A Multi-channel Smart Strain Sensor with IEEE 1451 Protocol

Darold Wobschall

Esensors Inc.

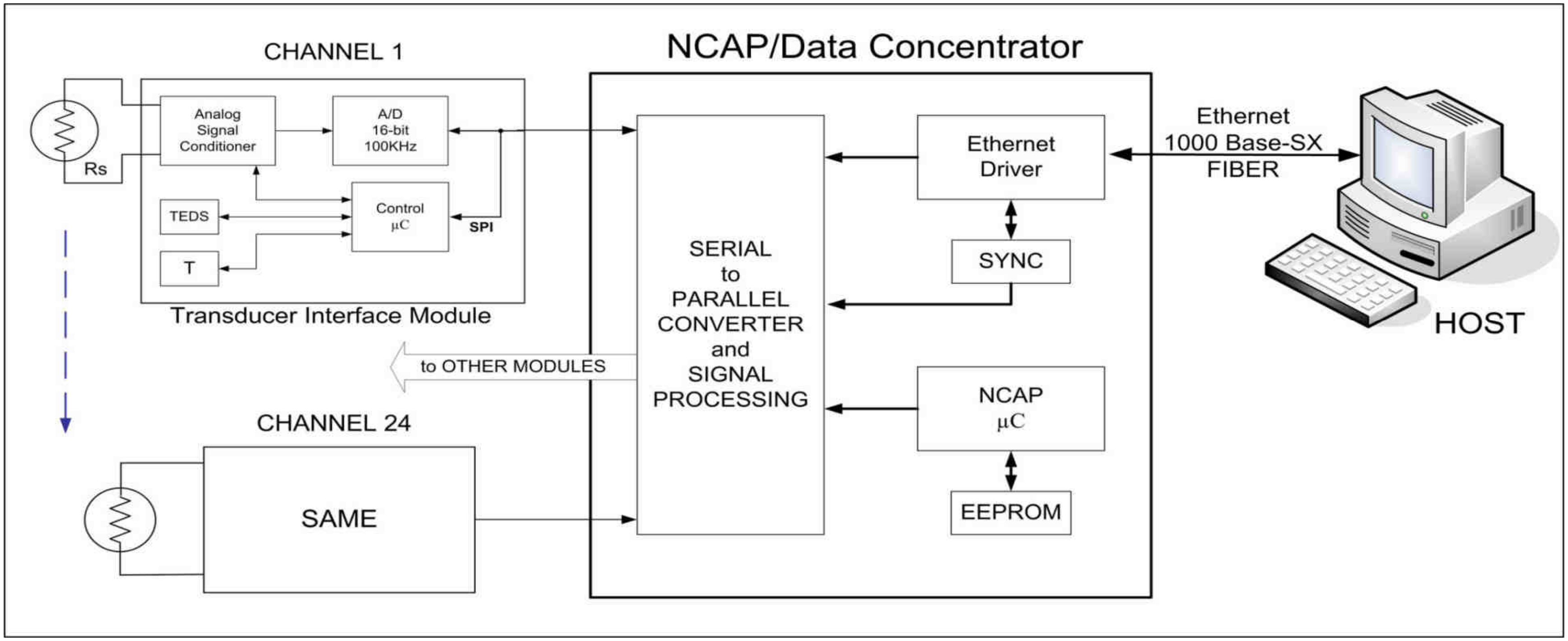
23rd Annual Transducer Workshop

Buffalo NY, June 2008

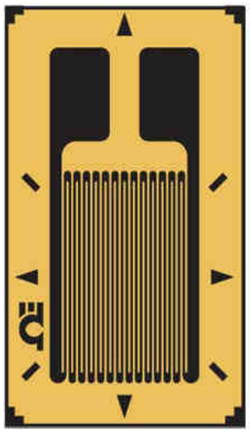
Project Goals

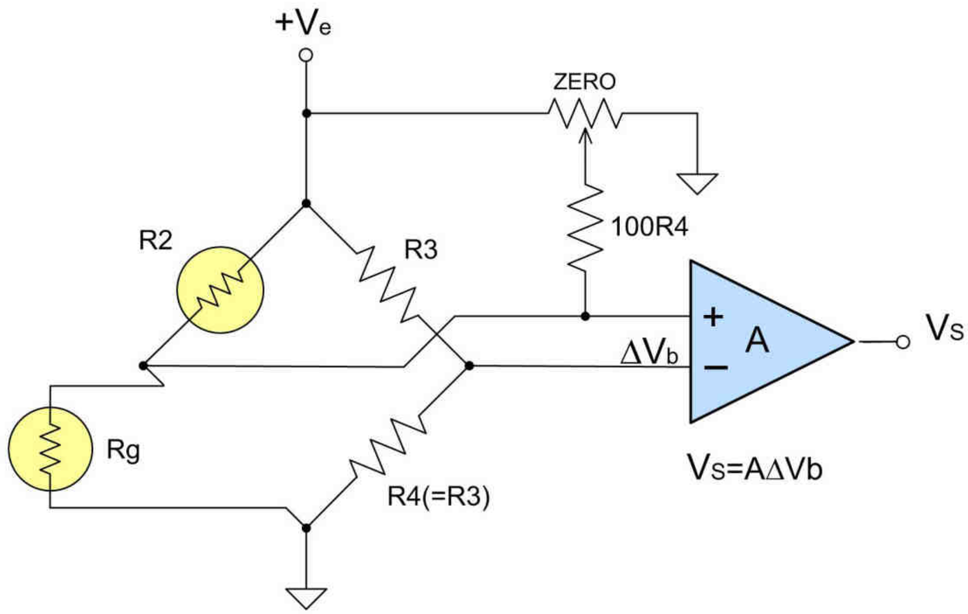
- Design & test high performance strain gage data acquisition system (up to 24-channel)
- Provide high speed real time data link
- Provide precision time stamp
- Use IEEE 1451 Protocol (emphasis of this presentation)

System Block Diagram



Basic Strain Gage Bridge





The bridge output, for one active element (1/4-bridge) is:

