Networked Sensors for Smart Buildings and the Smart Grid

Dr. Darold Wobschall

President, Esensors Inc.

IEEE International Conference on Smart Grid Engineering (2012)

Agenda

- Overview of the Smart Grid
- Smart sensor design aspects
- Sensor networks
- Metering and power quality sensors
- Sensors for smart buildings
- Smart grid networked sensor standards
- Application areas

Seminar intended for those with technical backgrounds

Overview of the Smart Grid

-- subtopics --

- What is it?
- Smart building/grid relationship
- NY ISO
- Framework
- Benefits
- Characteristics
- Architecture (3)
- Microgrid (4)
- IP Networks
- Interoperability
- Confidentiality

What is the Smart Grid?
(Wikipedia)

- The electrical grid upgraded by two-way digital communication for greatly enhanced monitoring and control
- Saves energy, reduces costs and increases reliability
- Involves national grid as well as local micro-grid ---
  power generation, transmission, distribution and users
- Real-time (smart) metering of consumer loads is a key feature
- Phasor network another key feature (Phasor Measurement Unit, PMU)
- Uses integrated communication (requires standards)
- Includes advanced features and control
  (e.g., energy storage, electric auto charging, solar power, DC distribution)

Relationship of
Smart Grid and Smart Building Sensors

- Many electrical devices (e.g. lighting, motors) are part of both smart grid and smart building areas
- Energy efficiency affects both
- Many smart sensors are used for both
- <u>Sensor networks are the same or similar for both</u>

Electric Grid in New York

- New York Independent System Operator (NYISO)

Niagara Falls
(where it started)

Networked Smart Grid Sensors

NIST Smart Grid Framework

- Report prepared by National Institute of Standards and Technology (NIST) and the Electric Power Research Institute (EPRI)
- Title: **NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0 -- Feb. 2012**
  http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf
- Release 1.0 and 2.0 used as reference for this presentation

Smart Grid Benefits

from Framework

- Improves power reliability and quality
- Optimizes facility utilization and averts peak load need
- Enhances capacity and efficiency of existing electric power networks
- Improves resilience to disruption
- Enables “self-healing” responses to system disturbances
- Facilitates expanded deployment of renewable energy sources
- Accommodates distributed power sources
- Automates maintenance and operation
- Reduces greenhouse gas emissions
- Improves cyber security
- Enables plug-in electric vehicles and energy storage options

Framework additions

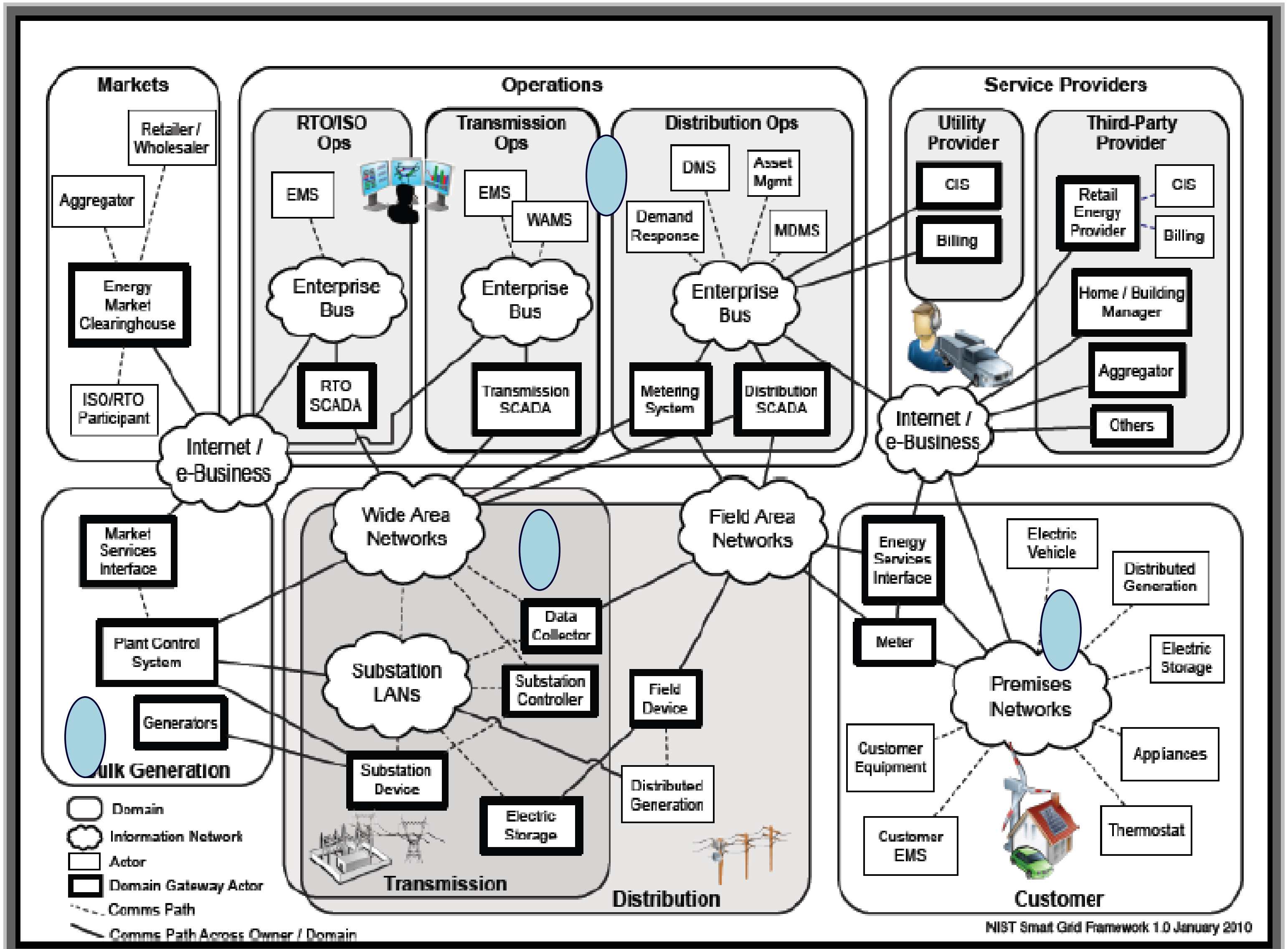
Distinguishing Characteristics

from Framework/Roadmap

- Increased use of digital information and controls technology
- Dynamic optimization of grid operations, with full cyber security
- Deployment and integration of distributed resources and generation
- Incorporation of demand response and energy-efficiency resources
- Deployment of ''smart'' technologies for metering, communications concerning grid operations and status, and distribution automation
- Integration of ''smart'' appliances and consumer devices
- Integration of electricity storage and peak-shaving technologies and electric vehicles
- Provision to consumers of timely information and control options
- Development of standards for communication and interoperability of appliances and equipment connected to the electric grid
- Lowering of barriers to adoption of Smart Grid technologies

Architecture

(NIST Roadmap)

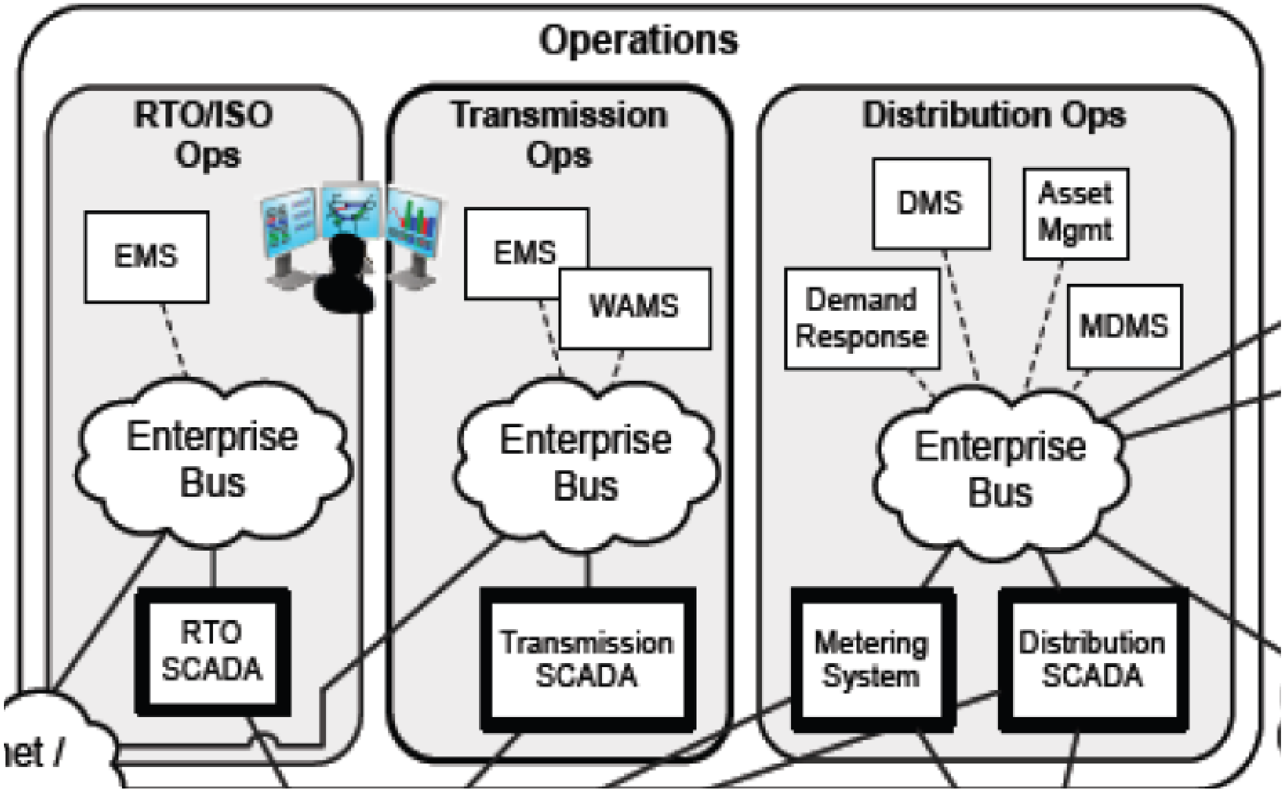


Smart Sensors & controls

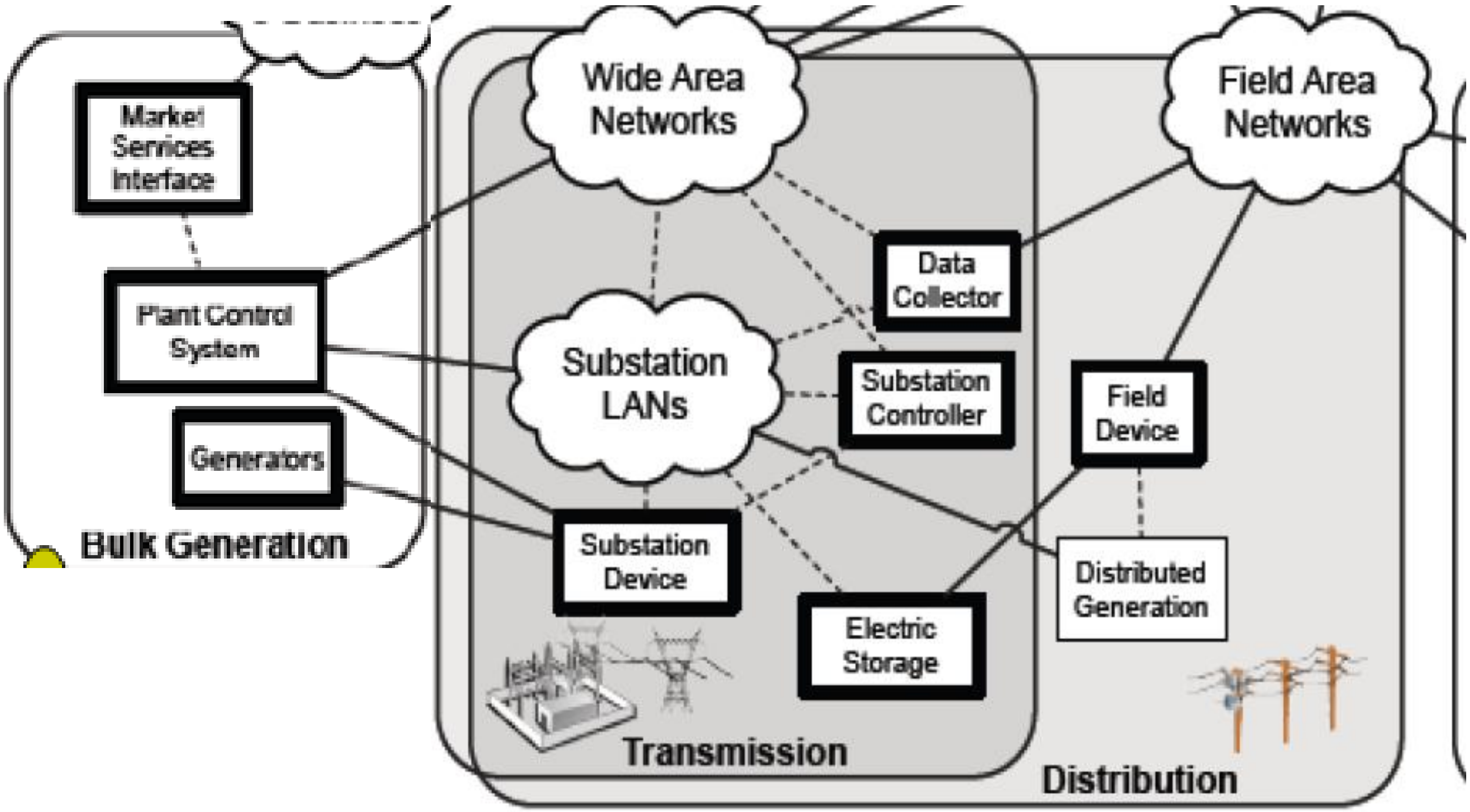
SCADA Monitoring and Control

SCADA: supervisory control and data acquisition

RTO: Regional Transmission Organization



Transmission and Distribution

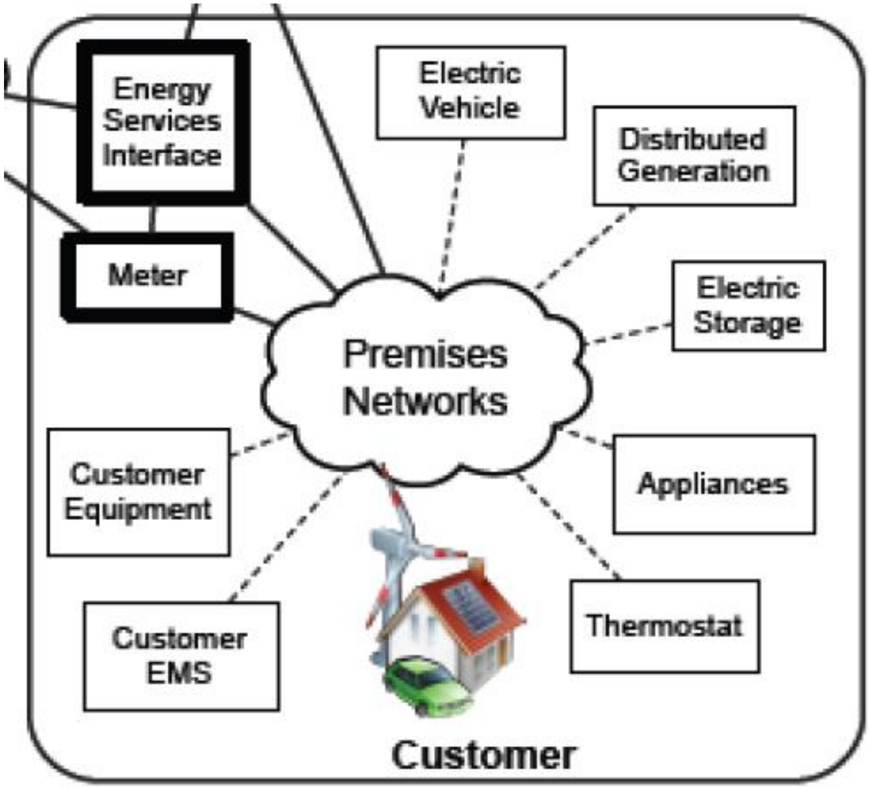


Microgrid and Subgrid

Microgrid is capable of operating independently or with macro-grid
Also a microgrid can function as a subgrid (building or campus)

