MSP430 E-meter ODW

MSP430 Asia Application Team

Percy Yu/AEC/MSP430

Agenda

- Introduction to Energy metering
- MSP430 E-meter solution briefing
- AFE25x E-meter demo set intro
- AFE25x E-meter firmware intro
- Meter Calibration
- Lab1: E-meter demo set setup
- Lab2: E-meter calibration
- Lab3: E-meter performance test
- Q&A

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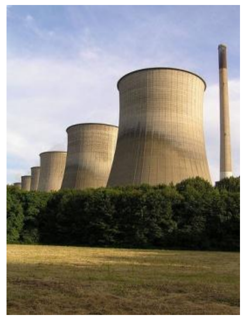
The energy landscape

Energy Sources

- ***Conventional Energy***
  (Coal, Oil, Natural Gas, Nuclear, etc...)
- ***Renewable Energy***
  (Solar, Wind, Hydro, Tidal, Fuel Cell, Geo-Thermal, etc…)
- ***Energy Harvesting***
  (Kinetic, Vibration, etc…)


Transmission & Distribution

- Metering & Smart Grid
- Automated Metering Infrastructure
  - Powerline Communications
  - Time of Use Billing
  - Broadband
- Monitoring & Management




Consumption & Usage

- Energy Efficiency Appliances
- HVAC
- Lighting
- Transportation
- Electronics
- Industrial
- Waste
- Water

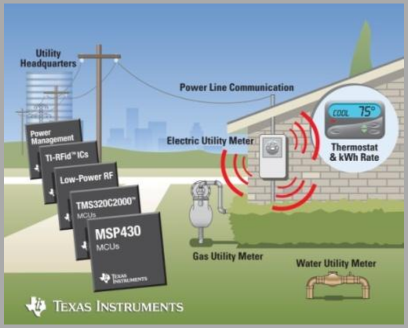
Make It

Move It

Use It

TI's comprehensive utility metering portfolio drives smarter grid solutions

Processors



Highly optimized application specific embedded processors, low power RF, power management and RFID

Applications

Electricity, water and gas metering, power line communications (PLC) and radio frequency (RF) interfaces for Advanced Meter Infrastructure (AMI)

Software Support

ZigBee
6LoWPAN
WMBUS
OFDM
SFSK

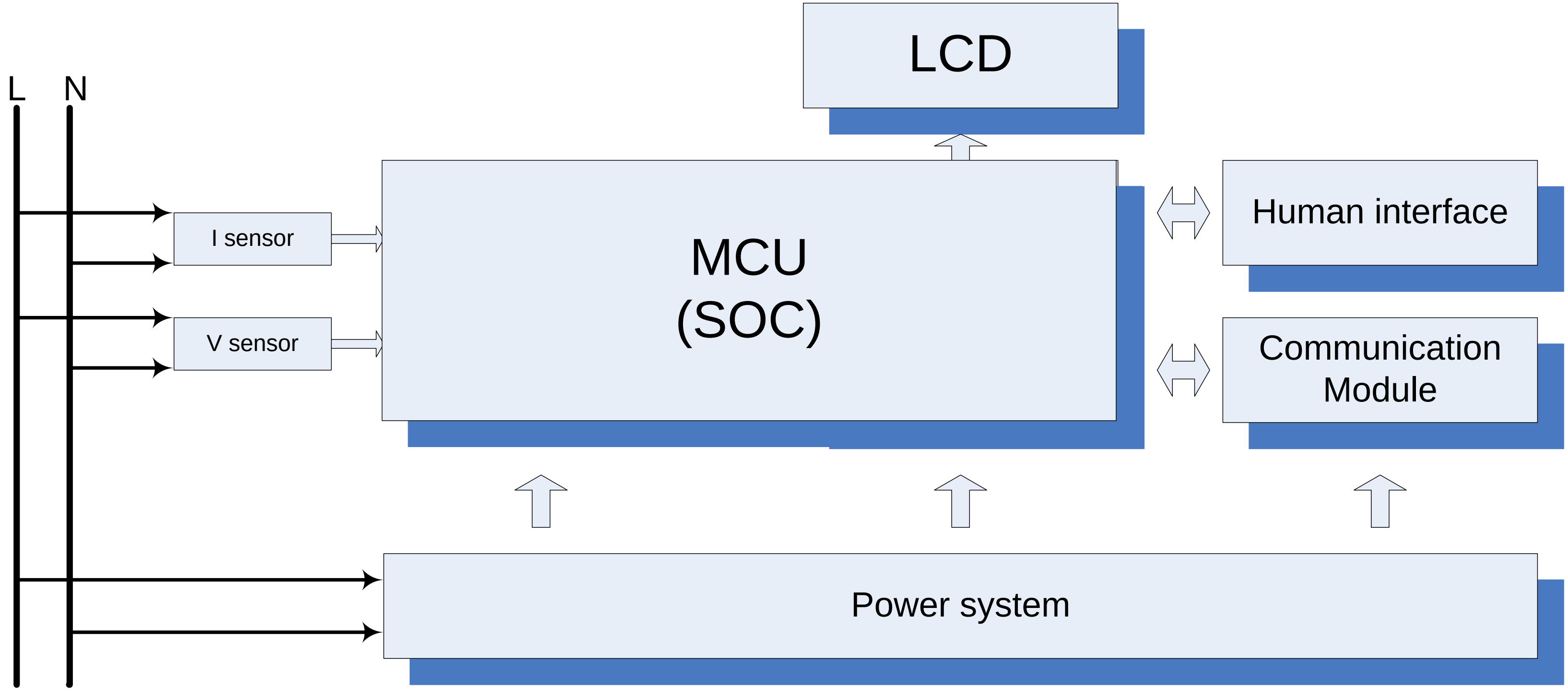
E-meter briefing

- E-meter
- Used to measure electricity energy power
- Always be considered to be a node of certain network instead of stand along device only
- For resident/industry metering or as consumer product (smart home)
- Single phase or 3-phase