$$\Delta V = \frac{Ve\,\Delta R}{4Ro} = \frac{Ve\,G_f\,\varepsilon}{4}$$

Strain gage signal conditioner

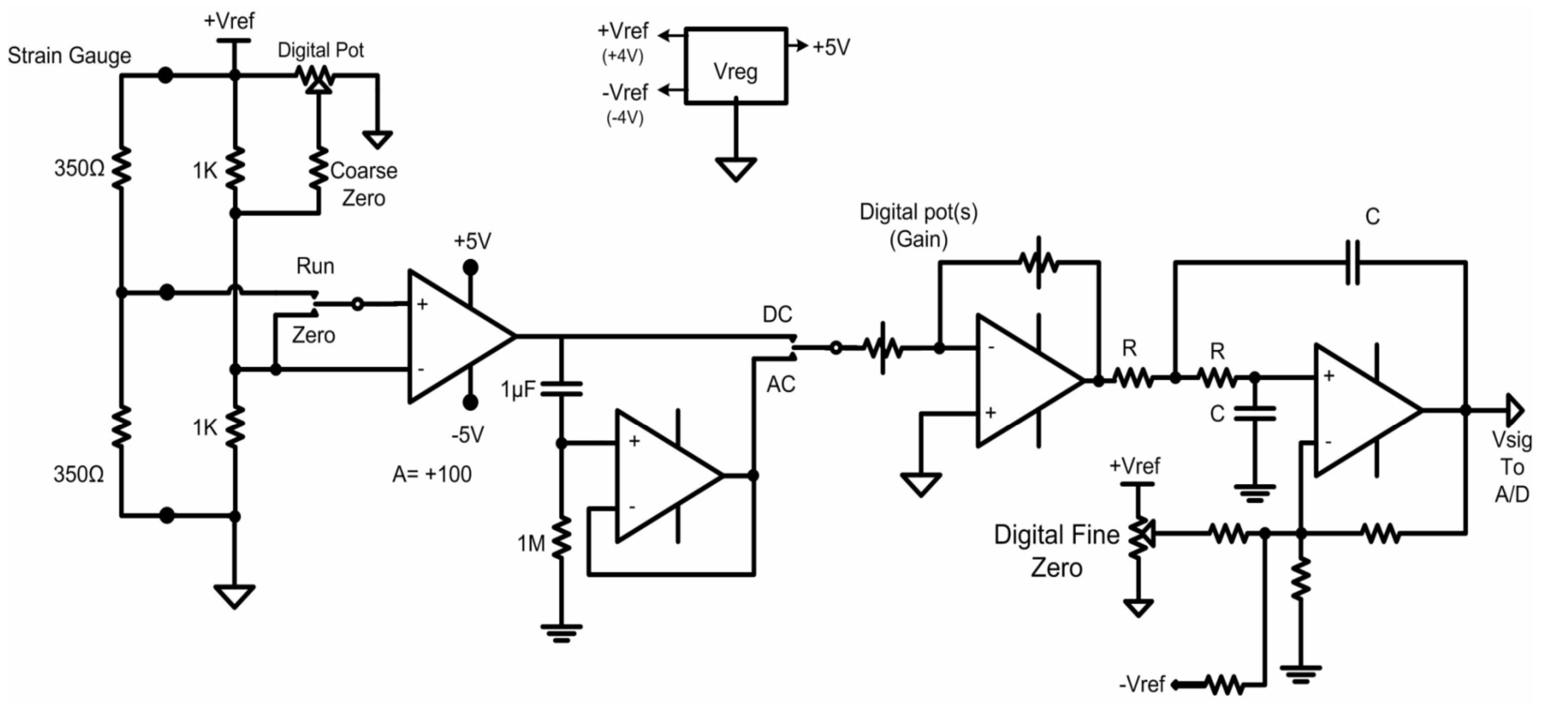
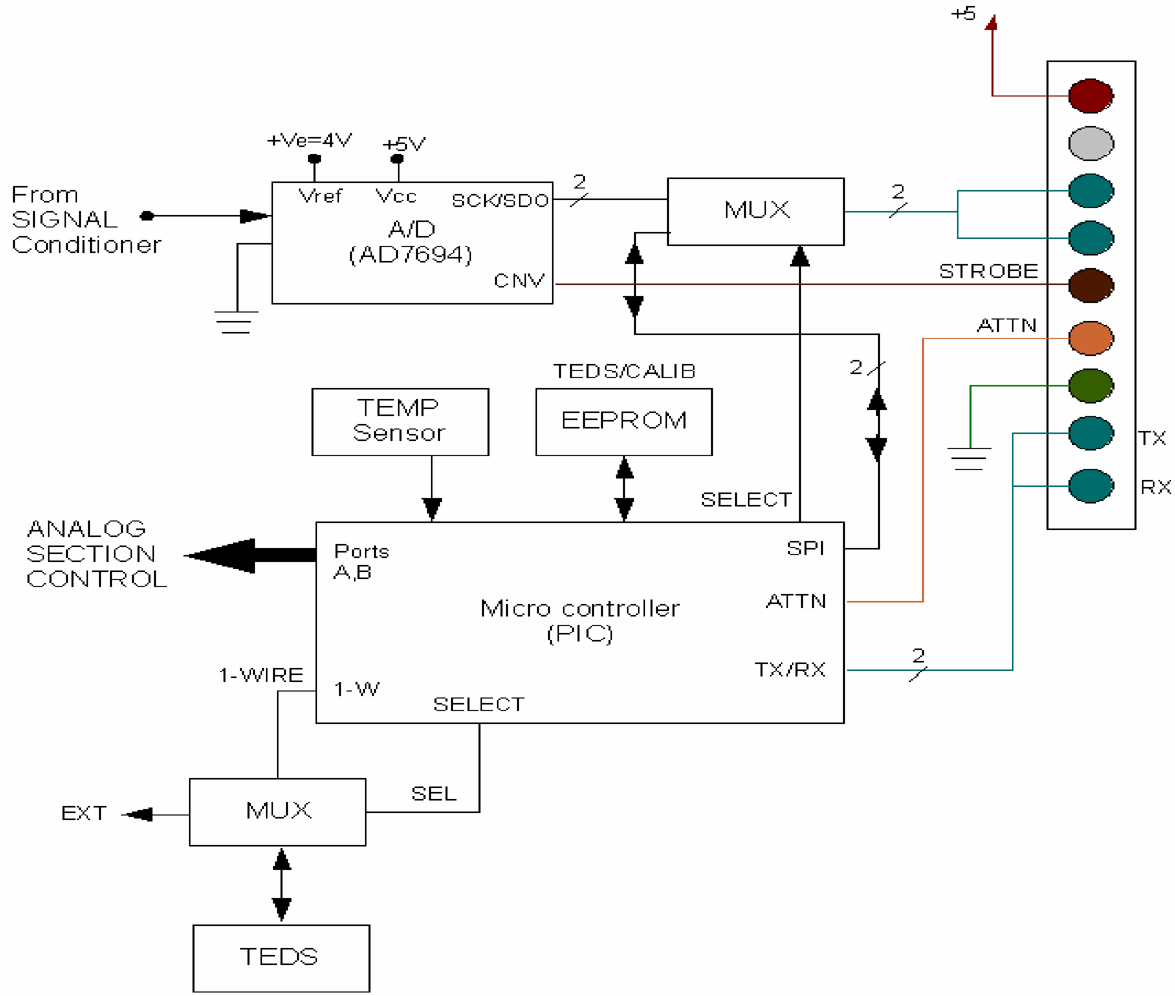


Figure 2.

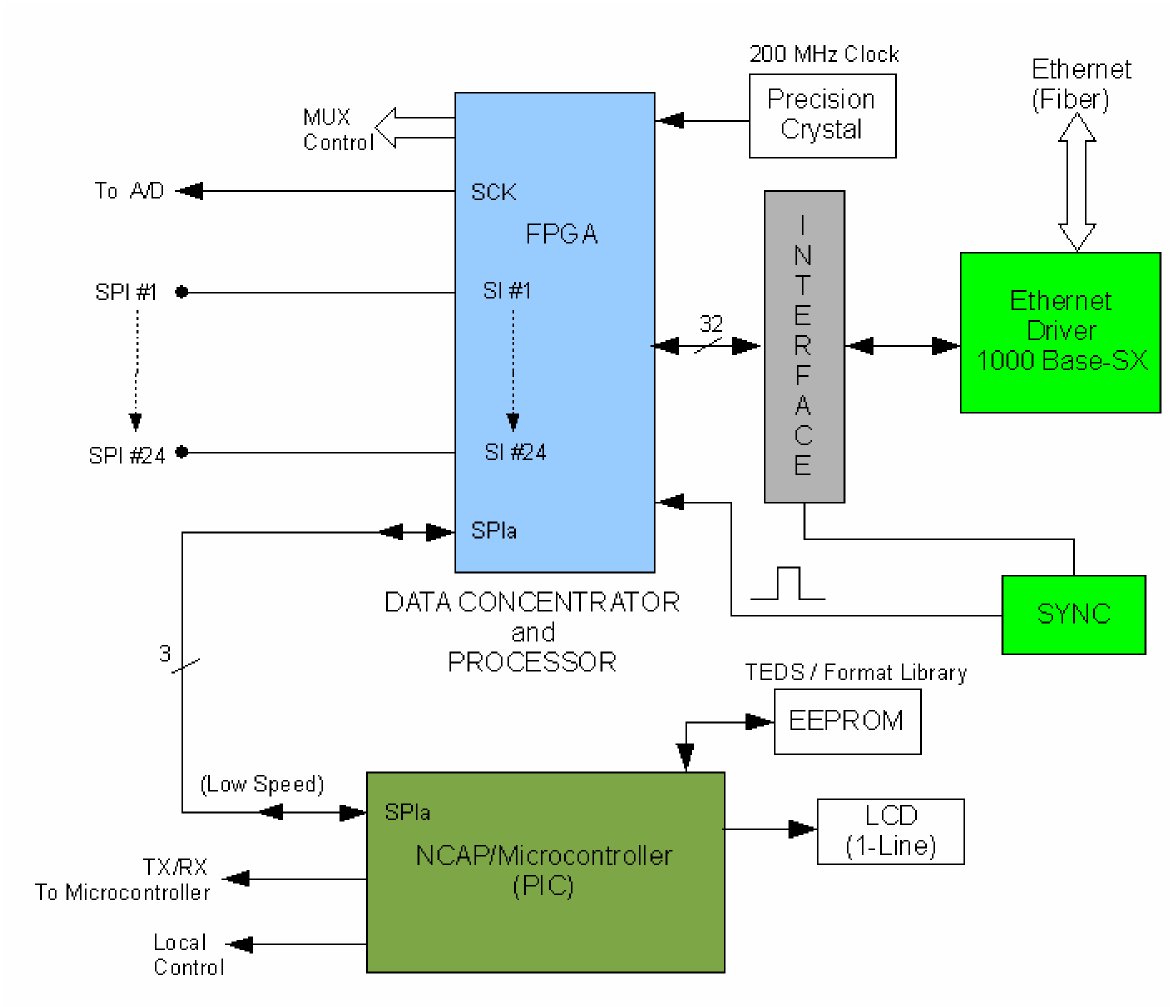
System Features

- Coarse and fine digitally controlled bridge zeros
- Full, half or quarter bridge
- Gain variable in x2 steps (digitally)
- Low noise, fast response amplifiers
- Adjustable high frequency break points
- AC or DC coupling
- Proper analog ground, bypass and shielding
- Transducer Electronic Data Sheet (TEDS)
- Expandable to various sensor technologies

