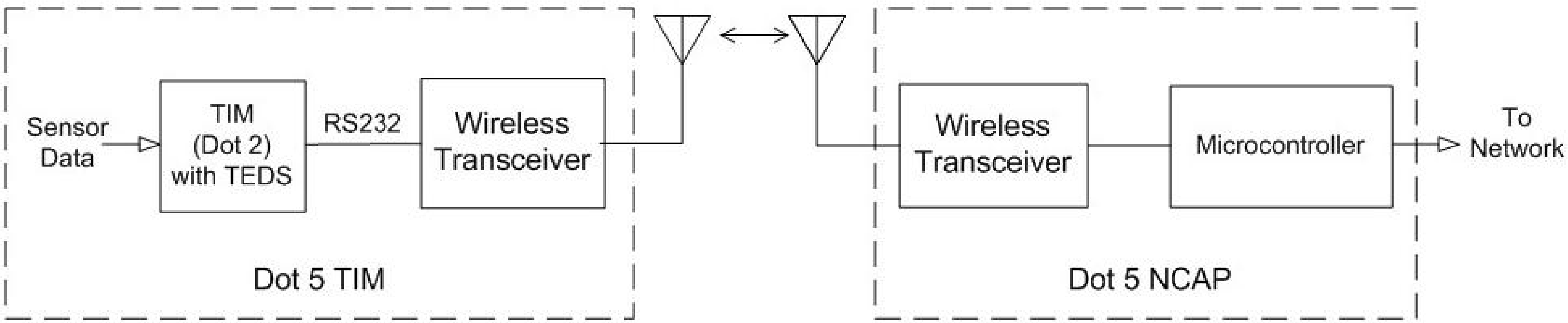
  (Checked against TEDS, error flag is not correct)

  Operating mode – actual sensor reading

  (Must be within sensor range)

Example – Wireless Connection

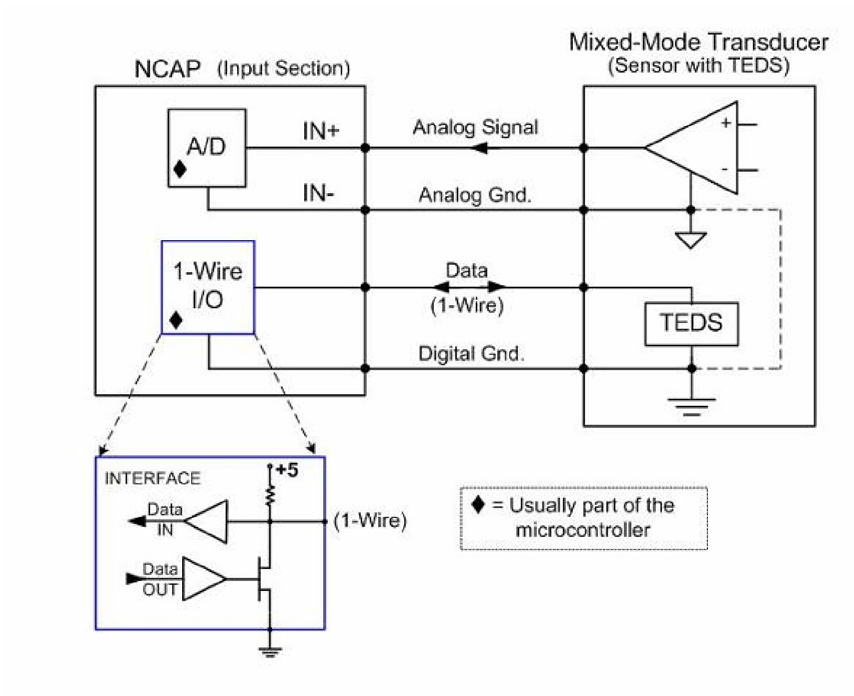
- <u>Wireless modules with RS232 I/O</u> when connected to Dot 2 TIMS are similar to IEEE 1451.5 TIMs (wireless version of IEEE 1451).
- Data format and TEDS are the same (both follow the Dot 0 standard)..

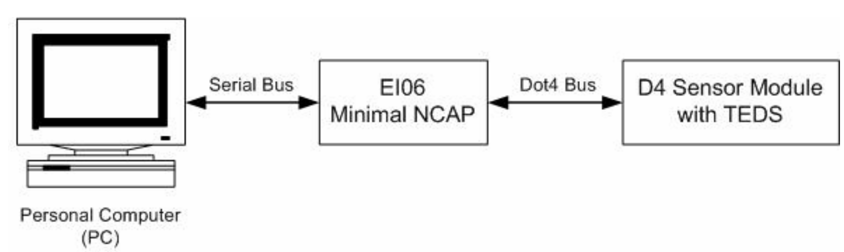


Dot 5 TIM built from a Dot 2 TIM and wireless transceiver

Alternative Tester for Dot 4 TEDS

IEEE 1451.4 (only) does not use the Dot 0 format TEDS. This is a small, TEDS-only version (no digital data format is specified by the standard).





