Build Your Own E-Meter

Bart Basile

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MSP430 Metrology

Smart Grid BU

Agenda

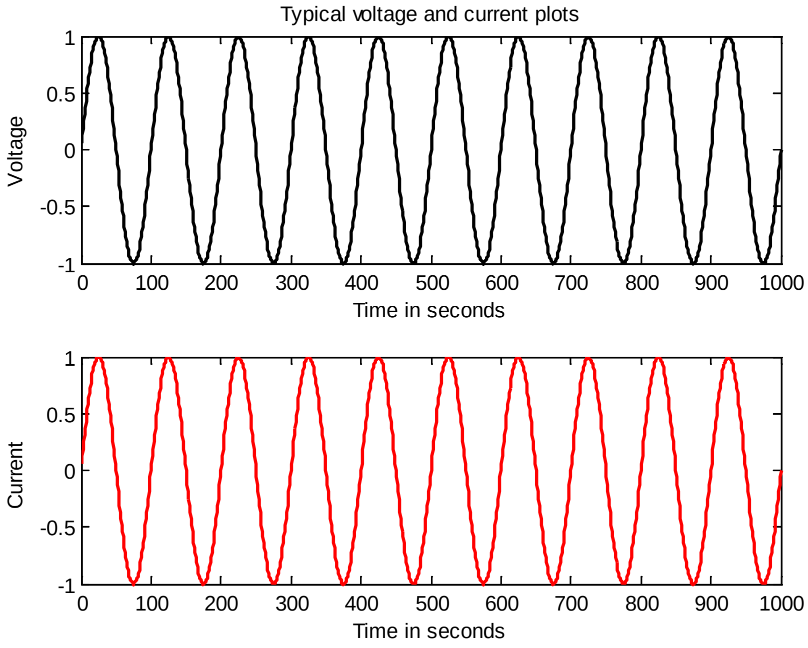
- Introduction to Energy metering (E-metering)
- Basics of E-metering
- Power Supplies for E-metering
- Why choose MSP430
- MSP430 Energy metering solutions
- Meter Calibration and its importance
- Using the EVM430-F6736 for energy metering
- Safety tips

What is "Energy"

- Energy is required by everything that is performing any sort of task, including us humans
- Energy created for different tasks
  - Gasoline → Powering all modes of transport
  - Electricity → Powering most equipments inside a home/office
  - Coal → Popular alternate source for the above two
- Extremely precious
  - Energy conservation is a primary goal for lawmakers today
  - Usage is increasing steadily
  - Running out of abundance soon!

What Does an Energy Meter do?

- Energy meters measures amount of electrical energy consumed
- Power is the product of instantaneous voltage and current
- Energy is the power integrated over time measured in kilo-watt-hours (kWh)



Types of Energy Meters Today

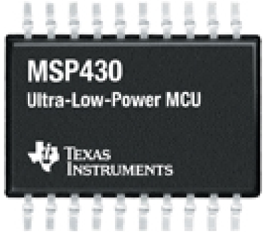
- **Electromechanical meters**
  - Most homes have these meters
  - Operates by counting the number of revolutions of an aluminum disc
  - The aluminum disc rotates at a speed proportional to the power usage
  - Reading of meter is done manually
  - Limited accuracy

- **Electronic meters**
  - Extremely favorable metrology with absolutely no moving parts
  - Uses microcontrollers, DSP processors or ASIC for the metrology
  - Self-energy consumption is negligible
  - Extremely accurate measurements with digital display
  - Robust tamper detection and protection
  - Support for Automatic Meter Reading (AMR) and Advanced Metering Infrastructure (AMI)

Types of measurements

- Single phase measurement
  - Common in most residential complexes
  - One voltage and one current to be measured
  - Supports low to medium load
- Dual phase measurement
  - Not common (Japan uses this)
  - Two voltages and two currents to be measured
  - Each phase is 180 degrees out of phase with the other
  - Supports medium to large load
- Three phase measurement
  - Common in large office spaces and industries
  - Consists of 3 separate phases to distribute AC power
  - Each phase is 120 degrees out of phase with the others
  - Three voltages and three currents to be measured
  - Designed for applications that service large loads

Agenda



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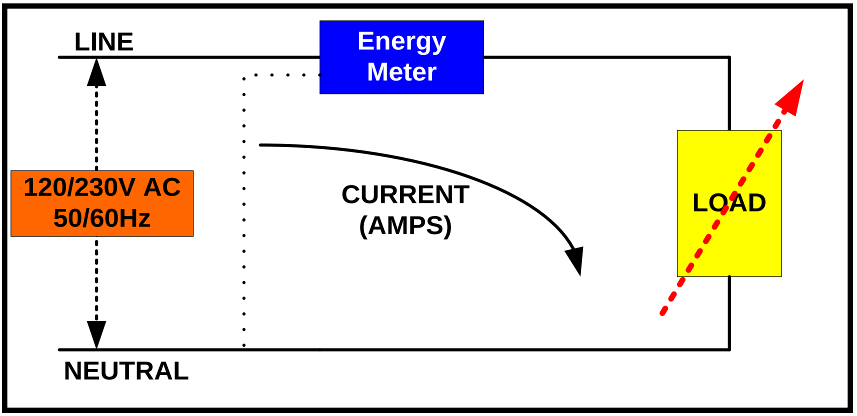
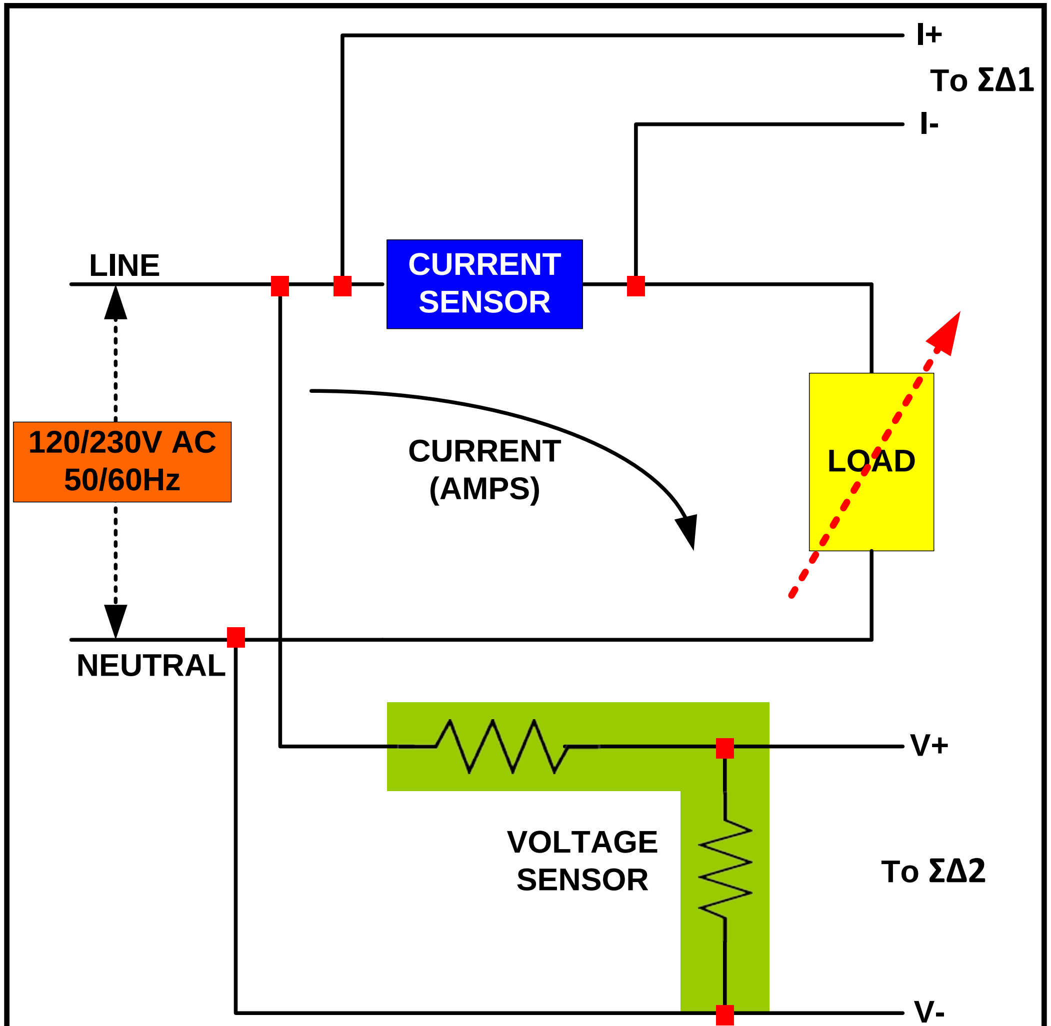
Meter Connections

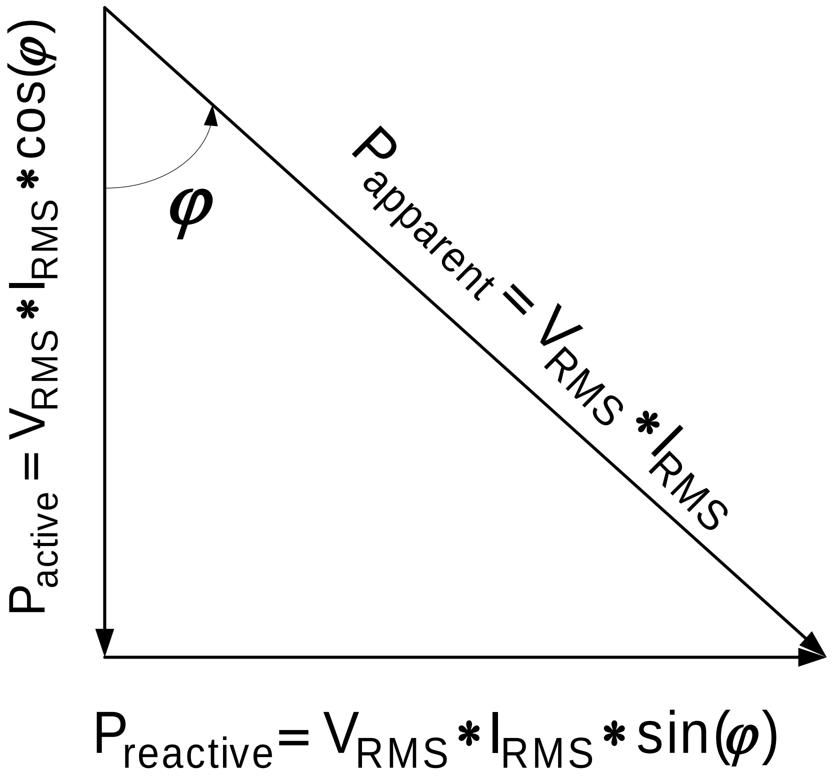


Typical 1-phase Connections



Connections with sensors

Metering parameters



- Energy
  - Active
  - Reactive
  - Apparent
- Power
  - Active
  - Reactive
  - Apparent
- Power factor ($\cos(\varphi)$)
- Voltage and Current
  - Peak
  - RMS
- Frequency
- Temperature
- Tamper detection
- Energy pulse output for calibration

Metering formulae

- V_{samp} →Voltage sample
- I_{samp} →Current sample

Typical formulae, Energy/Power are similar quantities

$$V_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V_{samp}(i) * V_{samp}(i)}$$

$$\text{Active Power} = \frac{1}{N}\sum_{i=1}^{N} V_{samp}(i) * I_{samp}(i)$$

$$I_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} I_{samp}(i) * I_{samp}(i)}$$

$$\text{Apparent Power} = V_{RMS} * I_{RMS}$$

$$\text{Reactive Power}_{PT} = \sqrt{\text{Apparent Power}^2 - \text{Active Power}^2}$$

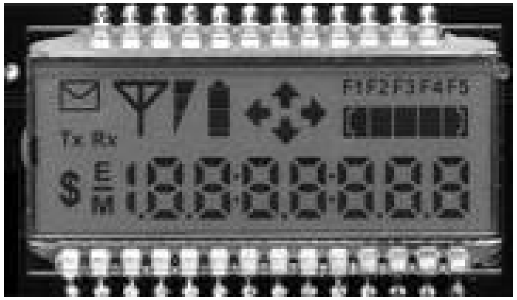
$$\text{Reactive Power}_{shift} = \frac{1}{N}\sum_{i=1}^{N} V_{samp,90}(i) * I_{samp}(i)$$

$$\text{Power Factor} = \cos\phi = \frac{\text{Active Power}}{\text{Apparent Power}}$$

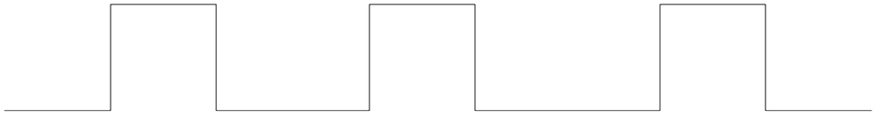
Samples of voltage and current are needed for all calculations

Energy translation

- Digital display
  - Good enough for installed meters
  - Does it truly reflect accuracy of a meter?
- Pulse output
  - A must for calibration
  - Pulses can be generated by a Timer with very good resolution using a very accurate clock source
  - Reference meters need them to report accuracy
  - Use an LED to have it read by an Optical sensor