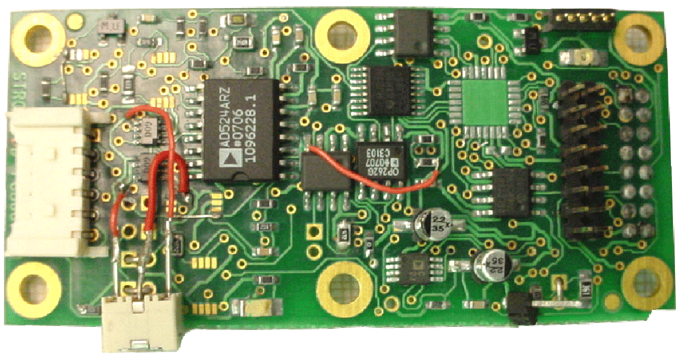
A/d and control section

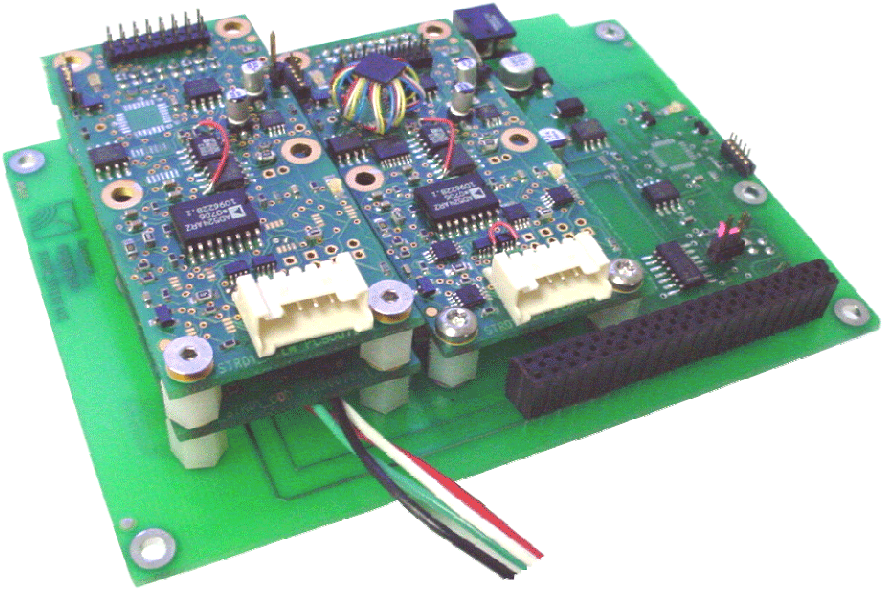


Signal assembly and reformatting

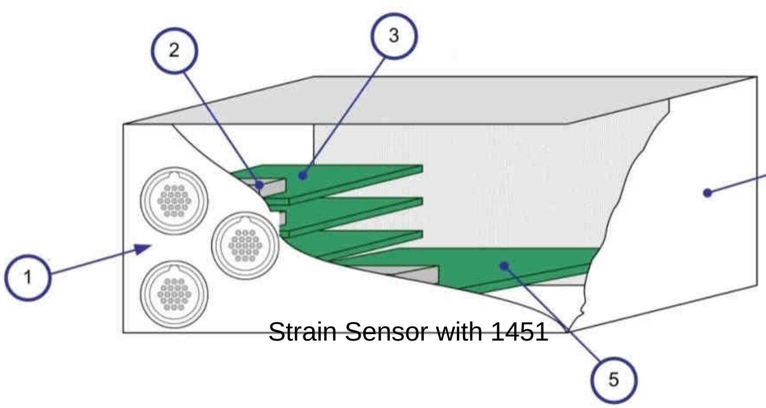


Circuit board realizations

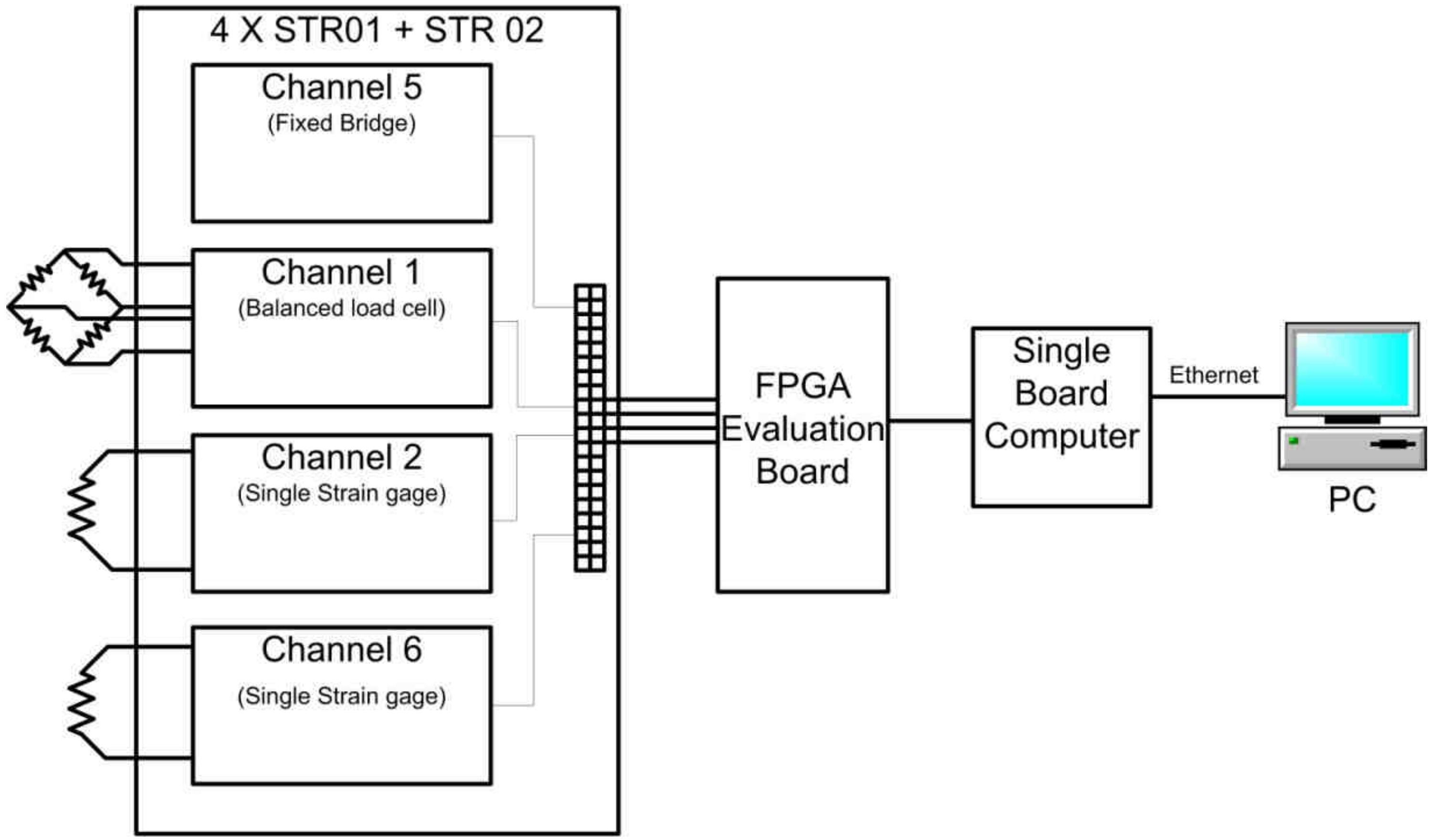




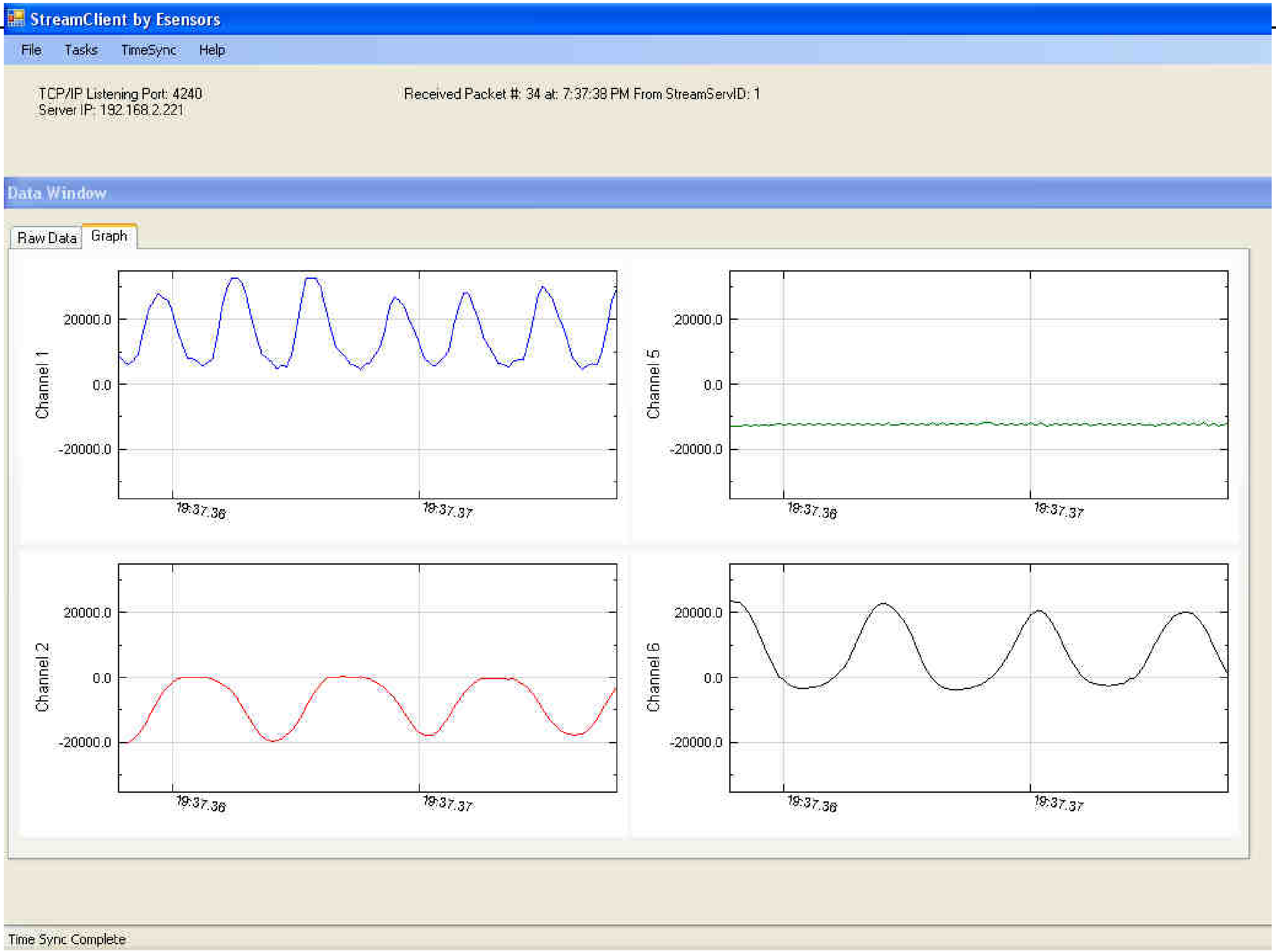
Signal conditioner board stacking