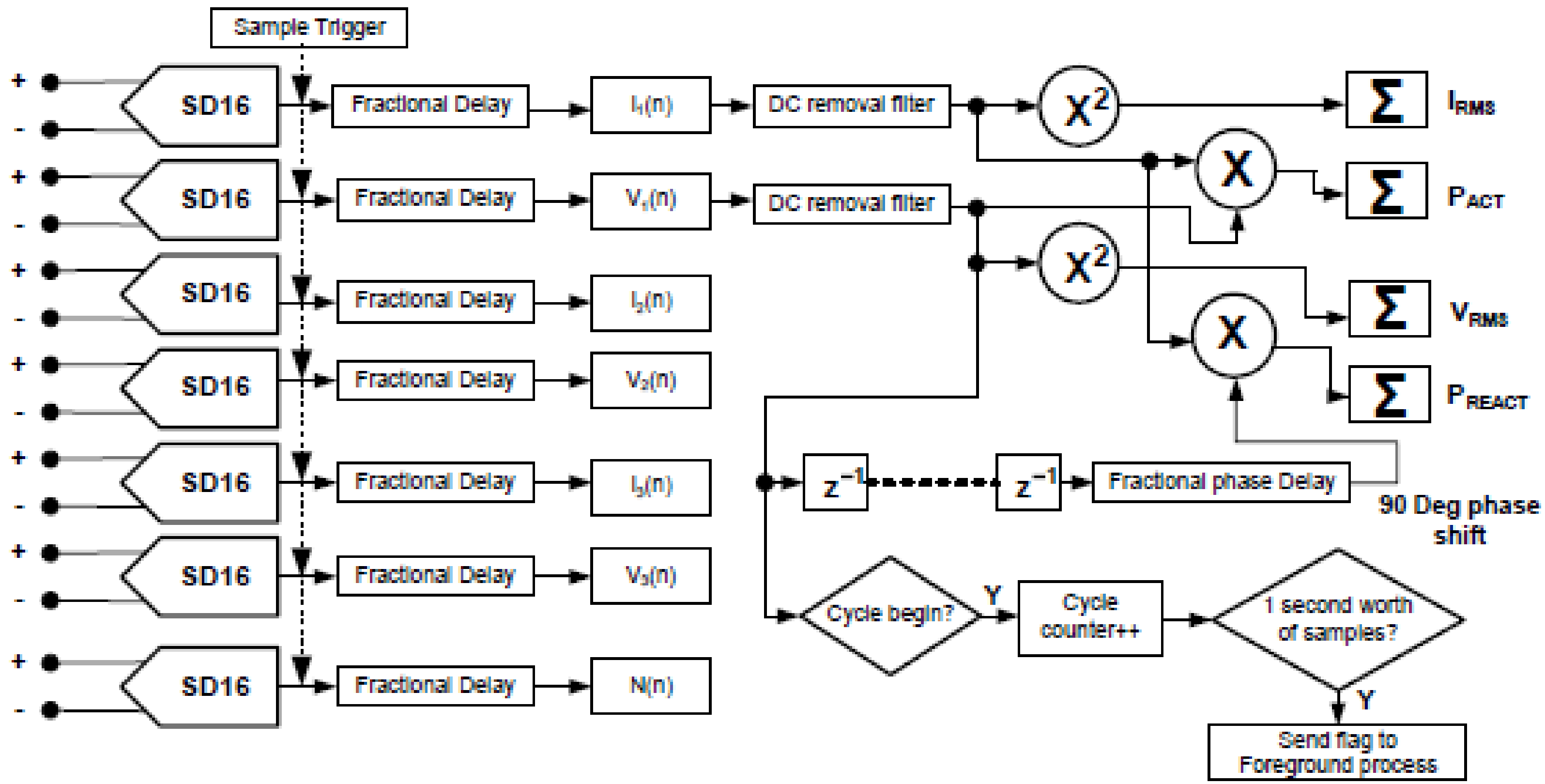
- E-meter function and requirement
- Measurement function: P, Q, S, IRMS, VRMS, F, etc.
- Ranking by grades：0.2S, 0.5S, 1S, 2S, etc.
- Display
- Meter reading (AMR through RS485/PLC/wireless/GPRS)
- Other requirement: toll (RTC), anti-tamper, electricity quality analysis, etc.

- Specification
- IEC--**International Electro technical Commission**
- GB/T--China