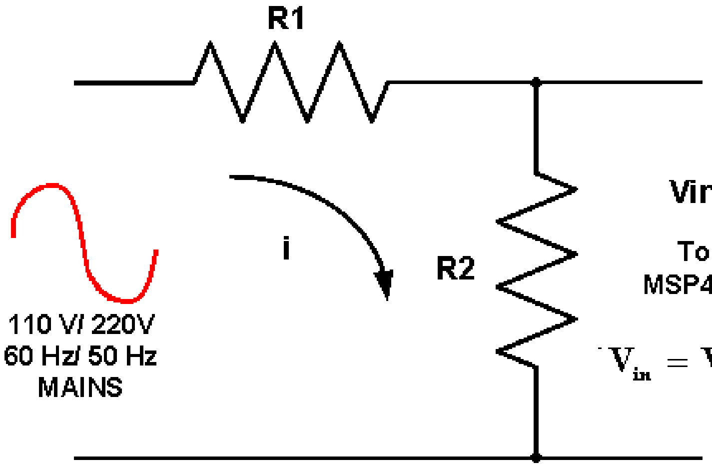
LCD Segment Display



Low energy consumption

High energy consumption

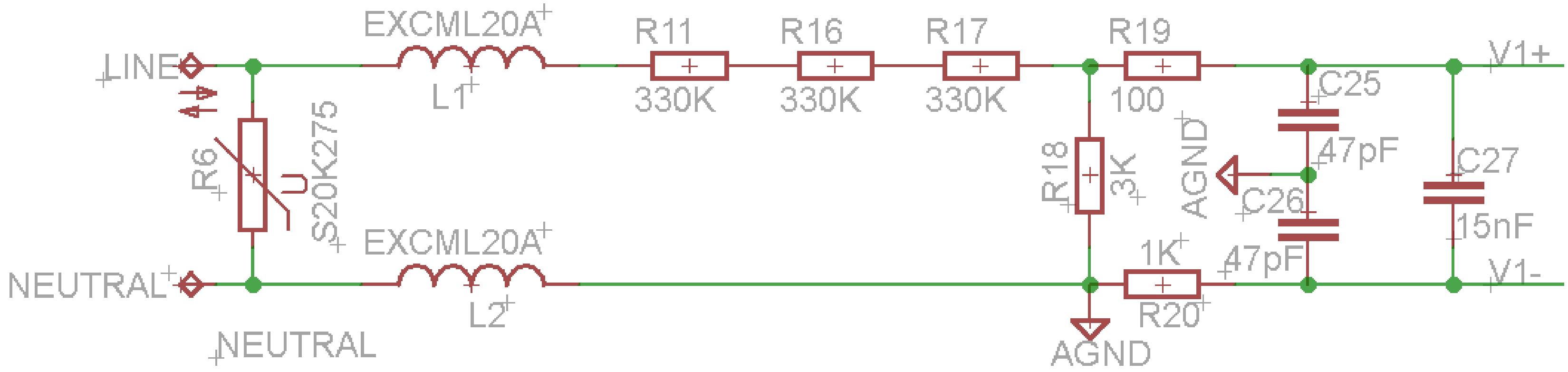
Voltage Sensor- Resistor



$$V_{in} = V_{mains}\left(\frac{R_2}{R_1 + R_2}\right)$$

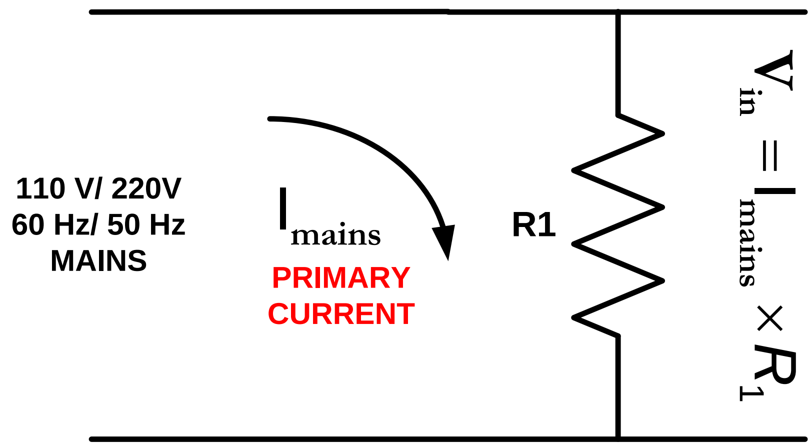
- Always used for voltage
- Simple and extremely cheap
- Values of R_1 and R_2 chosen depending on V_{mains} and desired range for V_{in} to A/D
- No level shifter necessary for differential inputs
- Gain amplifier stage not required

Voltage Front End



- Varistor R6 for spike protection
- Voltage divider to bring 220/110VAC to ADC input range
- Simple low pass anti aliasing filter

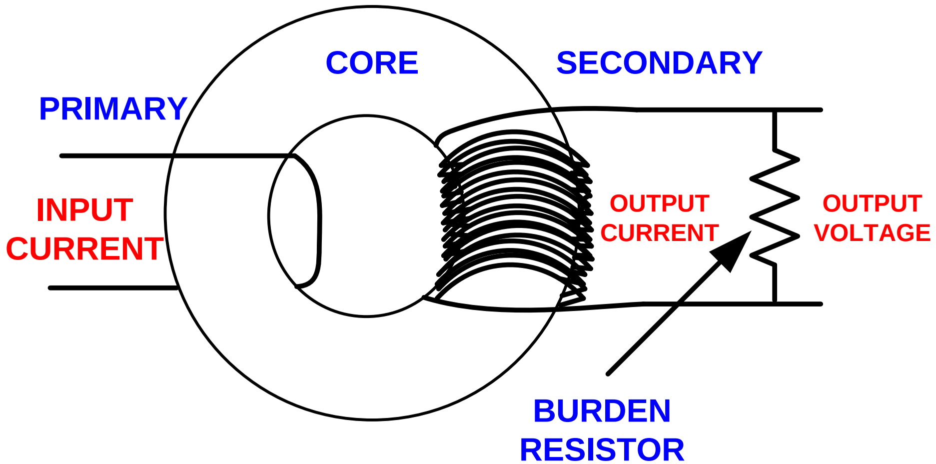
Current sensor-Shunt resistor



- Commonly used current sensor
- Simple to design, based on Ohm's law
- Inexpensive
- Always micro-ohms range to support a wide dynamic range of currents
- No magnetic effects
- Absolutely no inherent phase shifts

- Can be used only with single-phase measurement systems
- In almost all cases, resistance is not constant, stable or perfectly linear over temperature
- Limited accuracy
- No electrical isolation provided
- Self-heating due to power dissipation is a concern, posing limitations

Current sensor-Current transformer

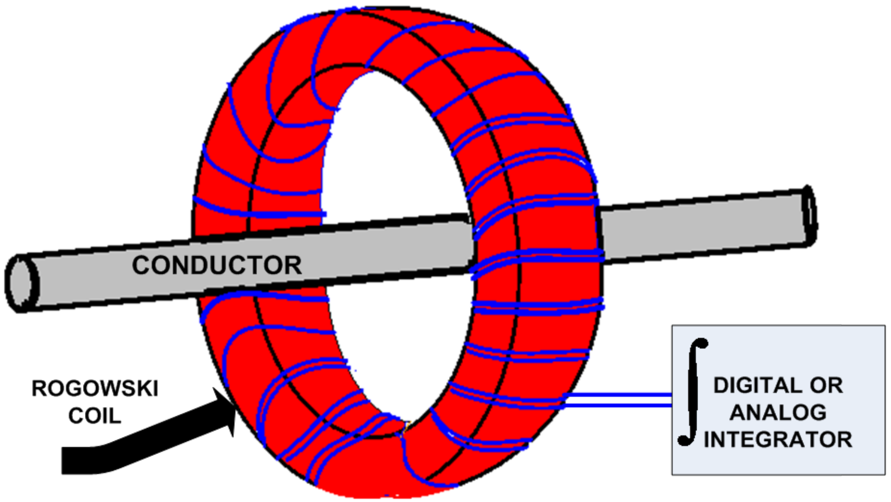


$$R_B = \frac{V_{sense,\max} * CT_{ratio}}{I_{prim,\max}}$$

- Provides electrical isolation protecting the measuring device
- Current in secondary is proportional to in current in primary.
- With zero losses, the secondary current is the primary current divided by N (number of turns on the core)
- Provides best accuracy

- Subject to internal phase shift that needs to be compensated
- Burden resistor (load) control the maximum input current to CT
- Load must never be disconnected from secondary when current is flowing at the primary
- Susceptible to external magnetic effects

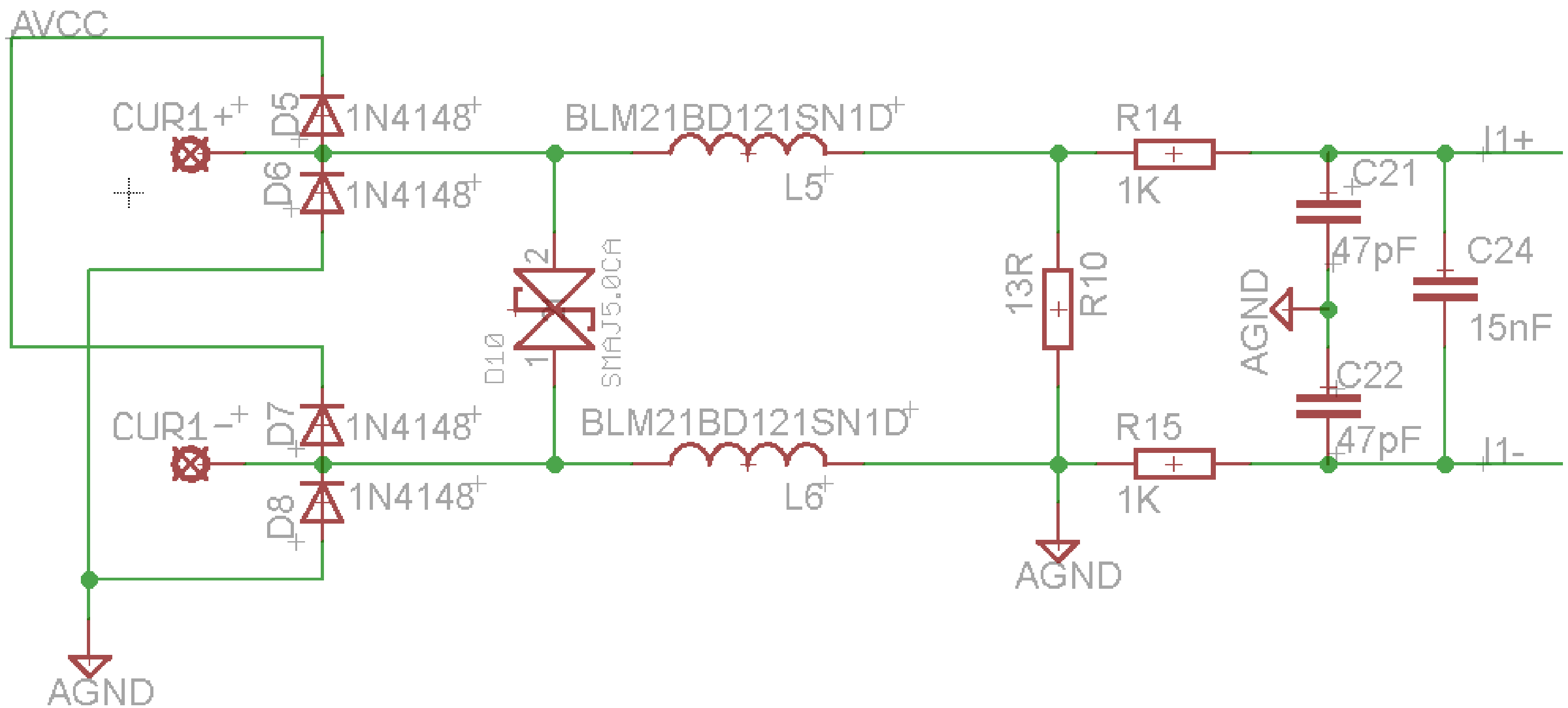
Current sensor-Rogowski Coil



- Rogowski coils are simple devices for measuring currents
- Based on Ampere's law
- Magnetic field produced by the current induces a voltage in the coil
- Output voltage proportional to the rate of change of current
- To get final voltage integration has to be performed

- Wide dynamic range
- Alternative to CTs
- Position sensitive
- Not very common for consumer E-metering
- Hard to find best match

Current Front End



- Similar filtering to voltage inputs
- Burden resistor R10 to convert CT output to voltage for ADC

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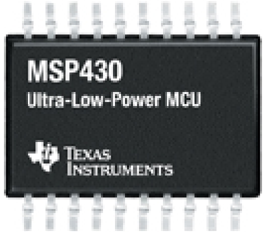

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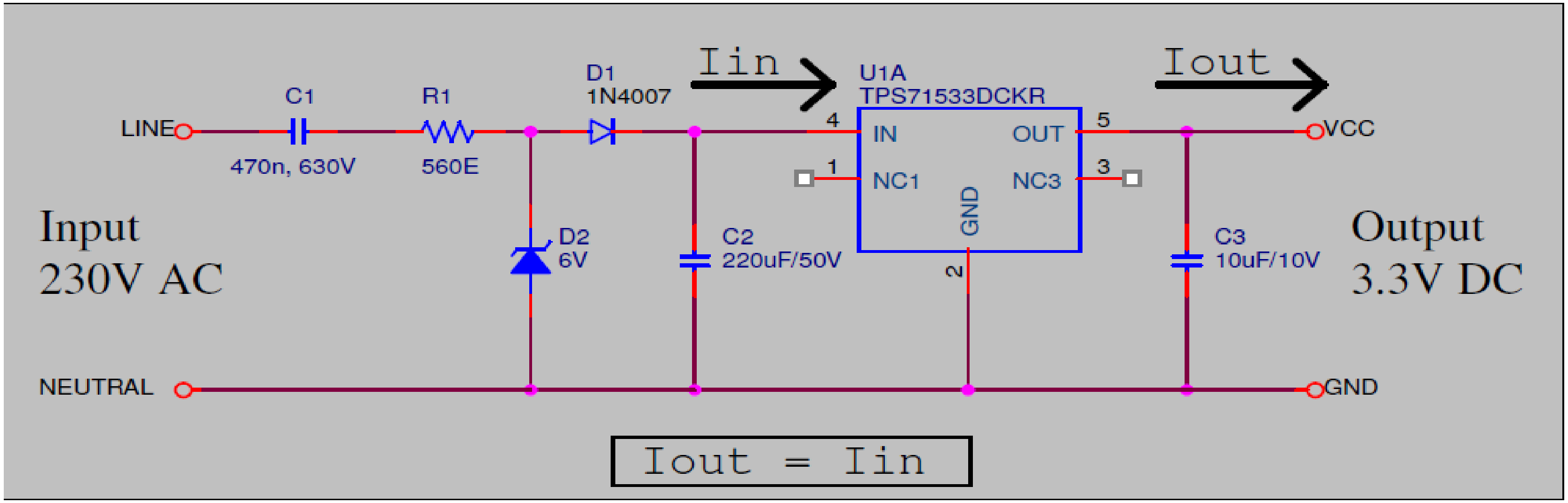
Power Supplies

- How are electricity meters powered?
- Requirements
  - Low-end anti-tamper meters, cost is the most important factor
  - Current sourcing designed with worst case scenarios in mind. E.g. all communication ports working
  - Low VA burden on the line
  - Small size and limited board space
  - Isolation required in some special cases
  - Magnetic susceptibility for anti-tampering
  - EMI / EFT performance conformance
- Types of Power Supplies
  - Capacitive Based
  - Switching mode Power supplies
  - Transformer Based