Many networked sensors used in Microgrid

EMS –
Energy Management System



Distribution and Microgrid

- Power generation (1), transmission (2) and substations (3) are under control of Utilities
- Commercial buildings (5) and part of distribution (4) are part of microgrid or subgrid
- All part of smart grid

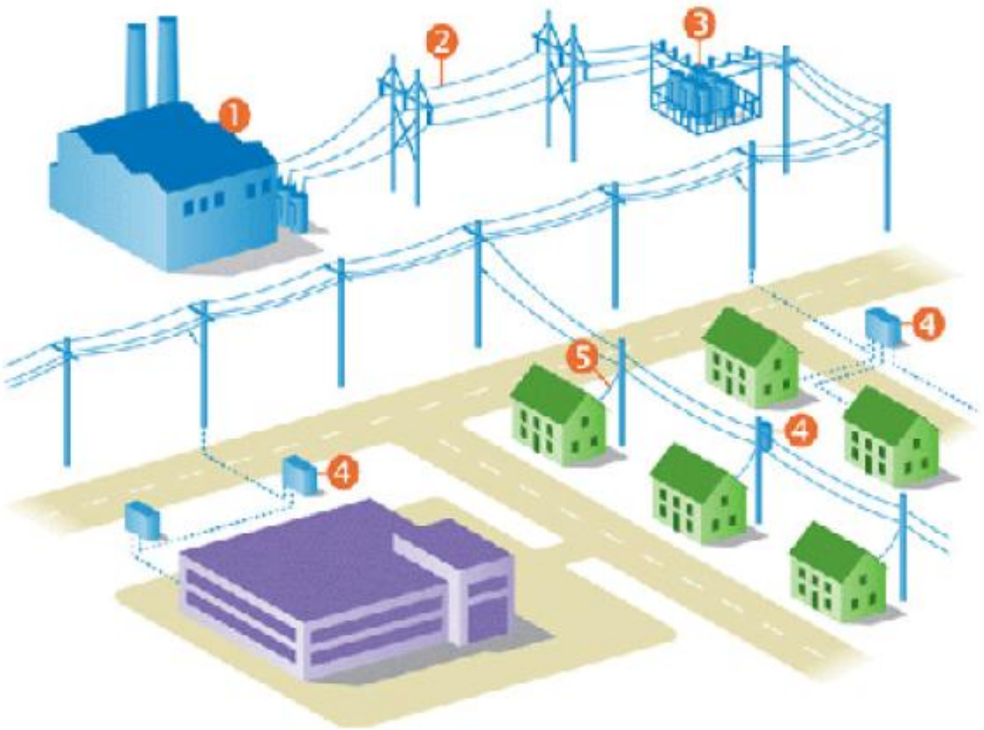


Figure --http://www.peco.com/pecores/customer_service/the_electric_system.htm

IP Based Networks

- Internet Protocol (IP) based networks are used for data communication involving the smart grid
- Acts as bridge between application and underlying sensor/control networks
- Used by both private (dedicated) and public networks
- Used also by local wireless networks

Standards and Interoperability

- TCP/IP is only the communication protocol
- Data carried as payload will be formatted by specific standards (e.g. SCADA or PMU)
- Over 100 Standards referenced in NIST Guidelines
- Sensor network standards discussed later

Confidentiality Concerns

- Data/commands requires proper level of protection
  - Data which could bring down parts of the Grid need highest level of protection
  - Encryption is needed at several levels but can be costly for small systems (more hardware, keys, permissions, etc)
  - For many local controls, encryption is unneeded and counter-productive (e. g. local thermostat)
- Users need privacy protection
  - Data transfer is two-way, including at the micro-grid level with commercial business and private homes
  - Confidential information might be gleaned from smart grid data and sold to third parties
  - Activists often block smart meter deployment
- Indirectly affects networked sensor design
  - Moderate encryption fairly easy
  - At what point is encryption necessary?

Smart sensor design aspects
-- subtopics --

- Background and Sensor types (6)
- Block diagrams (3)
- Features
- Examples (3)

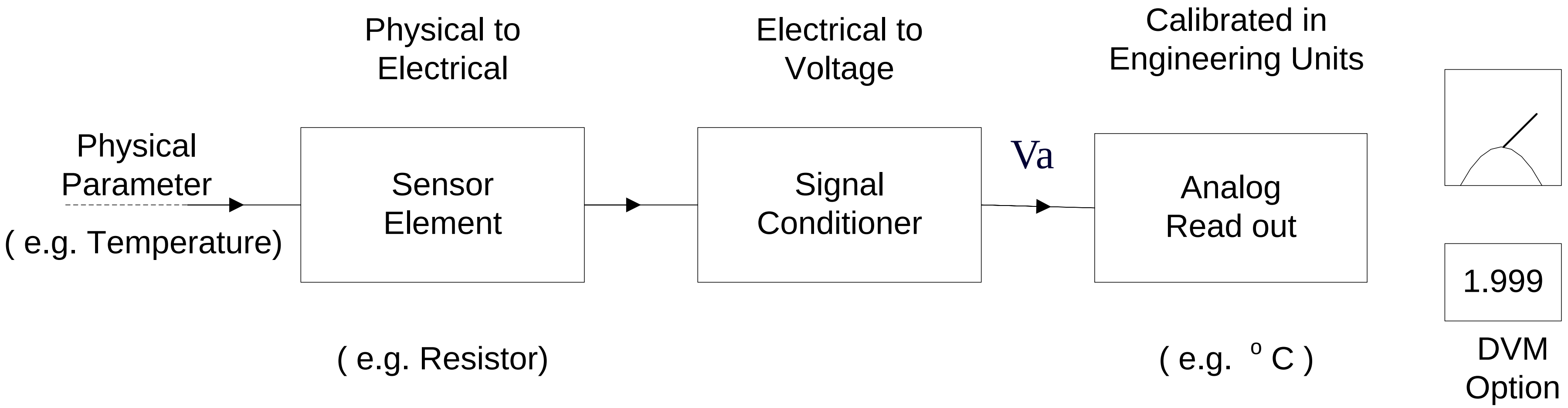
Sensor Development
past and future

- 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 and used by the **Smart Grid** and **Smart Buildings**

Sensor Classes

- Basic Sensors
- Smart Sensors
- Networked Sensors

Basic Sensor Electronics Block Diagram



Partial List of
Measured Parameters and Sensor Technologies

- Acceleration/vibration
- Level & leak
- Acoustic/ultrasound
- Machine vision
- Chemical/gas*
- Motion/velocity/displacement
- Electric/magnetic*
- Position/presence/proximity
- Flow
- Pressure
- Force/strain/torque
- Temperature*
- Humidity/moisture*

* Used by Smart Grid

Technologies

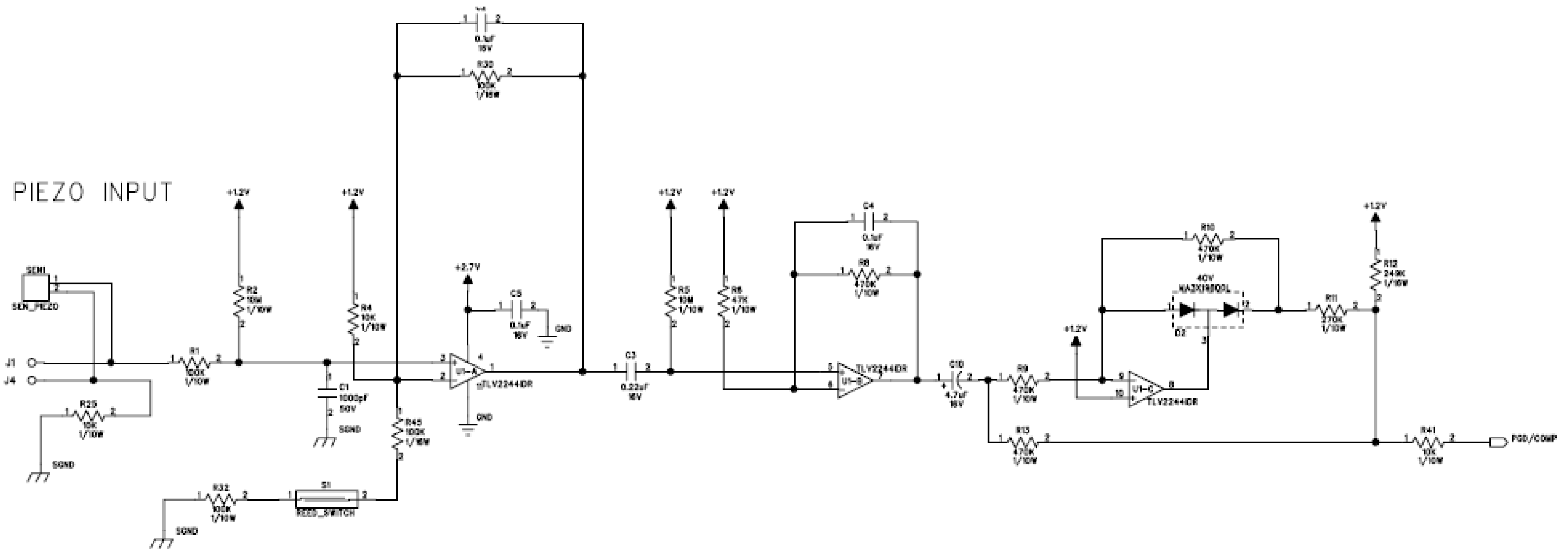
- Resistance
- Capacitance
- Inductance & magnetics
- Optical & fiber optic
- Voltage & piezoelectric
- Ultrasonic
- RF/microwave

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

1. Parameter measured
2. Technology
3. Application area

Analog Signal Conditioners

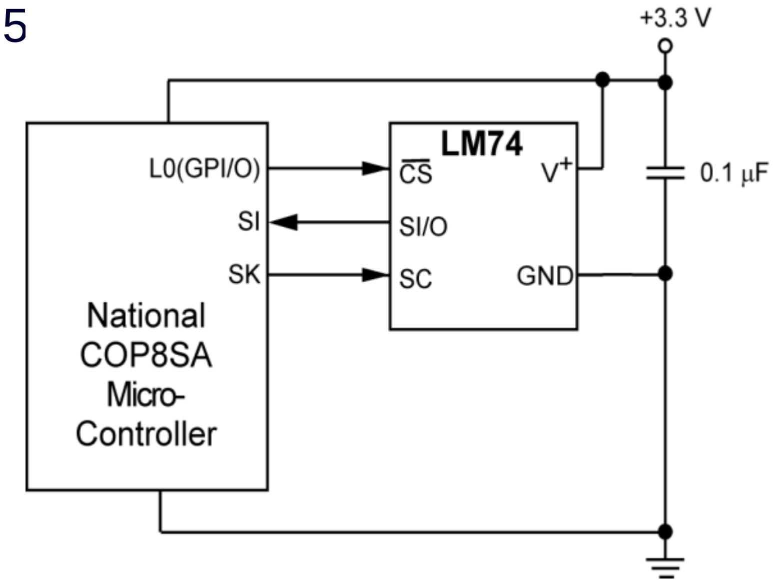
- Example of amplifier for piezoelectric motion sensor with demodulated signal is shown below:
- Amplifier is very low power so digital section can be in sleep mode



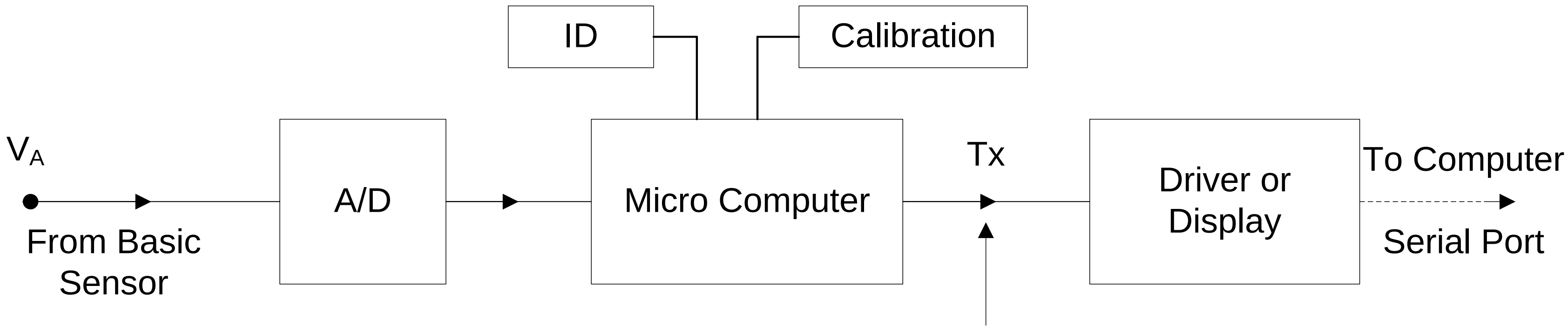
Sensors with Digital I/O

- More sensors with digital outputs (but with internal analog signal conditioners and a/d) becoming available.
- Output format is usually I2C or SPI and thus requires further reformatting – not a smart sensor in itself
- Example: temperature sensor (LM74)

  (SPI 12-Bit plus sign, +/- 0.0625



Smart Sensor Block Diagram



Smart (Digital) Sensor Features

- Analog/Digital Converter

  Typically 10-14 bits, usually internal
- Microcontroller (embedded)