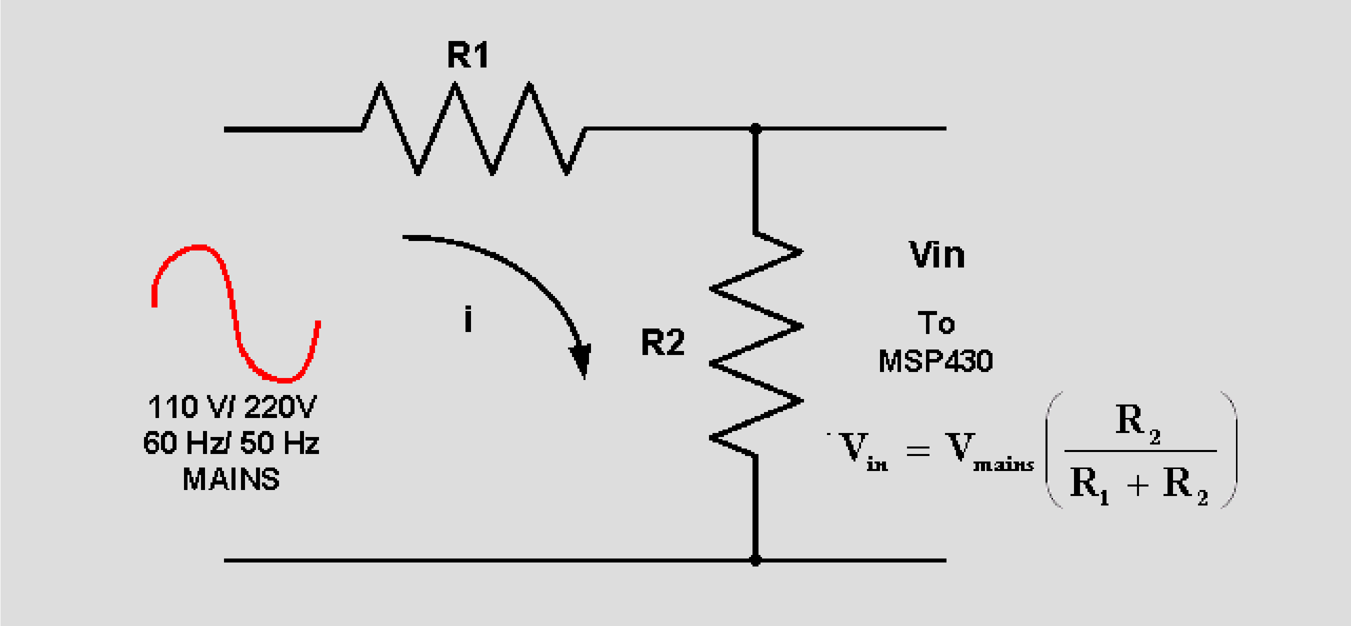
E-meter block diagraph



Metering function system graph
——Sample and Calculation

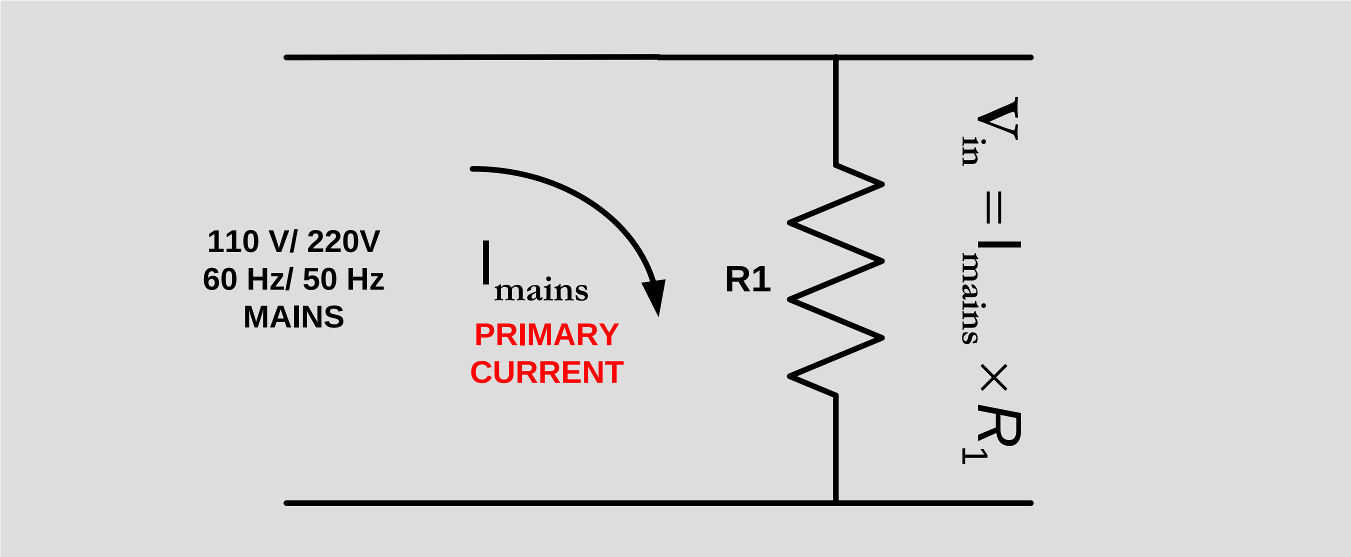


Voltage sensor – resistor



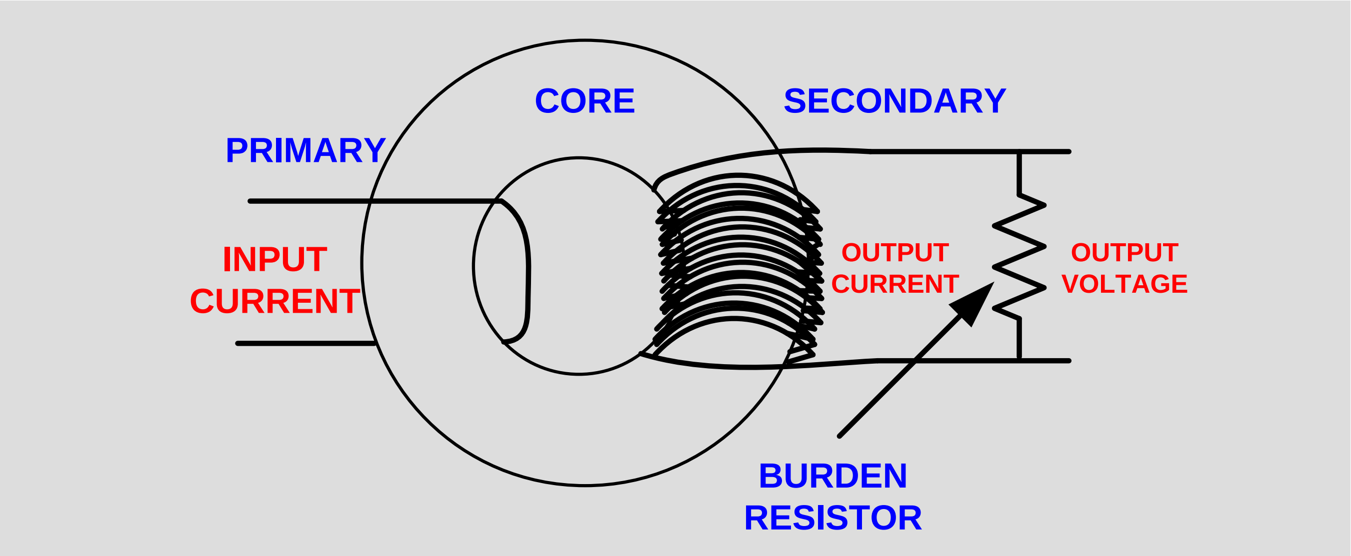
- Always used for voltage
- Simple and extremely cheap
- Values of R_1 and R_2 chosen depending on V_{mains} and desired range for V_{in} to A/D
- No level shifter necessary for differential inputs
- Gain amplifier stage not required

Current sensor-shunt



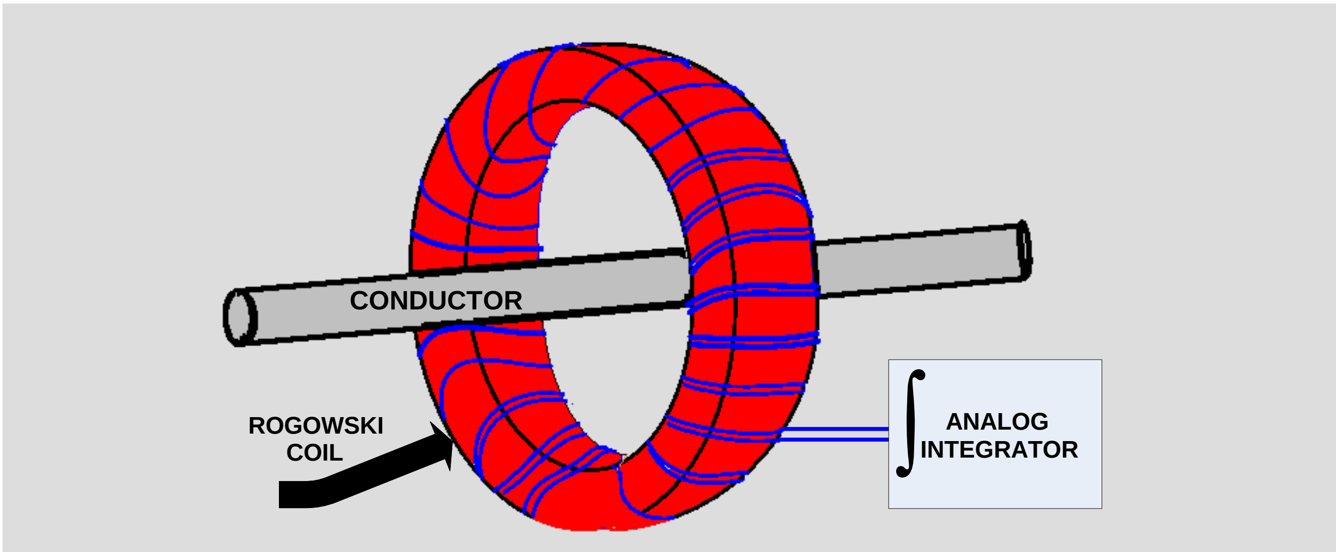
- Commonly used current sensor
- Simple to design, based on Ohm's law
- Inexpensive
- Always in micro-ohms range to support a wide dynamic range of currents
- No magnetic effects
- Absolutely no inherent phase shifts
- Can be used only with single-phase measurement systems
- In almost all cases, resistance is not constant, stable or perfectly linear over temperature
- Limited accuracy, resistor tolerances a concern for high precision meters
- No electrical isolation provided
- Self-heating due to power dissipation is a concern, posing limitations

Current sensor – current transformer



- 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

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
- Cheaper than CTs
- Integration adds to extra circuitry and delay that would have be compensated
- Limited accuracy
- Position sensitive
- Not very common for E-metering, hard to find best match

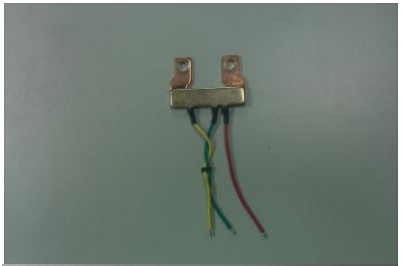
E-meter component—cont.

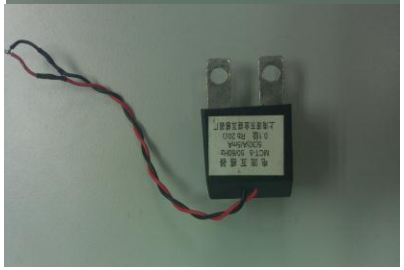
V-sensor

- Resister ladder.

I-sensor

- shunt.
  - Pros: cost effective, DC tolerant, high dynamic range
  - Cons: weak signal, no isolation
- Transformer
  - Pros: isolation, large signal
  - Cons: high cost, poor linearity over large dynamic range





Analog Front end

- ASIC.
- MSP430AFE25x.
- SOC.