Typical Power requirements

Type of Meter	Features	Current Required
Single Phase low-end anti tamper meter	8-16MHz , 3 SDs with 4ksps, 1 optical communication Port	~6-8mA
Single Phase smart meter with RF	8-24MHz, 3 SDs with 4ksps, 1 transceiver, may require another processor, may require amplifier	~45mA
Three Phase low-end anti tamper meter	8-24MHz , 7 SDs with 4ksps, 1 optical communication Port, 1 wired UART isolated port	~16mA
Three Phase smart meter with RF	16-24MHz, 7 SDs with 4ksps, 1 transceiver, may require another processor, may require amplifier	~70-100mA

Low cost capacitive power supply

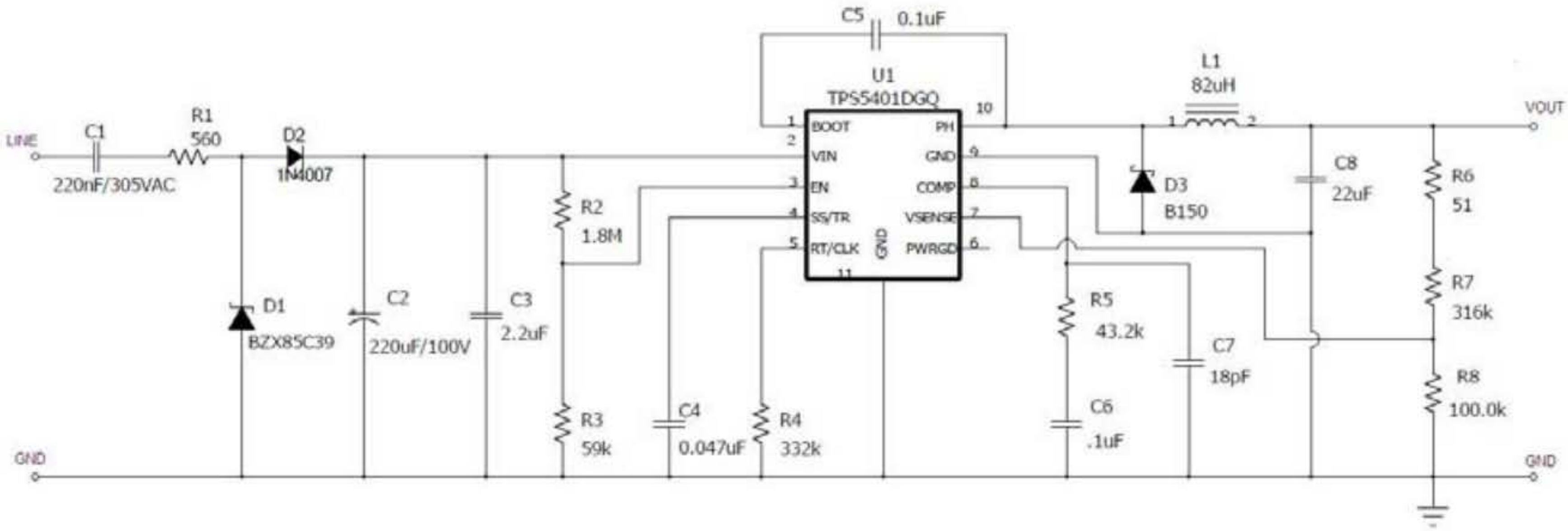


Vin	240	V	**Vz**	6	V	**Frequency**	50	Hz
C1	0.41	uF	VHRMS	234	V			
R1	560	E	XC1	7763.656				
Current	**28.11265**	mA						
VA	**6.747035**	VA						

Capacitive Power Supply-Merits/Demerits

- Advantages
  - Very Low cost
  - Small component count and board space
  - Low magnetic susceptibility
  - Low Conducted and Radiated EMI issues
- Disadvantages
  - Limited current capability at a given VA consumption
  - No isolation

Capacitive supply with Buck Converter

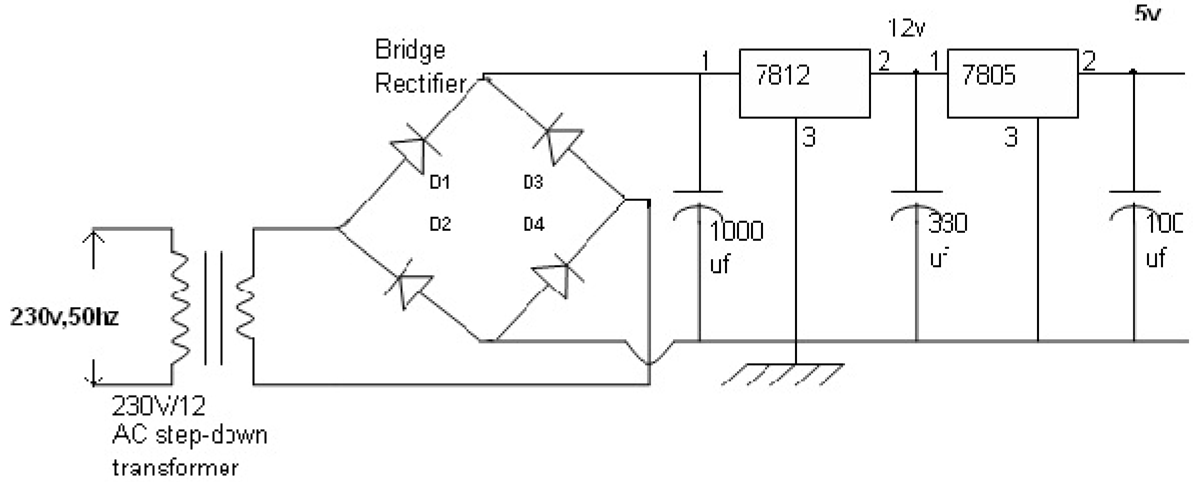


- **Specifications:**
  - Can work from 120V – 415V input voltage
  - Output: **3.3V@25mA from 230V input (self consumption limited to 4VA)**
  - Output **3.3V@13mA from 115V input.**
  - Output current can be raised to **50mA if 8VA** self consumption is acceptable.

Cap Supply w/ Buck Converter Merits / Demerits

- Advantages
  - Reliability
    - The series capacitor prevents any catastrophic failure to the supply
    - Since the buck switches on lower voltage levels, the Radiated Emission and Conducted Emission levels are lesser than SMPS and would need lesser constrains on the EMI filter
    - The power to buck converter is protected by the zener and hence it is much robust to Voltage Surge
    - The buck converter inductor will be more immune to high magnetic field compared SMPS transformer and will be more reliable
  - Lower Cost than SMPS supply
  - Less board space than SMPS supply
- Disadvantages
  - More components and board space that conventional cap drop supply
  - Slightly costlier than conventional cap drop supply.

Transformer Based supplies



- Use a combination a transformer, bridge rectifier and linear regulator.
- Advantages
  - A very good current drawing capability with a low VA burden
- Disadvantages
  - Transformer used is bulky
  - Size and cost is high
  - Very low magnetic susceptibilty
  - Almost impossible to use in three phase meters.

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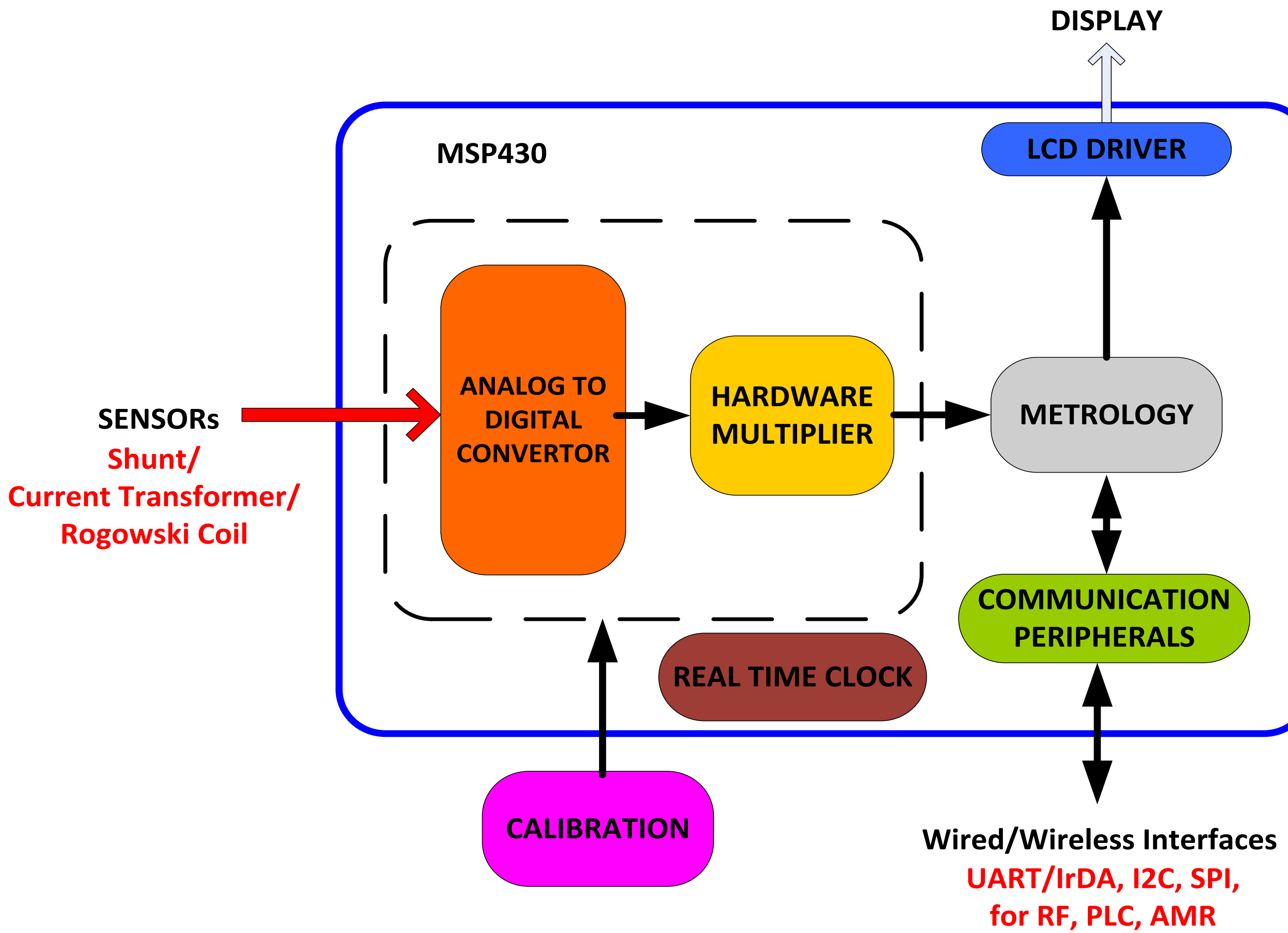
System-on-Chip (SoC) E-meter solution



MSP430 for E-metering?

- Powerful 24-bit Sigma Delta converter
  - Programmable gain amplifier for all types of sensors
  - Supports differential input
  - Multiple converters for simultaneous sampling of voltage and current
- Meter specific Hardware
  - Up to 32-bit x 32-bit HW multiplier for increased performance
  - Real-time clock with advanced features
  - Integrated LCD controller
- Ultra low-power features of the MSP430

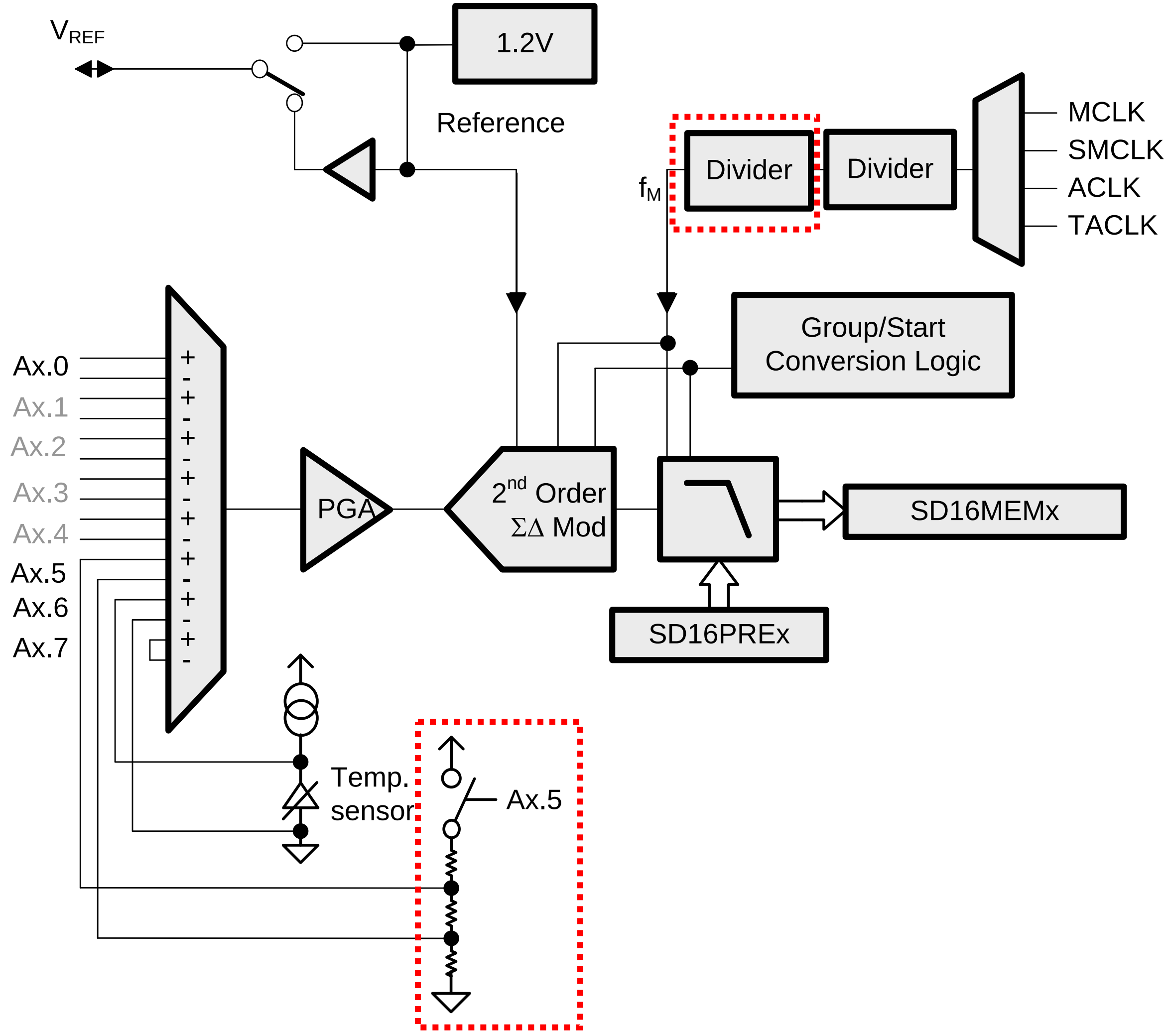
  Is it important in an energy meter application?
  - Power in active mode is low
    - Cheaper power supply
  - Power in low-power modes are low
    - Provides longer battery life in the absence of power
- Additional ADC for anti-tampering support and other sensors
  - Use the extra Sigma Delta or SAR for this purpose
- CPU independent metrology engine
  - ESP430 present on some devices