  PIC or similar 8-bit (or 16-bit) micro with appropriate features
- Sensor Identification (serial # etc)
- Calibration information

  Compensation for sensor variations; conversion to engineering units
- Data logging and real-time clock (optional)

Microcontroller Example

Pin Diagram

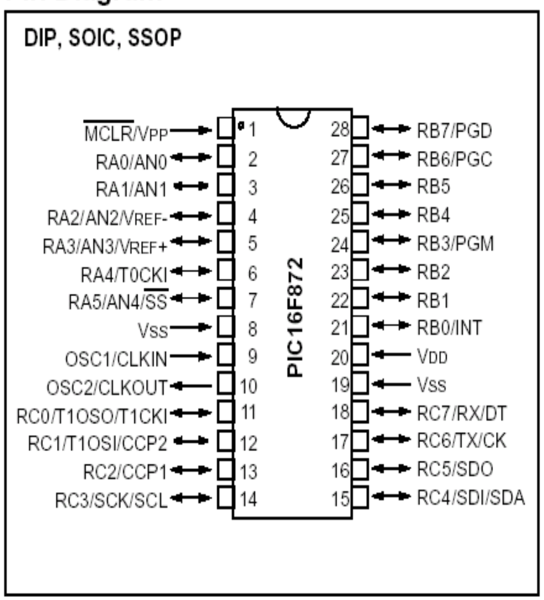
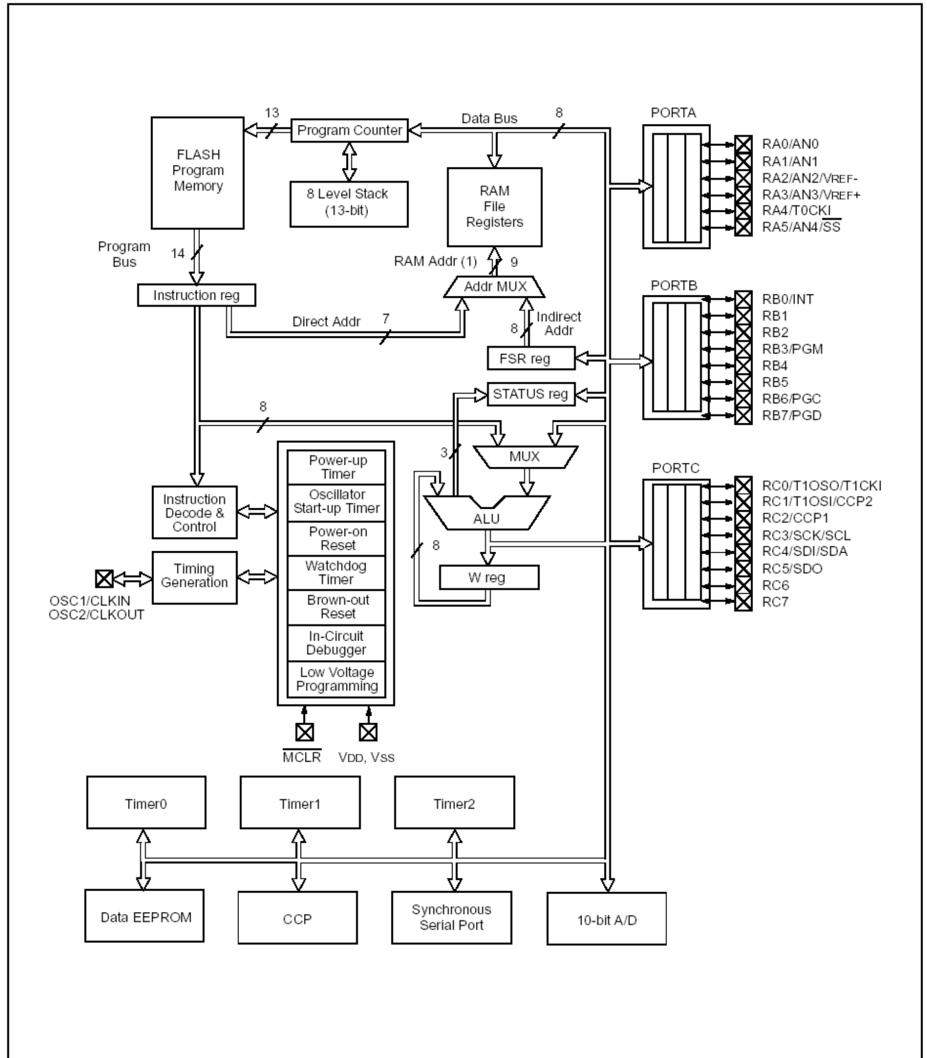


FIGURE 1-1: PIC16F872 BLOCK DIAGRAM



Note 1: Higher order bits are from the STATUS register.

Connection of Non-networked Smart Sensors to Computers

- Serial Data Lines: USB (best for PCs)
  or RS232 (best for Instruments)
- One line and port per sensor (a problem with large systems)
- Data is digital but format is often not standardized

Sensor Networks

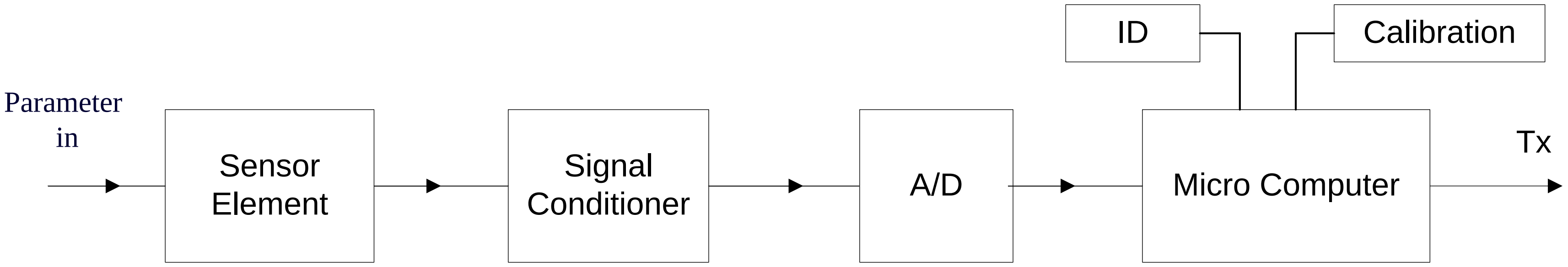
-- subtopics --

- Electronics block diagram
- Multi-level Data Protocols
- Transducer networks
- Serial bus examples
- Wireless sensors
- Data readout example

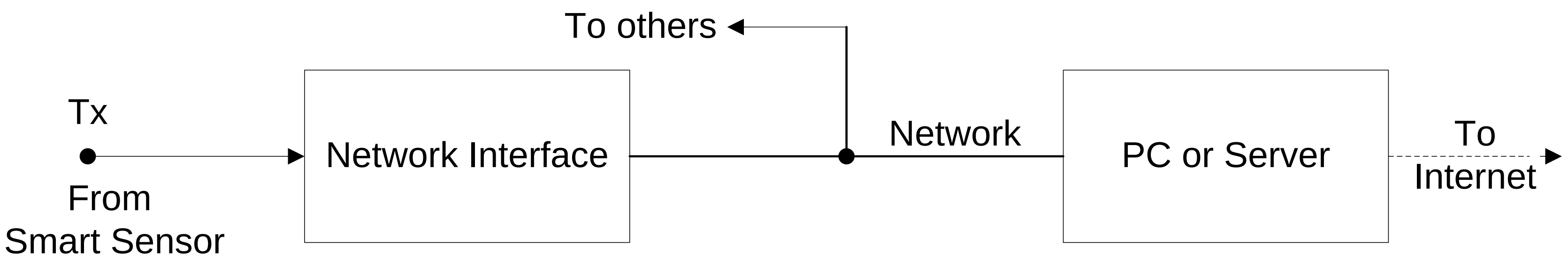
[Standards discussed later]

Networked Sensor Block Diagram

(local network or bus)



SMART SENSOR



Multi-level Data Protocols

- Data formats: How commands and transducer data are encoded (e.g. units, data type). Must be standard format for machine readability (M-to-M).
- Communication formats: How digital data is transmitted over network (e. g. IEEE 802.15.2g WiFi). Associated with physical (hardware) layer.
- Multi-level often has encapsulated data of form:

  Header(*Subheader*{data}*subfooter*)footer
- On Internet TCP/IP data often uses XML format
- Local sensor network standards sometimes combine data and communication formats

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

Serial Bus Examples

- RS232 or UART
- RS485 (multi-drop)
- USB
- SPI or I2C

Wireless Sensors

(Uses RF transceivers for short-range in unlicensed band)

- Significant power available
  - Line-powered or laptop sized battery
  - E.g. WiFi (IEEE 802.11b, 2.4 GHz)
  - Variation of TCP/IP protocol, mostly non-standard
- Medium low power
  - Re-chargeable batteries or shorter life applications
  - Cellular (GSM, 4G) – especially outside buildings
- Very low power (long life operation -years)
  - Batteries or energy harvesting
  - Low bandwidth, sleep mode
  - Sensor signal conditions must be low power

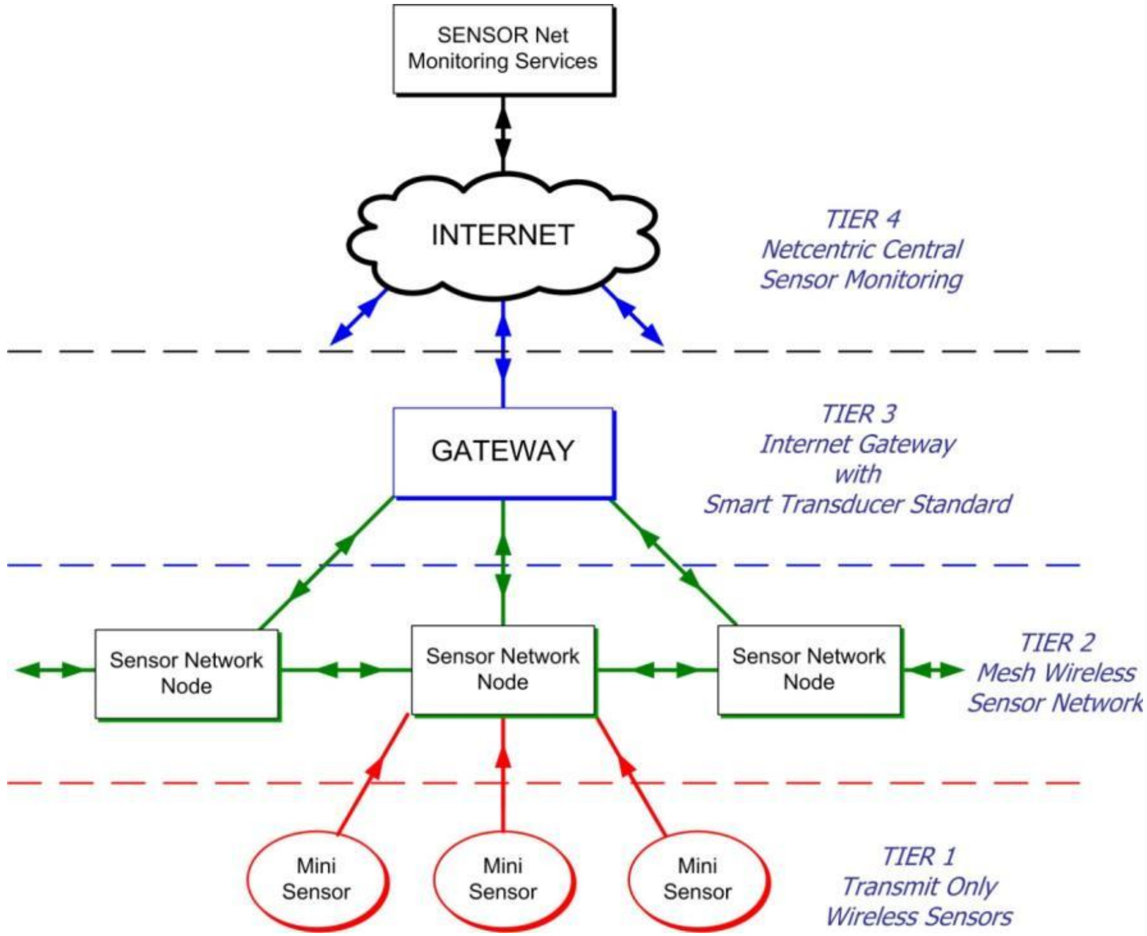
Wireless Sensors, cont.

- Popular Low-power (battery) options -

- WiFi (low power version)
  - Standard WiFi connect time too long
- Bluetooth (Low energy)
  - LE has better range, connects easily but low bandwidth
- Zigbee/6LoPAN (uses IEEE 802.15.4 technology)
  - Can form mesh networks allowing data hopping
  - Many similar proprietary networks available
- SubGHz (315, 433, 915 GHz)
  - Lowest cost and power
  - Often transmit-only

Four-tier Wireless Network

- a concept -



Internet Protocols

- Smart Grid uses Internet Protocol (IP) for all data communications
- Specific protocols are:
  - HTTP

    The most basic for data transfer
  - XML

    Widely used because of self-identifying format
  - SNMP

    Message protocol popular within data centers
  - SOAP

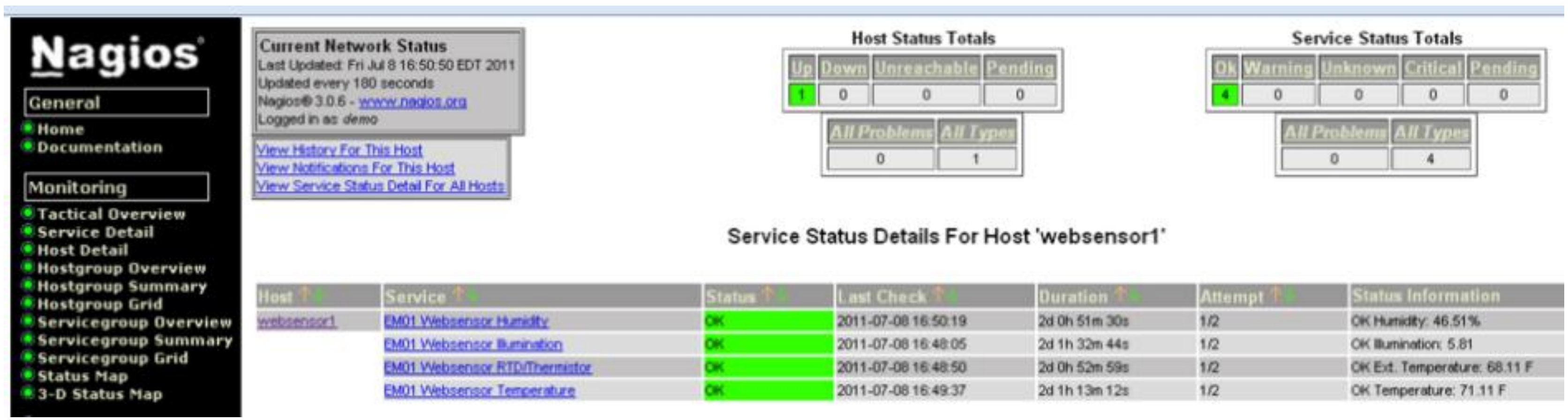
    XML-based protocol for cross platform communication

