Miniaturized Multi-Channel Thermocouple Sensor System

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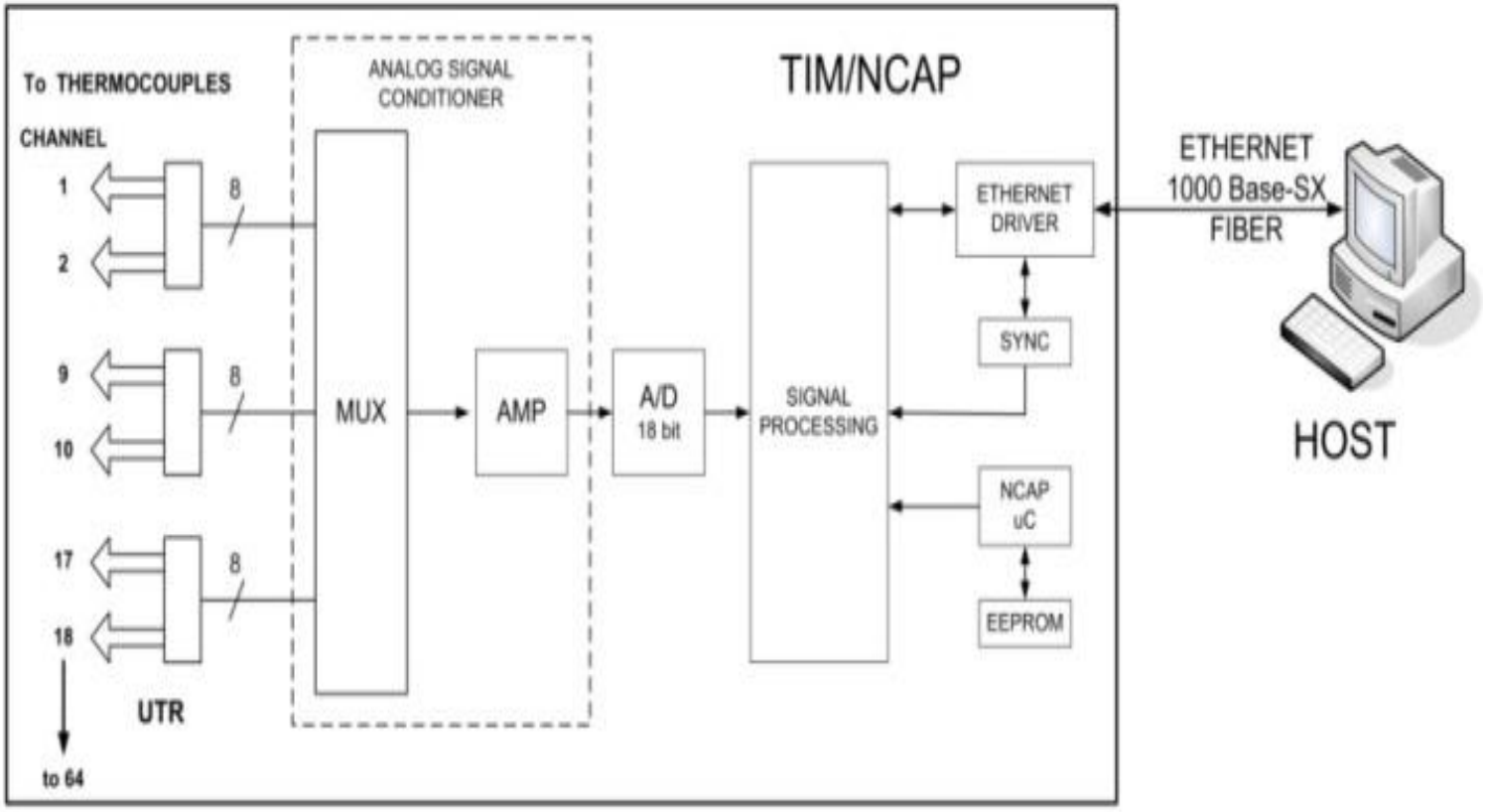
IEEE SAS 2011

Agenda

- Goals
  - Handles multiple thermocouples
  - Reference junction compensation
  - Fast and precise
  - IEEE 1451 format
- Contents
  - Thermocouple reference method
  - Amplifier and a/d
  - Data Concentration
  - IEEE format discussion