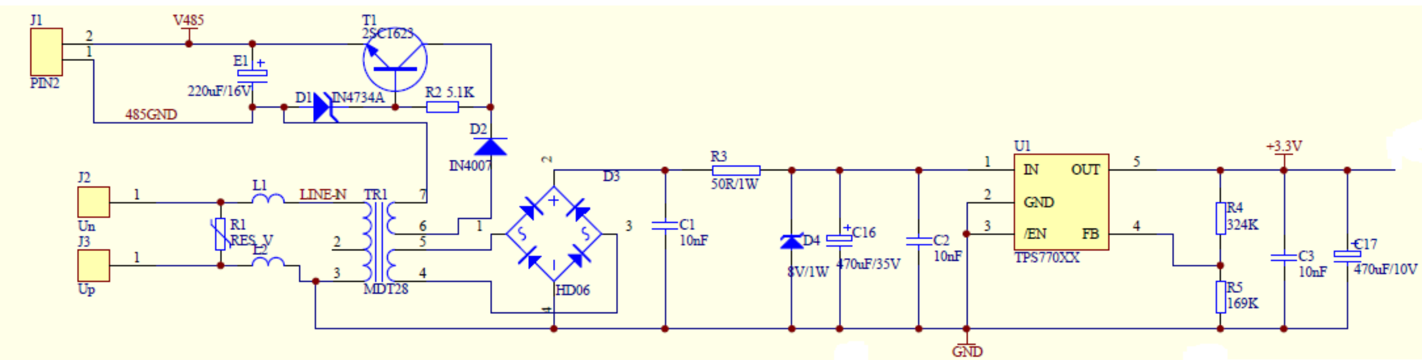
Peripheral

- RS485: SN65LBC184
- PLC: Piccolo
- Wireless: CC1100, CC430

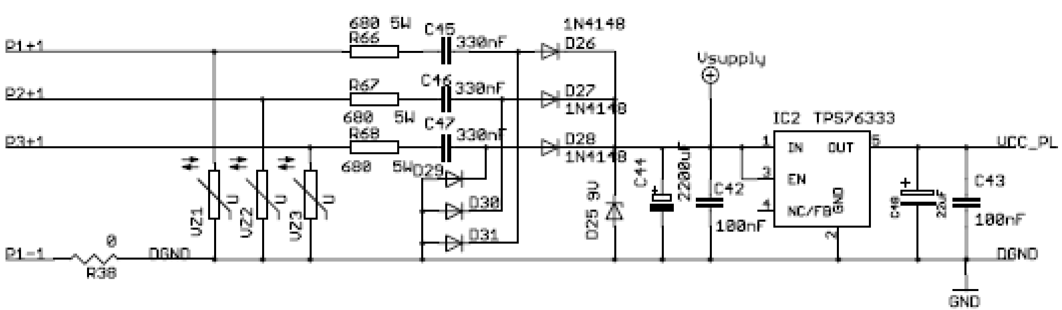
E-meter component

System Power

- Transformer
  - Pros: high driver ability
  - Cons: high cost



- RC
  - Pros: Cost effective, anti-tamper
  - Cons: low driver ability, high demanding on power quality



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What is important on a meter-chip?

- **Voltage and Current samples are a must for all calculations**
  - Voltage and current are analog → Good ADC
  - Processing is digital and all math → Powerful CPU, good digital peripherals

- **Accuracy of computation**
  - High resolution ADC → more the bits, better the conversion from analog to digital
  - Good libraries for common functions such as square root, square, division etc. on fixed-point machine

Small, secure and accurate energy monitoring

Leading accuracy for precise energy measurements

- 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

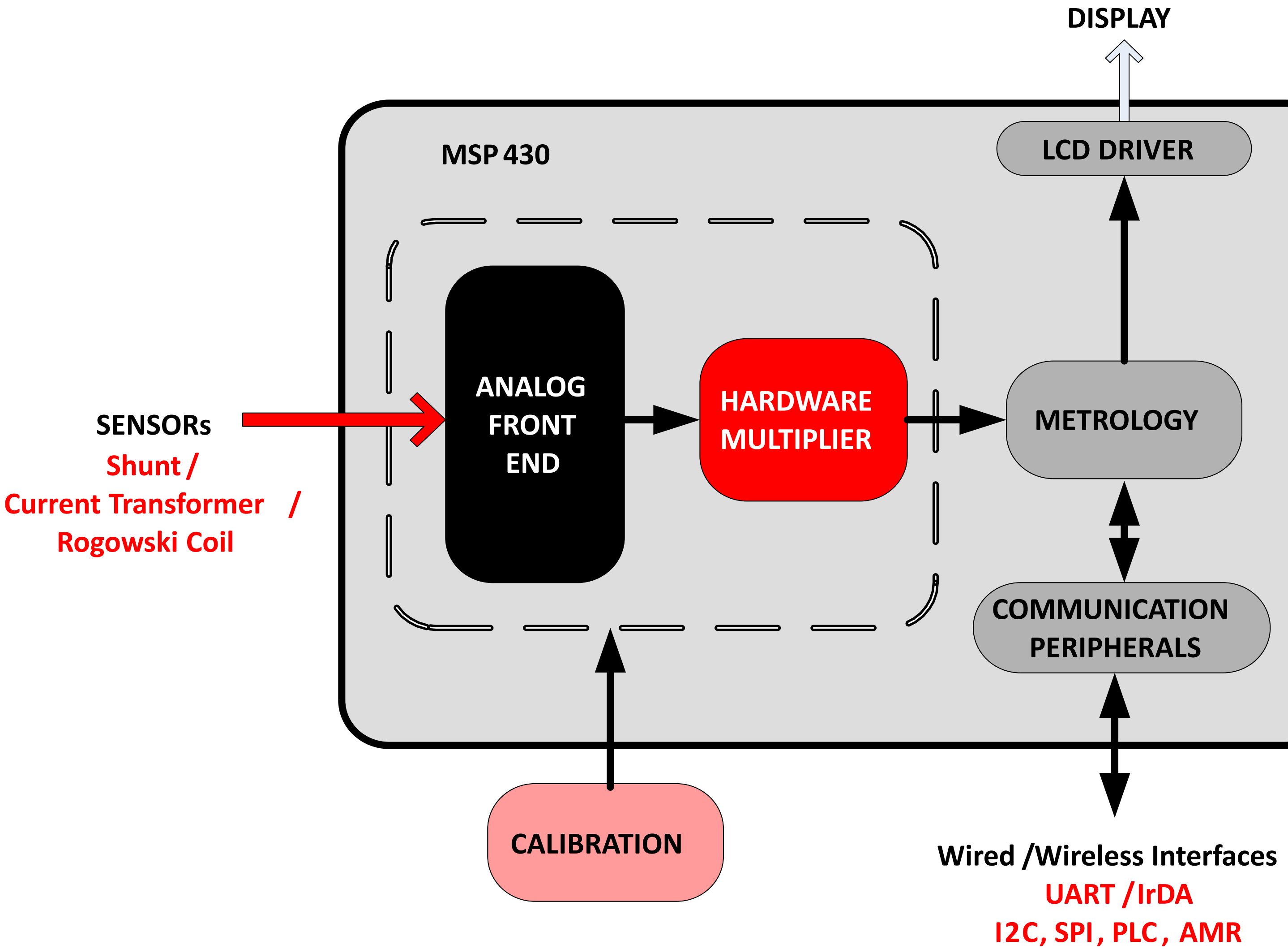
Ultra-low power consumption for system reliability

- 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

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



MSP430 for E-metering?