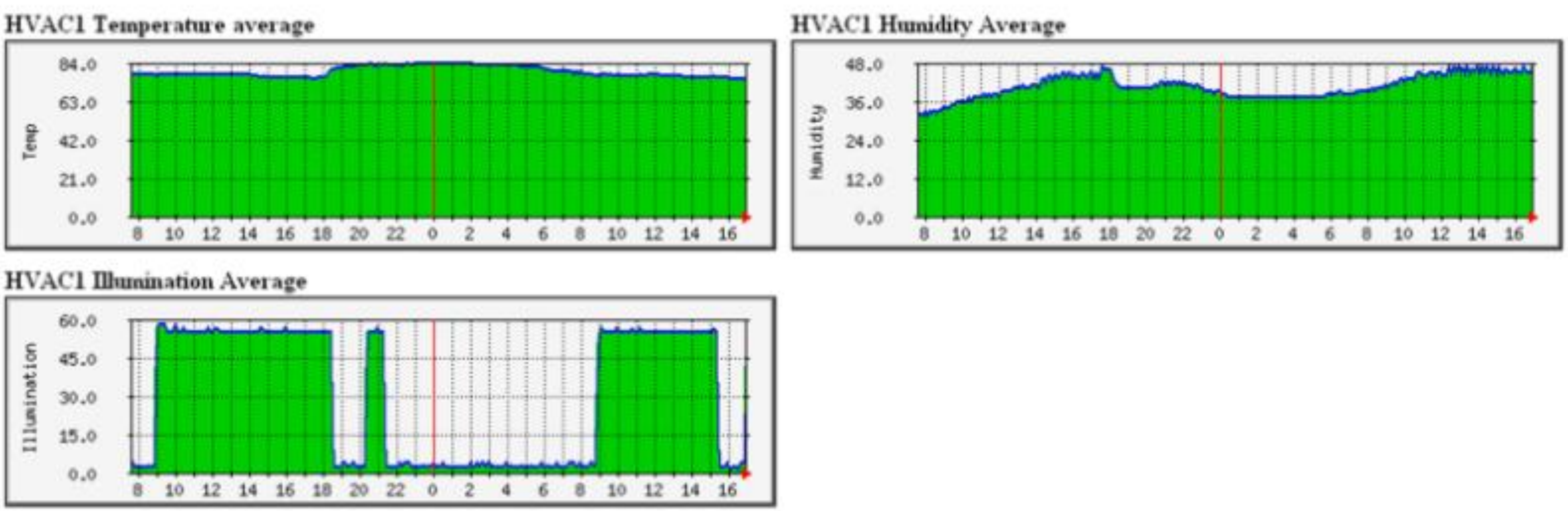
Examples of
Sensors with Internet Address

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

Websensor

Monitoring via Nagios
data retrieval, storage, analysis, graphing





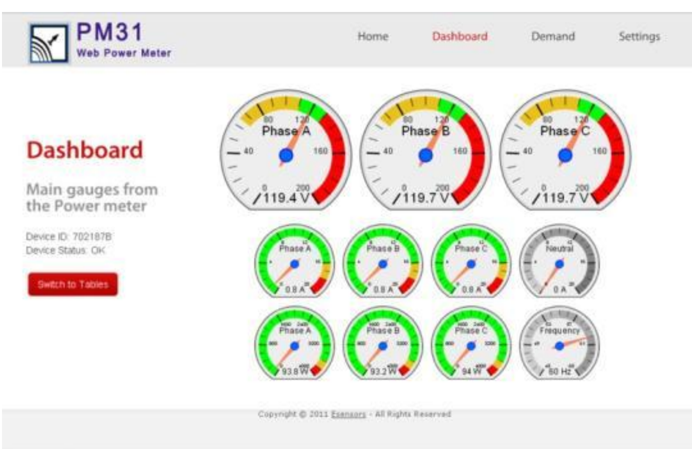
Sensor Web Enablement (SWE)

– an Emerging Sensor Internet Standard Set -

- Developed by OGC (Open Geospatial Consortium)
- Specific standards
- **Observations & Measurements** (O&M) - The general models and XML encodings for observations and measurements.
- **Sensor Model Language** (SensorML) - standard models and XML Schema for describing the sensor processes.
- **PUCK** - Defines a protocol to retrieve a SensorML description, sensor "driver" code. Used by oceanographic sensors.
- **Sensor Observation Service** (SOS) - Open interface for a web service to obtain observations and sensor descriptions.
- **Sensor Planning Service** (SPS) - An open interface for a web service by which a client can 1) determine the feasibility of collecting data and 2) submit collection requests.
- **Others as well**

Specialized Dashboards
– examples of proprietary displays --

- Iconics Energyanalytix
- Google Powermeter
- Esensors PM31 monitor



Networked Smart Grid Sensors

Metering and Power Quality Sensors
-- subtopics --

- Electrical Measurement
- Metering types
- Voltage Measurements
- Current Measurements
- Power measurements
- Frequency and Phase

Electrical Measurement Sensors

- Basic Parameters Measured
  - Voltage
  - Current
  - Time
- Derived parameters
  - True power and RMS values – averaged over cycle
  - Apparent power, power factor and VAR*
  - Accumulated energy (watt-hours)
  - Minimum and peak (e.g. voltage sag)
  - Harmonics, sub-harmonics and flicker
  - Phase and frequency

*Volts-Ampere Reactive (power)

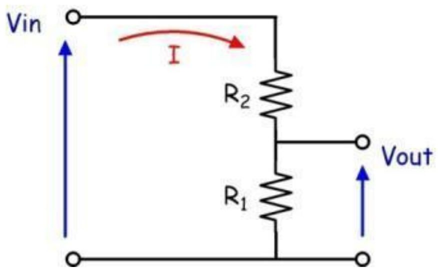
Metering types

- Power Quality
  - Measures all electrical parameters accurately (voltage, current, power, harmonics, phase)
  - Needed at substations and power distribution points
  - If updated each cycle, high bandwidth required
- Metering
  - Accurate (0.2%) measurement of true power (for revenue)
  - Energy (w-hr) calculated, often by time slots
  - Standard: ANSI C12
- Load monitoring
  - Low-cost, less accurate meters for point-of-load status
  - Voltage and current, but maybe not true power

Voltage Measurements

- Resistive Voltage Divider (N:1)

  Vin over 100 v, Vout under 1 v



- Potential Transformer (V:120v)

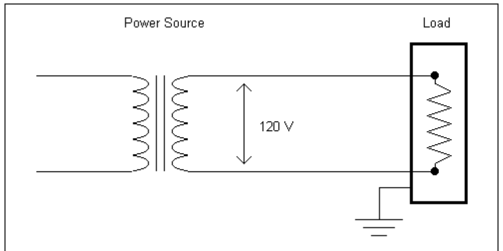
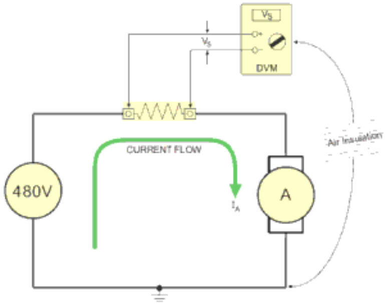
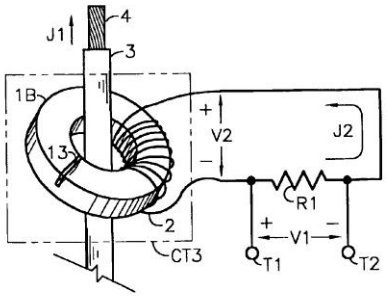


Fig. 3 120V. 60Hz power applied to a load in Transverse Mode.

Current Measurements

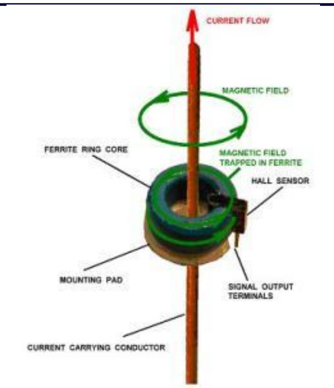
- Resistive Shunt
  - Typically lower currents (< 20 amp)
  - $V = R_S * I$
  - Not isolated line
- Current Transformer (CT)
  - Typically mid to high currents
  - Current reduced N:5 (output typically 5A)
  - Alternative: V output (type 0.3v fs)
  - Low resistance load or internal R
  - Isolated



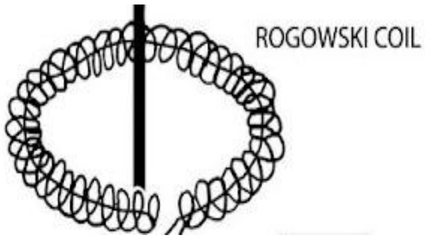


Current Measurement, Cont.
(less popular methods)

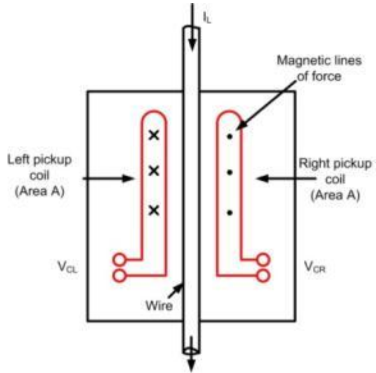
- Hall Sensor
  - Based on Hall Effect (V = k * I)
  - Excellent high frequency response (also DC)
  - Isolated



- Rogowski coil
  - Helical coil of wire
  - Lead returns through coil center to other end
  - Voltage output is derivative of current

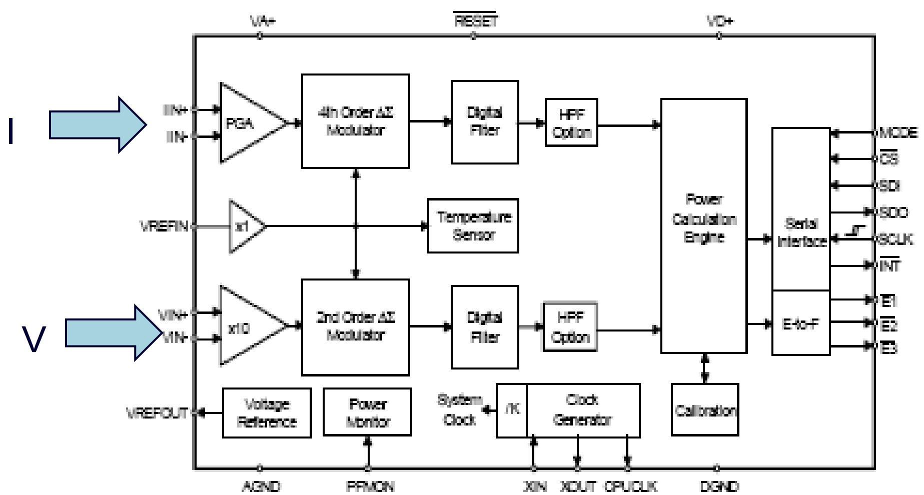


- Inductive Loop
  - Pickup coil on PCB next to wire
  - Induced voltage is derivative of current



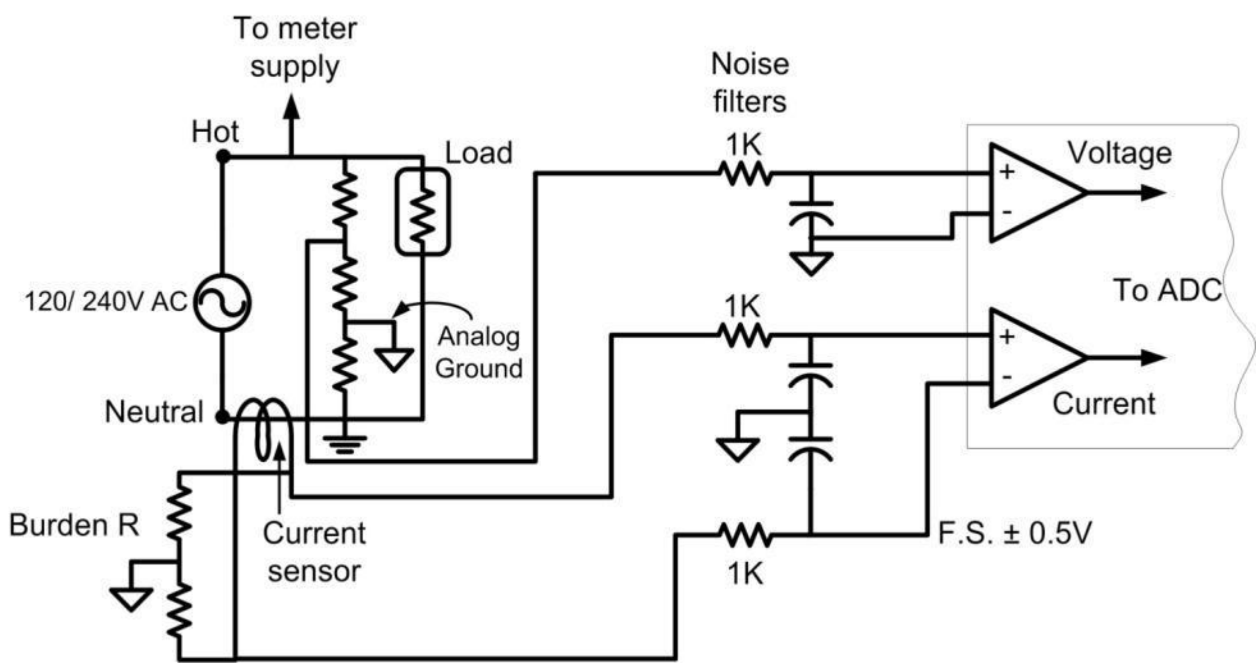
Power measurements

- True power (P_{true}) is average of P(t) = V(t)*I(t) over a cycle
  - Metering (revenue) always uses true power
- Apparent power (P_{apr}) = V_{rms} * I_{rms}
  - Greater than true power if load is partly reactive (e.g. motor)
- Power factor ($\cos \theta$) = P_{true}/P_{apr}
  - Less than 1.00 for non-resistive loads
- Precision of 0.1% requires 14-bit a/d or better
- True power meter chips available (e.g. CS5463)
- Often three phase needed