System Block Diagram



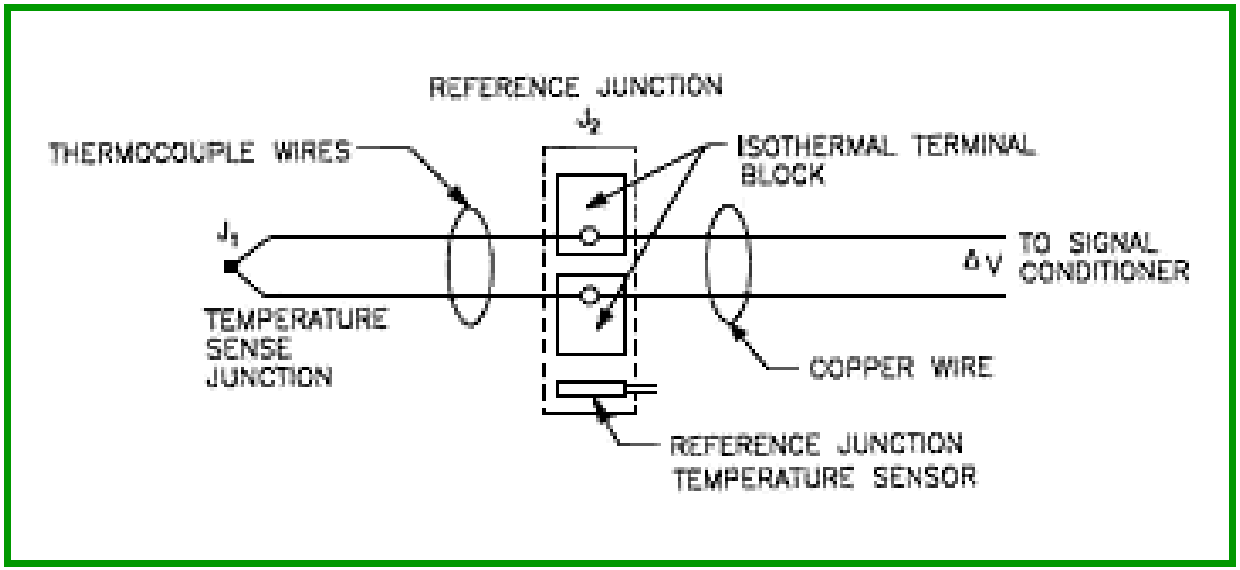
UTR: Uniform Temperature Reference

Features

- Grounded or ungrounded thermocouples
- 16 Channel (8 for prototype, later 64)
- Precision Uniform Temperature Junction (+/- 0.1 °C) using RTD
- Auto zero and thermocouple break test.
- Fixed gain input stage with anti-aliasing.
- Variable bandwidth (up to 2 kHz, 100 Hz initial)
- Low noise, fast response amplifiers
- Range of -100 mv to +100 mv (common TCs are -20 to +70 mv)
- Resolution of 1 µv
- Separate analog, digital and power ground, bypass and shielding
- Transducer Electronic Data Sheet (TEDS)
- Application: testing of engines

Thermocouple Reference Principle

- Law of the Junctions [$\Delta v = \alpha(T_1 - T_2)$]
  where reference temperature T_2 is same for both junctions
- Reference junction temperature measured precisely by RTD

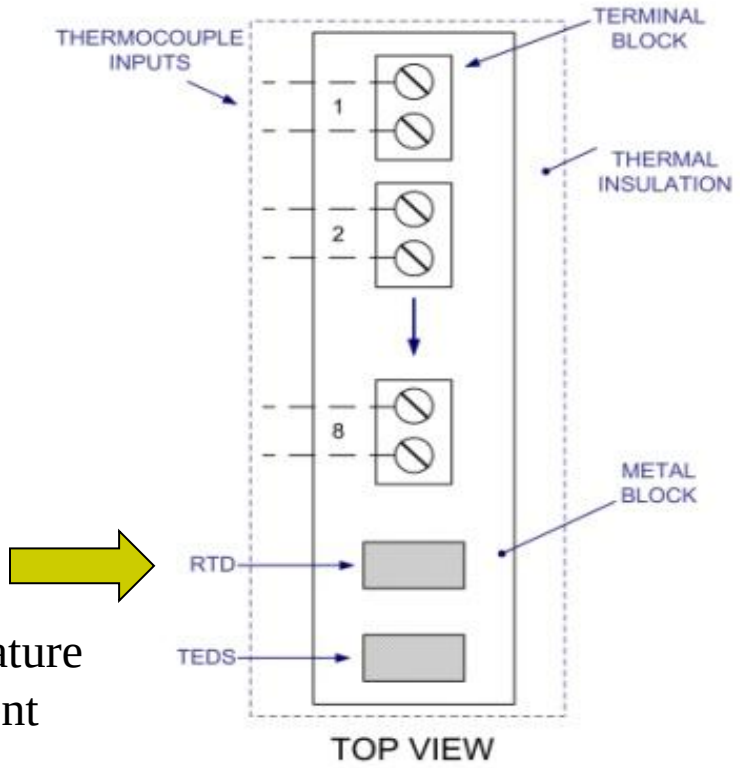


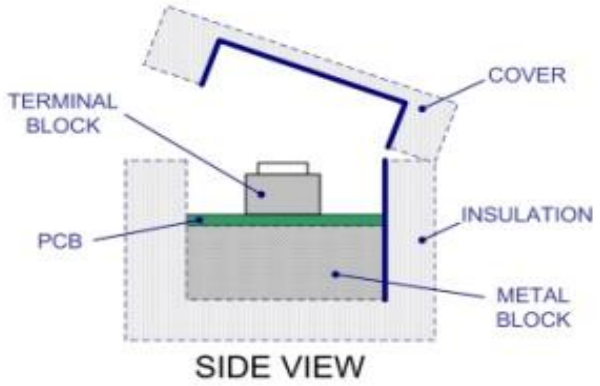
Principle of Reference Junctions

Thermocouple Reference

Uniform Temperature Reference

- (8 thermocouples for prototype)