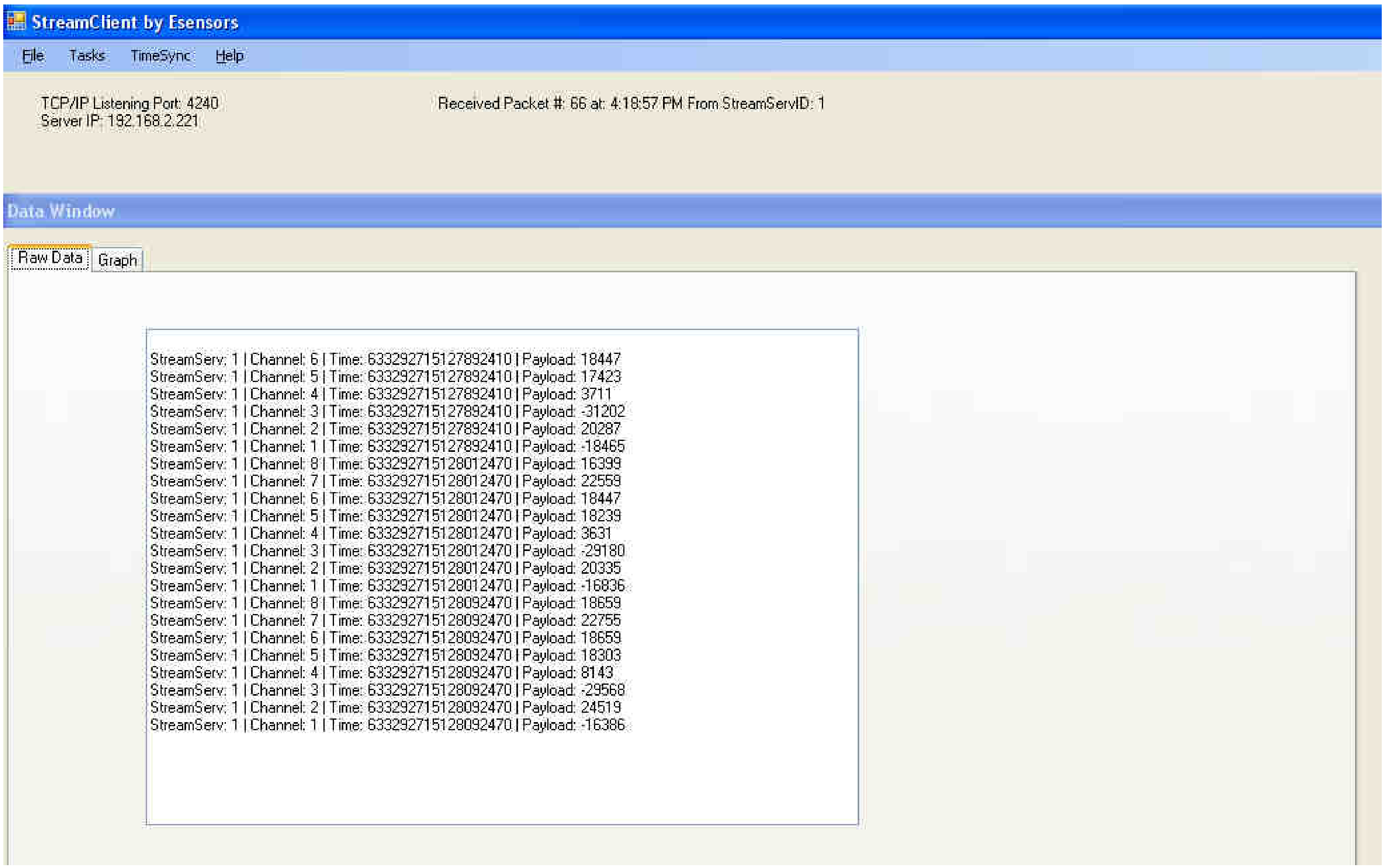
Test setup


4 X STR01 + STR 02
Channel 5
(Fixed Bridge)
Channel 1
(Balanced load cell)
Channel 2
(Single Strain gage)
Channel 6
(Single Strain gage)
FPGA
Evaluation
Board
Single
Board
Computer
Ethernet
PC

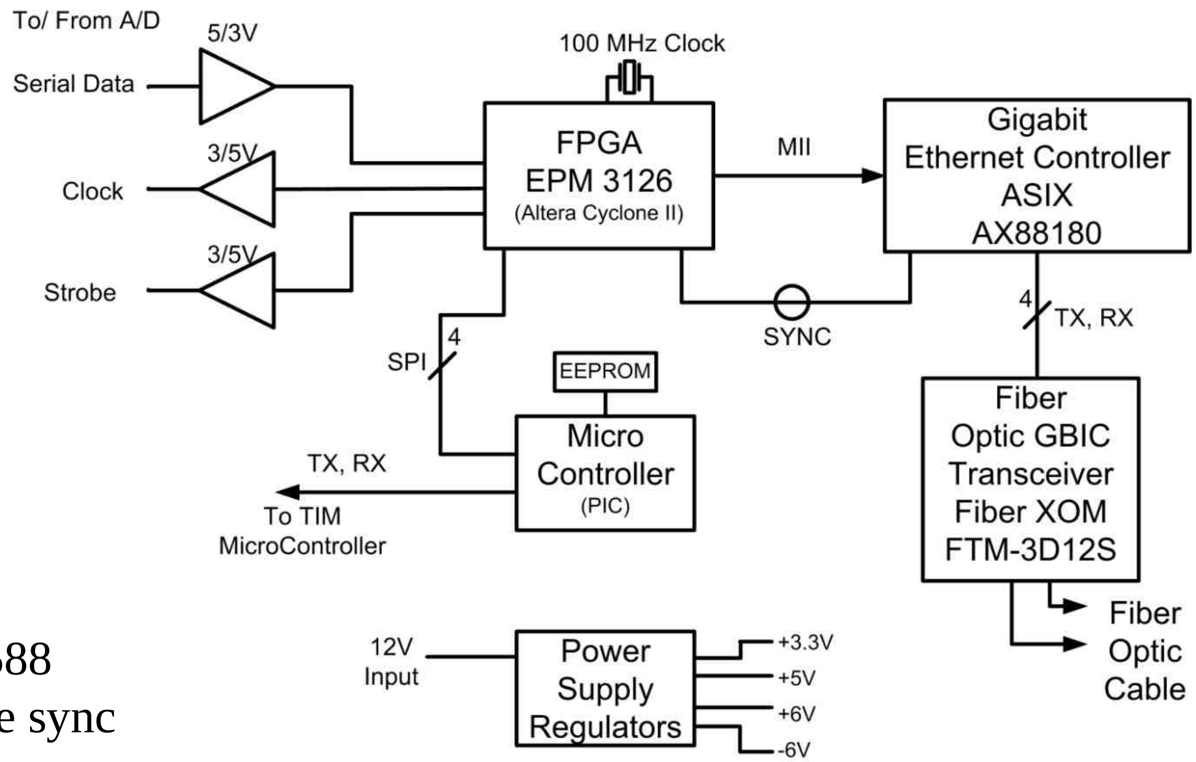
Test Results (analog)