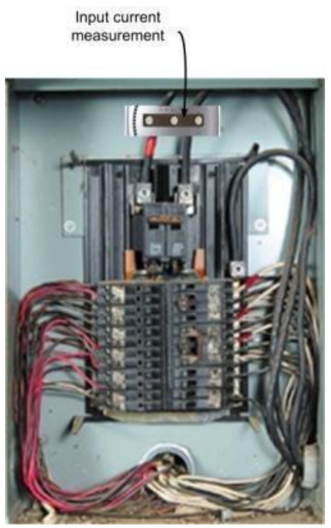
Circuit Details for IC Power Meter

- Current sensor type has voltage output (0.33v fs)
  with burden resistor (range: 20 to 1000+ Amps)
- Voltage divider resistor has high voltage rating
- Separated analog and digital (power) grounds
- Noise filter has minimal phase shifts

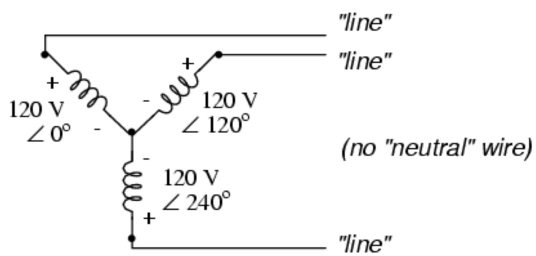


Split and 3-Phase Metering

- Most US houses have split phase
  - 120/120 v, 60 Hz (hot1, hot2, neutral, gnd)
  - Vis service panel
  - Current sensors needed on both input lines
  - Will discuss later (smart meter)
- Industrial and commercial buildings use 3 phase
  - 220/440 v – 3 wires (+ neutral)
  - Star and Y configurations
  - Current transformers (CT) usual
  - Potential transformers (PT) often
  - Metering must be configured (6/8 input)
  - Connectors screw terminals usually
  - High voltage/current have PT/CT so same meters used



3-phase, 3-wire "Y" connection

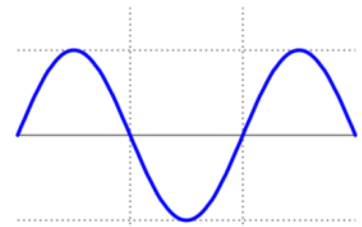


Star has neutral

Digital Power Meters

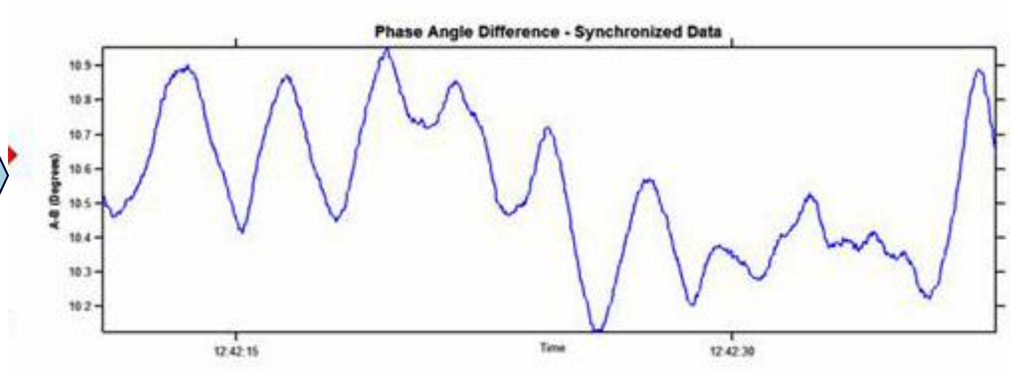
- RS485, Modbus and Ethernet are popular
- But Smart grid needs Internet connection

Frequency (f) and Phase (θ)



- Time derivative relationship: $F = d\theta/dt$
- Phase measurements use phase locked loops (zero crossing)
- Time accurate to 1 µs (GPS) preferred
- Phasor Grid Dynamics Analyzer™ (PGDA) v 1.0
- Phase resolution of 0.01 º *(below -- plot steps of 0.1 º)*
- Frequency resolution to 0.001 Hz

Range
10.1 to 10.6 deg



Non-Electrical Smart Grid Sensors

-- subtopics --

- Smart Building Concept
- HVAC
- Energy Conservation
- Substation/ Transmission

Smart Building Concept

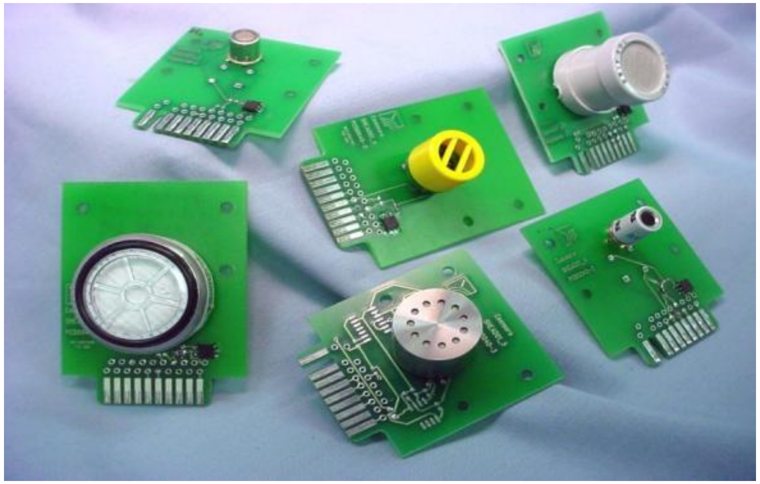
- Integration of HVAC, fire, security and other building services
- Reduce energy use
- Automation of operations
- Interaction with outside service providers (e.g. utilities)
- Three main wired standards:
  - BACnet , Lonworks and Modbus
- Poplar wireless standards:
  - WiFi , Zigbee (but Bluetooth, 4G, proprietary gaining acceptance)
- Two smart building organizations
  - ASRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers)
  - Remote Site & Equipment Management

HVAC Sensors
(Heating, Ventilation and Air Conditioning)

- Temperature
- Humidity
- Air Flow
- Air quality (gases: CO_2, CO, VOC)
- Also Actuators (control of heating, ventilation, AC)

Air Quality Sensors
for smart buildings

- Main gases:
  - Carbon Dioxide (CO_2)
    - CO_2 buildup in rooms when people present – signal for increased ventilation
  - Volatile Organic Compounds (VOC) and Carbon monoxide (CO)
    - Potentially harmful gases (possibly toxic also)
- Signal Conditioners
  - Requires both analog and digital
  - Multiple sensor technologies complicates design



Energy Conservation Sensors

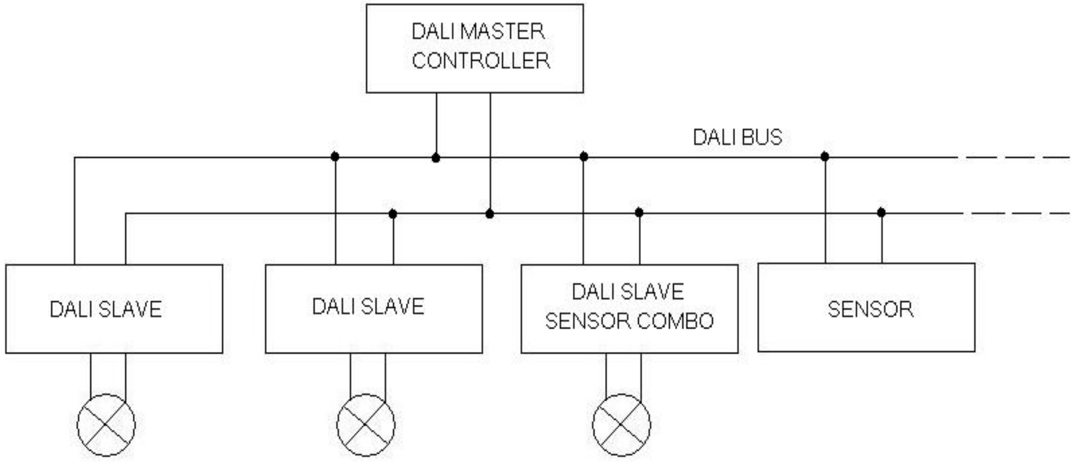
- Temperature
- Illumination
- Occupancy sensors
- Wireless room controls (e.g. lighting)
- Remote access (Smart grid, Internet)

DALI -- lighting

- Digital Addressable Lighting Interface (DALI) was developed for remote lighting control (e.g. dimmers)
- Rugged bus (64 devices, data & power on 2-wire bus)
- Asynchronous, half-duplex, serial protocol at 1200 Baud
- Requires controller (master) or gateway
- More popular in Europe

DALI – for sensors

- DALI extended to general purpose sensor bus (sensor is slave)
- Advantage of power and data on same 2-wire bus
- Higher data rate (9600 baud)
- Allows mix of standard and sensor DALI format on bus
- Allows TEDS and standard formats for sensors
- Actuators also



Smart building communication choices
with connection to Internet

- Ethernet
  - Lowest cost to Internet
  - Installed base but often not at sensor site
- Other wired*
  - USB, RS232, RS485, Lonworks, DALI
- WiFi
  - Mobile and convenient (if router * already present)
  - Requires power at sensor (usually), somewhat costly
- Local wireless (LAN)*
  - Mesh: Zigbee, 6LoWPAN, Wireless HART, ISA100
  - Star: 2.4 and sub-GHz, mostly proprietary
  - Low-power (battery), small size, lowest cost
- Powerline*
  - Attractive concept but both narrowband and wideband not fully proven
- Cell phone
  - SMS, G4 modems available but costly (and requires higher power)
  - Highly mobile and convenient

** Requires gateway to reach Internet*

Power Line Communication (PLC)

- Narrow-band (NB) Devices
  - Low frequency operation (e.g. 10 to 500 kHz)
  - Low data rate but good match for most sensors
  - Typically aimed at home (120v) – but also some high voltage applications
  - "X10" is the oldest protocol (pulses at zero-crossing)
  - Noise/interference and phase-to-phase loss are significant problems
  - Various new protocols and ICs have been developed – next slide
  - Usually more costly than wireless
- Broad-band devices
  - HomePlug HomePNA) AV (IEEE 1901) becoming used (carries Internet)
  - Frequency range: 4.5 to 20.7 MHz
  - Speed of 500 Mbits/sec (up to 100 MHz)
  - Interference a continuing problem (notching required by FCC)

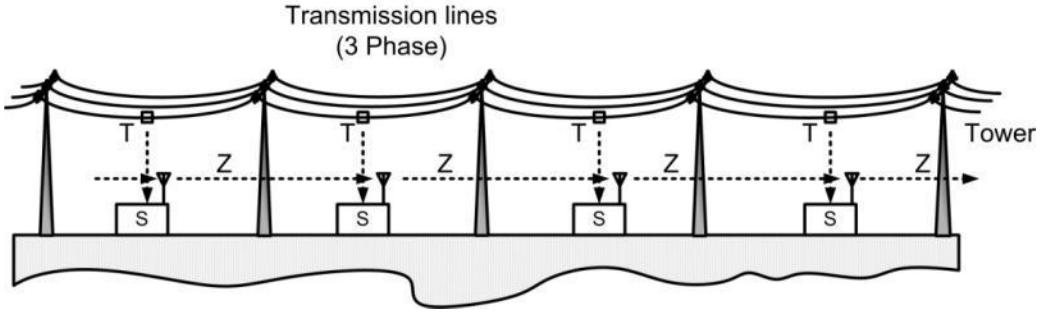
Emerging NB PLC Protocols

- Narrow-band (NB) low freq operation (10 to 500 kHz)
- Older Standards
  - X10 (industry standard) - X-10 industry standard home automation protocol
  - INSTEON - dual-band mesh topology invented by SmartLabs, Inc.
  - IEC 61334 a similar standard for wide-area power line communication
- Newer G3-PLC Standard
  - Based on IEEE® P1901.2 , up to 300 kbps, 6km range
  - Effective OFDM Modulation and channel notching
  - MAX 2992 G3-PLC MAC/PHY Powerline Transceiver Available
  - Two layers of error correction to minimize noise
  - Built-in encryption (AES-128)
  - Suggest TI031-AFE Analog Front End
- My Comments
  - PLC seems like a natural network for power meters and controls

    --- But so far has a reputation for unreliability
  - Most devices cost more than wireless

Substation/ Transmission Sensors

- Substation Equipment monitoring
  - Temperature
  - Transformer oil moisture
  - Breaker SO_2
- Weather
- Transmission Line Sag



Time Synchronization

-- subtopics --

- Precision
- GPS time
- Via Ethernet [IEEE 1588] (2)
- Via Wireless

Clock Precision needed

For measurement of :

Phase (at critical sites)	1 µs
Sensor synchronization (some)	1 ms
Loads (most)	1 sec

Needs vary widely

GPS Time Clock

- Derived from Global Positioning System (NAVSTAR)
- Accurate time (from NIST) within 0.5 μs (non-mobile installations)
- Precision clock instruments available for multiple vendors
- Normally used at generating stations and key distribution points on Grid

Via Ethernet (Internet)

- Time in µs available from NIST via Internet in several formats (widely used). --Accuracy typically 0.1 sec
- For local synchronization a master clock on one Ethernet node is used which is synchronized to other nodes via IEEE 1588 Precision Clock Synchronization Protocol
  - Relative precision typically 0.05 µs between local nodes
  - Wireless precision to 1-10 µs (over IEEE 802.15.4)
- NTP format -- 64-bit timestamp containing the time in UTC sec since EPOCH (Jan 1, 1900), resolved to 0.2 µs
  - Upper 32 bits: number of seconds since EPOCH
  - Lower 32 bits: binary fraction of second

Smart Grid Sensor Network Standards

-- subtopics --

- Smart Grid Standards Examples (2)
- SCADA and PMU
- Building control
- Industrial control
- Transducer Data Standard [IEEE 1451] (5)

Standards Examples #1*
(from NIST Framework)

4 DNP3 - This standard is used for substation and feeder device automation as well as for communications between control centers and substations.

8 IEEE C37.118 - Synchrophasor Protocol (synchrophasor):

This standard defines phasor measurement unit (PMU) performance specifications and communications.

9 IEEE 1547 Suite - This family of standards defines physical and electrical interconnections between utility and distributed generation (DG) and storage. [http://grouper.ieee.org/groups/scc21/dr_shared/]

19 IEEE P2030 Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with Electric Power System (EPS) and End-Use Applications and Loads.

- Standards, guidelines to be developed by IEEE P2030 Smart Grid Interoperability.

23 IEEE C37.2-2008 - IEEE Standard Electric Power System Device Function Numbers - Protective circuit device modeling numbering scheme for various switchgear.

*D. Hopkins “Smart Grid” Webinar

Standards Examples #2
(selected from 100+)

24 IEEE C37.111-199 - IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems (COMTRADE) - Applications using transient data from power system monitoring, including power system relays, power quality monitoring field and workstation equipment.