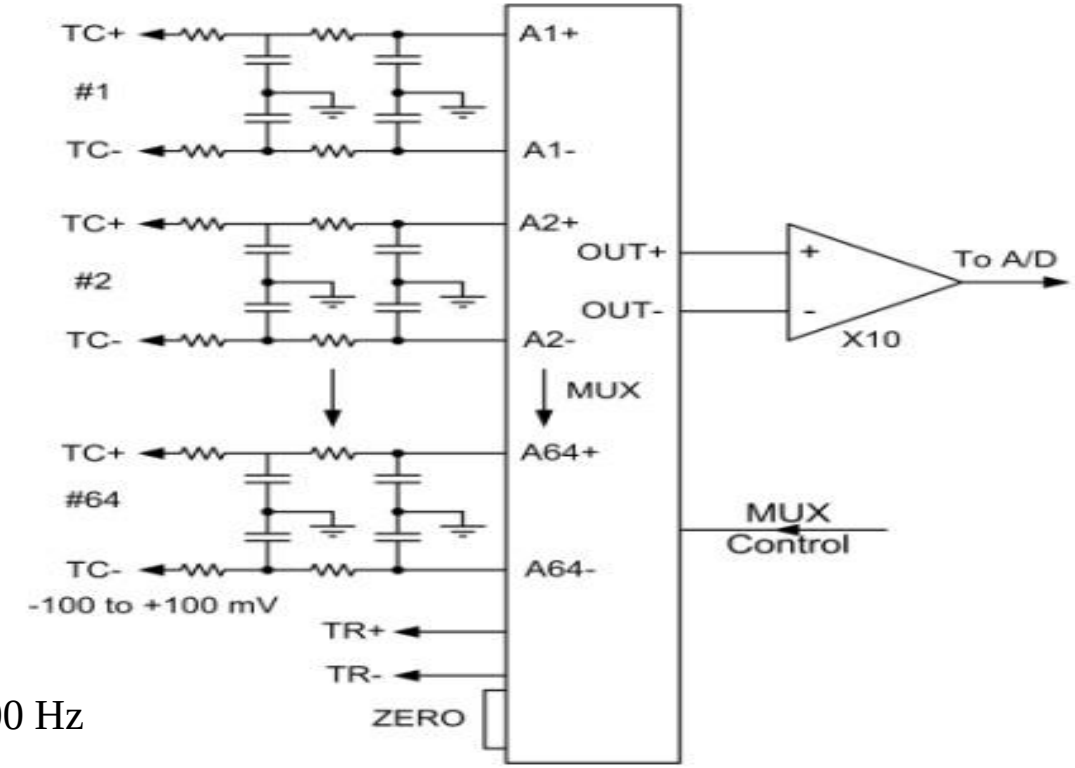




Block temperature measurement

Input Section
(with filters and multiplexer)

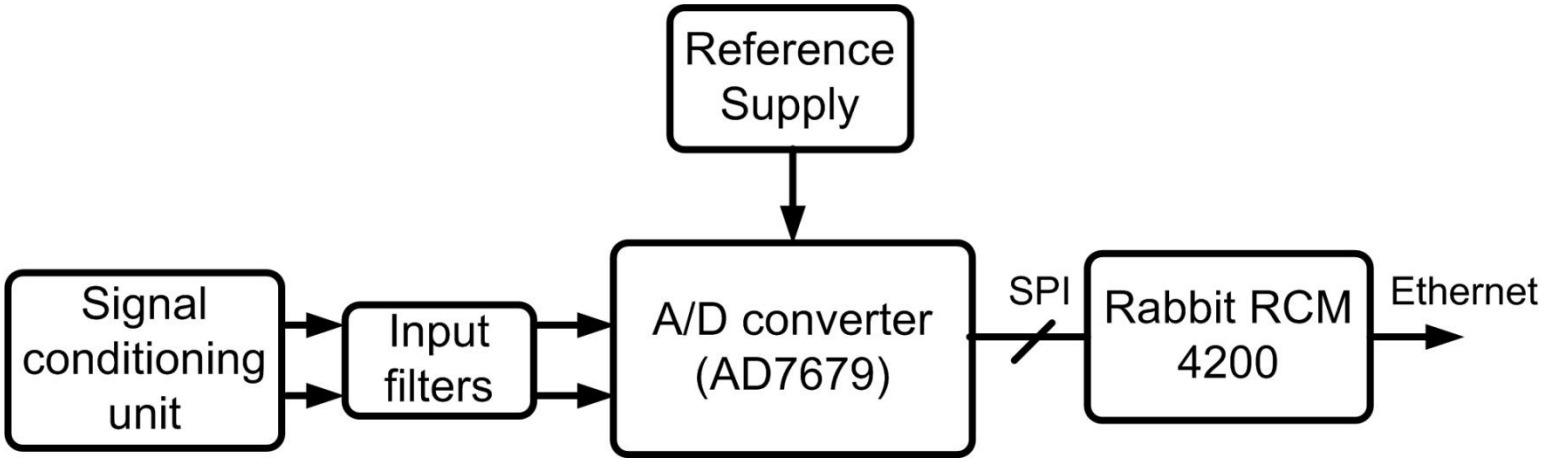
- 3 of 8 channels shown – differential inputs