Transducer Electronic Data Sheet (Dot 4 TEDS)

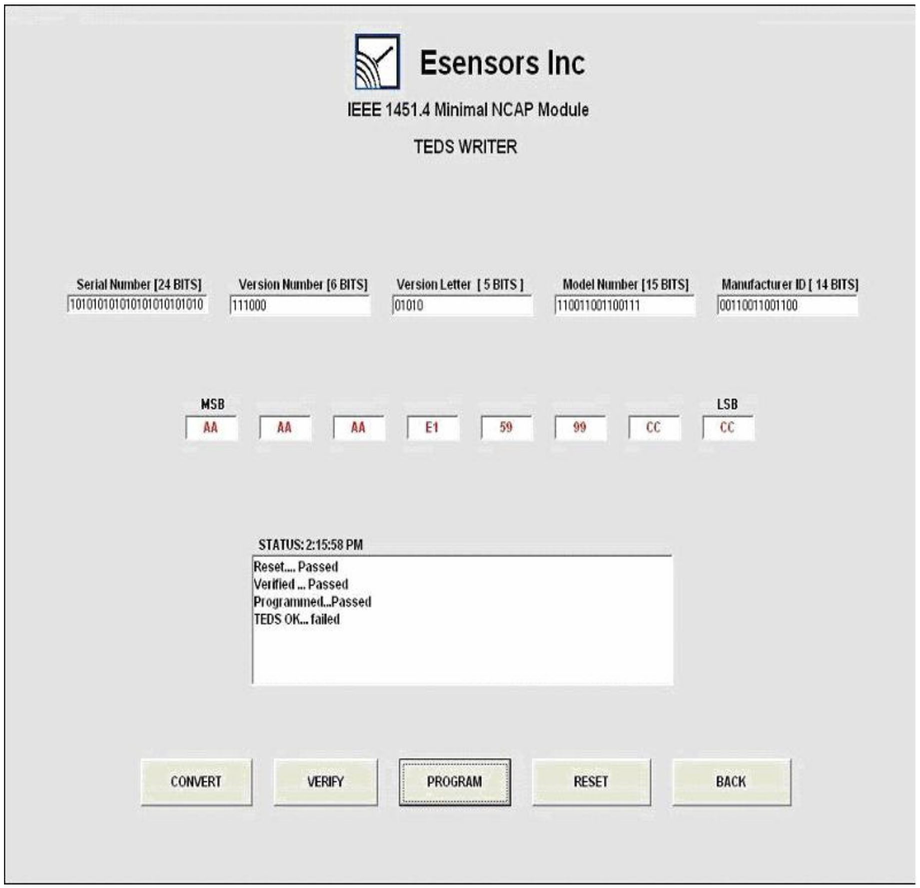
- UUID (Universal **Unique** Identifier)
  Supplied by EEPROM (DS2433) manufacturer (6 bytes)
- Basic TEDS (8 bytes)
  - Model Number (15 bits)
  - Version Letter (5 bits, A-Z)
  - Version Number (6 bits)
  - Manufacturer ID (14 bits)
  - Serial Number (6 bits)
- Manufacturer's TEDS
  Sensor type and calibration parameters (16 bytes)

Conversion to Dot 0 TEDS possible (but not unique)