MSP430 Sigma Delta Analog to Digital Converter

- Architectural Features
  - 24-bit mode operation
  - Second order architecture
  - Any OSR up to 1024 on latest generation of devices
  - Sampling clock of up to 2MHz
  - Software selectable internal/external reference
  - Integrated temperature and/or battery voltage sensor
- In-built PGA
  - When shunt resistors or Rogowski coils are used, complete dynamic range can be used without any external gain amplifiers
- Differential inputs
  - Very good for AC measurements
  - Accepts inputs from current sensor as is without a need for level shifting
- Multiple converters
  - Independent converters for voltage and current and tamper detection
- Simultaneous conversions
  - Common trigger for simultaneous sampling of voltage and current
  - No inherent delay between voltage and current samples
  - SW compensation for sequential sampling not required

SD16_A/SD24_A Overview

- MSP430F47x4, MSP430F471xx, MSP430AFE2xx
- Multiple channels
- 30kHz to 1.1MHz modulation frequency
- Modulation frequency divider
- Up to 1024 OSR
- Temperature sensor
- AVCC measure

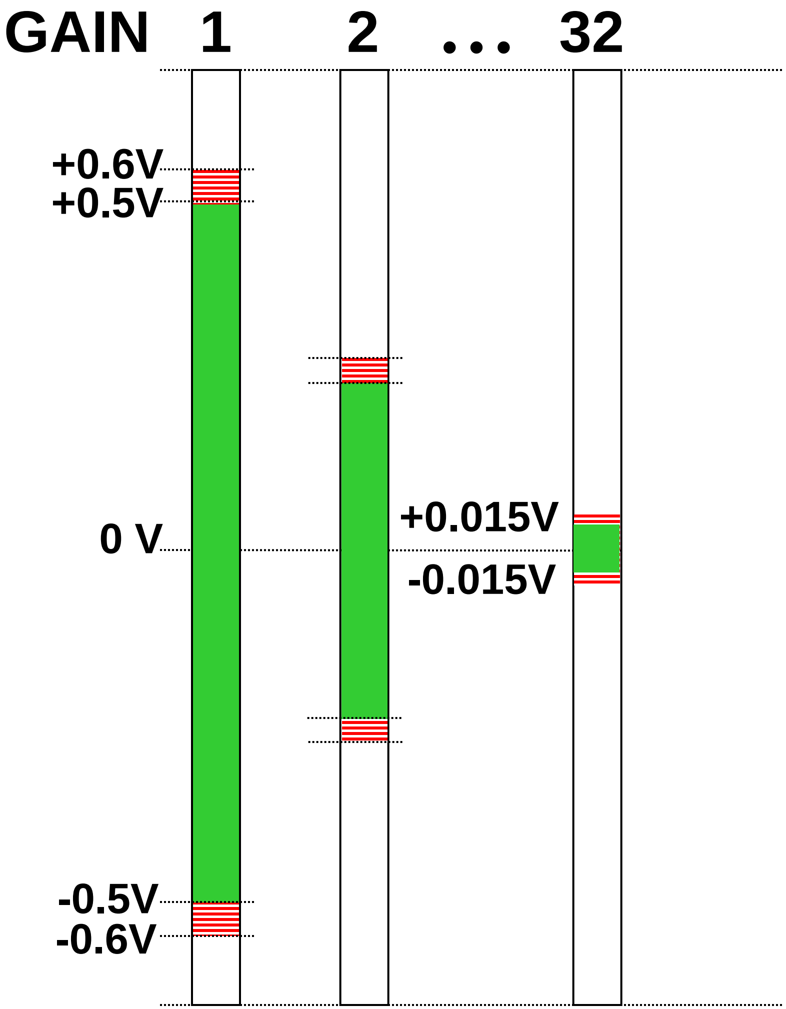


Texas Instruments

Analog Input range

- What is V_{REF}?
- What is the PGA setting?
- Applies to all inputs & modes
- Input ranges even higher on devices with SD24_B

$$V_{FSR} = \frac{V_{ref}/2}{GAIN_{PGA}}$$



Note: Diagram shows the differential input voltage V_{IN} for 4xx

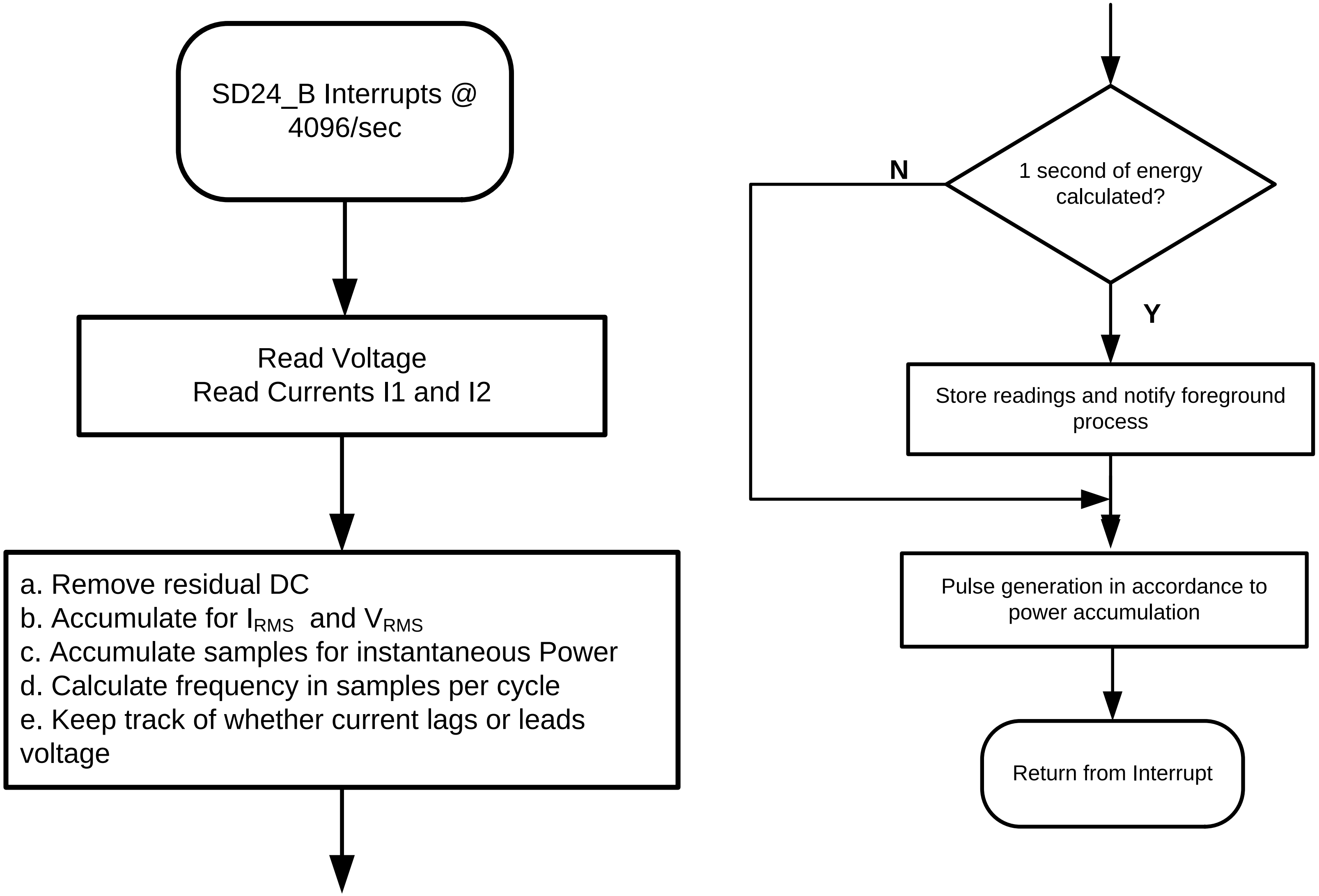
Hardware multiplier

- Ideal for energy calculation to multiply voltage and current readings
- Signed and unsigned multiply
- Signed and unsigned multiply and accumulate (MAC)
- 16-bit HW multiplier
  - supports 16×16 bits, 16×8 bits, 8×16 bits, 8×8 bits
- 32-bit HW multiplier
  - supports in addition all combinations with 24-bit and 32-bit data
  - supports fractional mode for operands
- DMA trigger available on devices with DMA module
- Available for all devices on MSP430 E-metering portfolio

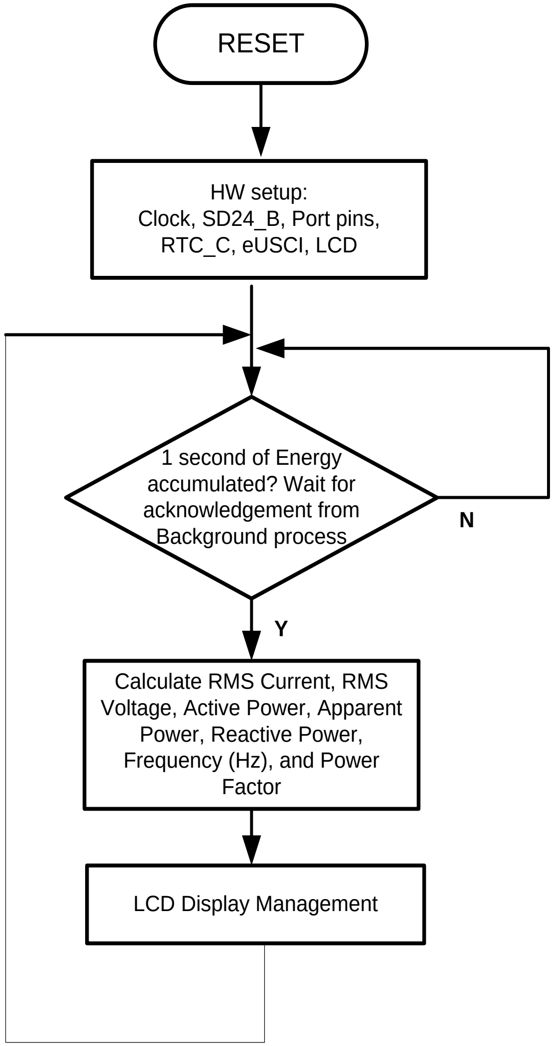
Software Topology for Metrology

- Setup/Initialization Include File
  - Macro definitions
  - Functionality selections
- Setup/Initialization Source Code
  - Setup Clock system and clock frequencies
  - Setup default calibration values
  - Setup MSP430 Peripherals
- Background Process
  - Coordinate with the ΣΔ interrupts → Typical sampling frequency of 4096Hz
  - Calculate intermediate results with each sample arriving
  - Pulse generation
- Foreground Process
  - Wait for Background process to finish → 1sec
  - Compute parameters that require 1sec updates → Vrms, Irms, average active power, etc.
  - Send results to UART, LCD and other indicators
- GUI communication
  - Calibration
  - Metrology Parameter Display

Background Process



Foreground Process

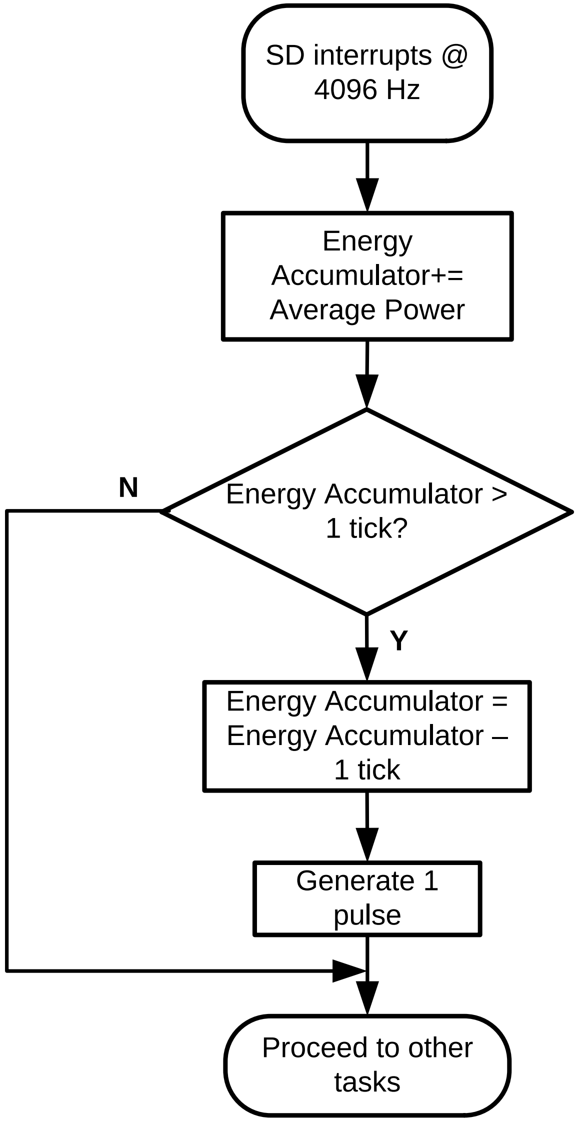


Pulse Generation

Average power is in units of 0.01W

1kWh threshold =
1/0.01 * 1KW * (Number of interrupts/sec) *
(number of seconds in 1 Hr) = 100000 * 4096 * 3600
= 0x15752A00000

1 tick= (1KWh threshold) / (pulses per kWh setting)