26 IEEE 1159.3 - Recommended Practice for the Transfer of Power Quality Data - Applications using of power quality data.

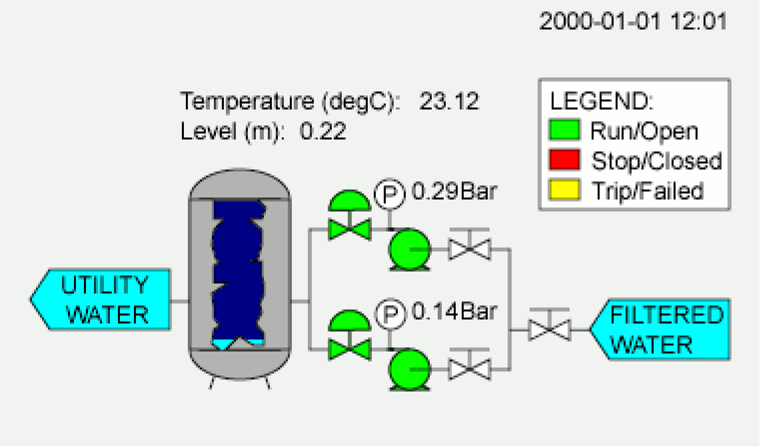
27 IEEE 1379-2000 Substation Automation - Intelligent Electronic Devices (IEDs) and remote terminal units (RTUs) in electric utility substations.

38 SAE J1772 - Electrical Connector between PEV and EVSE - Electrical connector between Plug-in Electric Vehicles (PEVs) and Electric Vehicle Supply Equipment (EVSE)

40 SAE J2847/1-3 - Communications for PEV Interactions; J2847/1 Communication between Plug-in Vehicles and the Utility Grid; J2847/2 Communication between Plug-in Vehicles and the Supply Equipment (EVSE); J2847/3 Communication between Plug-in Vehicles and the Utility Grid for Reverse Power Flow.

SCADA and PMU Standards

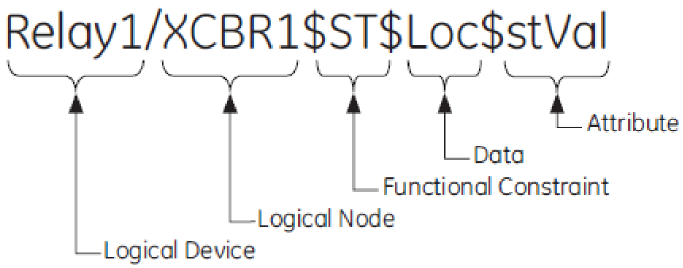
- **Supervisory Control and Data Acquisition** is current control system which has these parts:
  - Human-Machine Interface (HMI)
  - Remote Terminal Units (RTUs) – converts sensor signals to digital data (alternative: Programmable Logic Controller)
  - Communication infrastructure connects to the supervisory system
- Uses Modbus and other sensor networks (also TCP/IP extensions)
- Phasor Measurement Unit protocol uses cycle by cycle phase measurements plus SCADA and other information via dedicated network

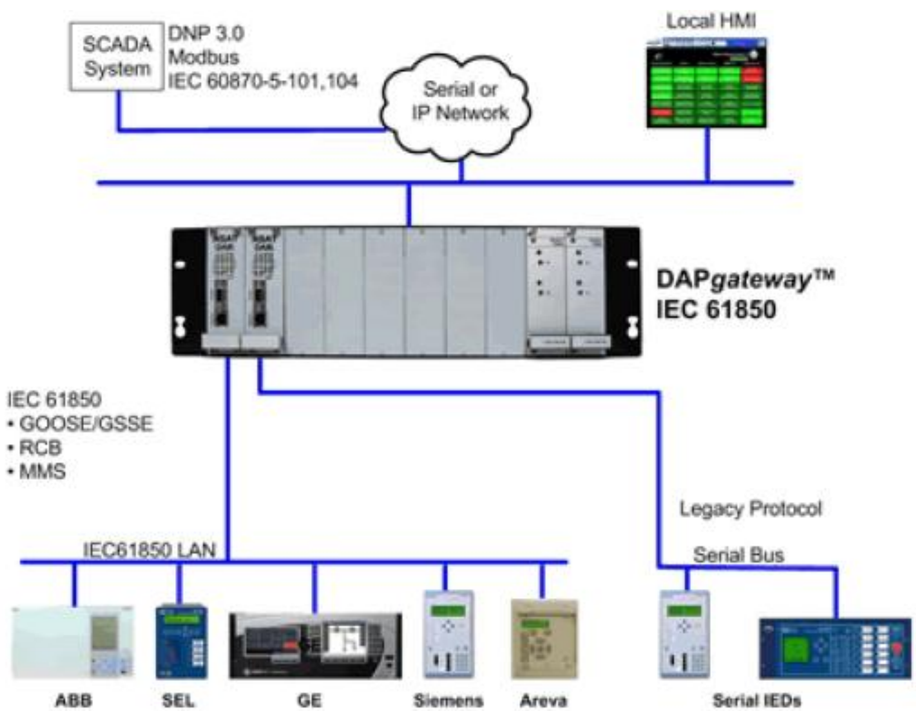


Human-Machine Interface
(from Wikipedia)

Substation Network Standard (IEC 61850)

- Communication networks and systems in substations
- Migration from the analog world to the digital world for substations
- Multi-vendor interoperability -- vendor protocol of choice





Not directly involved with sensors

http://seclab.web.cs.illinois.edu/wp-content/uploads/2011/03/iec61850-intro.pdf

Building Control Networks
(HVAC, lighting)

- Modbus (RS232/serial originally)
- BACnet - building automation and controls network (originally RS485)
- LonWorks (2-wire proprietary)
- All have TCP/IP (Ethernet) extensions, now commonly used
- Wireless versions (WiFi, Zigbee,6LoWPAN)
- Some command examples (BACnet)
  - Read Property
  - Write Property
  - Device Communication Control
  - ReinitializeDevice
  - Time Synchronization

Industrial Control Networks and Busses

- Over 100 networks in use
- Industrial Ethernet popular for base communication
- Older, still used alternatives: RS232/RS485
- Popular Digital Buses
  - HART (over 4/20 ma loop)
  - Profibus/fieldbus
  - OpenCAN/DeviceNet
- Wireless HART/ISA 100

Mod-bus

- Monitoring and control for HVAC and industrial applications
- Simple format and limited functions, developed for PLCs
- Originally RS232 and RS485 (serial)
- Industrial Ethernet (TCP/IP) version popular

Modbus TCP Frame Format		
Name	**Length**	**Function**
Transaction Identifier	2 bytes	*For synchronization between messages of server & client*
Protocol Identifier	2 bytes	*Zero for MODBUS/TCP*
Length Field	2 bytes	*Number of remaining bytes in this frame*
Unit Identifier	1 byte	*Slave Address (255 if not used)*
Function code	1 byte	*Function codes as in other variants*
Data bytes	n bytes	*Data as response or commands*

Network Sensor Applications

- Automatic testing
- Plug and play
- Multiple sensors on one network or bus
- Machine to Machine (M2M) sensor data communications
- Wide area (Nationwide) data collection ability

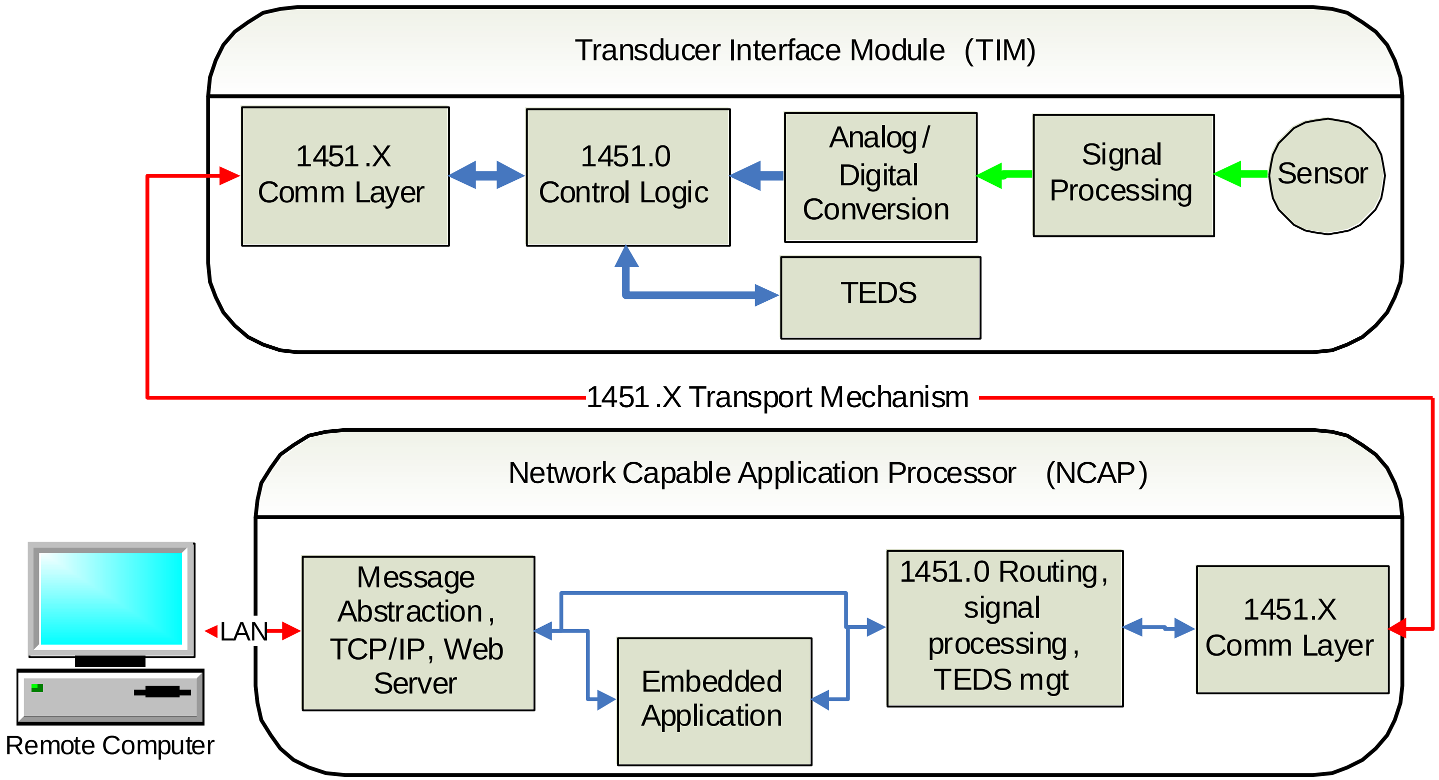
IEEE 1451 – the Universal Transducer Language

- Problem: 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
  - Solution: the IEEE 1451 Smart Transducer Protocol open standard is the best universal solution
  - Supported by NIST, IEEE and many Federal agencies

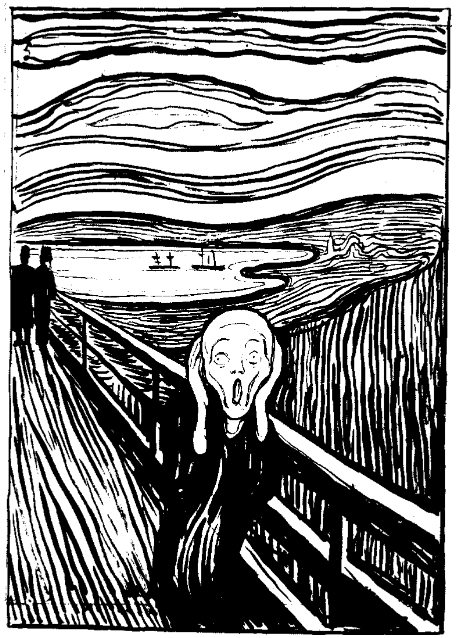
A review of the

IEEE 1451 Smart Transducer Concept



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 a design is correct



Munch –The scream

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

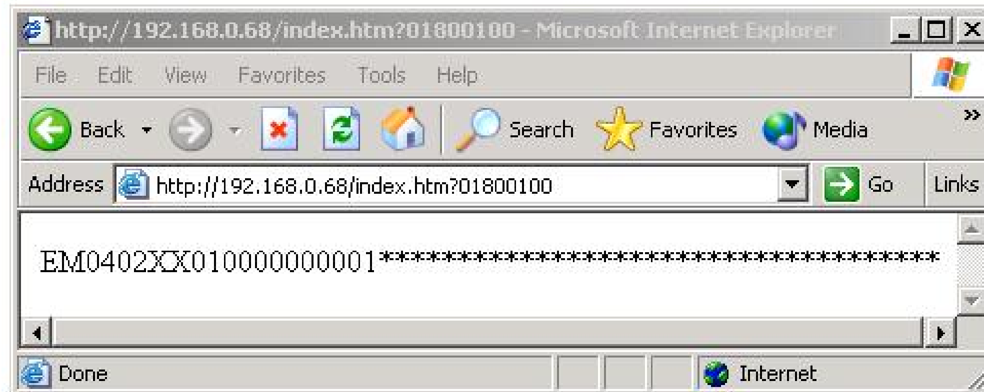
  (Checked against TEDS, error flag is not correct)

  Operating mode – actual sensor reading

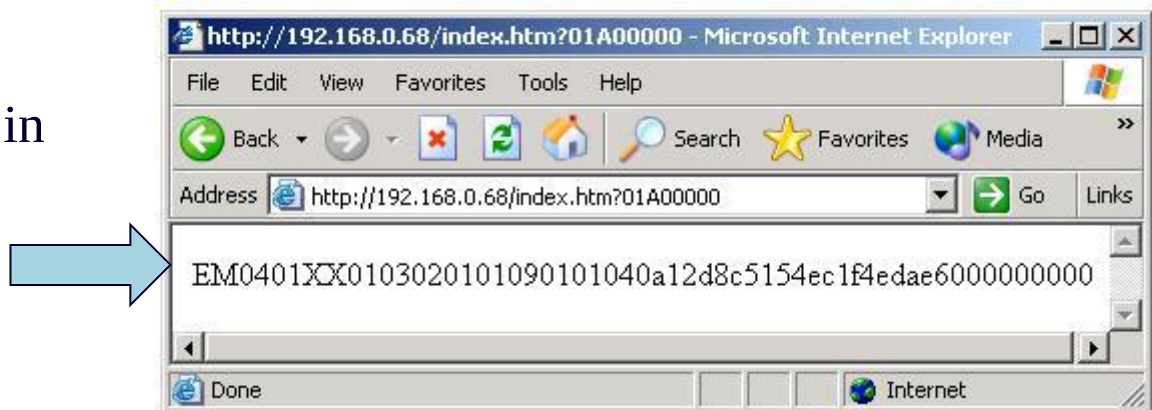
  (Must be within sensor range)

Data Readout Examples
(via Internet)