Example of Transmitted Data



Proposed 24-channel system



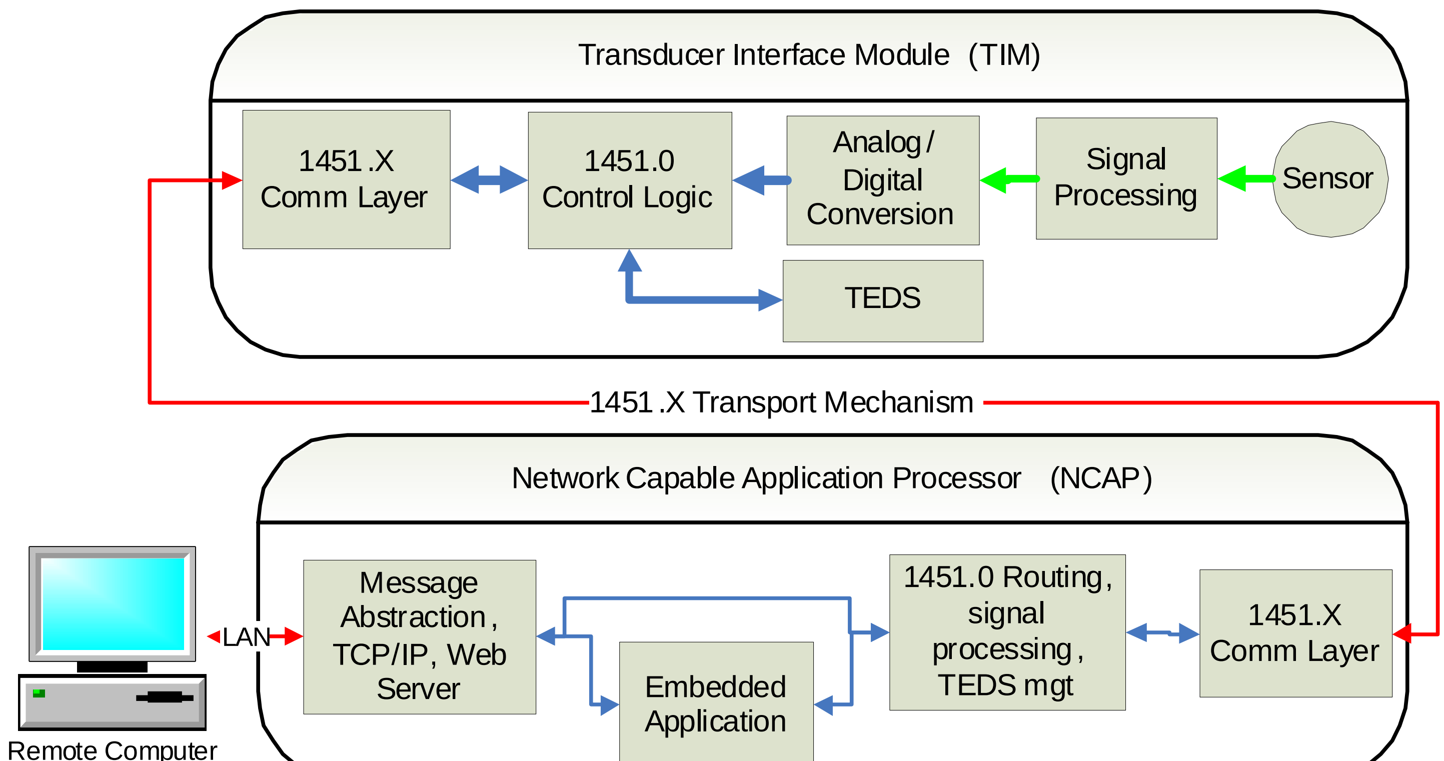
Uses IEEE 1588
concepts for time sync

Use of
IEEE 1451 Universal Sensor Format

- Provide full, unambiguous data transfer format
- Allow mix of multiple sensors
- Automatic configuration (plug and play)
- Transducer Electronic Data Sheet (TEDS)
- Provide time synchronization option

A review of the

IEEE 1451 Smart Transducer Concept



IEEE 1451 Advantages

- 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).
- Comprehensive enough to cover nearly all sensors and actuators in use today (not 20/80% approach)
- Efficient binary protocol (especially suitable for wireless)
- Standard is 400+ pages for basic part, over 1500 page total

Status of Various Parts of IEEE 1451

1451.0 – Basic data/TEDS format	**Done (2007)**
1451.1 – NCAP/Computer Interface	Done (1999)*
1451.2 – RS-232	Done (1997)*
1451.3 – Wired Multi-drop	Done (2002)*
1451.4 – TEDS Only	Done (2005)
1451.5 – Wireless (WiFi, Zigbee, etc)	Done (2007)
1451.6 – CAN Bus	In process
1451.7 – RFID	In process

* Needs revision

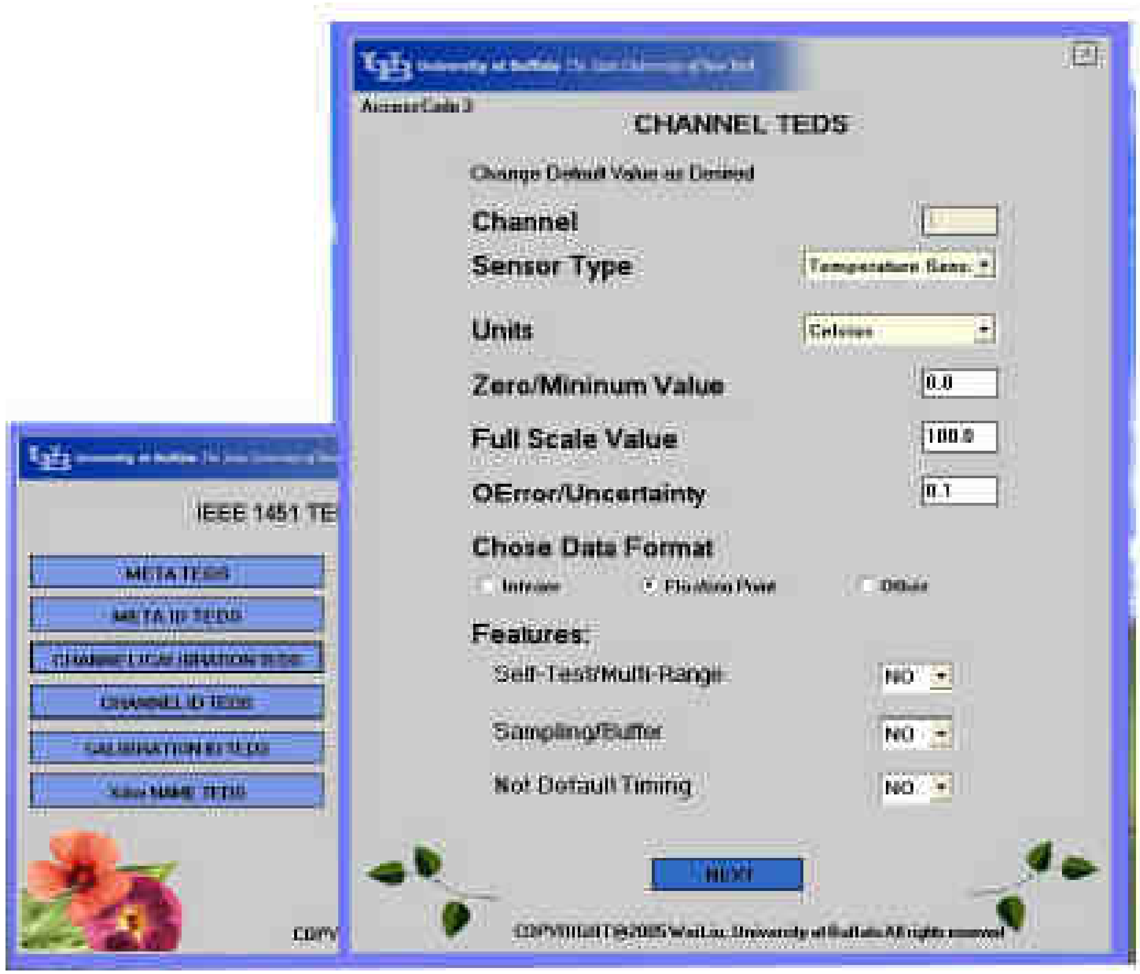
IEEE 1451.0 (Dot 0) TEDS Format

- 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 Compiler

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



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

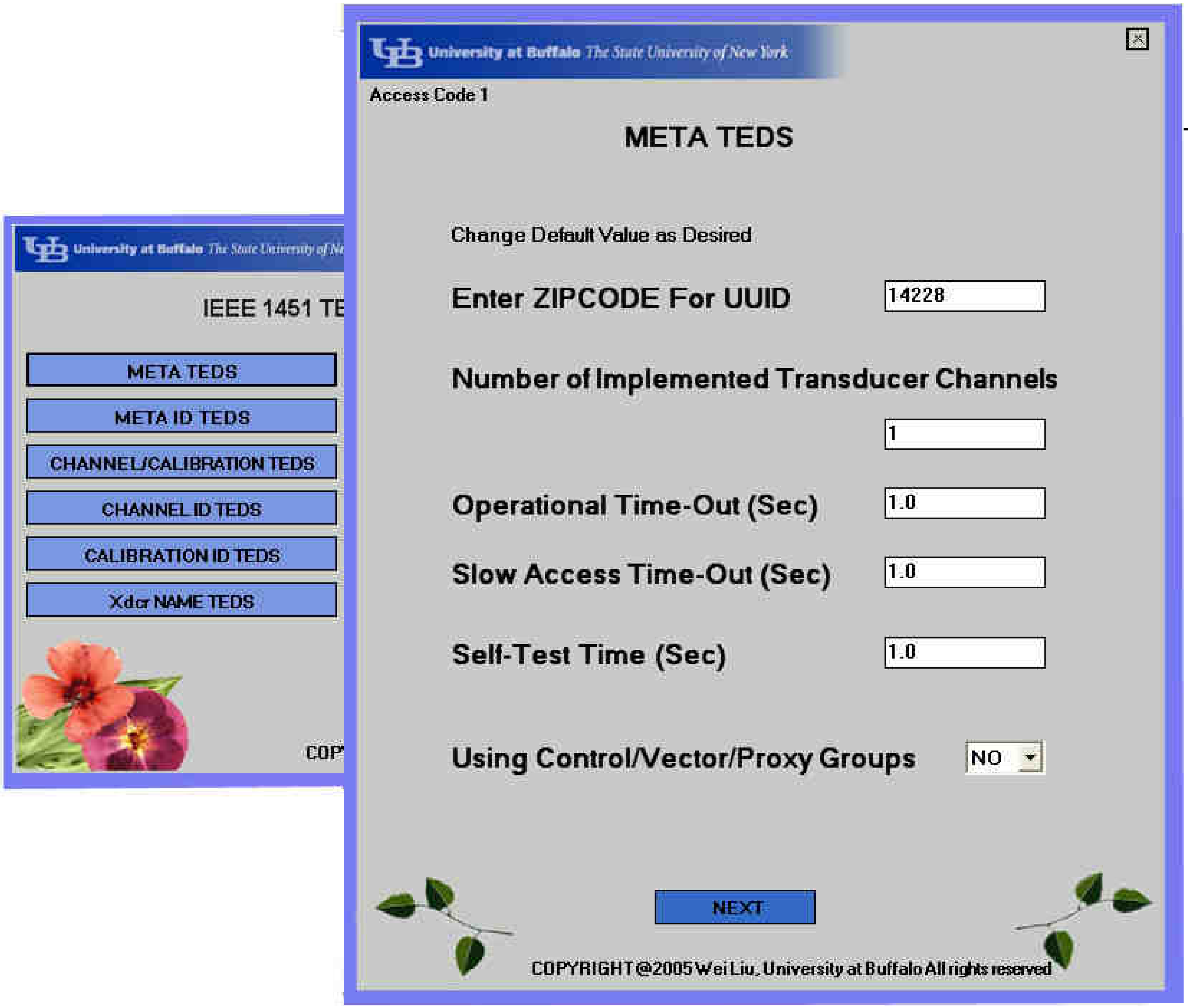
Byte Number	Description
1	Destination Transducer Channel Number (Most significant byte)
2	Destination Transducer Channel Number (Least significant byte)
3	Command Class
4	Command Function
5	Length (Most significant byte)
6	Length (Least significant byte)
7-N	Command dependent bytes