- **Powerful A/D converter**
  - Operates in 24-bit mode
  - 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 better accuracy
  - Real-time clock
- **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
- **Multiple communication peripherals**
- **Support for anti-tampering**
  - Use the extra Sigma Delta for this purpose
- **CPU independent metrology engine**
  - ESP430 present on some devices

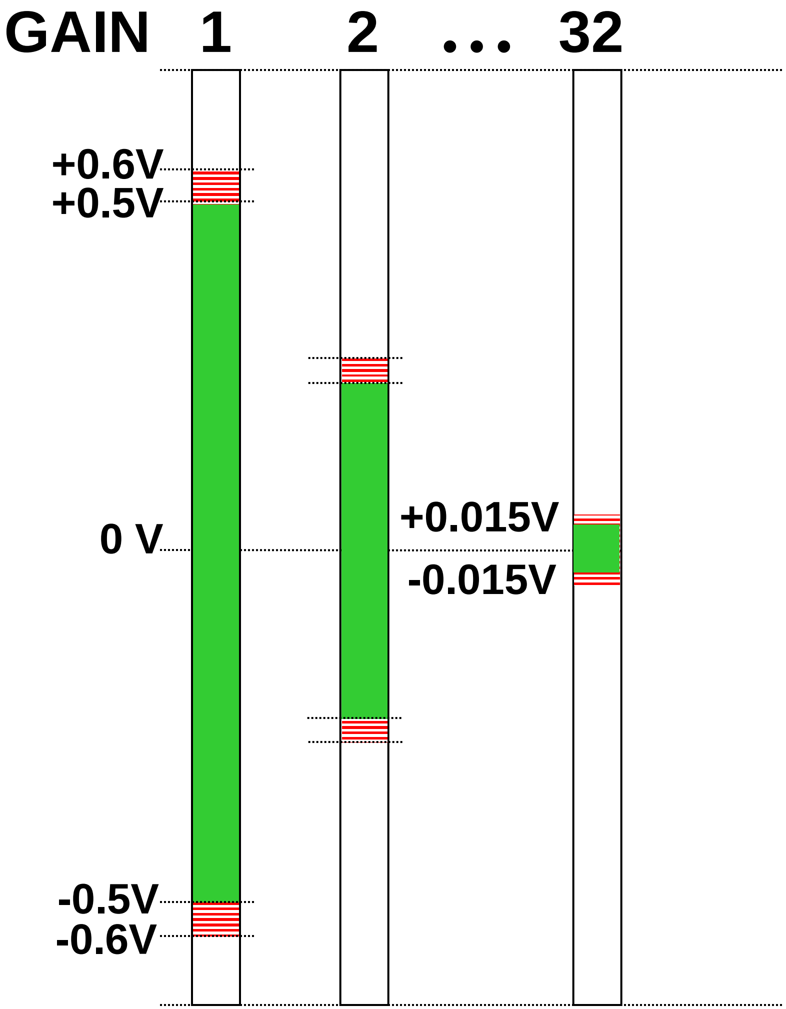
Advantages

- **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
  - Independent converter for tamper detection
- **3 or 4 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
- **In-built PGA**
  - When shunt resistors or Rogowski coils are used, complete dynamic range can be used with any external gain amplifiers

Analog input range

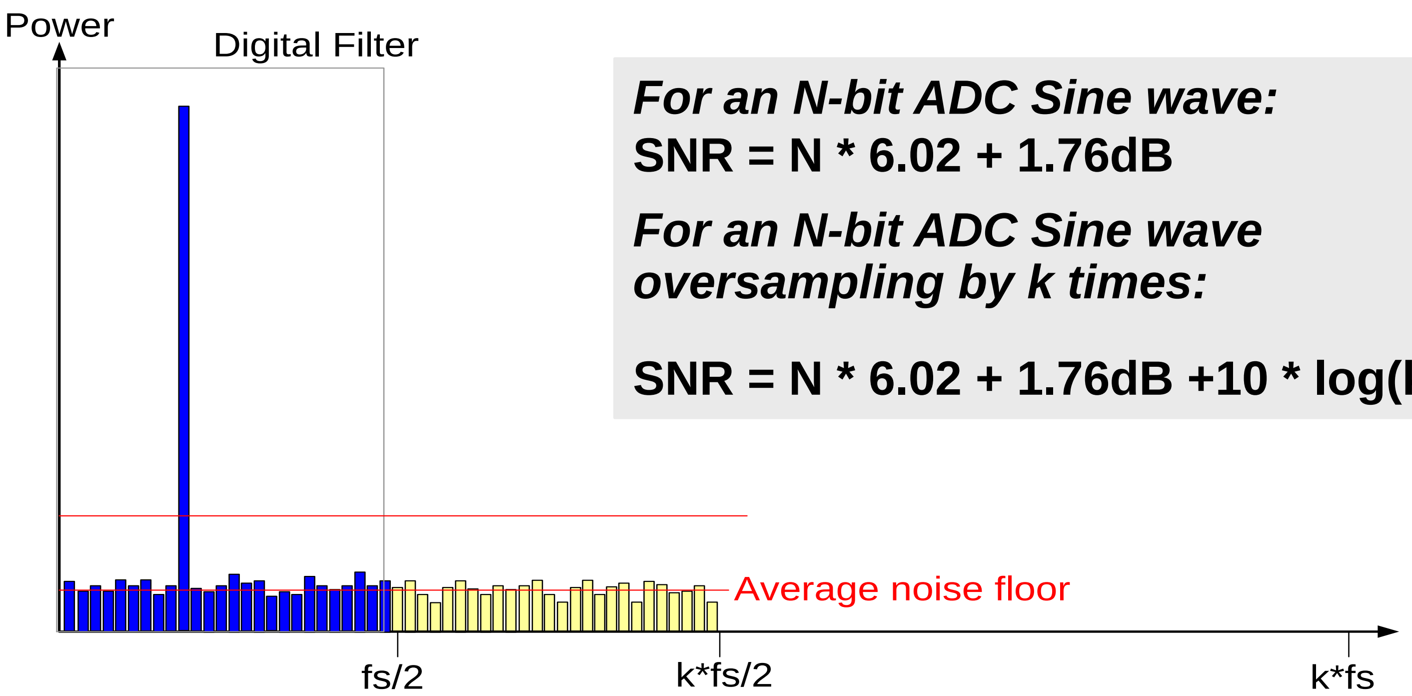
- What is V_{REF}?
- What is the PGA setting?
- Applies to all inputs & modes

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



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

Oversampling ratio



For an N-bit ADC Sine wave:

SNR = N * 6.02 + 1.76dB

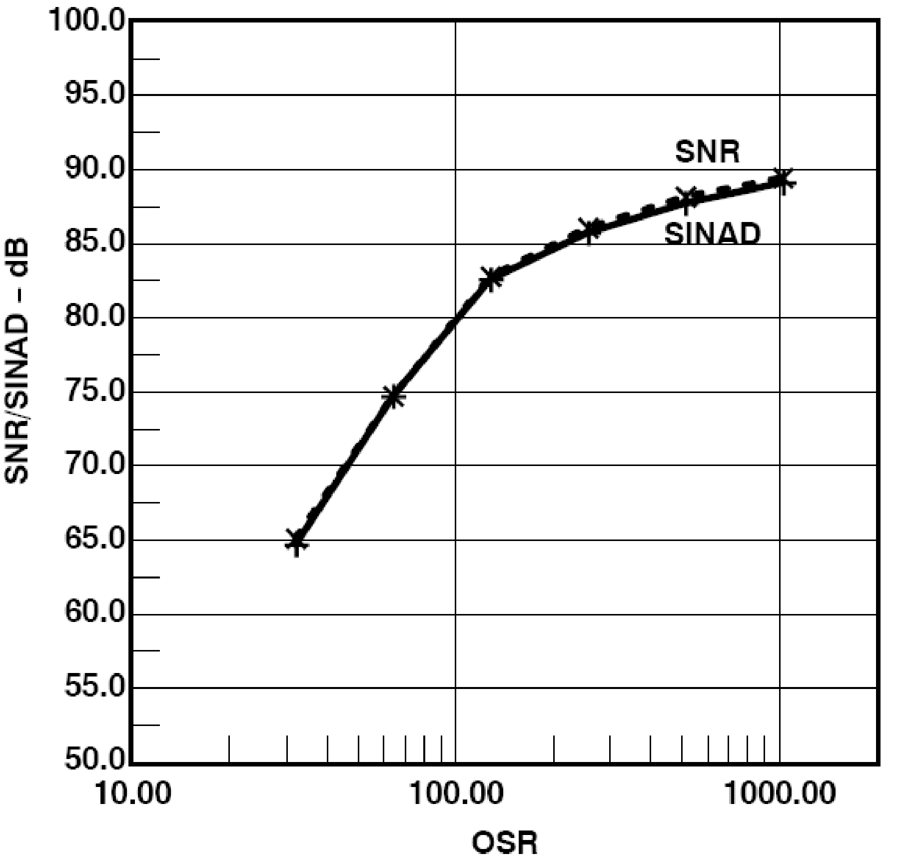
For an N-bit ADC Sine wave oversampling by k times:

SNR = N * 6.02 + 1.76dB +10 * log(k)

- Same total noise - spread over more frequencies
- Gentler transition band for anti-aliasing filter (AAF)

ΣΔ: SNR/SINAD over OSR

$$SINAD = 20\log\frac{S}{N+D}$$



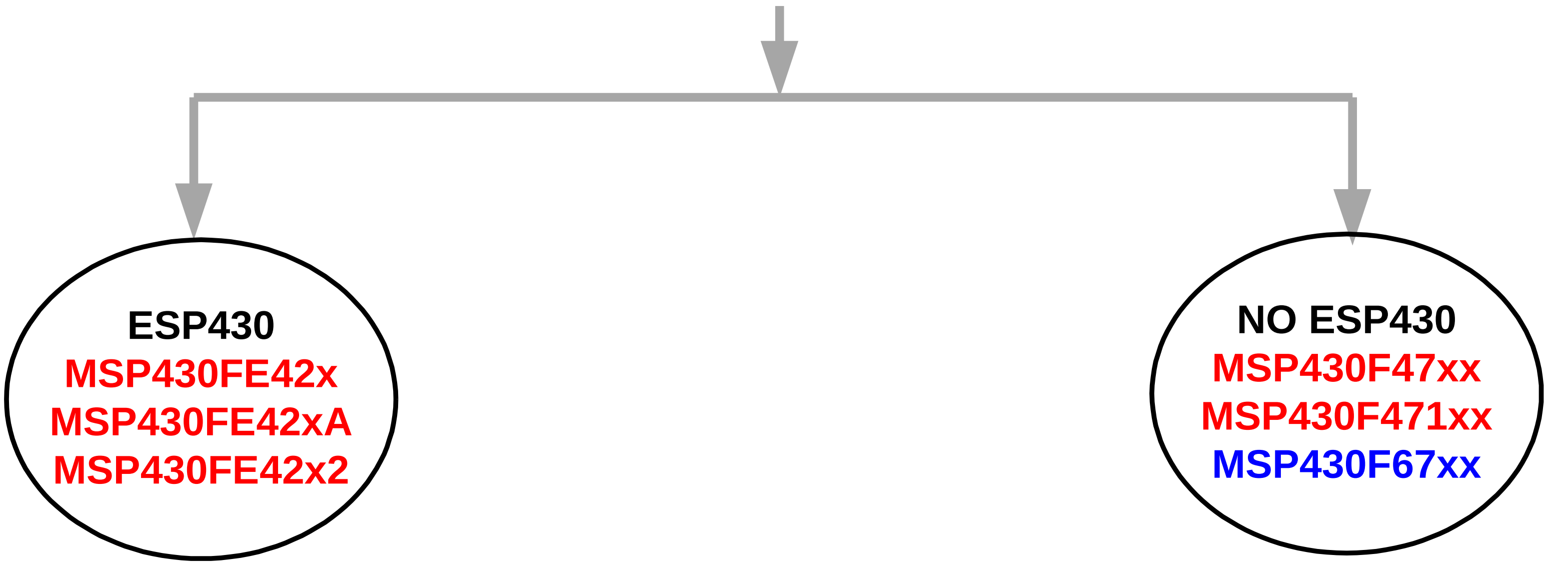
† SNR/SINAD performance over OSR

OSR = 1024: Overall SINAD improvement of 25dB

SINAD of 90dB equals 14.66 bits on MSP430

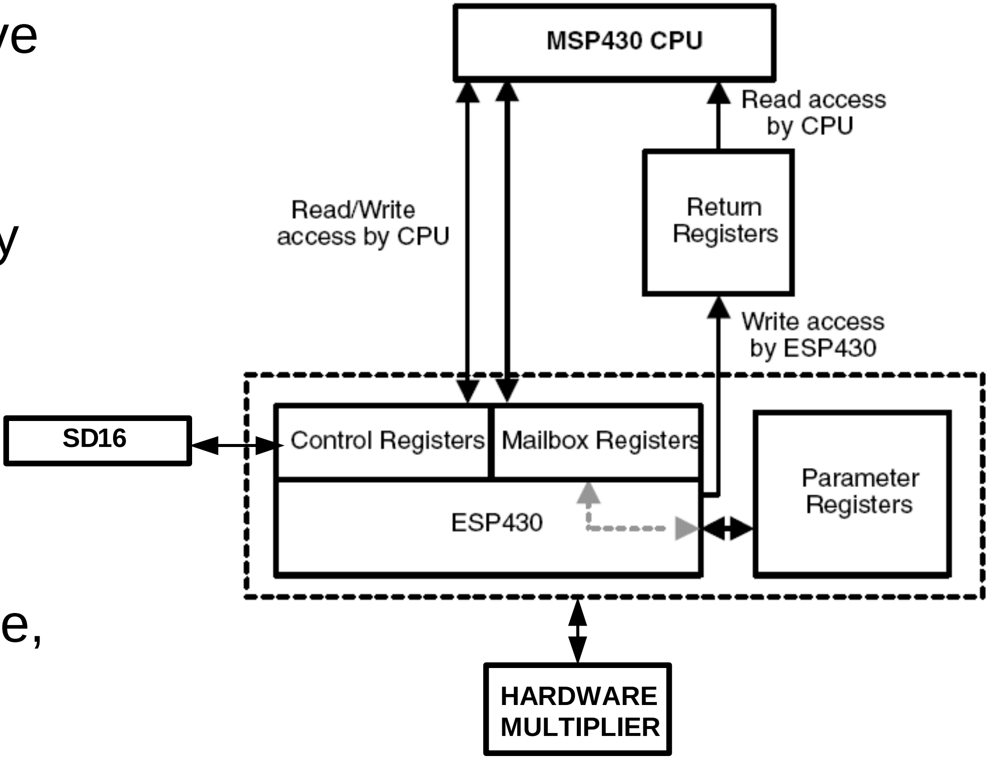
† Chart from F47xx D/S

MSP430 E-meter metrology options

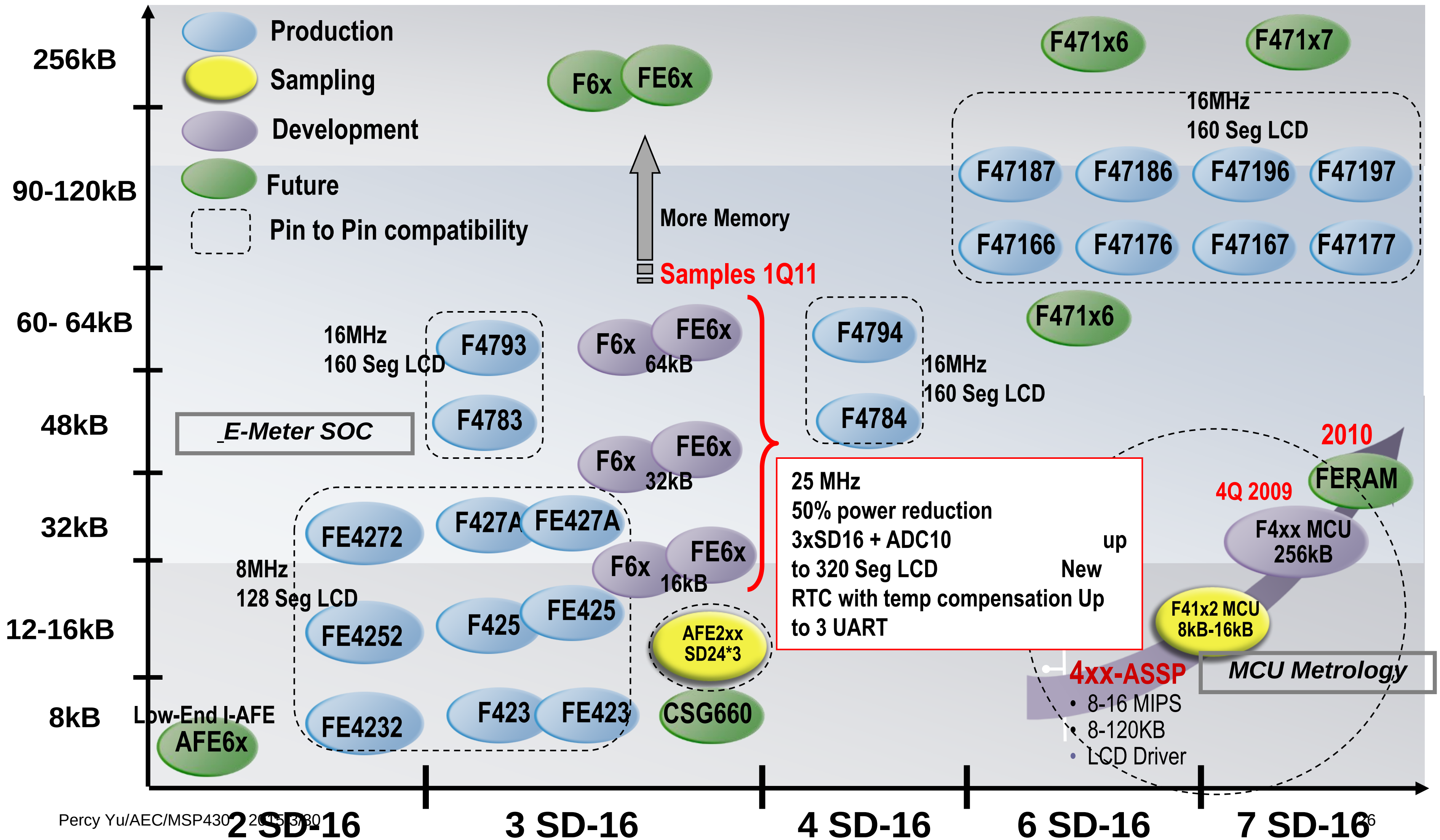


ESP430 block diagram

- Embedded signal processor present on all devices that have an “E” in its nomenclature