- Sensor data converted to ASCII for display

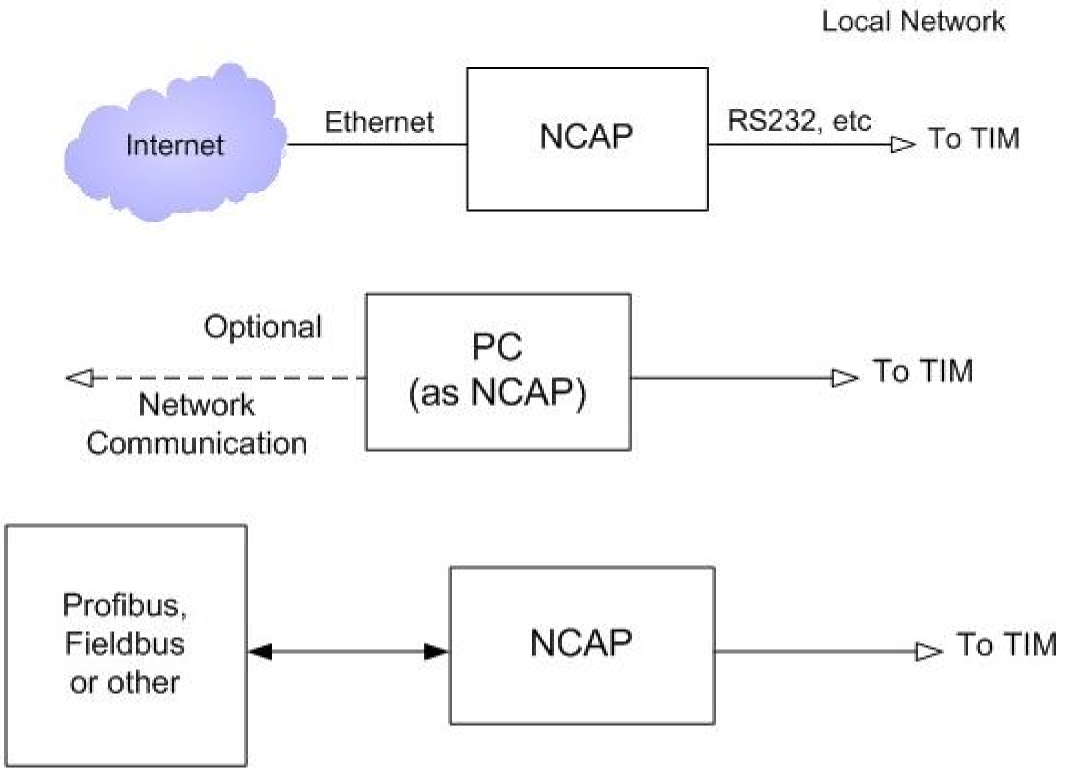


- TEDS data is displayed in hexadecimal form



Network side (NCAP) options (wired)

- Internet/Ethernet
- PC Readout
- Industrial network



All use Dot 0 protocol

Some Application Areas for Smart Grid

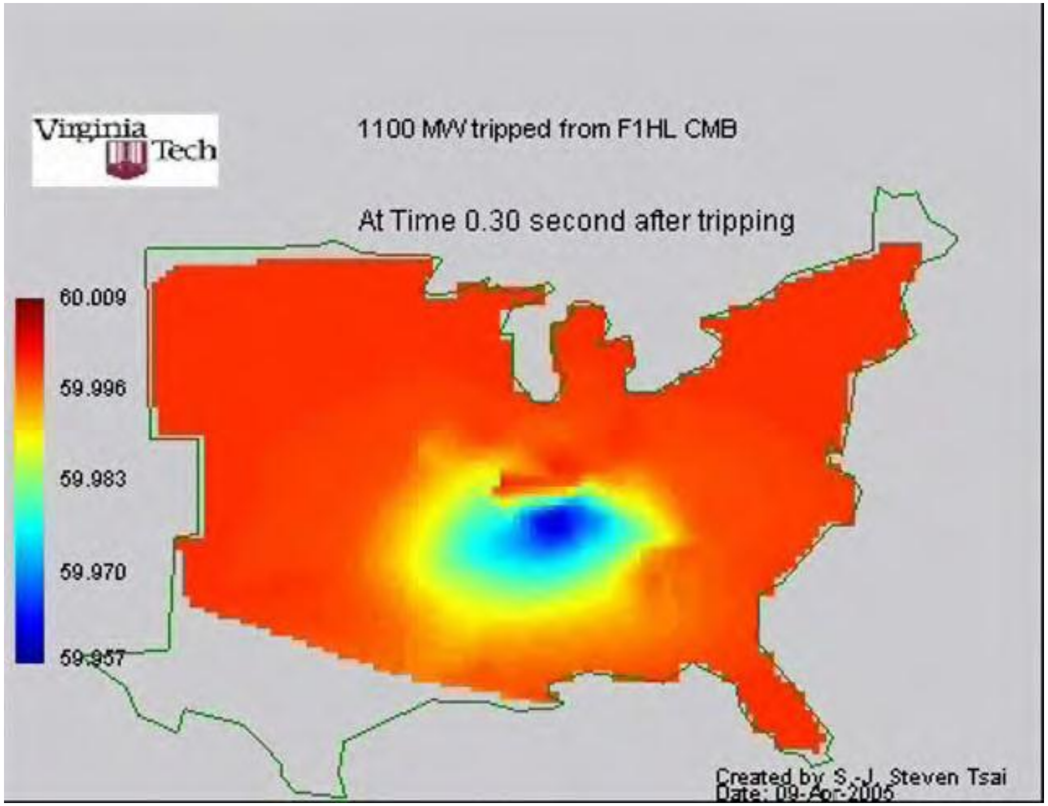
-- subtopics --

- Blackout avoidance (3)
- Smart metering
- Demand/ Response
- Energy Conservation (2)

Frequency shift and blackout

- Shifts preceding blackout (ref: SERTS report -- 2006)
  http://phasor-rtdms.com/downloads/presentations/DOE_Briefing.pdf
- -0.06 Hz near fault area
- Identifies trouble spots for response
- Fast reaction needed
- Phase relation:

  F = dθ/dt



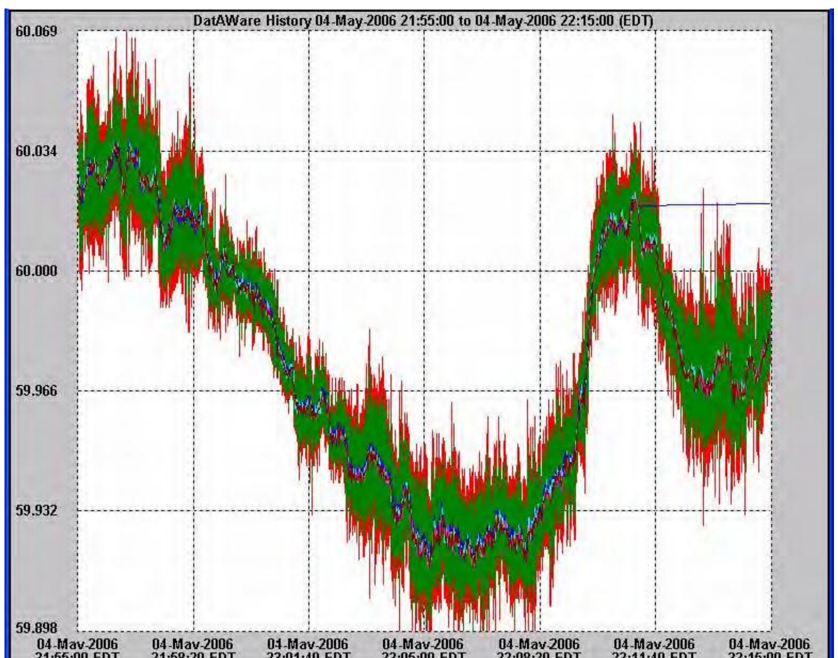
Abnormal frequency variations over time

- Large variations are a pre-backout warning
- A cause for concern already in June 2006 ---

  60.07 to 59.90 Hz. in plot below
- Relaxing precise control to 60 Hz is under consideration

  (slightly longer term drifts allowed – relaxes need for instant energy)

60.000 Hz



Measurement Points

- ***PMUs Offer Wide-Area Visibility***
- Phasor Measurement Units will extend visibility across Eastern Interconnection
- Ability to triangulate the location of disturbances
- All were coordinated with reliability councils & ISOs–Ameren–Entergy–Hydro One

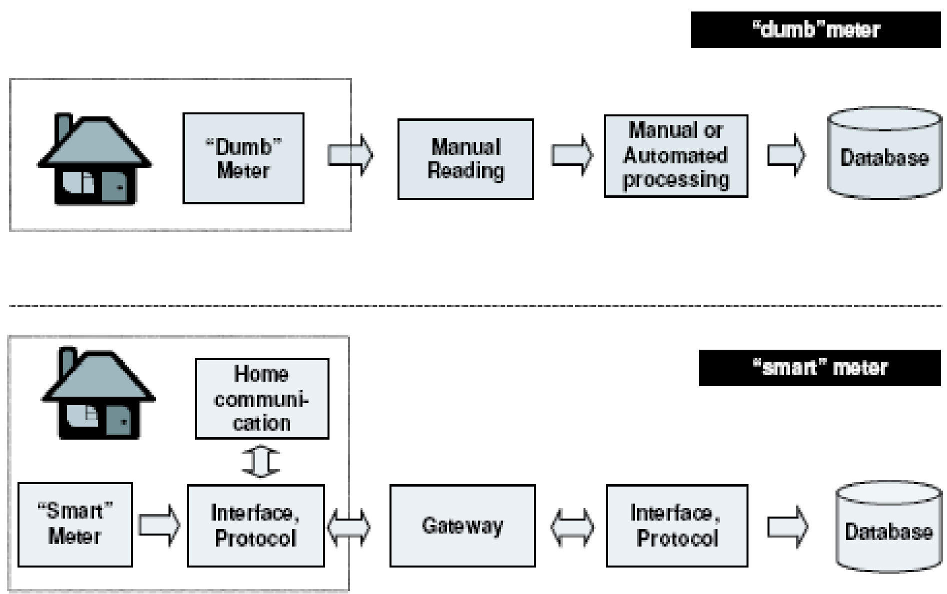
Automatic meter reading (AMR)

- Improved is Advanced Metering Infrastructure (AMI) or Smart meters (2-way)
- Used for revenue
- Wireless based
  - Many proprietary
  - Moderate range, drive-by reading
  - Mesh (Zigbee) and WiFi sometimes
  - Usually not Internet connected
- About 50M AMR/AMI installed (USA)
- Suggested standard: ANSI C12.18

Energy Conservation --1

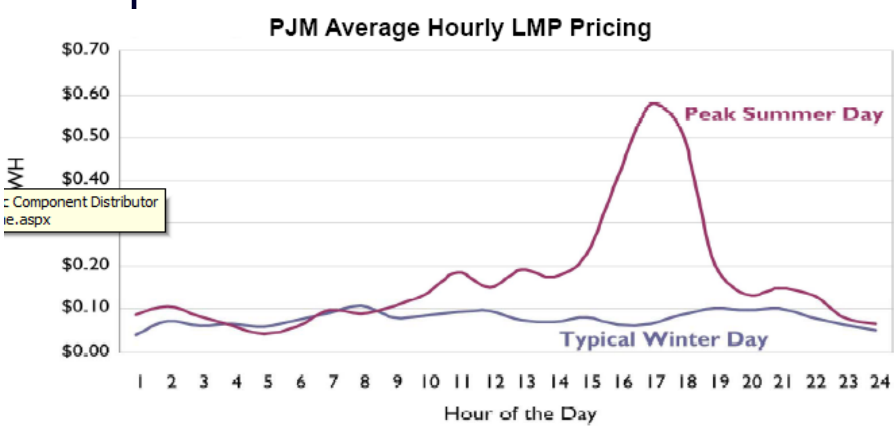
- Smart meters (at Microgrid level) provide information needed to analyze energy usage and thus allow energy minimization algorithms to be implemented
- Real time data, best at individual loads
- Control programs by utilities or private companies

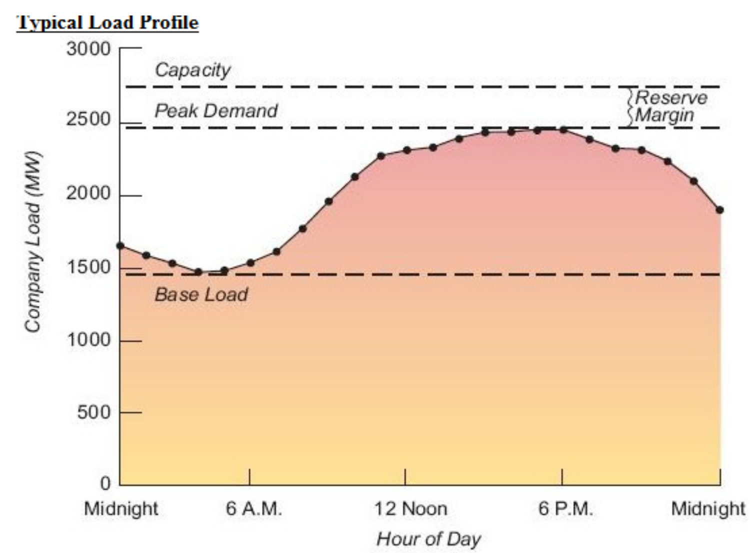
New ZigBee Smart Energy Version 1.1 Now Available



Demand/Response

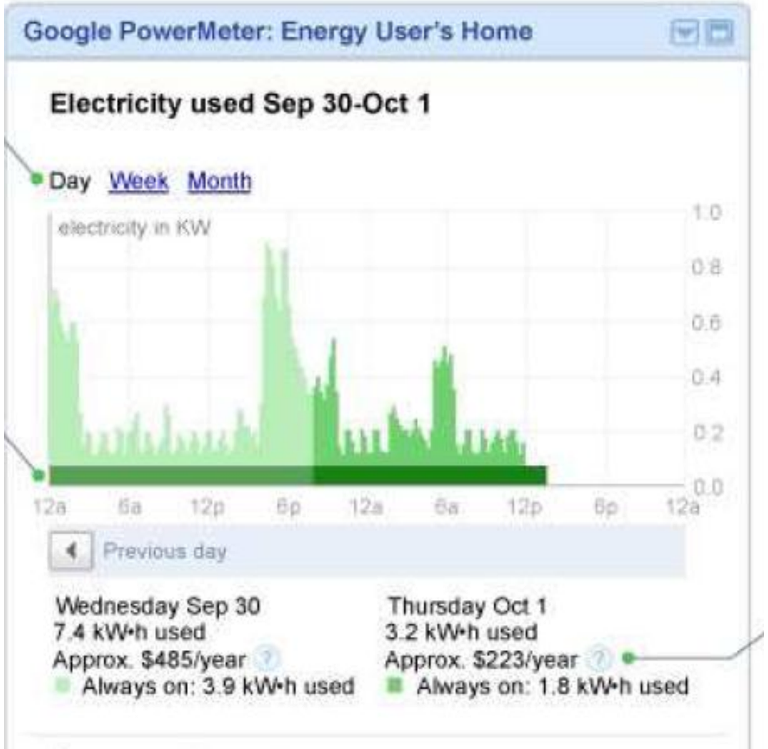
- Electrical load reduction (load shedding) in response to high demand on the grid (utilities issue alert)
- Purpose is to shave peak demand and reduce reserve power requirements (and build fewer power plants)
- Large rate increases during peak demand discourage consumption
- Implemented by utilities or third parties through contract (shed load when requested in return for lower rates)
- Requires smart meter at customer site





Energy Conservation -- 2

- Energy usage monitoring websites
- Power use vs time ($ calculated)
- Google Powermeter and MS Hohm discontinued
- Others available – eMonitor, Tendril, Wattvision, PowerCost Monitor
- 5% to 30% (15% avr) savings reported in usage studies



Prospects for Smart Appliances

- Examples: smart refrigerator, smart dryer
- Two-way communication via Internet
- Logical extension of smart grid/buildings
- Technically possible for years but …
  - Hardware costs high
  - Installation may be complex (best plug & play)
  - Standards lacking
- Will disconnect feature be implemented?
- Privacy concerns high
- Benefits unclear
- Futuristic discussion mostly

All Whirlpool Appliances to be 'Smart' by 2015

If a couple of conditions are met by the private and public sectors, the company will build only products that can communicate with a smart power grid.