NCAP Command Message Structure

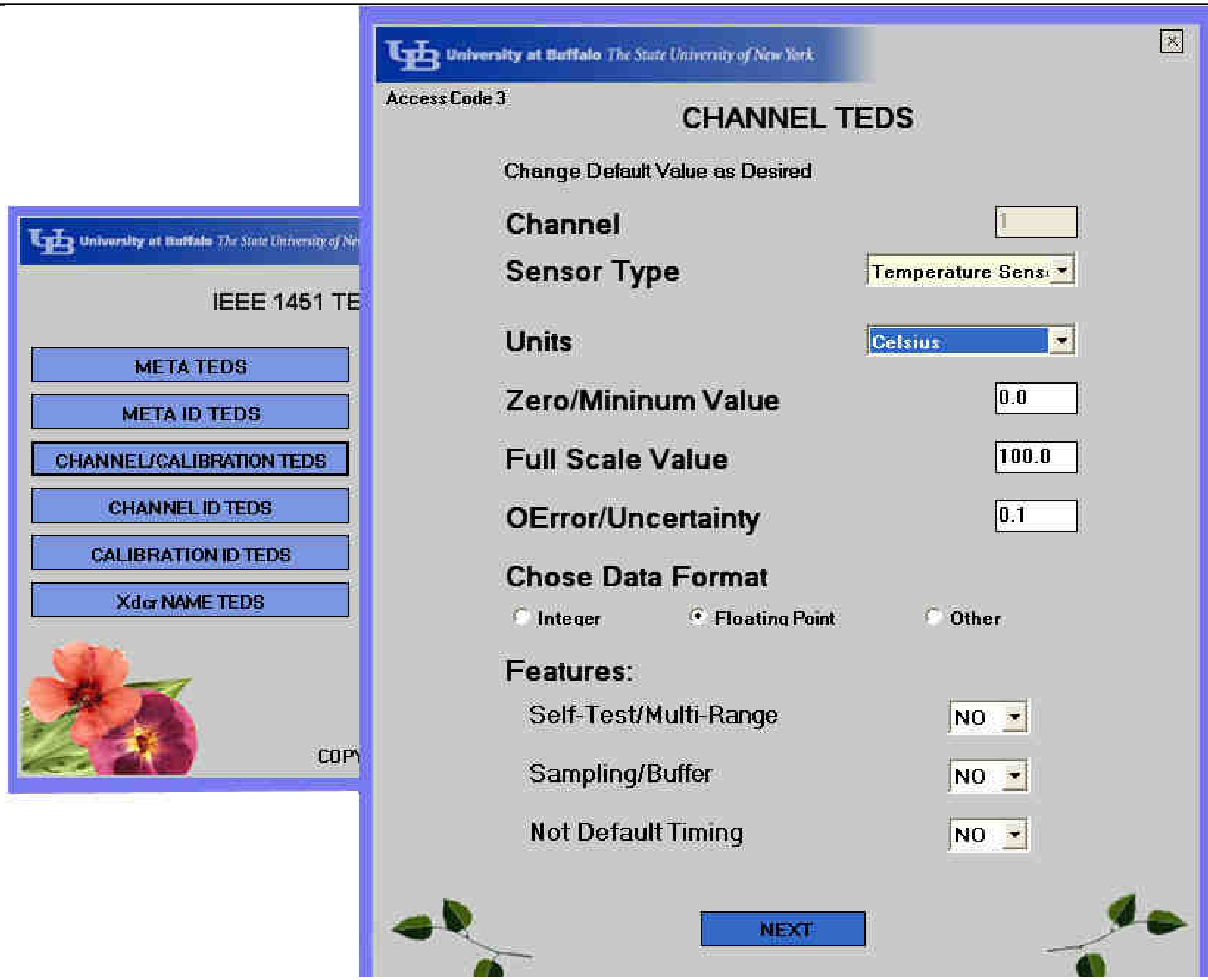
Byte Number	Description
1	Success/Fail Flag
2	Length (Most significant byte)
3	Length (Least significant byte)
4-N	Reply dependent bytes

TIM Reply Message Structure

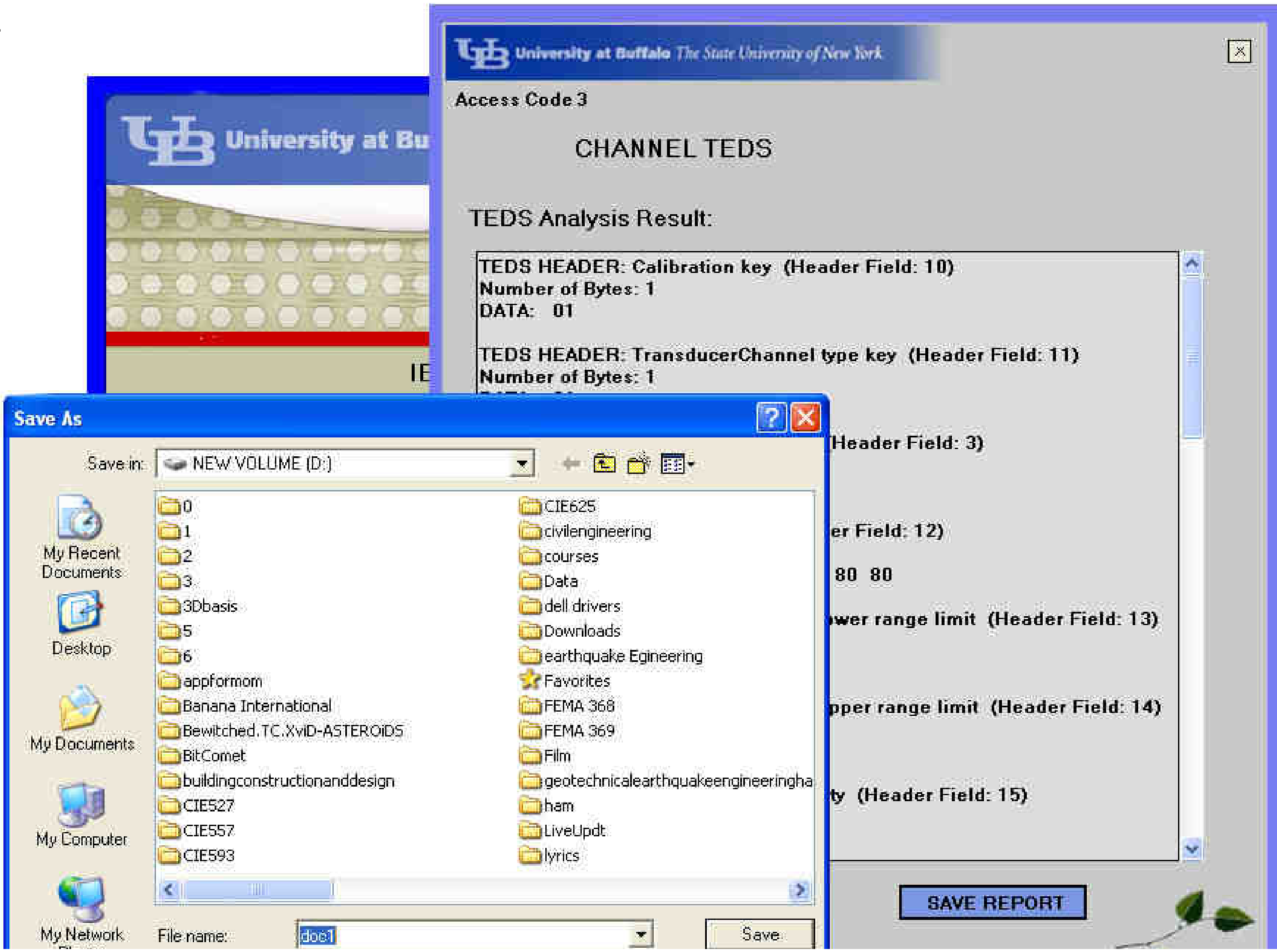
Meta-TEDS Writer Screen



Channel/Calibration TEDS (for linear sensors)