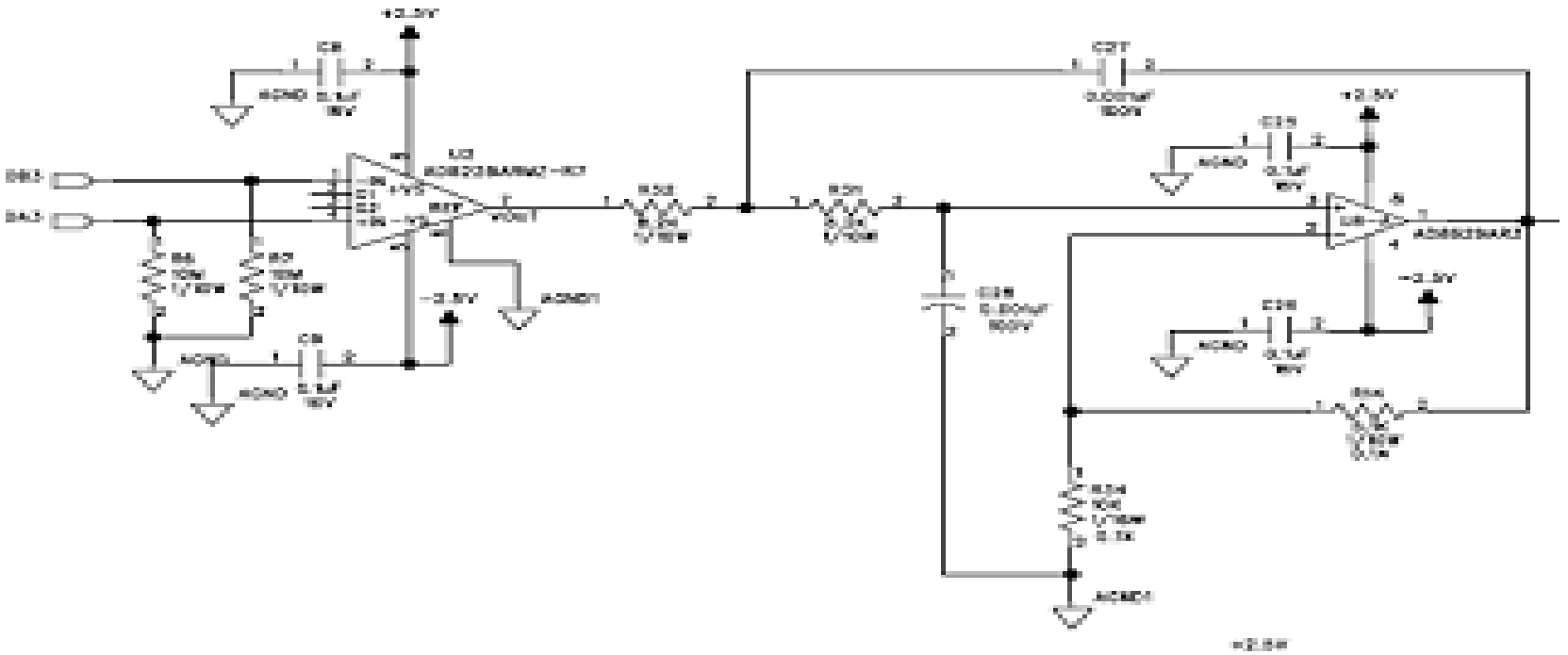
Filter break points at 100 Hz

Electronics Block Diagram

- Production versions uses FPGA



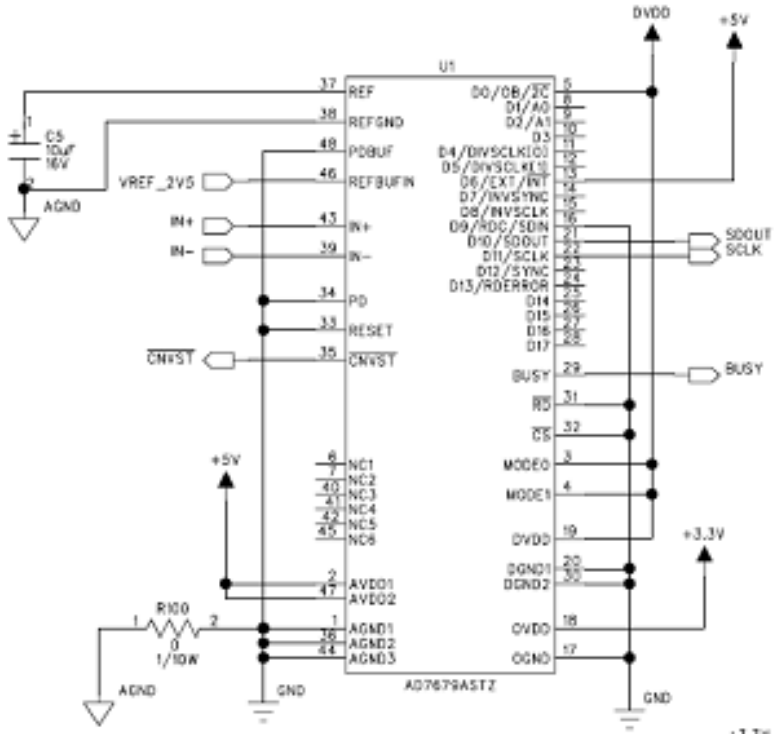
Analog Input Section



- Differential inputs to instrumentation amplifier
- Low pass filter for noise reduction and anti-aliasing