Whirlpool is on a mission to smarten up its appliances.
By 2015, the company will "make all the electronically controlled appliances it produces—everywhere in the world—capable of receiving and responding to signals from smart grids," says Bracken Darrell, president of Whirlpool Europe.
A smart grid is the wiser version of the old-fashioned electrical grid that powers this and other countries.

Summary of Topics Covered

- Overview of the Smart Grid
- Networked smart sensor design aspects
- Sensor networks
- Metering and power quality sensors
- Environmental and related sensors
- Time Synchronization
- Smart grid networked sensor standards
- Application areas

Contact: designer@eesensors.com

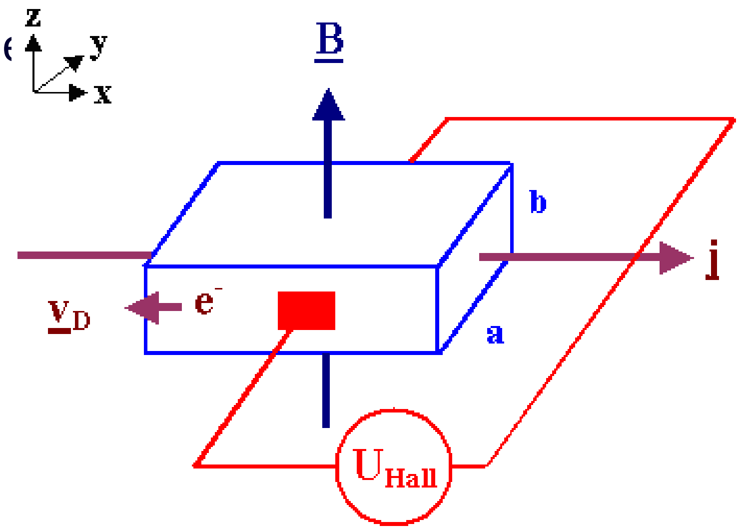
End

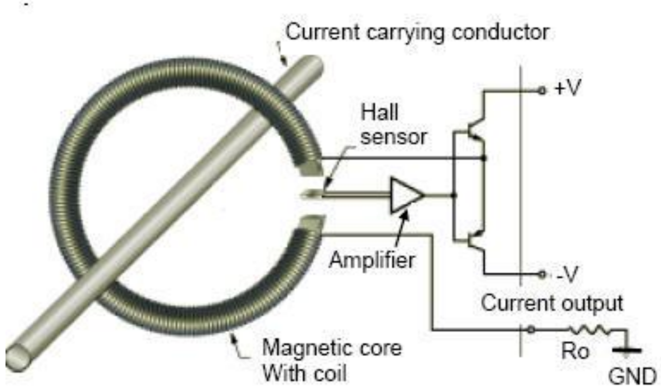
- Backup Slides Follow

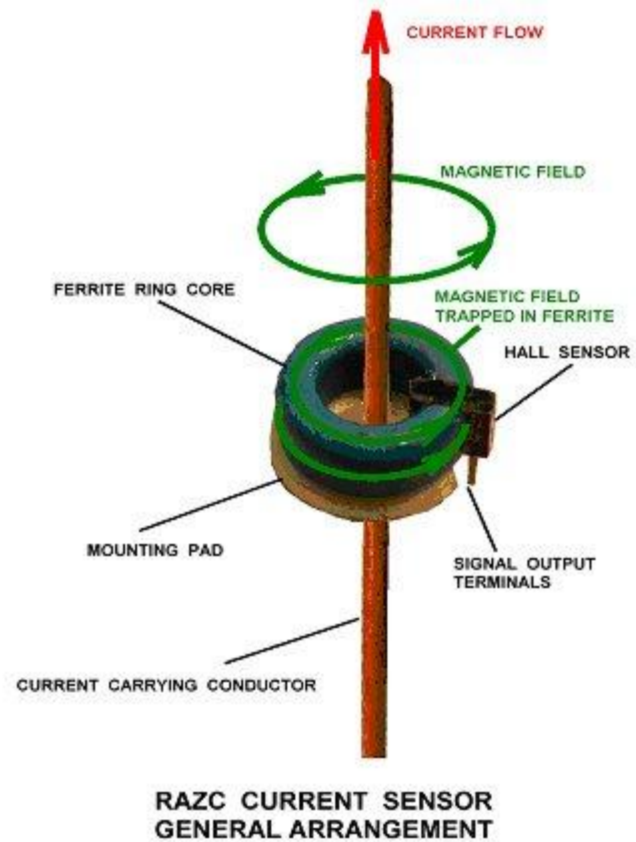
www.eesensors.com

Hall Current Sensor Basics

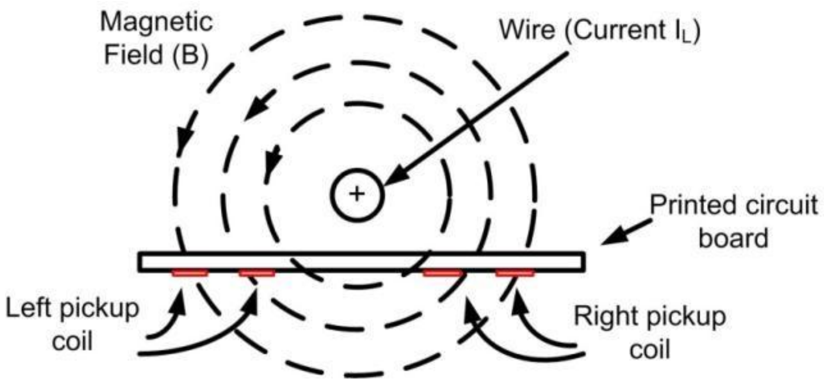
- Re

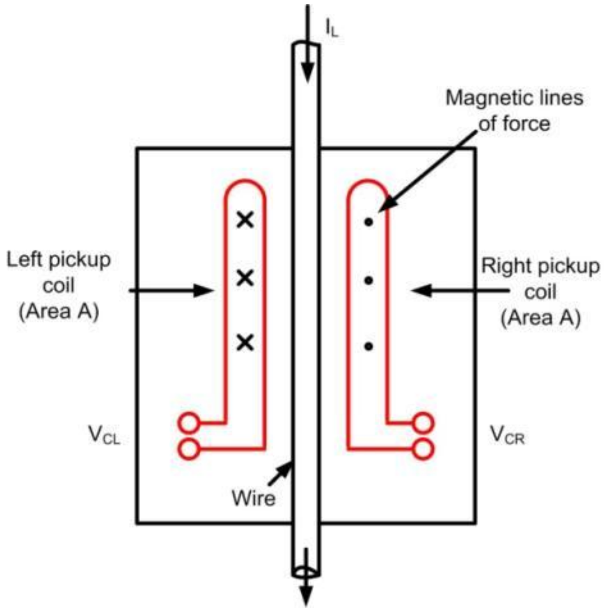






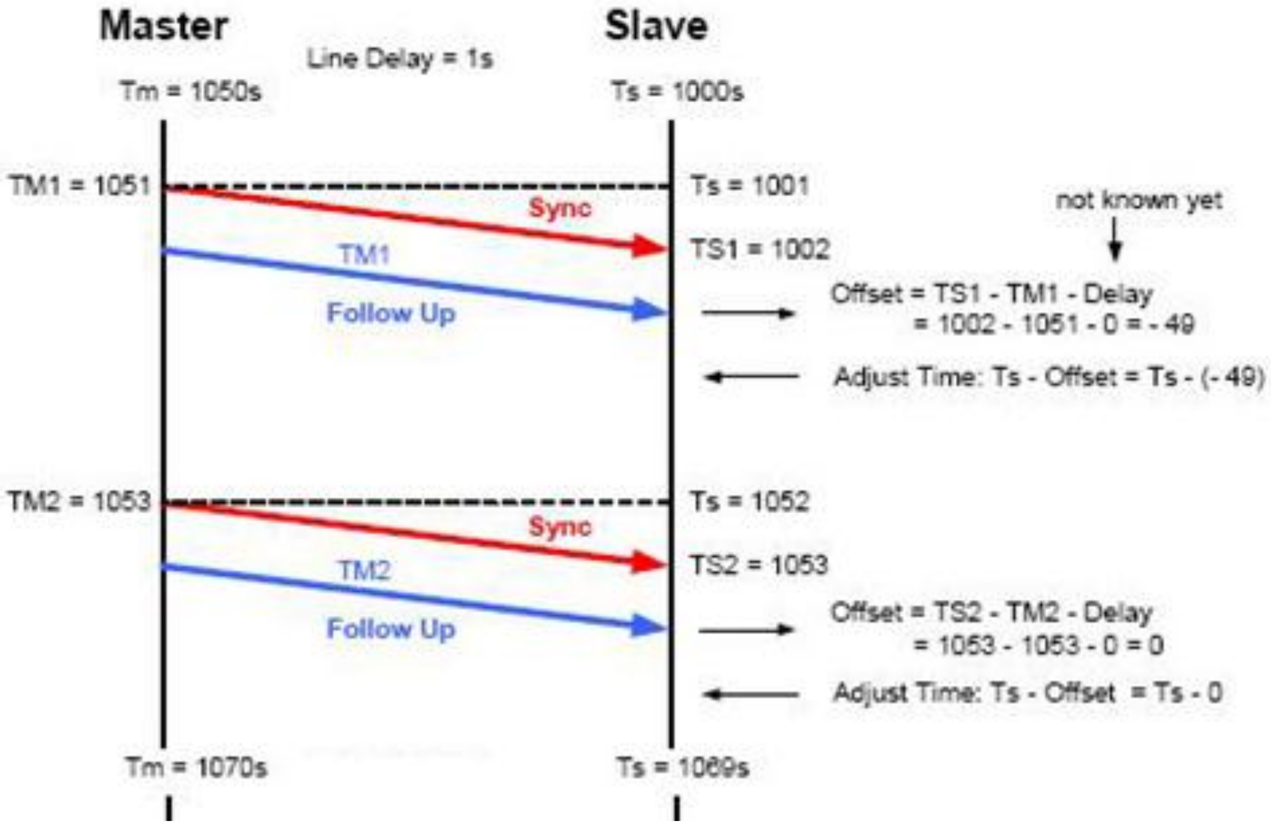
Inductive Current Sensor
(Esensors patent pending)





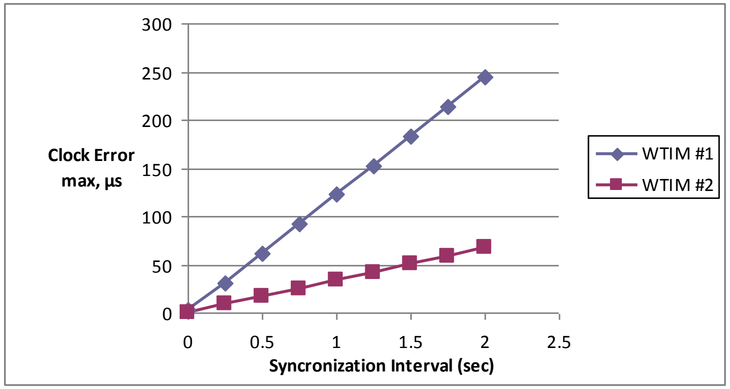
IEEE 1588 Protocol

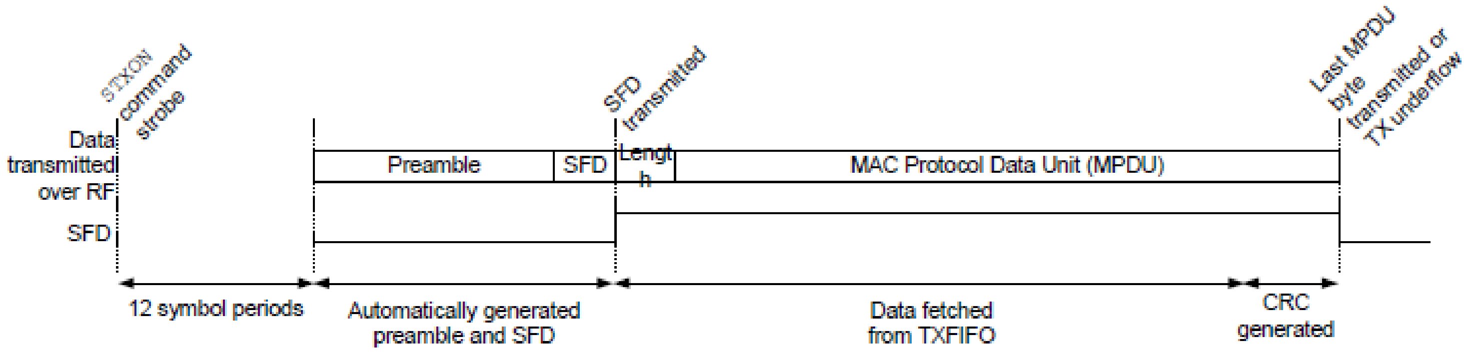
- Transmission delay time measured and compensated



IEEE 1588 Via Wireless

- Wireless node to wireless node synchronization more difficult than Ethernet because of transmission delays
- Synchronized via SFO flag
- Variation of IEEE 1588
- Power/bandwidth limit update times and thus precision (10 -100 µs possible)





Esensors Products

Websensor

Temperature, humidity, illumination

Digital Power Meters

Voltage, current, true power & other

Data transmitted to Internet via Ethernet or WiFi

www.eesensors.com