- Energy metrology engine running parallel to CPU activity
- Dedicated use of ΣΔs and Hardware multiplier
- Combines analog and digital signal processing
- Returns energy, power, voltage, current and power factor measurements



E-meter component—cont.



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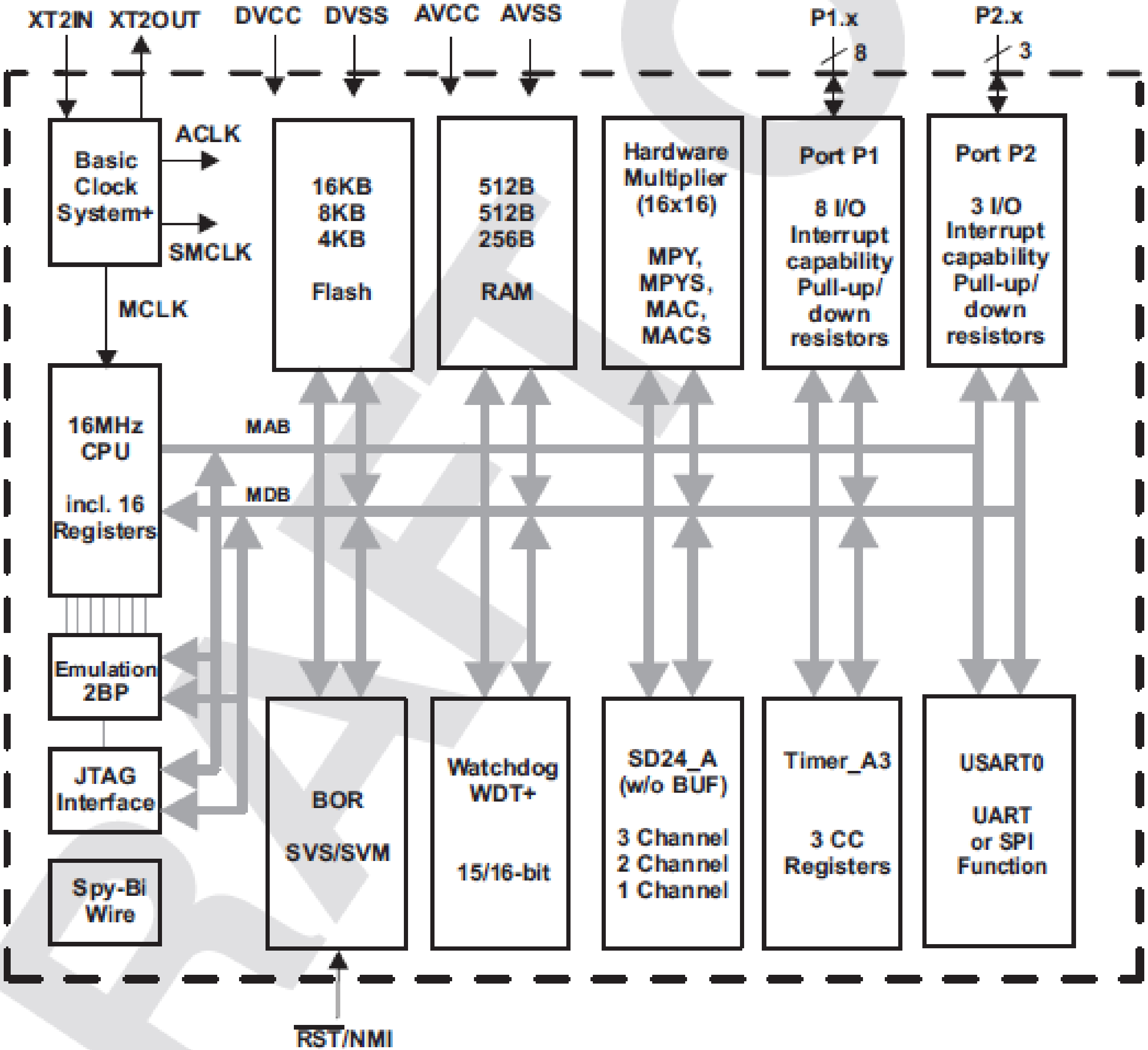
MSP430AFE25x briefing

- MSP430AFE25x is
- Mixed signal processor based on MSP430F2xx family MCU.
- Targeting analog front end for electricity meter and sub-meter applications.
- Firmware dependent device for different application