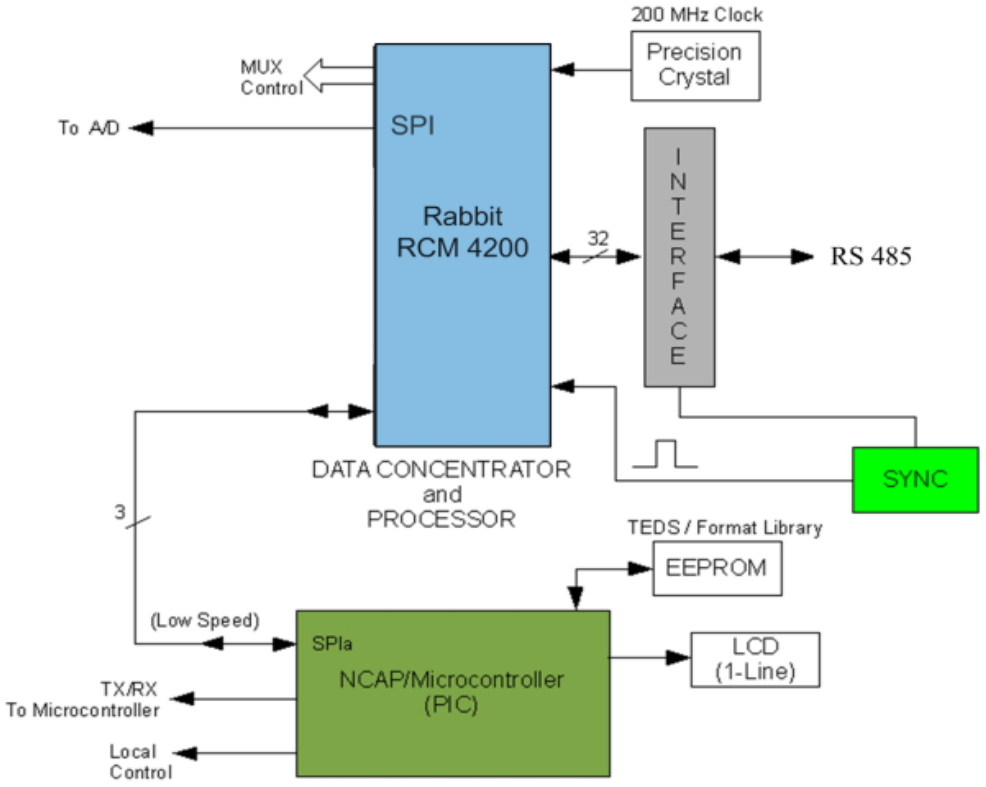
A/d Specifications

- 570 kSPS sampling frequency
  (up to 35kHz for 16 channels)
- 18-bit resolution
- Single a/d converter multiplexed for each thermocouple channel
- Mid-scale (2.00 v) zero using intermediate X2 amp (not shown)
- SPI (serial) output
- Serial outputs combined next stage
- Data displayed on PC for test



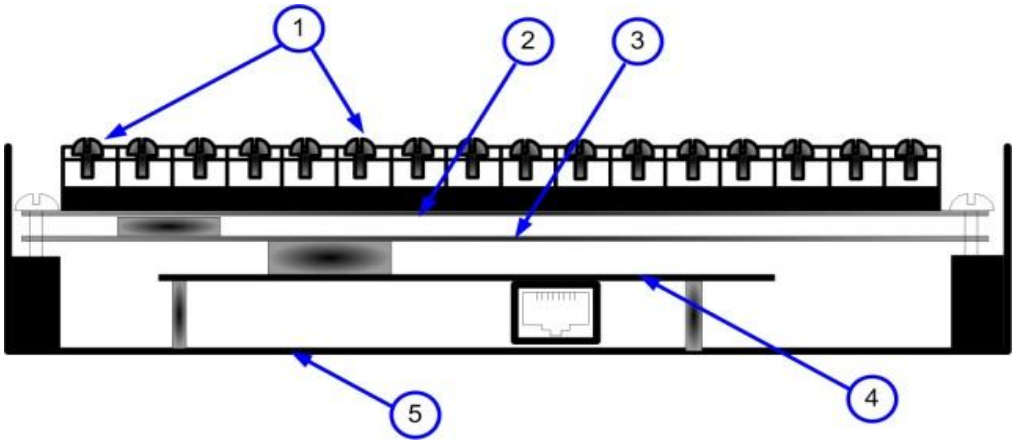
Data Concentrator (and NCAP)

- Controls a/d and mux
- Inserts time stamp
- Reformats (IEEE 1451)
- Data driver (RS485 , USB or Ethernet)
- Production versions uses FPGA
- Sampling rate (16 channels) is 10 kHz
- Provides time stamp (IEEE 1588)

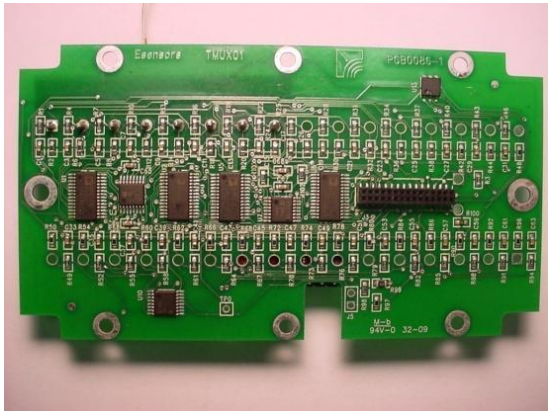


Circuit Layout - 1

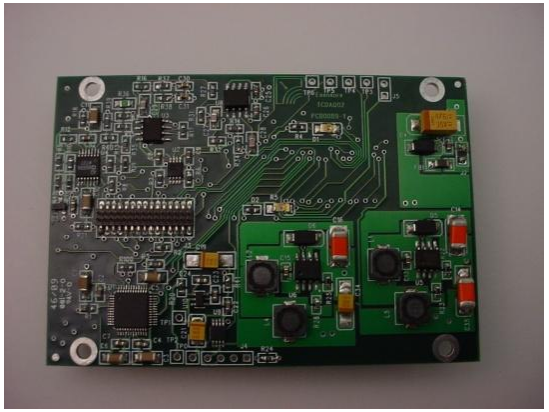
1. Connectors to thermocouples.
2. PCB with channel multiplexer circuitry
3. PCB with signal conditioning circuitry
4. Controller board with communication ports
5. Enclosure housing PCBs and board electronics