Dot 4

Dot 4 TEDS Writer and Reader

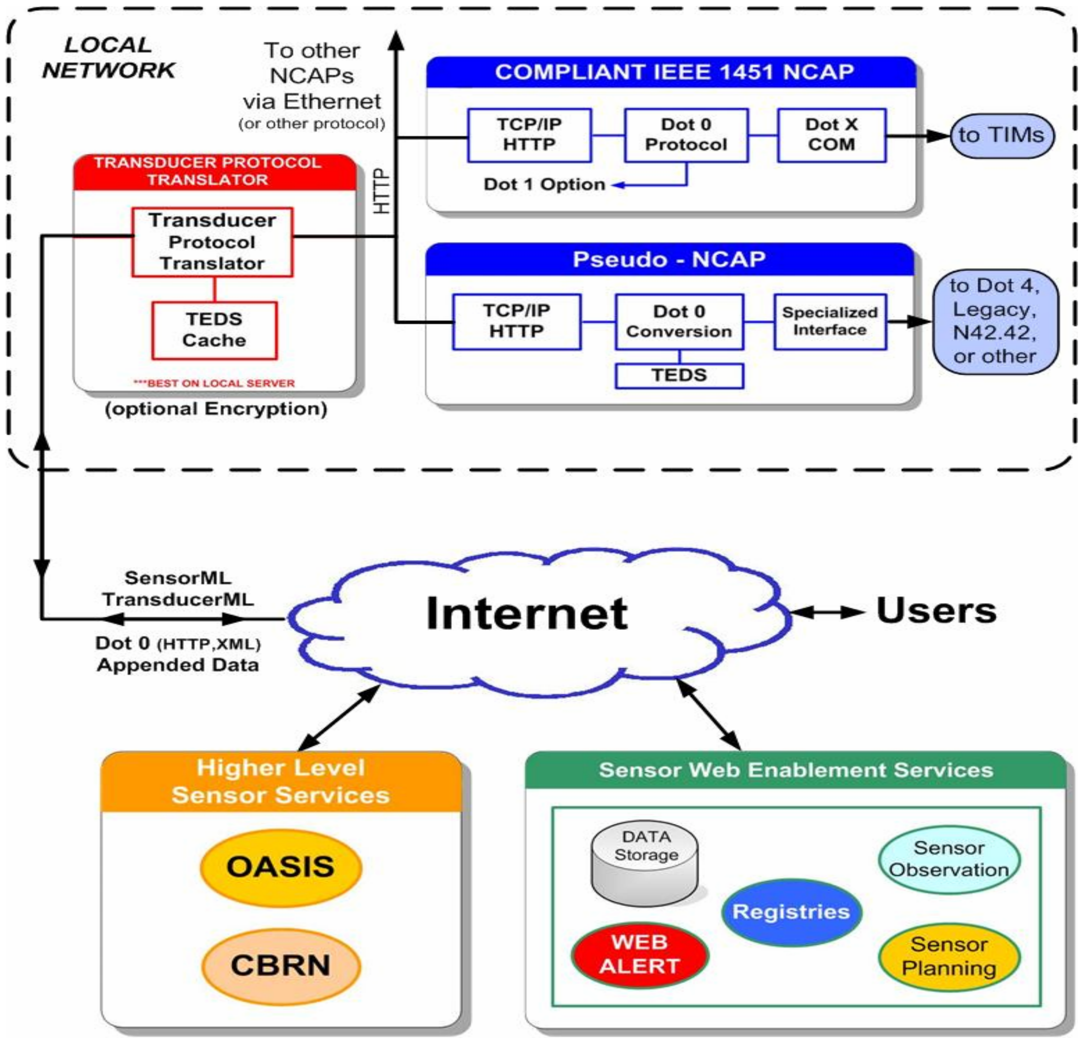
(PC Screens)



Writer

Reader

Harmonization of IEEE 1451 with other sensor standards

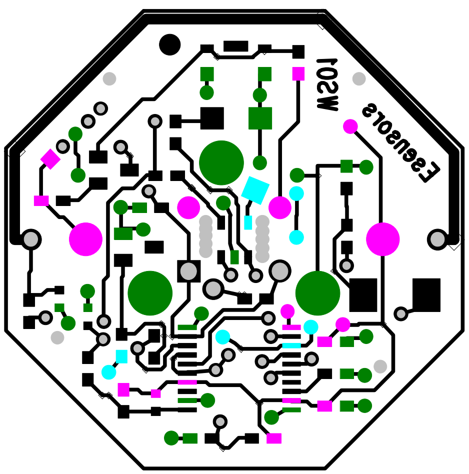


Wireless Sensor Networks

- Currently fashionable in academic and VC circles
- Recently available low-cost, high performance RF transceiver chips greatly simplify design
- Improvements in embedded microcomputers and smart sensor design also make wireless sensors much more practical now
- Can be lower cost and easier to use than wired sensors
- Point-to-point and mesh protocols available.
- Specialized sensor networks (e.g. Zigbee) much more efficient for wireless sensors, especially battery operated.
- Lack of standards inhibiting growth of industry.

Wireless Sensor Example

- WS01 wireless temperature sensor
- 433 MHz FSK – range 10 to 100 meters
- 3-volt coin battery



Printed Circuit Board (back)

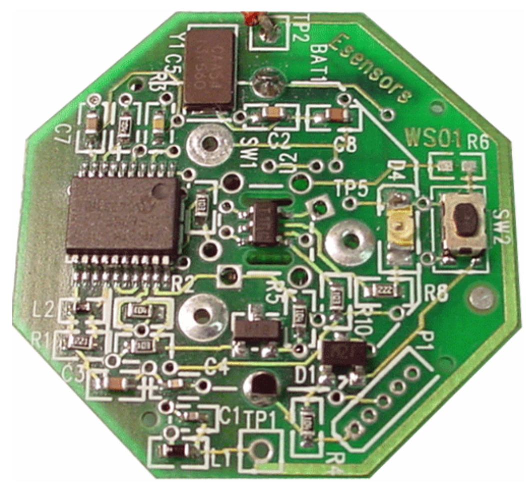


Photo (front)

RFID with Sensors

- Combines Radio Frequency IDentification with sensors
- Uses standard (ISO/IEC) RFID communication/format with additional sensor memory section
- Sensor format is based in IEEE 1451 protocol
- Typical application is tracking and monitoring perishable shipments (temperature, shock/vibration)

Summary

- Electronic sensors and signal conditioners were reviewed
- Smart sensor design examples given
- Wired and wireless sensor networks were discussed
- The importance of sensor network standards (IEEE 1451) were stressed
- Comment made on networked sensor futures

Contact: designer@eesensors.com