Smart Energy Monitoring, Metering and Control
Session Agenda

- Introduction to Smart Energy
- Energy Measurement
- Processing and Storage
- Google PowerMeter
- Data Communication
- Wrap-up
Introduction to Smart Energy
New Smart Energy Applications
Smart Grid

- Adds Intelligence for Real Time
  - Monitoring
  - Data Processing
  - Demand Response
- Controls Seamless Integration
  - Wind
  - Solar
  - Energy Storage
Washing Machine Evolution

Manual Control
Dangerous

Automatic Cycles
Mechanical Control
Inefficient Motor

Advanced User Interface
Communication
Real-Time Pricing

High Efficiency Motor
Uses Less Water
Electronic Control
Motor
User Interface
Data Center Evolution

Inefficient Space Heaters

Virtualization Temperature Compensating

Users Demanded Lower Power Lower Heat Dissipation OS Optimization for Efficiency

Communicate Energy Consumed Manage Peak Usage Energy Star Rated
Energy Monitoring Block Diagram

- Sensors
- Measurements
- Energy Calculations
- Control
- Storage
- Human Interface
- Wireless Communication
- Wired Communication
Energy Measurement
Energy Measurement

- Energy determined by measuring current & voltage
  - Post processing needed for various measurements
- Accuracy requirements often determine cost
- Bandwidth requirements determine sampling speed

![Diagram showing the process of energy measurement by measuring current and voltage using ADCs and calculating energy](attachment://energy_measurement_diagram.png)
Current Sensing Technologies

- **Shunts**
  - Simple resistor, typically 100 $\mu\Omega$ to 500 $m\Omega$
  - Limited current sensing due to self heating

- **Current transformers**
  - Isolation at the sensor
  - Higher accuracy and currents than shunts

- **Rogowski coils**
  - Isolation at the sensor
  - High current measurements
  - Integrator needed in measurement ICs
Energy Measurement Accuracy

- Often given in % error over a given dynamic range
- Determine hardware used
- Many factors
- Need to limit error contribution of measurement ICs
  - Harmonic distortion and noise
  - Linearity
Measurement ICs often characterized by resolution only

Need more information to properly characterize contribution to overall error
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The amount of total non-linear distortion is:

\[ THD = \frac{P_{\text{Harmonics}}}{P_{\text{Signal}}} \]
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The amount of total non-linear distortion is:

$$THD = \frac{P_{\text{Harmonics}}}{P_{\text{Signal}}}$$

Adding noise to the equation

$$THD + N = \frac{P_{\text{Harmonics}} + P_{\text{Noise}}}{P_{\text{Signal}}}$$
Measurement ICs often characterized by resolution only
- Need more information to properly characterize contribution to overall error
The amount of total non-linear distortion is:
\[ THD = \frac{P_{\text{Harmonics}}}{P_{\text{Signal}}} \]
Adding noise to the equation
\[ SINAD = \frac{1}{THD + N} = -(THD + N) \text{dB} \]
Accuracy Improvement: Linearity

- The measure of the variation of the A/D converter performance relative to the ideal transfer function
- Measured as Integral Non-Linearity (INL)
Dithering Improves Accuracy

- The addition of small random non idealities at the inputs
- Often increases the output white noise, but removes spikes in the output spectrum

Typical injection points of the dither signal (random or pseudo-random)
Harmonics & Noise Improvement

- Dithering improves THD & SINAD

**Total Harmonic Distortion vs. Oversampling Ratio**

**Signal-to-Noise and Distortion and Effective Number of Bits vs. Oversampling Ratio**
Dithering improves INL (Integral Non-Linearity)

Figure 1: Without Dithering

OSR = 256
SCK = 8 MHz

Figure 2: Dithering Block Active

OSR = 256
Dithering ON
SCK = 8 MHz
Energy Measurement with Microchip

- Proven analog performance
  - MCP390X devices use 16/24-bit ADCs with 91 dB SINAD and -104 dB THD performance
  - Measurement Error of 0.1% (typ) exceeds IEC requirement for energy meter designs
MCP3901 Analog Front End

- Dual 64 ksp 16/24-bit ADCs
- 91 dB SINAD, -104 dB THD (exceeds IEC class 0.2)
  - Includes dithering block
- Interfaces to all 3 current sensor types

![Diagram of MCP3901 Analog Front End with PGA (1:32) and ΔΣ ADC stages connected to SPI interface.]
MCP3901 AFE Evaluation Kit for PIC24/dsPIC33F