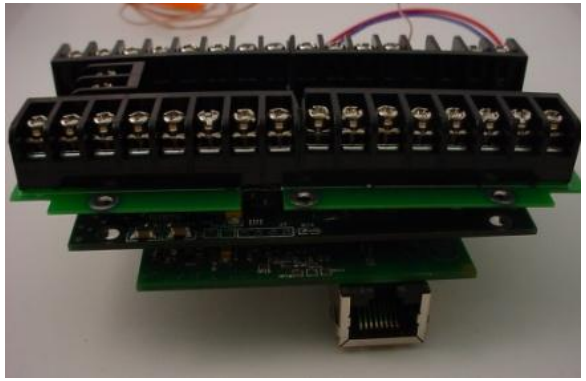
Circuit Layout - 2



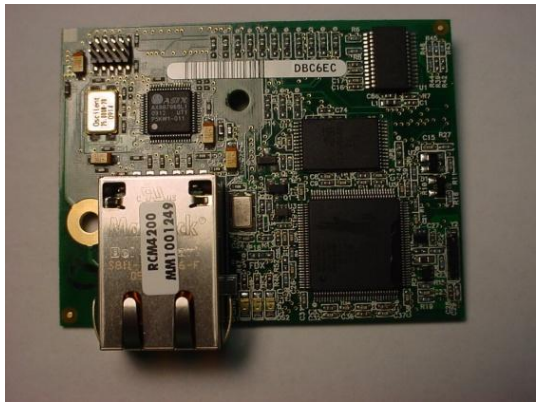
Multiplexer input



Signal Conditioner



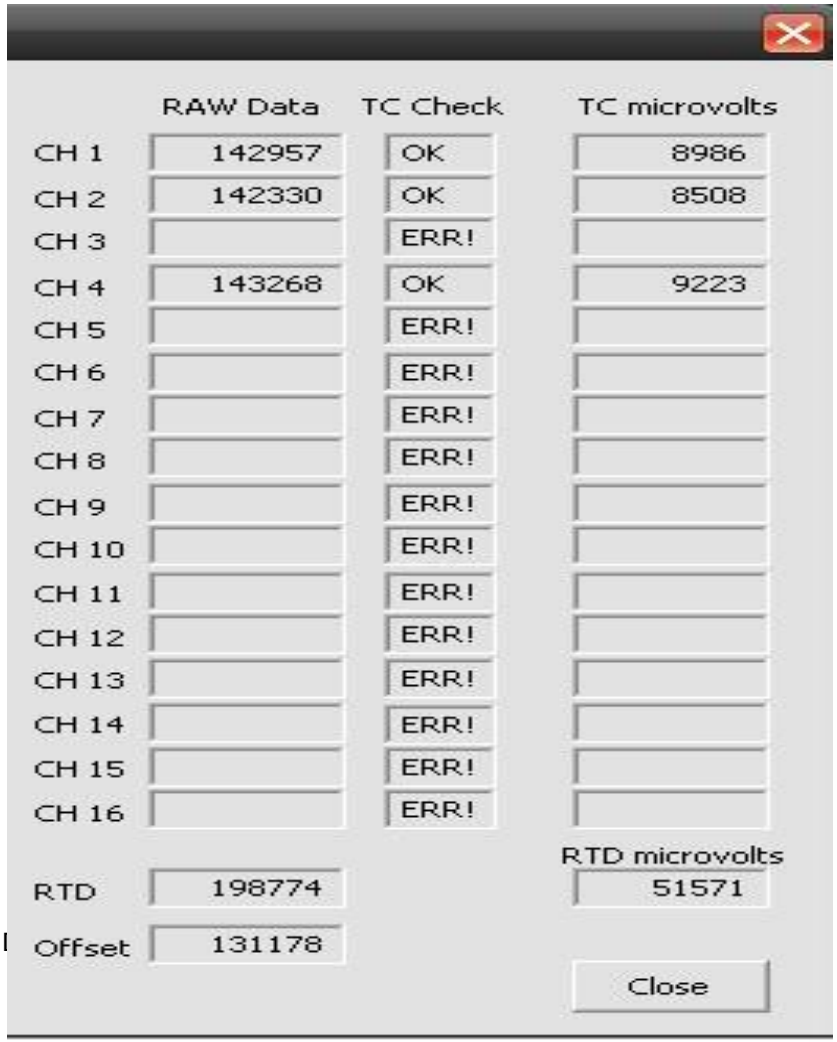
TC Terminal strip, side view



Microcontroller

Data Readout
(test display)

- Raw data is a/d reading (18 bit)
- TC Check detects open inputs
- Output is TC voltage in µv
- RTD reading in µv
- Conversion to °C done on PC
  (could be done here if desired)
- 8 channels tested



Temperature Measurement Precision

- Law of the Junctions [$\Delta v = \alpha(T1 - T2)$]