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MS430F67xx Family Overview

- MSP430F67xx Single Phase Family (MSP430F673x)
  - Up to 25 MHz
  - Up to 128kB Flash, 4kB RAM
  - 50% power reduction compared to 4xx
  - Up to Three 24-bit ΣΔ + 10-bit SAR ADC with temp and offset calibration
  - Up to 320 segment and 8-MUX LCD driver
  - RTC with temp compensation
  - Up to 3 UARTs and 4 Timers
  - Auxiliary Power Supply option
  - LPM 3.5 mode supported
  - CRC16
  - Port Mapping Controller
- MSP430F67xx Three-Phase Family enhancements (MSP430F677x)
  - Up to 512kB Flash, 32kB RAM
  - Up to 7 24-bit ΣΔ + 10-bit SAR ADC with temp and offset calibration
  - Integrated AES128 crypto module on select devices
  - Integrated Comparator
  - RTC back-up registers and event timing capture
  - Up to 4 UARTs and 4 Timers

ΣΔ24_B Overview

- Enhancements
  - Dedicated 32-bit result registers
  - Modulation frequency up to 2 MHz
  - Flexible OSR values
  - Bit stream output and input modes supported
  - Auto power-down mode
  - Flexible clock divider selections (1 to 31 followed by 1,2,4..128)
  - Includes 64 and 128 PGA gains
  - External trigger options available
  - Can trigger the ADC10 conversions

High Level Module Comparisons

	Parameter	ΣΔ16	ΣΔ16_A/ΣΔ24_A	ΣΔ24_B
1.	Modulation Frequency	1 MHz	1.1 MHz	2 MHz
2.	Oversampling Ratio (OSR) supported	256	1024	1,2,….1023,1024
3.	ΣΔ Clock dividers	Limited to 4	16 unique	256 (some repeats)
4.	Conversion result register	Single (multiple reads yields 24-bits)	Single (multiple reads yields 24-bits)	Two independent 16-bit high-low result registers
5.	Battery/Supply measurement	NO	YES (integrated)	YES (ADC10/REF)*
6.	External triggers	NO	NO	YES
7.	Internal trigger generation	NO	NO	YES
8.	Digital input/output bit-stream	NO	NO	YES
9.	PRELOAD register limit	256	256	1024
10.	Auto power down mode	NO	YES	YES

LCD_C Overview

- Enhancements
  - Up to 8-MUX operation
  - Up to 320 Segment drive capability
  - Individual segment versus port/peripheral selection
  - Programmable segment blinking frequency
  - Individual segment blinking
  - Contrast control in SW
  - Configurable frame/LCD frequency with increased dividers
  - Dual display memory
  - Damage prevention during charge pump selection
  - Interrupt capabilities
  - External Charge pump voltage option

RTC_C Overview

- Enhancements
  - External clock output frequency (for initial calibration, done over 60secs)
  - Pre-scalers available for event generation
  - Selectable BCD or binary format
  - Real-time Temperature compensation
  - Real-time offset calibration
  - Calendar mode with leap-year correction
  - Flexible, programmable alarm
  - Protection of RTC registers
  - Operation in LPM3.5
  - Separate voltage supply pin
  - 7 Interrupts available with some configurable for various timing events
  - Two external event captures possible
  - Integrated memory for event capture storage

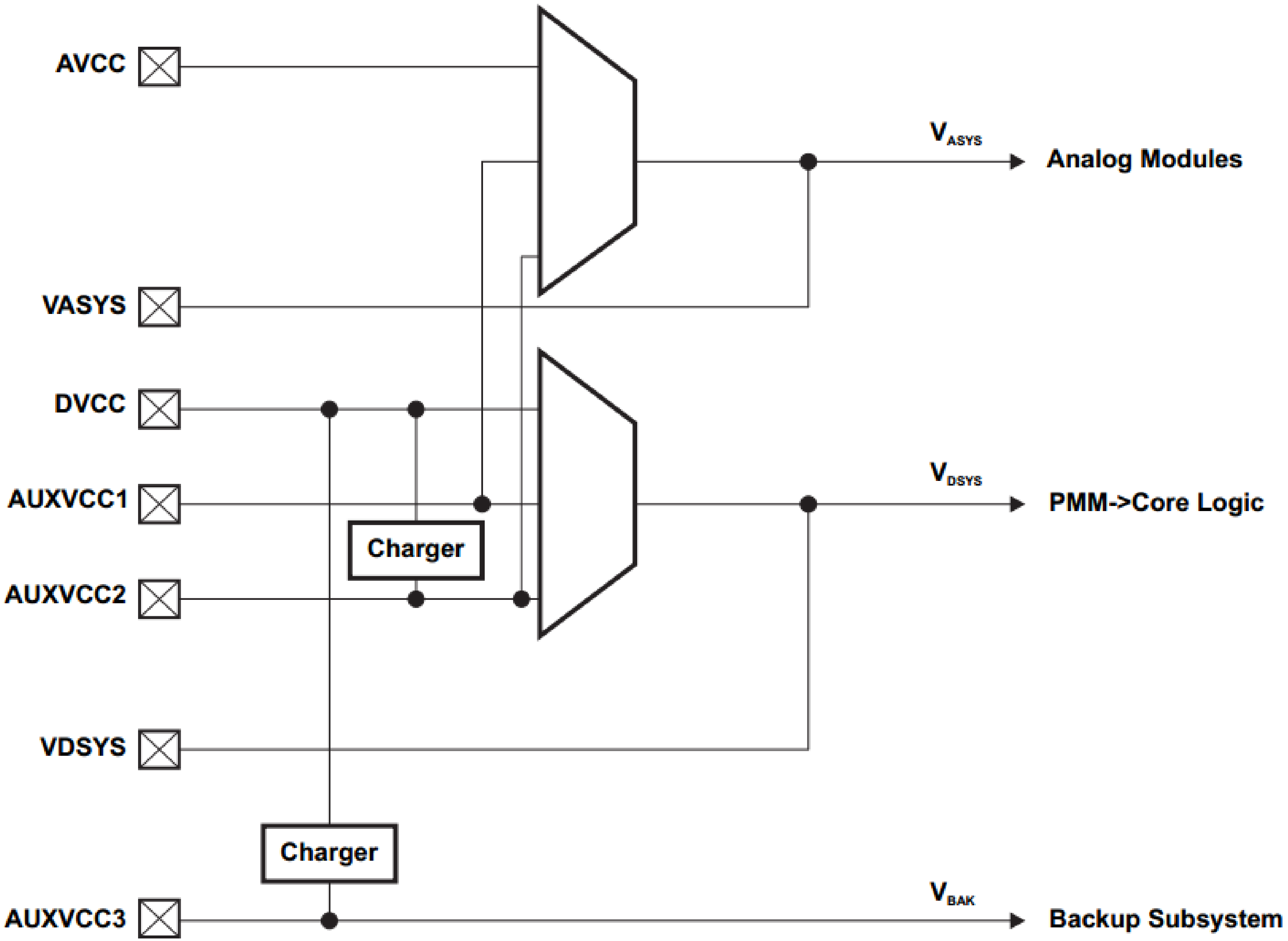
High Level Comparison→ Differences

	Parameter	RTC	RTC_A	RTC_B	RTC_C
1.	Calendar Mode	Yes	Yes	Yes	Yes
2.	Counter Mode	Yes	Yes	No	Optional (device-dependent)(1)
3.	Programmable Alarms	No	Yes	Yes	Yes
4.	Password Protected Calendar Registers	No	No	No	Yes
5.	Input Clocks	ALCK, SMCLK, Basic Timer	ALCK, SMCLK	32-kHz XTAL	32-kHz XTAL
6.	LPM3.5 Support	No	No	Yes	Yes
7.	Offset Calibration Register	No	Yes	Yes	Yes
8.	Temperature Compensation Register	No	No	No	Yes
9.	Frequency Adjustment Range	N/A	-128 ppm/+256 ppm	-128 ppm/+256 ppm	-240 ppm / +240 ppm
10.	Frequency Adjustment Steps	N/A	-2.035 ppm / +4.069 ppm	-2.17 ppm / +4.34 ppm	-1 ppm / +1 ppm
11.	Temperature Compensation	No	With software, manipulating offset calibration value	With software, manipulating offset calibration value	With software using separate temperature compensation register
12.	Calibration/Compensation Period	N/A	64 min	60 min	1 min
13.	BCD / Binary Conversion	Yes	Integrated for Calendar Mode	Integrated for Calendar Mode + separate conversion registers	Integrated for Calendar Mode + separate conversion registers

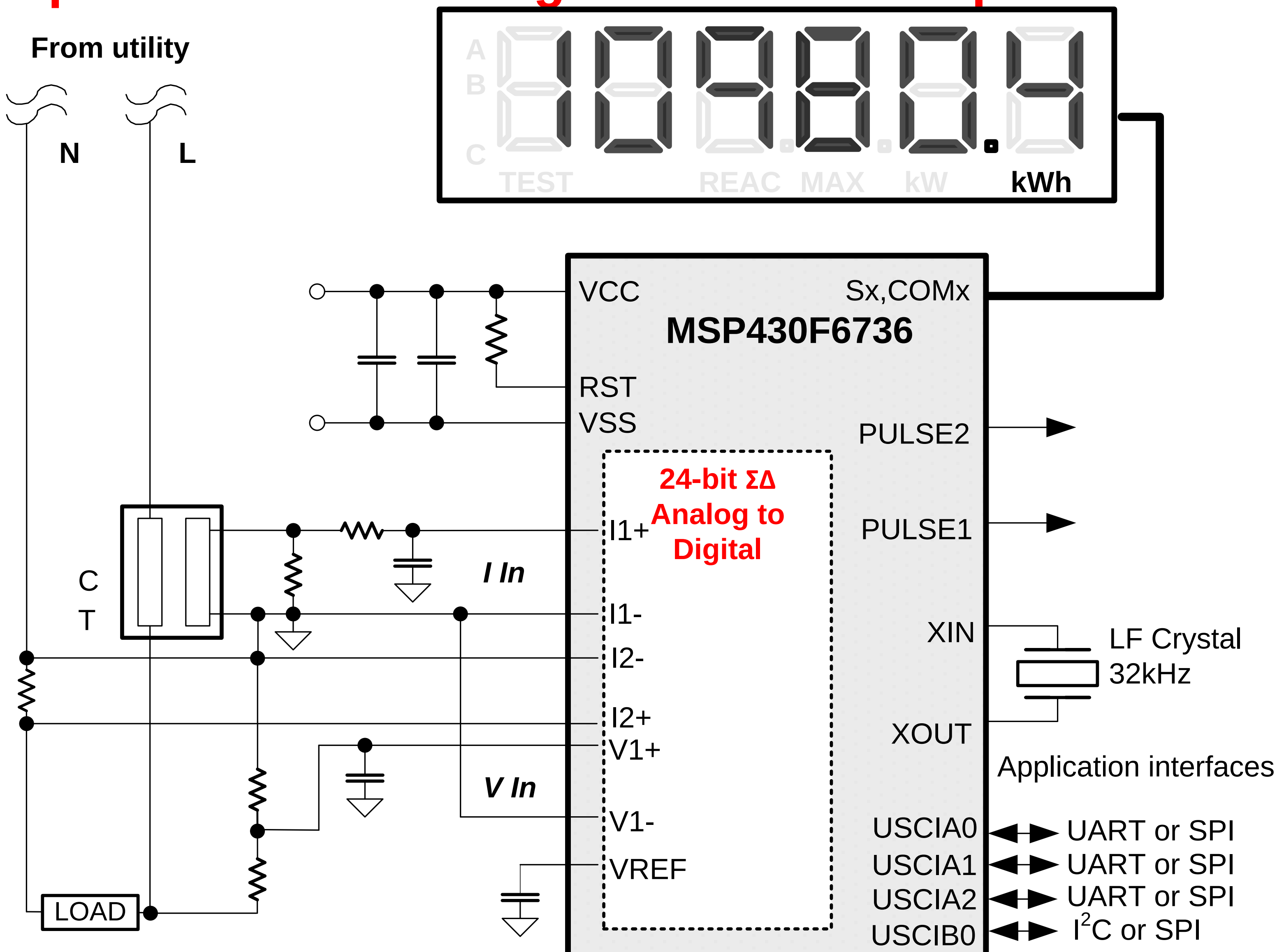
AUX Power Supply Overview

- Automatic or manual switching from the primary supply to an auxiliary supply while maintaining full functionality.
- Three Auxiliary supplies (AUXVCC1, AUXVCC2 and AUXVCC3)
- Automatic threshold-based monitoring of primary and auxiliary supplies.
- At startup, automatically chooses between the primary supply (DVCC/AVCC) and AUXVCC1, based on which one is higher voltage.
- A separate auxiliary supply (AUXVCC3) can power a backup subsystem (RTC, 32k Crystal Osc, Backup RAM).
- Simple charger for capacitors on AUXVCC2 and AUXVCC3.
- Power supply failure is a typical use case in energy meters

Functional Block Diagram



Single-phase E-meter using F6736 with Tamper Detect



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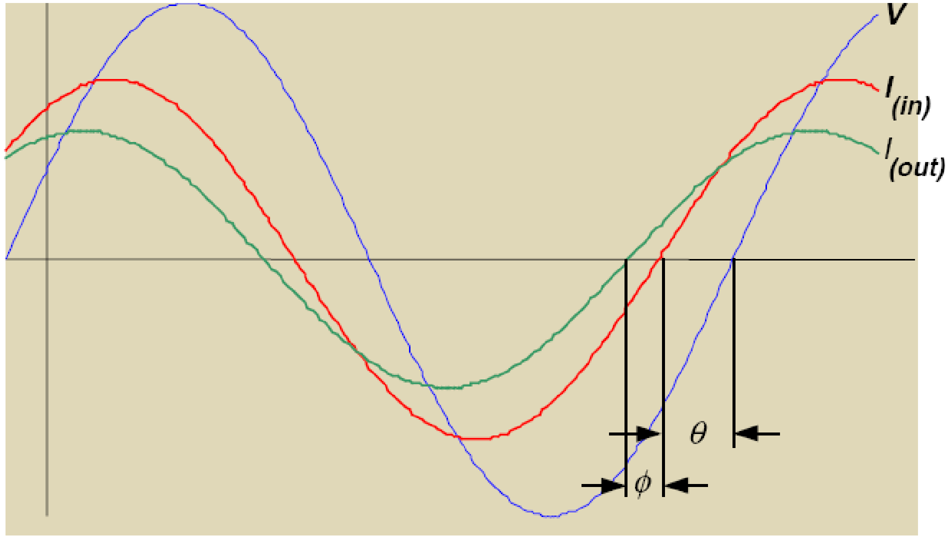
Calibration