- Compatible with Explorer 16
- PIC24 & dsPIC33F modules
- LabVIEW graphical user interface
Processing and Storage
Processing Solutions

- Microchip’s PIC® MCU and dsPIC® DSC portfolio brings wide range of options for energy measurement
  - Easy migration between MCU families
    - Common toolset
    - Match micro cost/performance to application
  - Connectivity for energy meter reading and calibration such as WiFi®, MiWi™, ZigBee®, Ethernet, Infrared
MCU Solutions for Energy Monitoring

- **Power Monitoring**
  - 16F1947
    - 28K
    - 64 pins
    - LCD
  - 16F1933
    - 7K
    - 28 pins
    - LCD
  - 12F1822
    - 3.5K
    - 8 pins

- **Simple Metering**
  - 18F87J72
    - 128K
    - 80 pins
    - XLP, LCD
  - 18F86J90
    - 128K
    - 80 pins
    - XLP
  - 18F66J11
    - 64K
    - 64 pins

- **Multi-function Metering**
  - 18F87K90
    - 128K
    - 80 pins
    - XLP, LCD
  - 24FJ256GA110
    - 256K
    - 100 pins
  - dsPIC33FJ128
    - 128K
    - 64 pins
  - 24FJ256GA110
    - 256K
    - 100 pins

- **Full AMI Metering**
  - 32MX695F512
    - 512K
    - USB/Ethernet/RTCC
    - 100 pins
  - 32MX440F128
    - 128K
    - USB/HW RTCC
    - 100 pins
  - 18F87K22
    - 128K
    - 80 pins
    - XLP
  - 18F87J72
    - 128K
    - 80 pins
    - XLP
  - 18F87K90
    - 128K
    - 80 pins
    - XLP
  - 24FJ256GA110
    - 256K
    - 100 pins
  - dsPIC33FJ128
    - 128K
    - 64 pins
  - 32MX440F128
    - 128K
    - USB/HW RTCC
    - 100 pins
PIC18F87J72 with Energy Measurement AFE
Single-Phase Energy Meter Reference Design with PIC18F87J72

- Full evaluation kit: hardware & firmware
- Active/Reactive/Apparent Power, and RMS Current/Voltage
- Better than IEC Class 0.5 performance
- Low cost shunt based design
- Serially accessible calibration registers
Additional Reference Designs

- 1-phase Low Cost Power Monitor
  - MCP3901 AFE + PIC18F25K20

- 1-phase LCD Energy Meter
  - MCP3909 AFE + PIC18F85J90

- 3-phase Harmonic Analysis Energy
  - MCP3909 + dsPIC33F
Low Cost 1-phase Energy Monitoring

- PIC18F87J72
- LCD Panel
- LCD Driver 192-Seg
- 16-bit ADCs
- Flash 64-128 kB
- MSSP
- Power supply
- Voltage Sampling
- Current Sampling
- Load
- Backup Battery
- Low Voltage Detect
- Low Cost
- AC
- 10-bit 12-ch
- IR Transceiver
- RS485 and PLC
- MCP79400 RTC
- EEPROM

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3-phase High-End Energy Measurement with Prepayment Interface

- PIC24FJ256GA110 Family
  - Flash 128-256 KB
  - ADC 10-bit 16-ch
  - GPIO
  - SPI
  - UART
  - RTCC 32KHz
  - NTC Thermistor
  - Prepayment Card
  - Smart Card Reader
  - PLC
  - IrDA
  - RS485

- MCP3903 6-ch AFE
  - Current Sampling
  - Voltage Sampling
  - Power supply
  - Battery
  - Load
  - ~AC

- Low Voltage Detect

- LCD Driver
  - LCD Panel

- EEPROM

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Monitoring Time of Usage

■ Energy billing purposes
  ■ Accurate time & energy usage monitored and stored

■ Smart energy communications
  ■ Timestamp usually included with messages
  ■ MAC address loaded in MCU or RTCC with unique ID

■ Periodic system status to validate meter operation
  ■ Timestamp logged each time a self diagnostics is performed
Stand-Alone
I²C™ Real-Time Clock/Calendar

- Low voltage
- 1.8V operating, 1.3V timekeeping & SRAM retention
- Automatic battery switchover
- Programmable alarm output (VCC or VBAT)
- 1 Kbits EEPROM plus 64-bit Unique ID (protected EE)
- 64 bytes of SRAM
- Digital Trimming
  - Resolution: 1 ppm
  - Range: ±127 ppm
- I²C Serial Interface