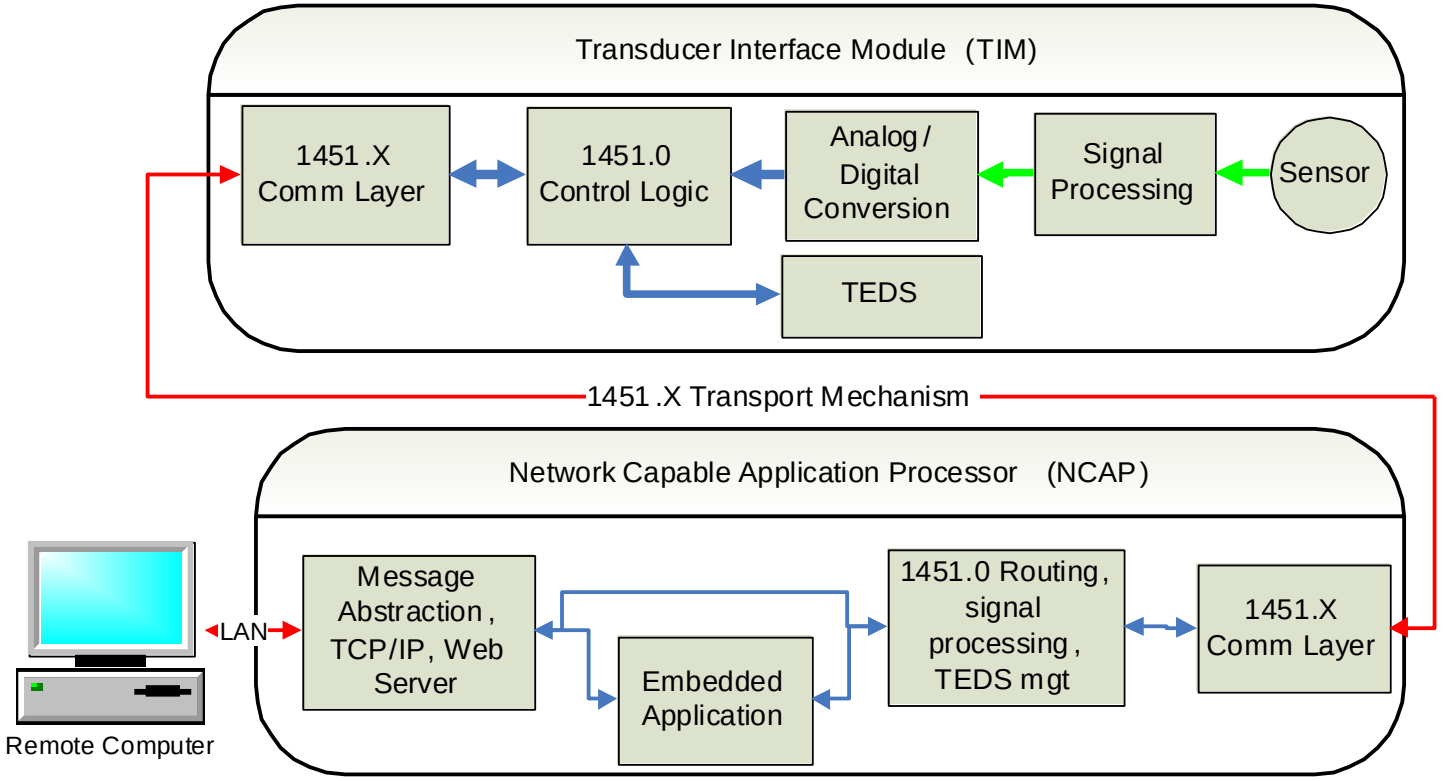
  where reference temperature T2 is same for both junctions

  and α depends on thermocouple metal composition
- Thermocouple α (slope) varies by factor of 10 in value and also accuracy varies due to alloy composition (see table)
- For type K, a 1 μv input precision corresponds to +/- 0.03 °C but absolute accuracy is less due to TC (and maybe ref junc) variations

Type	Metals	Range (°C)	Tol. (°C)	α (μv/°C)
K	Chromel-alumel	0 to 1100	1.5	40
J	Iron-constantan	0 to 750	1.5 to 3	51
R	Platinum-Rhodium (13%)	-50 to 1700	1 to 3	5.4
C	Tungsten-rhenium	0 to 2320	4 to 22	14
T	Copper-constantan	-250 to 400	1.5	39
E	Chromel-constantan	-40 to 900	3	59

Accuracy or tolerance varies over range and with class of thermocouple

A review of the
IEEE 1451 Smart Transducer Concept



IEEE 1451 Format

- Many advantages
  - Cover nearly all sensors and actuators
  - Many operating modes
  - Extensive units, linearization and calibration options
  - Multiple timing and data block size constraints
  - Compatible with nearly all wired and wireless sensor buses/networks
- Main parts
  - TEDS
  - Standard data transmission format (suitable for M2M)
- Configuration used
  - Combined TIM and NCAP (Ethernet as network)

Status of Various Parts of IEEE 1451

1451.0 – Basic data/TEDS format	**Done (2007)**
1451.1 – NCAP/Computer Interface	Done (1999)*
1451.2 – Serial	Revised (2011)
[1451.3 – Wired Multi-drop	Done (2002)*]
1451.4 – TEDS Only	Done (2005)
1451.5 – Wireless (WiFi, Zigbee, etc)	Done (2007)
1451.7 – RFID	Done (2010)

* 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

IEEE 1451.0 Headers

- **Command message structure**
  - Destination TransducerChannel Number (most significant octet)
  - Destination TransducerChannel Number (least significant octet)
  - Command class
  - Command function
  - Length (most significant octet)
  - Length (least significant octet)
  - Command-dependent octets . . .
- **Reply message structure**
  - Success/Fail Flag
  - Length (most significant octet)
  - Length (least significant octet)
  - Reply-dependent octets

Data Readout Example

- IEEE 1451 Data output string

0x01C98C880F4F4B0E (Time Stamp) 0xB8922B6D, (Channel 1 data) 0xB892EC71, (Channel 2 data) 0xAF215520, 0xAF221559,

0xB8A33696, 0xB8A44BD3, 0xB8A370C9, (Channel 7 data) 0xB8A4118E (Channel 8 data)

- Data is 32 bit floating point SI units (volts, with °C as option)

  (as specified by TEDS)

- Time stamp format (TAI, IEEE 1588)
  - 0x01C98C880F4F4B0E in hexadecimal

    Wed, 11 February 2009 15:35 (date and time from first 32 bits)
  - # of nanoseconds (lower 32 bits, 0F4F4B0E): 256854798

Data Output on Network

- Network Options
  - Ethernet (100 Mbits/sec Base T) as standard
  - Fiberoptic (1 GHz) as alternate
  - USB (2.0) as option
  - RS485 for testing
- Speed
  - Data block (64 TC) is 2116 bits
  - Includes timestamp and header
  - At max bandwidth (2 kHz, 4 ksamples/sec), the data rate is 8.5 Mbits/sec
  - Time sync and housekeeping data increases to about 9 Mbits/sec
  - Time sync (1588) precision is 1 µs (100 µs would be ok)

Summary

- Thermocouple reference discussed
- Electronics sections described
  - Amplifier and a/d
  - Data Concentration
- IEEE format discussion

Supported by USAF Arnold AFB (SBIR)