- Mandatory for every meter
- Corrects inherent errors
  - Digital Phase Correction (Current channels)
  - Offset Correction (Current, Voltage, Power)
  - Gain Correction (Current, Voltage, Power)
- For best accuracy, reference meter and generator should be used for calibration of power
  1. Generator supplies voltage and current to the meter
  2. Energy meter outputs pulses based on energy consumption
  3. Reference meter uses these pulses to calculate the error of the meter
  4. The error of the meter is used by the user to calculate new calibration values to minimize the error of the meter
- Single point and double point calibration
  - If the single point calibration is used, only the slope (Gain Correction) is calculated
  - If the double point calibration is used, the slope (Gain Correction) and the offset (Power Offset) are calculated

Phase error due to CT

- CT introduces additional phase shift between V and I
- A phase error of .01 degrees corresponds to .03% error at PF=0.5
- Phase compensation needed is measured during calibration time
- A simple FIR filter is used to provide this compensation OR,
- PRELOAD register on MSP430 ΣΔ that helps in providing phase correction due to current sensors in SW

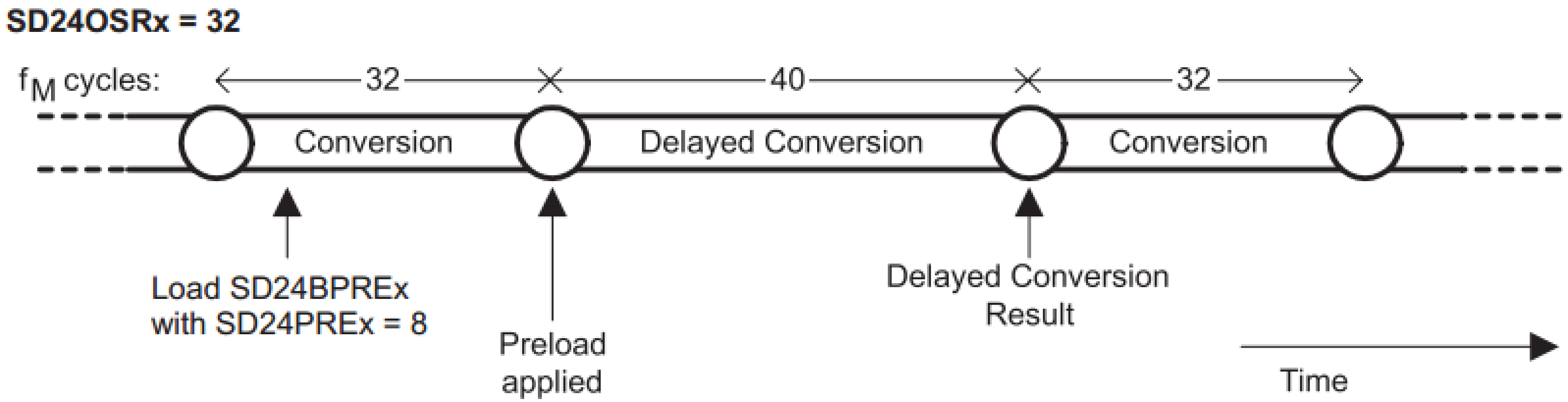


θ = Phase shift between V and I

ϕ = Phase shift in I due to CT

ΣΔ: Grouped Channels with Pre-Load

- PRELOAD register is 8-10 bits wide and present in every ΣΔ
- Intentionally delays the sampling instant on a specific converter
- Control timing delay between grouped channels
- Delay is with reference to the modulator clock
- Can be modified on the fly for temperature compensation of CT

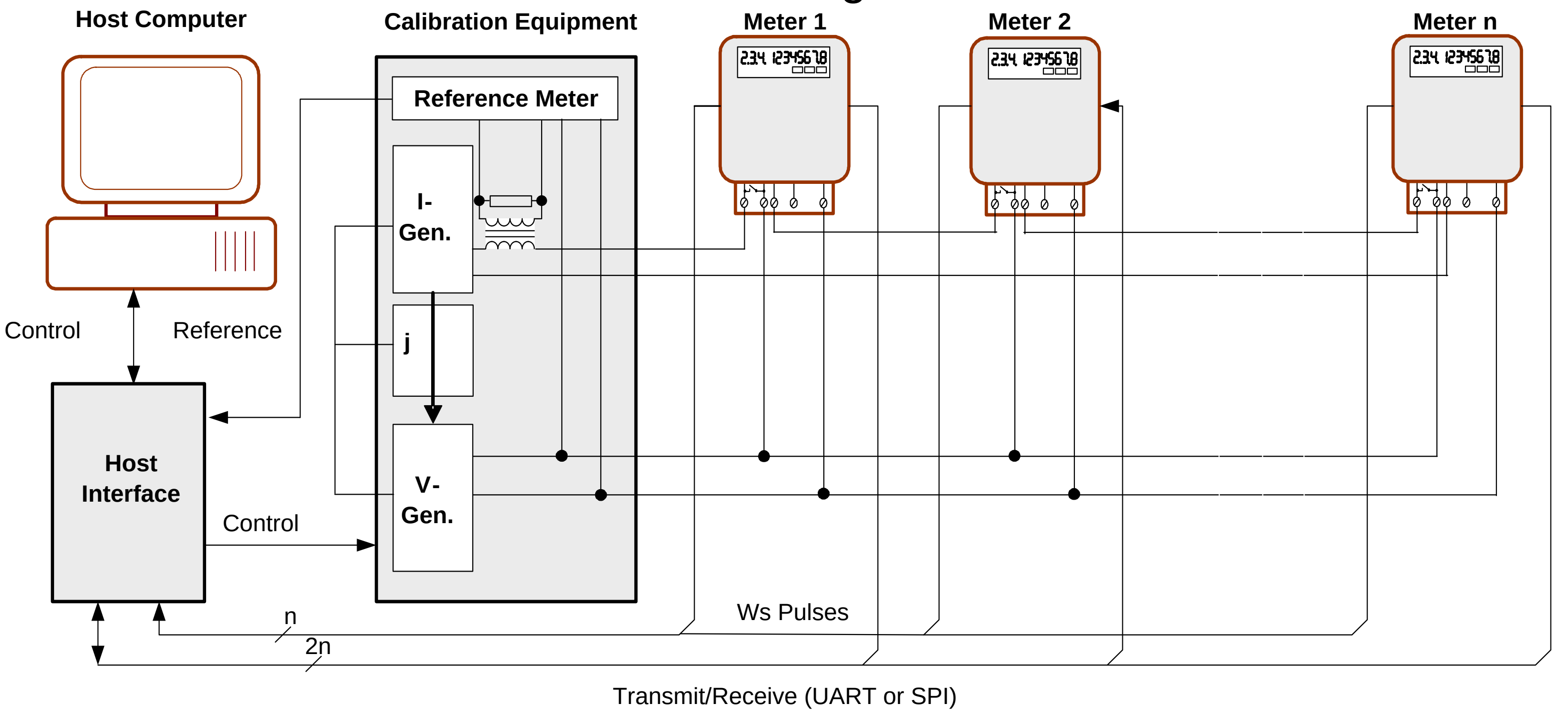


$$\text{Delay resolution}_{Deg} = \frac{360^{o} \times f_{in}}{OSR \times f_{s}} = \frac{360^{o} \times f_{in}}{f_{m}}$$

$$\text{Delay} = \text{Delay resolution}_{Deg} * \text{PRELOAD}_{value}$$

Calibration setup

- The main runs automated calibration algorithm to calibrate the meter



- Several meters can be calibrated simultaneously
- Calibration constants are programmed in-system to the Flash memory
- A host PC can completely automate a production calibration run

Agenda

- Introduction to Energy metering (E-metering)
- Basics of E-metering
- Power Supplies for E-metering
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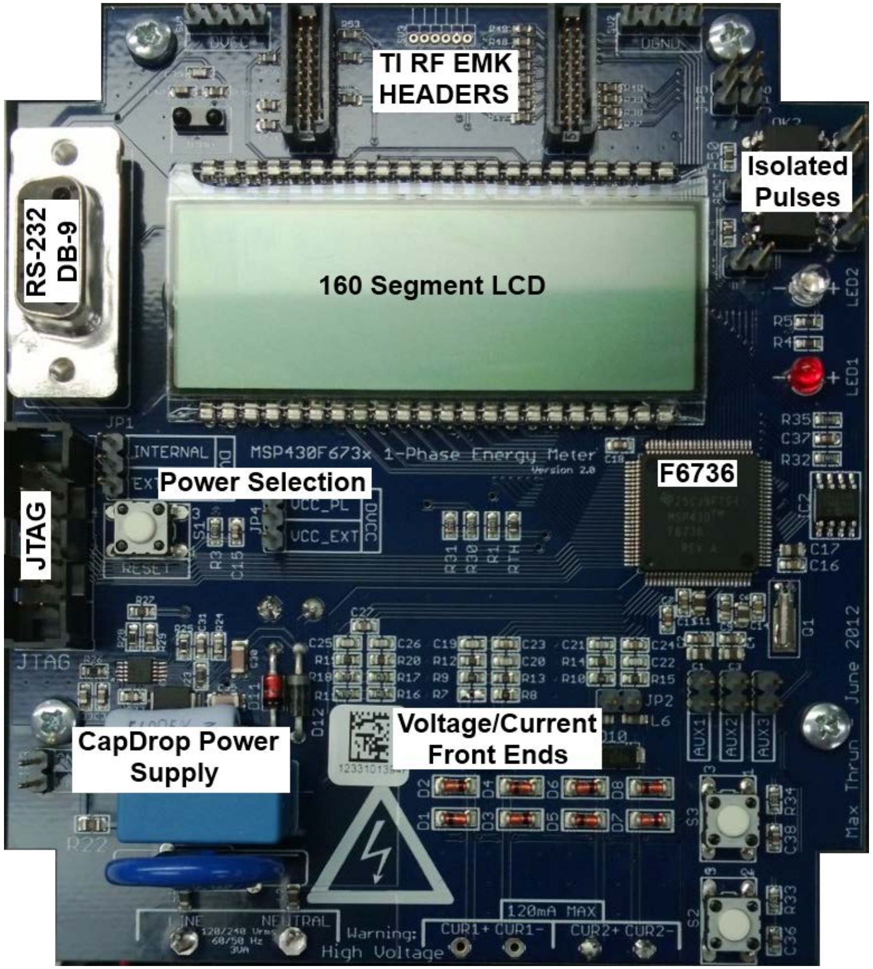
- Using the EVM430-F6736 for energy metering
- Safety tips

1 phase EVM using the F6736

Now Available on eStore!