Crystal 32.768 kHz

Alarm Output
1 Hz to 32 kHz

Vcc

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Data Storage in Energy Monitoring

- **Data Logging:**
  - Meter operation is periodically monitored & recorded
  - Energy usage by the consumer is measured and stored
    - High endurance memory is a requirement

  ![Diagram with Serial EEPROM and Serial SRAM]

  - Energy usage saved every minute / hour
  - High Endurance
  - Higher Endurance
  - Up to 525,600 Write Cycles / Year

- ** Calibration:**
  - Calibration parameters stored in non-volatile memory
3-phase High-End Energy Measurement with Wireless AMI

- dsPIC33FJ128 Family
  - Flash 64-128 KB
  - ADC 10-bit 16-ch
  - SPI
  - GPIO
  - UART
  - I²C
- LCD Driver
- LCD Panel
- MCP3903 6-ch AFE
- Current Sampling
- Voltage Sampling
- Power supply
- Battery
- Load
- MCP79400 RTC
- NTC Thermistor
- Home Area Network
  - PIC24F256GA110
  - MRF24J40
- Utility Office
  - PIC24F16KA102
  - MRF49XA
- PLC
- IrDA
- RS485
- ~AC
- SPI
- Low Voltage Detect
- x 3
- Battery
Data Communication
Data Communication

- Methods vary by
  - Physical environments
  - Standard protocol interfaces

- Wireless
  - ZigBee®, WiFi®, MiWi™, Z-Wave, proprietary

- Wired
  - PLC, Ethernet, USB, Home Plug, BACnet, proprietary

- Protocols
  - DLMS, COSEM, Smart Energy Profile
Microchip Wi-Fi® Solution

- Driver incorporated into Microchip TCP/IP stack
- Compatibility across nearly every major Microchip MCU family
- Demo Source Code and Applications
- PICtail™ boards and PICtail board based development kits shipping now
Microchip Sub-GHz Wireless Solutions

- Multiple frequency options
  - 868/915/950 MHz
  - FSK/OOK Modulation

- Low current operation
  - Low Rx Current = 3 mA
  - Low Tx Current = 25 mA @ +10 dBm

- Integrated power amplifier (+12.5 dBm)

- High receiver sensitivity
  - -107 dBm FSK/ -113dBm OOK)

- Automatic frequency control (AFC)

- Module features:
  - FCC (U.S.A.), IC (Canada), and ETSI (Europe) compliant
  - Surface-mountable PCB
Microchip 2.4 GHz Solutions

- **Transceiver Features:**
  - 2.4 GHz IEEE 802.15.4 compliant
  - Supports MiWi™, MiWi P2P & ZigBee®
  - In-line/stand-alone encryption
  - Automatic MAC retransmit
  - 18 mA(RX)/22 mA(TX)/2 µA(Sleep)

- **Module Features:**
  - Integrated PCB antenna
  - FCC (U.S.A.), IC (Canada), and ETSI (Europe) certified
Example: Home Area Networks

- Enables in-house devices to connect with utility via meter or gateway
  - Demand response
  - Power consumption per device
- Provides greater consumer awareness

Optional bridge

Energy Measurement IC
MCU
Wired or Wireless

802.11

Internet

OR

To utility company
Google PowerMeter
Smart Energy Monitoring with Google PowerMeter

- A free energy monitoring tool
- View your home's energy consumption online
- Uses energy information provided by smart meters and energy monitoring devices,
  http://www.google.com/powermeter/
Application Example

Power Distribution Unit (PDU) Compatible with Google Power Meter
Reference Implementation/ Demo Tool for Google PowerMeter

- Measure energy with Energy Monitoring PICtail™ board (ARD00330)
- Communicate to Internet with Ethernet (AC164123) or Wi-Fi (AC164136-4) PICtail board
Wrap Up

- Smart energy requirements moving to a variety of application areas
- Energy measurement requirements determine hardware selection
- Wide variety of communication methods and protocols for sending and displaying energy data
- Microchip provides wide range of solutions spanning low-end to high-end energy monitoring & metering applications
Questions?
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**Coupon Number: ESC#2011SV**
This coupon is good for registration fees for one Microchip Regional Training Center course held in North America May 1st, 2011 through December 31st, 2011.

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