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End

- Backup Slides Follow

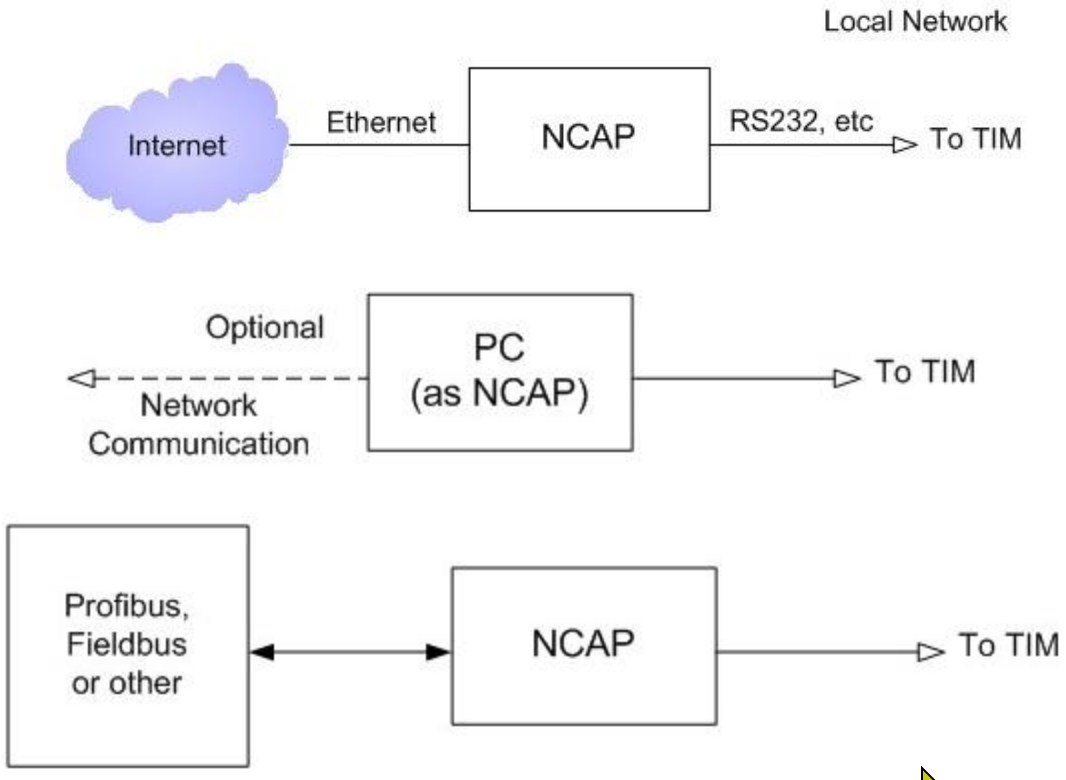
www.eesensors.com

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

Network side (NCAP) options (wired)

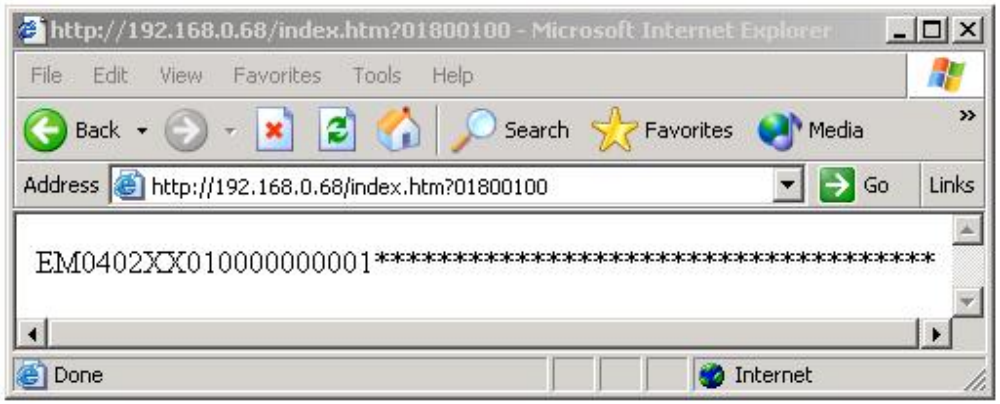
- Internet/Ethernet
- PC Readout
- Industrial network



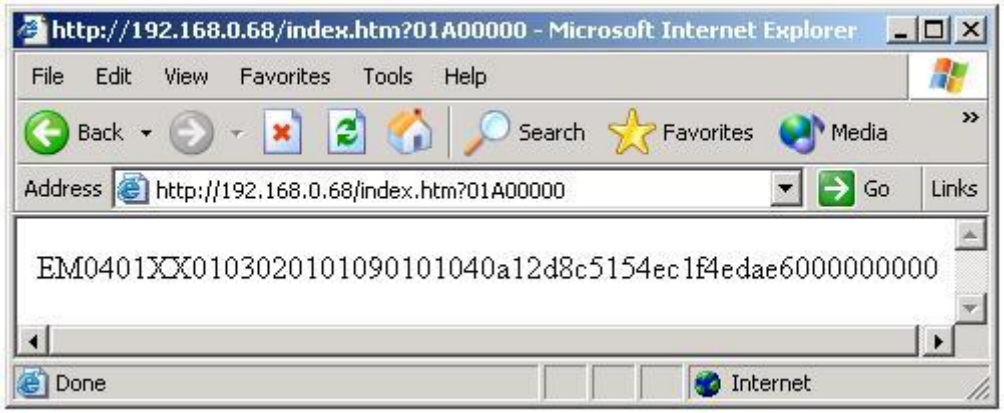
All use Dot 0 protocol

Data Readout Examples
(via Internet)

- Sensor data converted to ASCII for display



- TEDS data is displayed in hexadecimal form



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