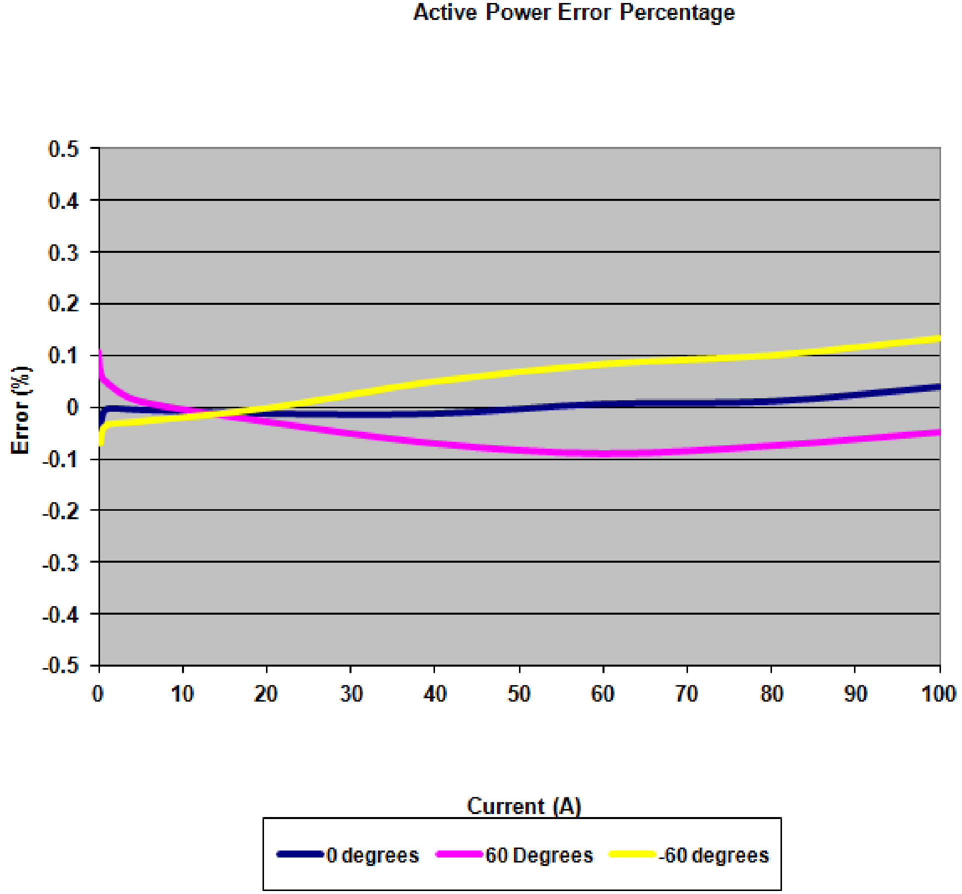


http://www.ti.com/tool/evm430-f6736

Measurement Results

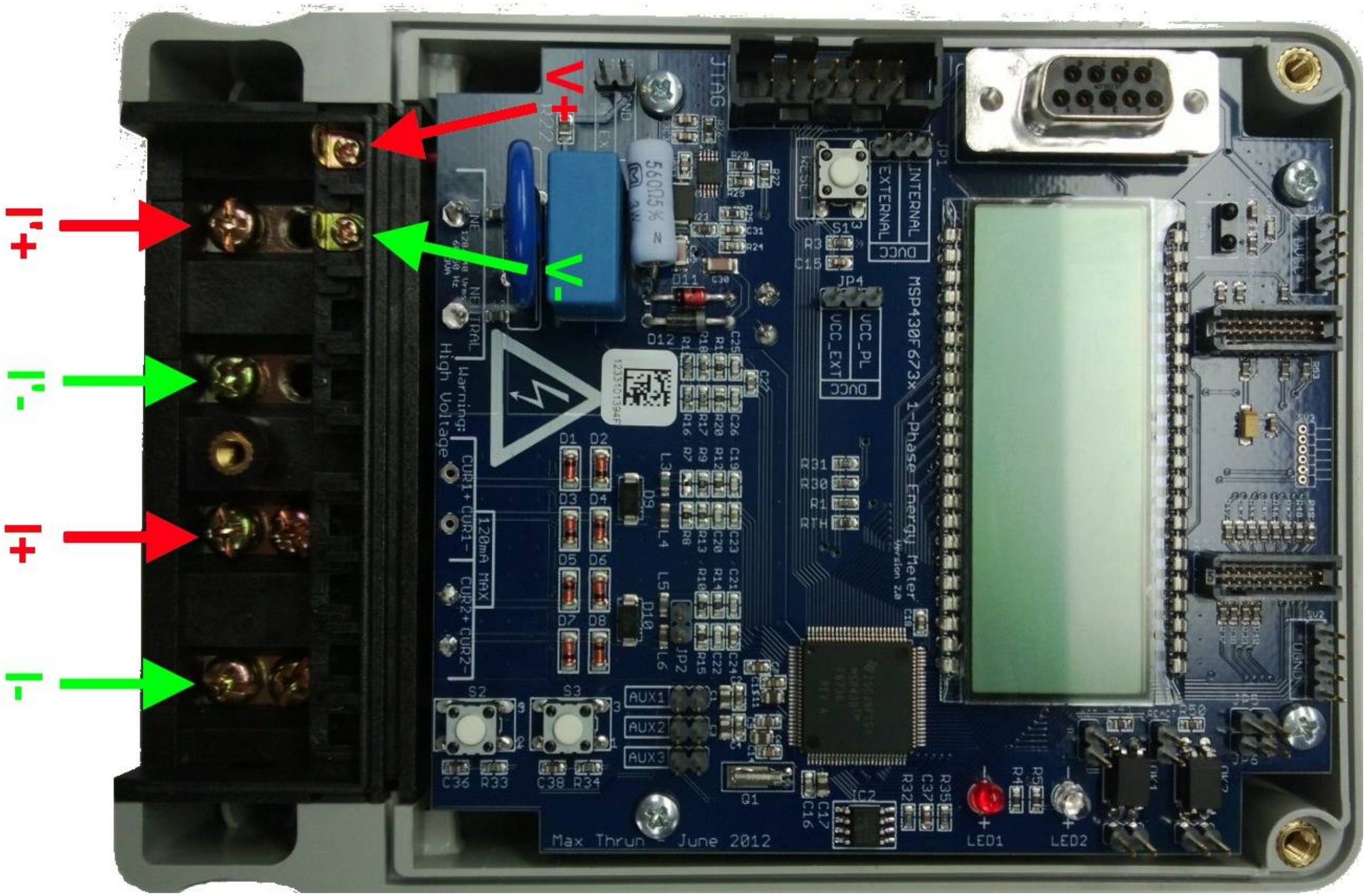
Calibrated at 230V, 10A, and 50Hz

Current (Amps)	-60Deg (PF =-0.5) Error (%)	0 Deg (PF =1) Error (%)	60 Deg (PF=0.5) Error (%)
0.05	-0.0447	0.109	-0.07
0.25	-0.045	0.0705	-0.07
1	-0.0023	0.0493	-0.0353
5	-0.0037	0.012	-0.028
20	-0.011	-0.0277	-0.0023
40	-0.011	-0.0703	0.0493
60	0.008	-0.09	0.083
80	0.0127	-0.0747	0.1
100	0.0407	-0.0483	0.1327

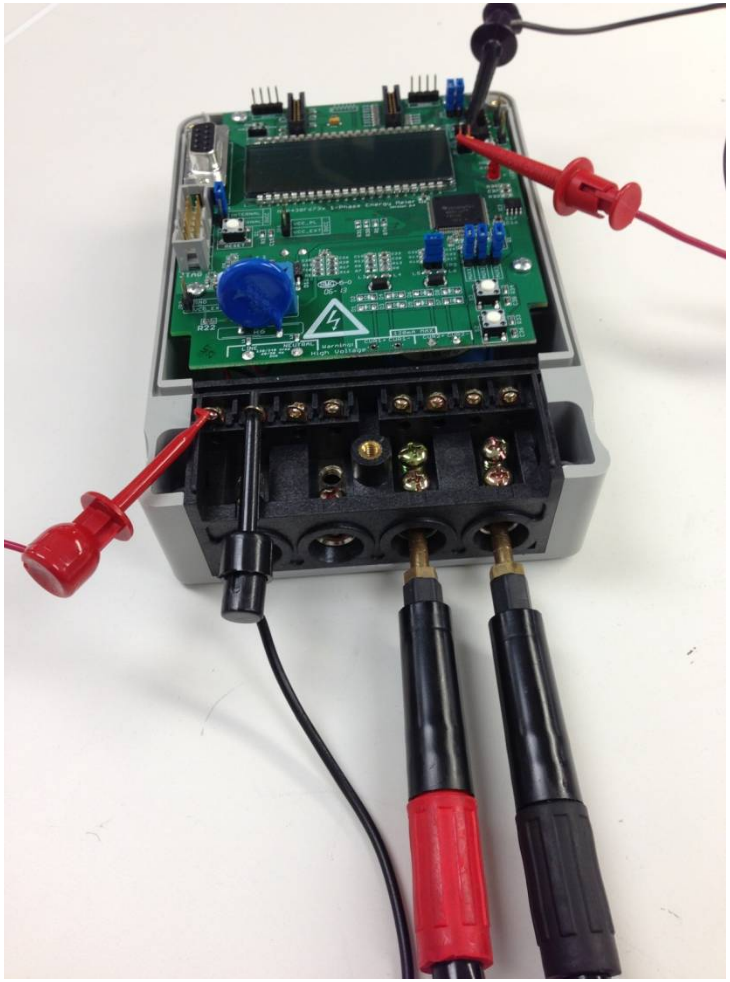


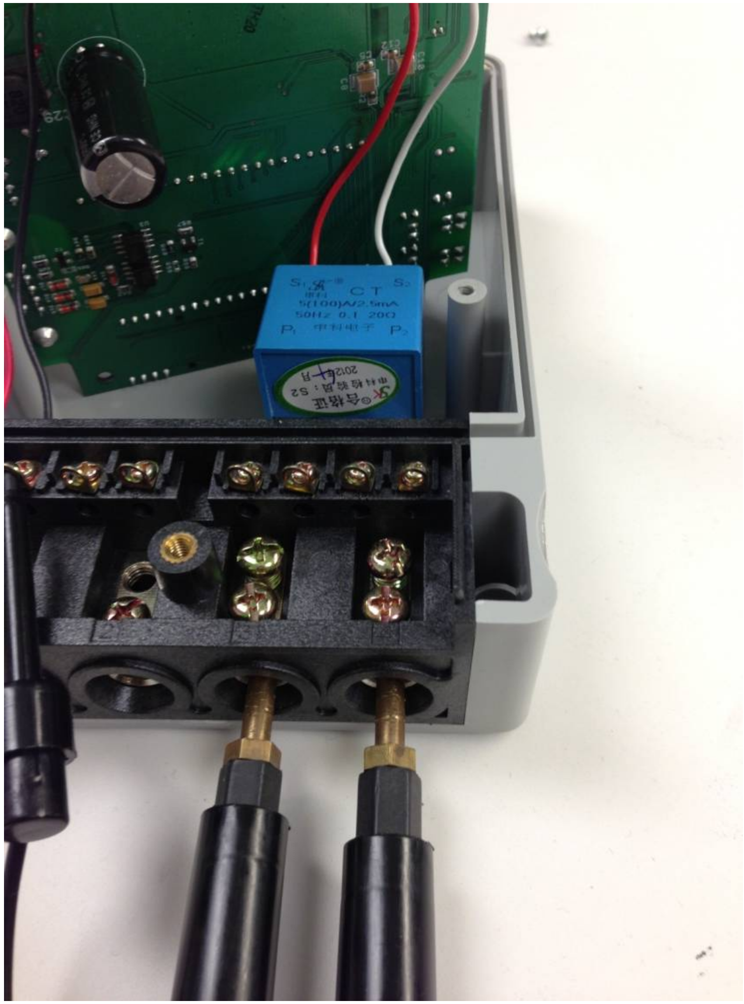
Texas Instruments

Connections to a reference source



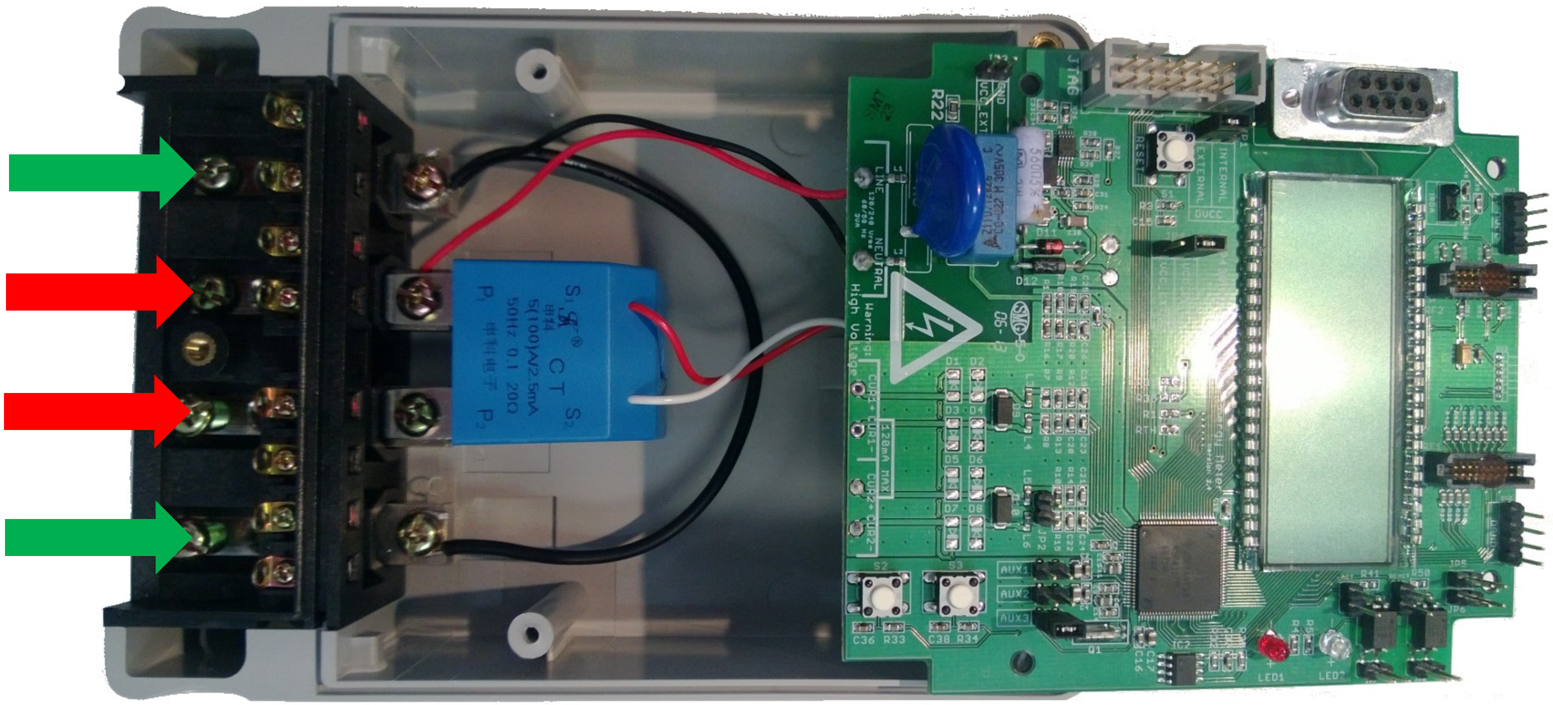
Connections to a reference source





Connections For This Lab

Voltage Source



Test Load

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Basic Steps to Connect

- Find RS-232 header
  - Use a standard RS-232 cable connect one end to this header (female DB-9)
  - Connect other end to the PC (male DB-9 connector)
  - If there are no DB-9 ports on your machine (see next slide)
- Secure high current inputs
  - Make sure that the EVM current inputs are thoroughly screwed down
- Locate high voltage inputs
  - Connect the reference source voltage inputs to the two input terminals on the EVM