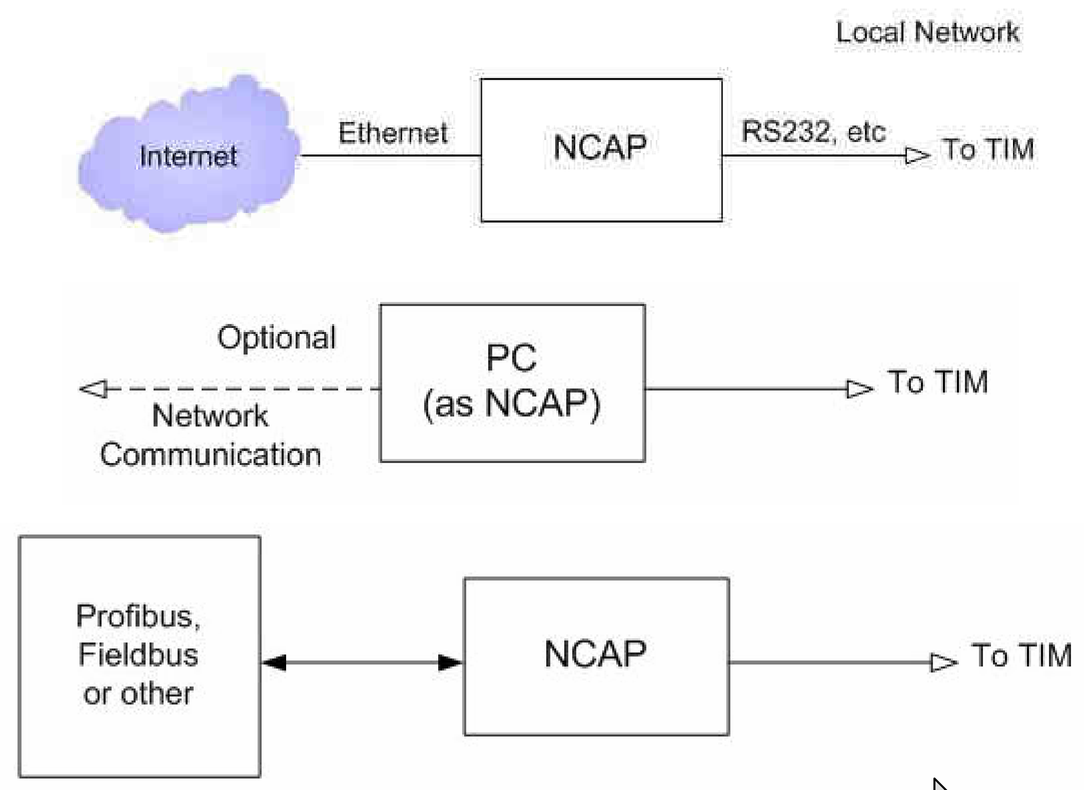


TEDS Reader


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
SAVE REPORT
Save As
Save in: NEW VOLUME (D:)
My Recent Documents
Desktop
My Documents
My Computer
File name: doc1
Save

Network side (NCAP) options
(wired)

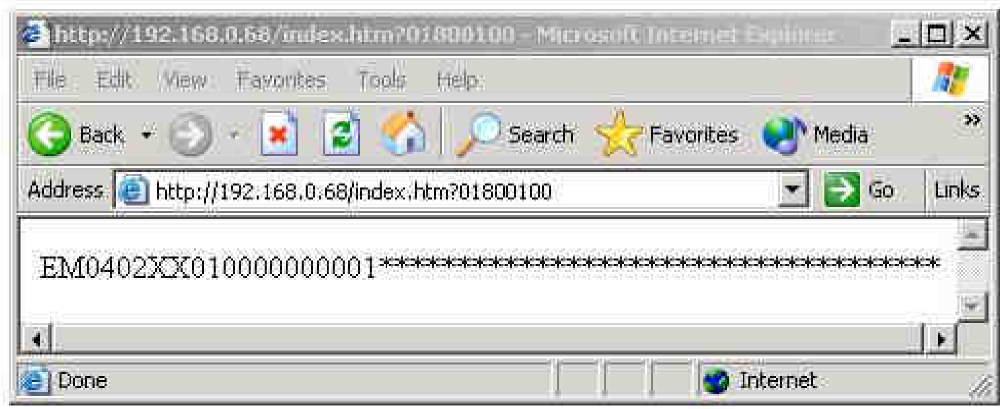
- Internet/Ethernet
- PC Readout
- Industrial network



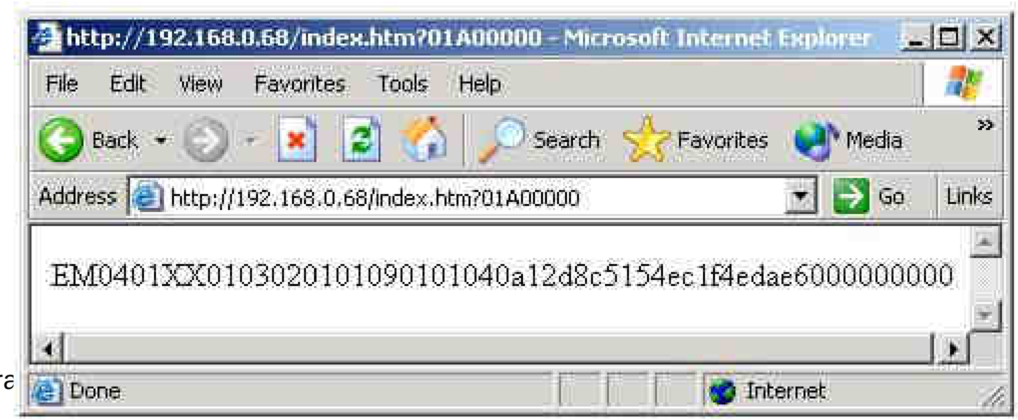
All use Dot 0 protocol

Data Readout Examples
(via Internet)

- Sensor data converted to ASCII for display



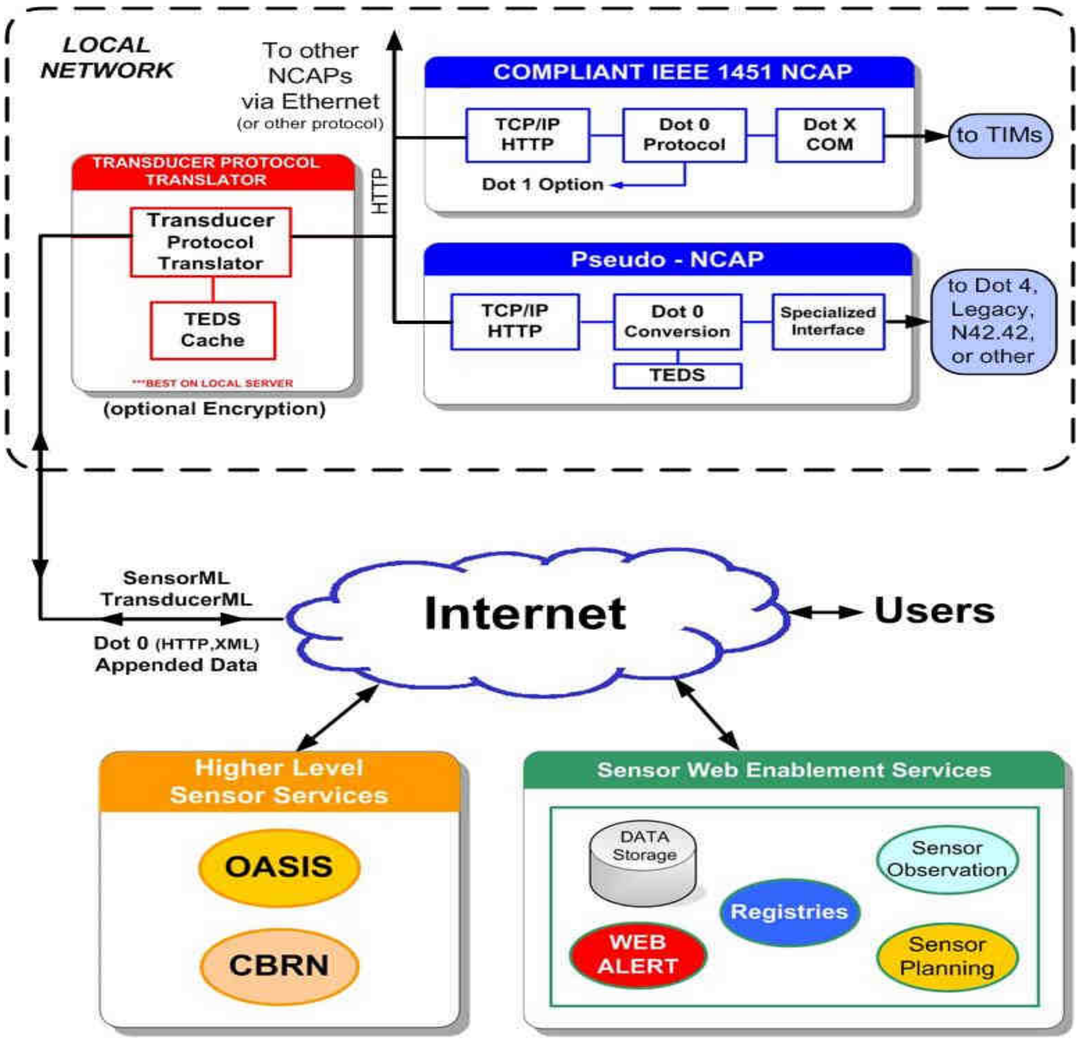
- TEDS data is displayed in hexadecimal form



IEEE 1451 as a Universal Digital Sensor Base Format

- Specialized networks can handle only a limited number of sensor types or uses non-compact format
  - 1451 is much superior at the sensor end
- Most applications require individualized displays or graphical user interfaces – 1451 is a fixed format and poorly suited at the user end
- Network oriented applications prefer XML or similar formats which are convenient, but are too verbose at the sensor end
- 1451 at the sensor end (Sensor Fusion level 0) combined with translators is the best solution.