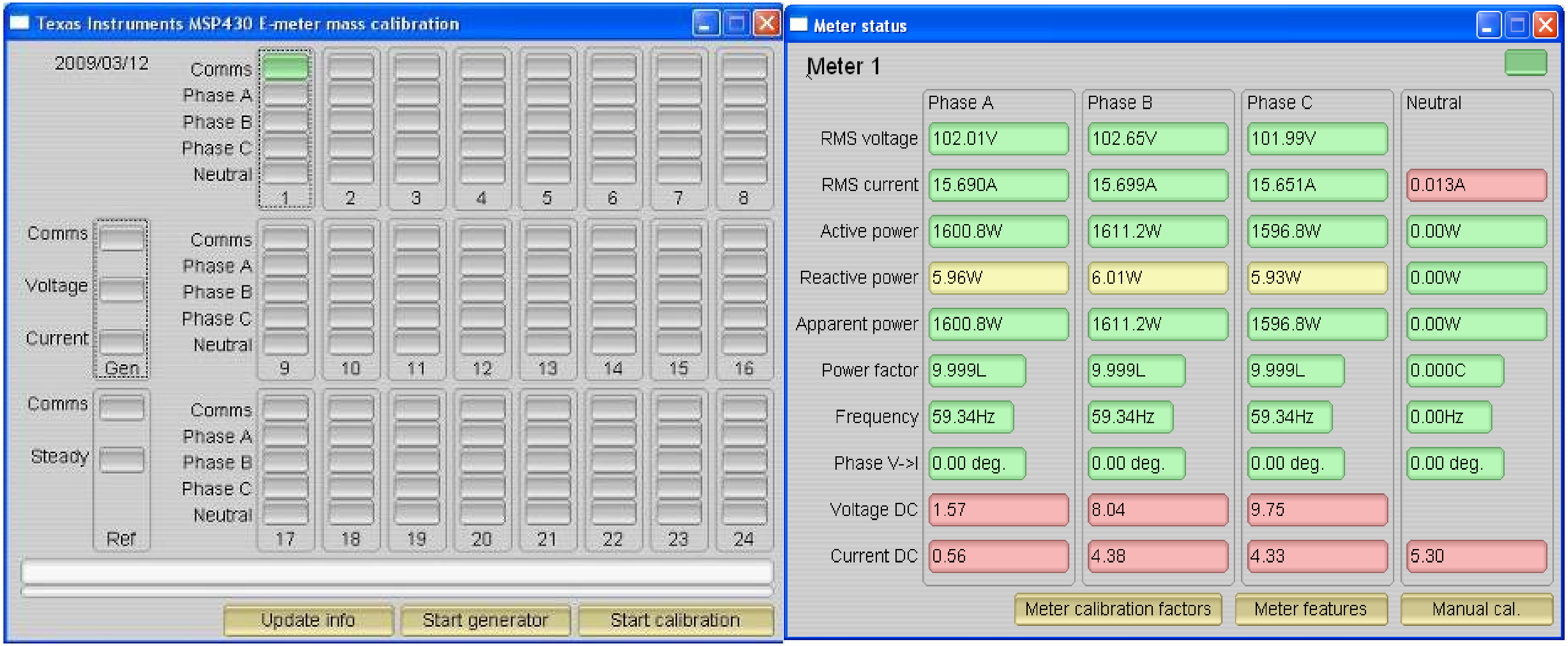
DB-9 to USB connector conversion

- Use a standard USB to RS-232 converter
  - Install the required drivers for this converter
  - Find the COM port associated with this converter from the properties of “My Computer”
  - Click “Device Manager” tab under “Hardware” menu
- Configuring the GUI
  - GUI is setup with default port as COM1
  - Under the GUI folder open the file “calibration-config.xml” with Wordpad
  - Change highlighted text
    - It is almost at the very end of the file
    - Replace “com1” with your new COM port for this interface
    - com1 → comXX


```
      <step current="17.000" phase="0.0" gain="1.0"/>
      <step current="18.000" phase="0.0" gain="1.0"/>
      <step current="19.000" phase="0.0" gain="1.0"/>
      <step current="20.000" phase="0.0" gain="1.0"/>
      <step current="21.000" phase="0.0" gain="1.0"/>
      <step current="22.000" phase="0.0" gain="1.0"/>
      <step current="23.000" phase="0.0" gain="1.0"/>
      <step current="24.000" phase="0.0" gain="1.0"/>
      <step current="25.000" phase="0.0" gain="1.0"/>
      <step current="30.000" phase="0.0" gain="1.0"/>
      <step current="35.000" phase="0.0" gain="1.0"/>
      <step current="40.000" phase="0.0" gain="1.0"/>
      <step current="45.000" phase="0.0" gain="1.0"/>
      <step current="50.000" phase="0.0" gain="1.0"/>
      <step current="55.000" phase="0.0" gain="1.0"/>
    </correction>
  </phase>
  <temperature/>
  <rtc/>
</cal-defaults>
<meter position="1">
  <port name="\\.\com1" speed="9600"/>
</meter>
<reference-meter>
  <port name="com2" speed="9600"/>
  <type id="kaipu-p3001c"/>
  <log requests="on" responses="on"/>
</reference-meter>
<generator>
  <port name="com2" speed="9600"/>
  <type id="kaipu-p3001c"/>
  <log requests="on" responses="on"/>
```


Texas Instruments

Running the GUI



- GUI is used to view results and calibration
- Open the executable “calibrator.exe” in the GUI folder
- If RS-232 interface is properly installed you should see screen 1
- Click on green button “Comms” to get meter data

Calibration (Source information)

- Calibration will assume an accurate source was connected
- Reference source voltage and load values will be determined
- Objective is to ensure meter readings match the measured references

Connect Voltage Source and Load

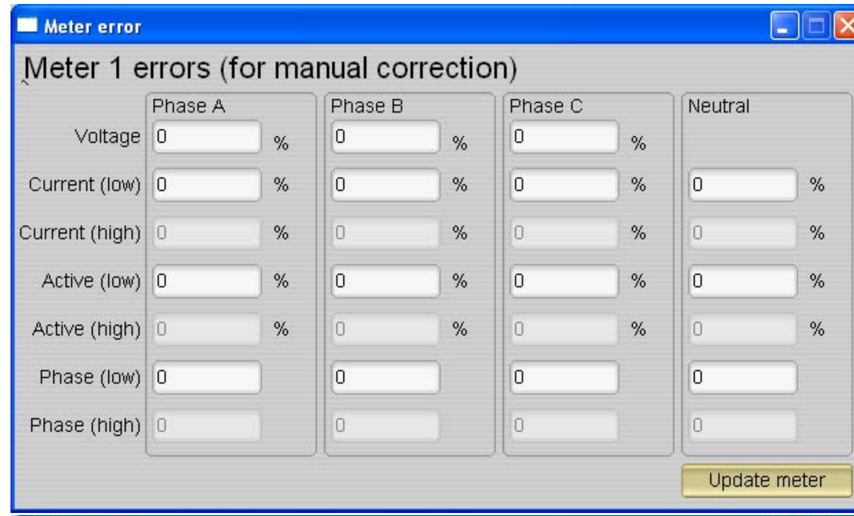
1. Ensure supply is unpluged
2. Connect the voltage source to the EVM inputs
3. Connect a test load
4. Plug in reference voltage
5. Using a DMM, measure and record the reference voltage
6. With measured voltage, determine real current using resistor value

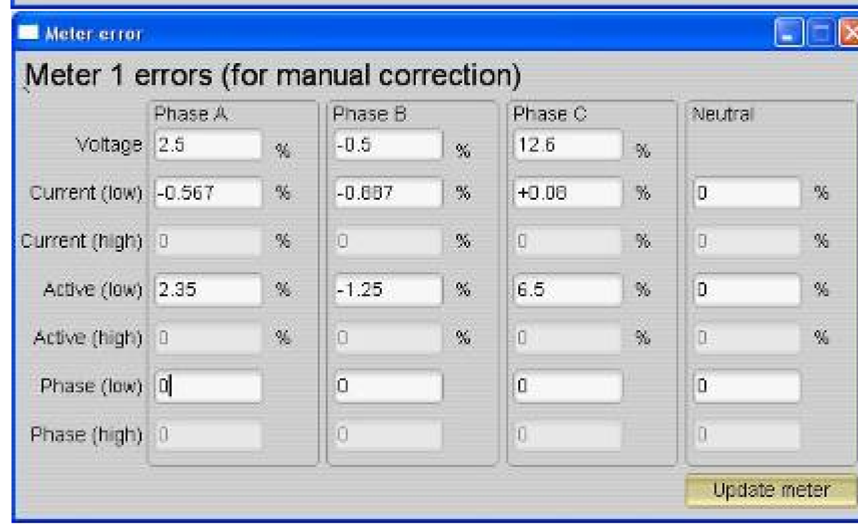
Calibration (Voltage and Current)

- Voltage and Current readings are available in the GUI for all 3 phases
- Click on Manual calibration on the results window to give you this screen
- The objective is to fill in all the zeros for voltage and current (low) values with the error %

$$\%_{VAL} = \left(\frac{V \text{ or } I_{\text{Observed}}}{V \text{ or } I_{\text{Desired}}} - 1\right) \times 100$$

- See example on second screen
- Enter all calculated values and click on “Update Meter”





Calibration (Active Power)

- Using measured voltage and current, calculate expected power
  - P=V*I
  - Use same formula from V and I calibration for power
  - Enter correction factor into GUI and save new settings
- More accurate method needs active energy pulses and reference meter
  - Actual error % values will be obtained by accurate reference meter
  - Usually done one phase at a time (turn OFF current on remainder phases, but have all voltages ON in source generator)
  - Use same formula to get error values
  - Enter in GUI for “Active (low)” error parameter for all 3 phases
  - Click on “Update meter”
  - Pulse Timing Equation: Watts = (3600000/(Tpulse*PulseMacro))

Calibration (Load Phase Calculations)

- The provided reference inductor is connected in series with a resistor in order to create a phase shift that is approximately 60deg
- The inductor is 1H, and the resistor is 400ohms
- The phase shift is determined by a load's reactive and resistive parameters

$$\Theta = \arctan(\frac{X_L - X_C}{R})$$

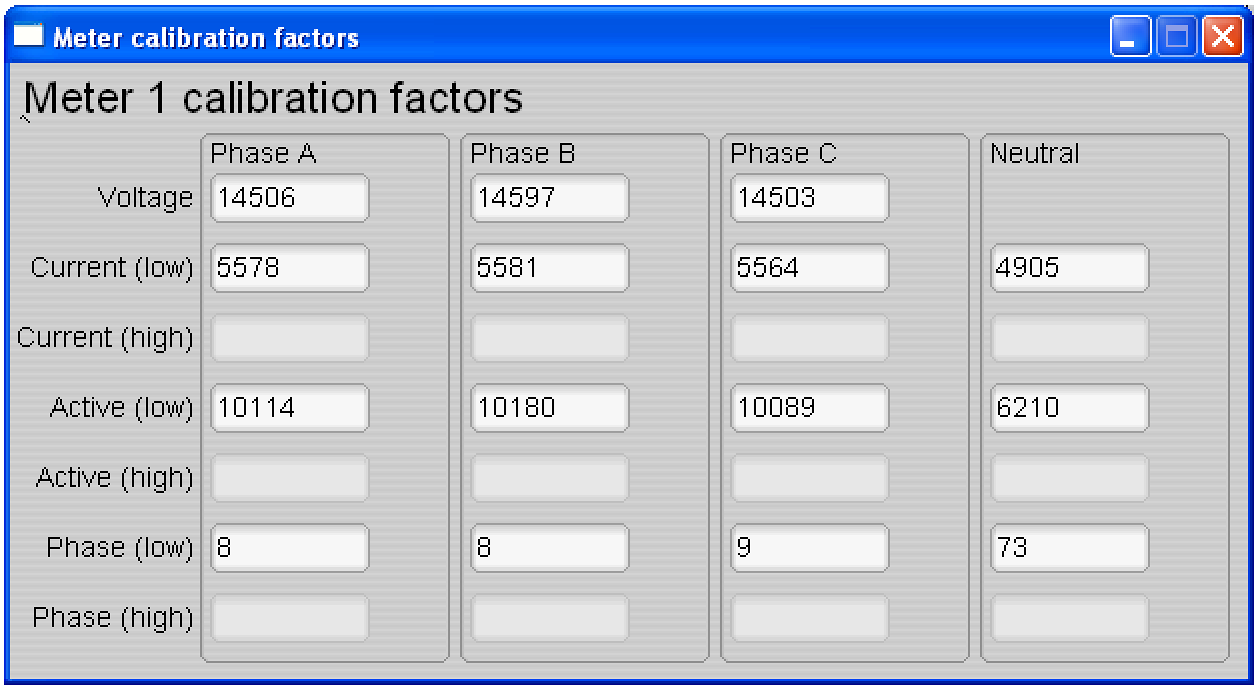
- In this case, X_L=2πfL, or X_L=2*π*60*1=376.9ohms
- Since we have no X_C element, the phase shift is: arctan(376.9/400)
  - This resolves to 43.23 deg in our real load
- A more useful number is the power factor: cos(43.23) = 0.728

Calibration (Phase correction)

- Phase calibration is required to remove any effects the CT or the tolerances of the analog front end have on the current reading
- Use RMS Voltage and RMS Current to determine Apparent power
- Active Power = Power Factor * Apparent Power
- The inductive load will be used to simulate a phase shift as seen in the last slide, with the respective active and reactive power
- Enter in GUI for “Phase (low)” parameter
- Increment /Decrement value to achieve correct readings on active power
- Click on “Update meter”
- Stop when closest possible values have reached

Saving calibration values

- Important, save your calibration data whenever you overwrite the SW
- On the GUI screen click “Meter calibration factors”
- Note it down, can always be re-entered



More Accurate Calibration Procedures

- Reference Generator with pulse feedback
  - Costly equipment, but absolutely required for sub 1% calibration
  - Injects known, stable, voltage and current
  - Automatically calculates expected power
  - Using pulses, calculates percent error, and reports it to user
  - This can be used directly in the calibration GUI
- Voltage Source and Load with Power Quality Meter
  - Similar to today's lab
  - Rather than calculate expected values, real voltage, current, power, and phase shift are measured
  - PQMs are a cheaper alternative to a full test setup, but do not support pulse feedback

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What is our Objective

- Energy meters are complicated systems
  - Risk of shock and injury
  - Dos' and Don'ts'
- Importance of what to look for in a meter
  - Asking the right questions
    - There is always a set of "must ask" questions
    - New design or existing design
  - Option of programmability
    - How can you help the customer on site?
  - Interface to a test setup
    - Helps in checking accuracy and calibration
- Calibration process
  - Help customer use TI tools available today

Dos and Don't's

- **Always carry a multi-meter**
  - Check for short between Line and GND before powering
  - Measure resistances for voltage divider for voltage sensor
  - We must have a burden resistor (CT only) and make sure it has the recommended value for CT selected
- **Always check with designers**
  - The designer always will know the safety points on their board
  - Double check with schematic for safety
- **Do not touch anything when meter is running even if it is a GND point**
- **Do not attempt to connect JTAG to program when meter is running**
  - OK if the USB-FET is isolated (**TI USB-FETs are not isolated!**)
  - OK if laptop is used with battery (do not connect laptop power supply)
  - UART communication is always isolated, so calibration GUI can be used
- **Never connect to the mains**
  - Even if someone insists, you should decline explaining the hazards
  - Every energy meter developer should have a test setup or access to one
    - Test setups are inherently isolated, better to check before hand
    - It is an Energy meter designer's best friend
  - Connecting to the mains increases risk of shock, fire and damage to the board

Ask the right questions

- New design
  - Type of measurement, single to three-phase
  - Accuracy needed (Class of meter)
  - Type of sensor desired → Explain pros and cons
  - Always have a working demo to show meter functionality
  - Always know the advantages of using MSP430
- Old or existing design
  - What is the problem?; it is usually
    - Accuracy
    - Calibration
  - Connect them with TI EVM to run TI SW to show correctness
  - Customer maybe using a part that is a not a best fit
    - Metering portfolio has had tons of newer parts the last few years
    - Try to propose newer solution
      - They always have the latest and the greatest collateral and support information
      - The EVMs are up to date
      - We are constantly adding new features

Summary (Small, secure and accurate energy monitoring)

- Better than 0.1 percent accuracy rate for most ranges
- Wide dynamic range of up to 2400:1 providing support for high and low currents

Ultra-low power consumption for system reliability

- Low power support of real-time clock when running on back-up battery during power outage
- Simpler, more cost effective power supply design due to reduced active power consumption

Simultaneous sampling and support of tamper detection

- More robust performance and software development with simultaneous sampling
- 3rd / 7th sigma delta provides high precision measurements in parallel, such as temp and humidity, and support of tamper detection

Questions?

THANK YOU