Harmonization of IEEE 1451 with Internet sensor standards

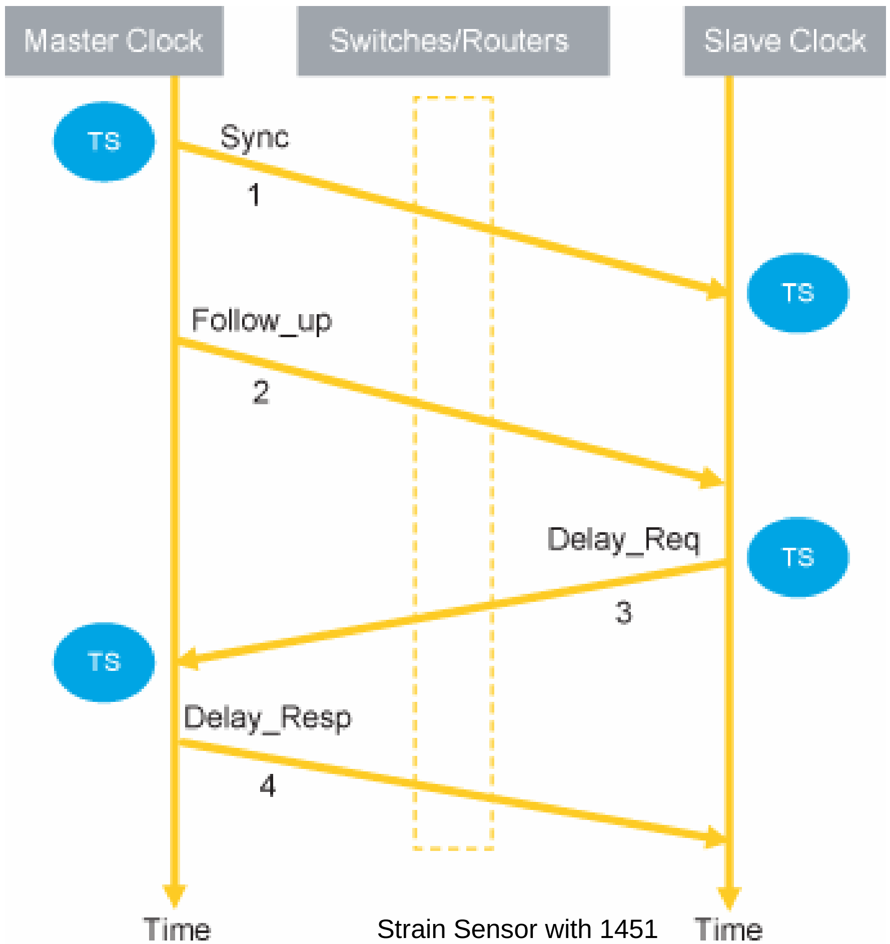


Future Prospects for IEEE 1451

- There has been little interest in previous parts of IEEE 1451 (Dots 2, 1 & 3), except for Dot 4 in certain areas.
- The basic Dot 0 (and Dot 5) are more carefully composed and thus likely to be accepted.
- The compiler may answer the complexity issue but still implementation of any full-featured standard will be difficult.
- The US government may mandate a sensor data standard and the NIST-supported IEEE 1451 is the most recognized candidate.
- The sensor industry, especially the wireless network sector, must recognize the business advantages of a single sensor data standard.

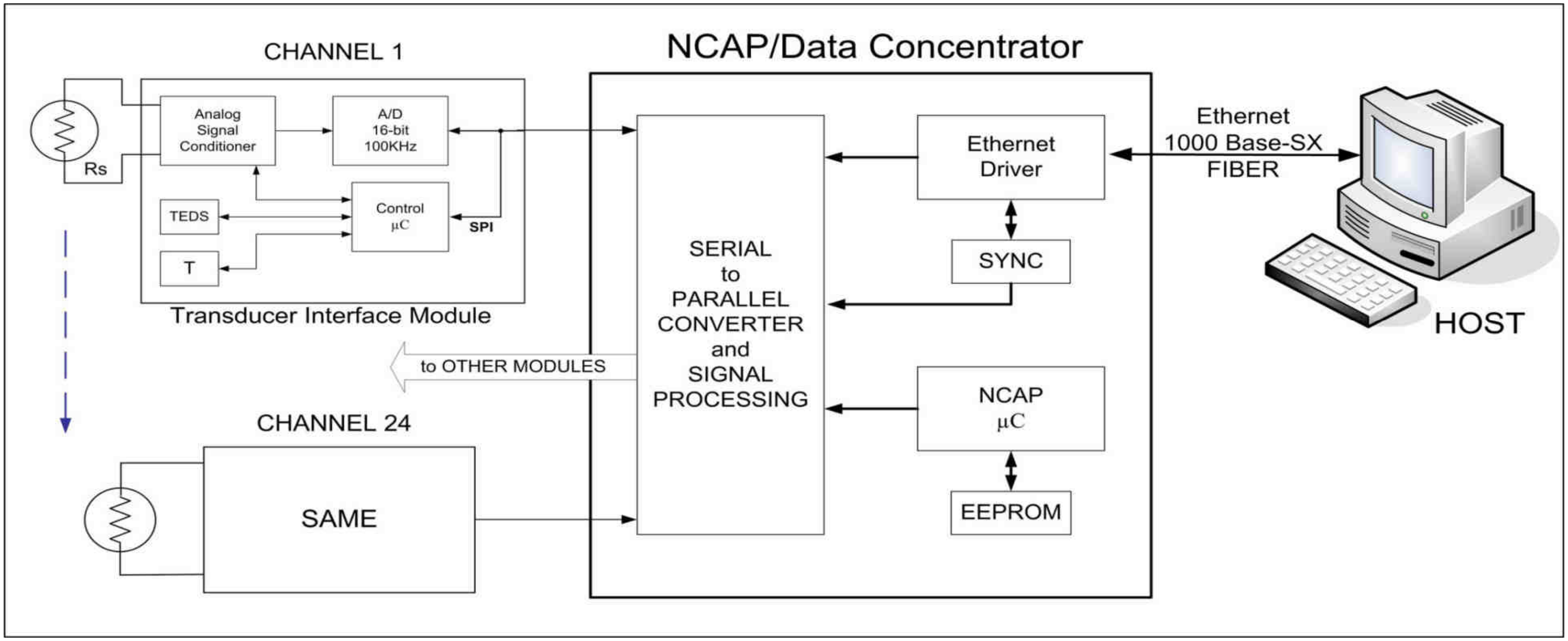
Time Synchronization

30



Based on IEEE 1588

Recall
System Block Diagram



Applications

- Especially suitable for mix of networked sensors
- Provides basis for plug and play
- Prov
- Present system easily adapted for:
  - stain
  - force
  - pressure
  - temperature
  - acceleration

Acknowledgements

- Supported by Arnold Air Force Base (SBIR, Ph I)
- Participating engineers
  - A. Cherian
  - K. Sielski
  - K. Chow
  - J. George
  - W. Liu

Summary

- High performance strain gage data acquisition system designed and tested
- Provides high speed real time data link
- Provides precision time stamp
- Uses IEEE 1451 Protocol

(which was discussed in some detail)

Contact: designer@eesensors.com

End

- Backup Slides Follow

www.eesensors.com

Harmonization Meeting Summary

(Held at NIST quarterly)

- 25-50 attendees, mostly government
- DOD, DHS, DJ, DS represented (also NASA subcontractor)
- All working under directives to implement standards
- DHS new directive requires new sensors to use existing open standards if available (not proprietary or invent new)
- DOD joint task group working on standards and expects to support test bed. Possible FY’10 requirement.
- Several test beds involving IEEE 1451 started (Esensors has some part in all).

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.

Future of Networked Sensors

- Computer-based monitoring and control applications are increasing in commercial, industrial and military sectors.
- Networked, and often wireless, sensors offer performance and cost advantages over traditional methods.
- Wider use of networked sensors is inhibited by lack of standards (especially National scale networks, wireless and multi-vendor, long-term installations).
- I expect sensor standard and harmonization efforts to succeed within 2 to 5 years and Federal Agencies (DHS, DOD; NASA) to favor IEEE 1451.

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

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)