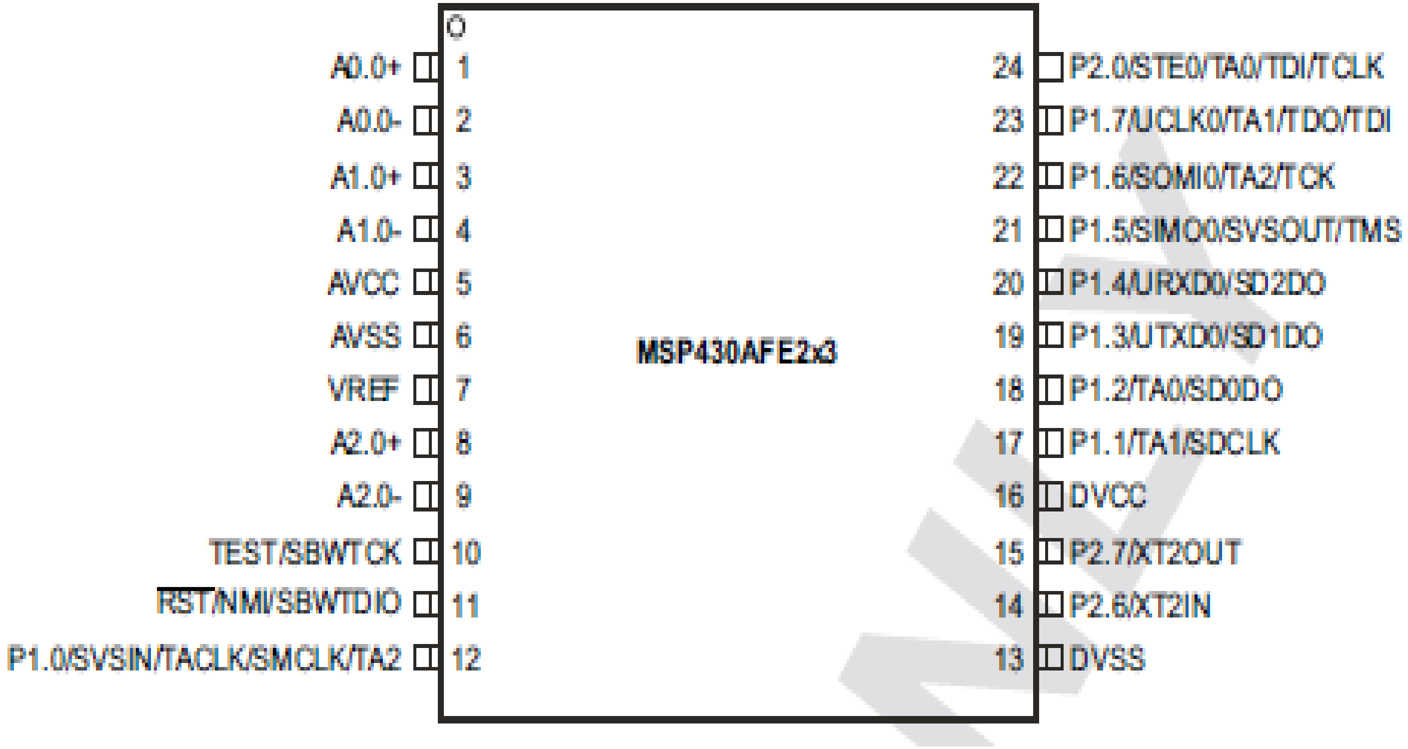
- Is NOT
- ASIC chip
- For China SG specification only
- Targeting SOC E-meter solution

MSP430AFE25x function block diagram

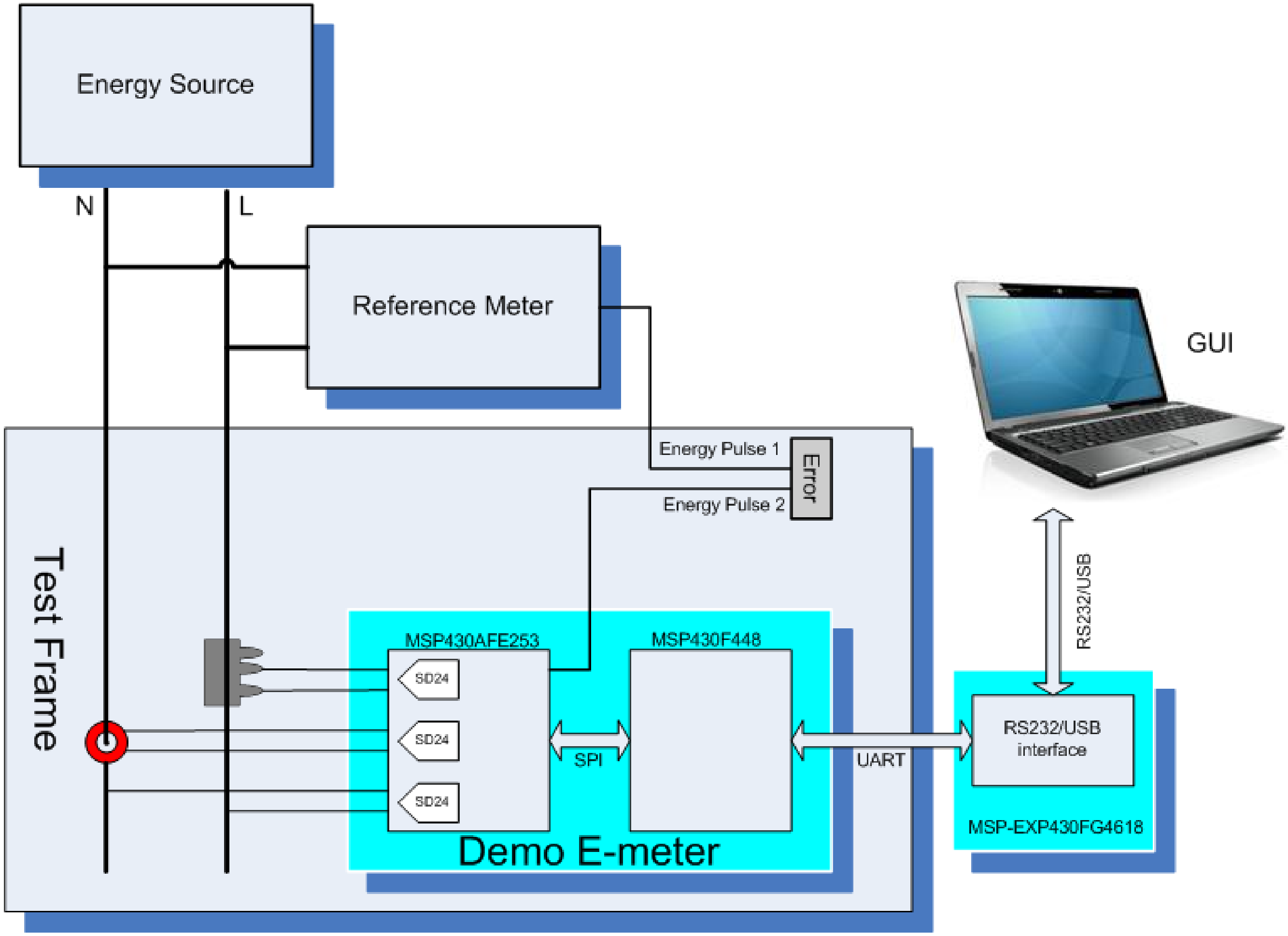
- Key Feature
- 16KB flash
- 512B ram
- 3 channels SD24_A
- 16*16 Multiplier
- USART0
- Watchdog, BOR



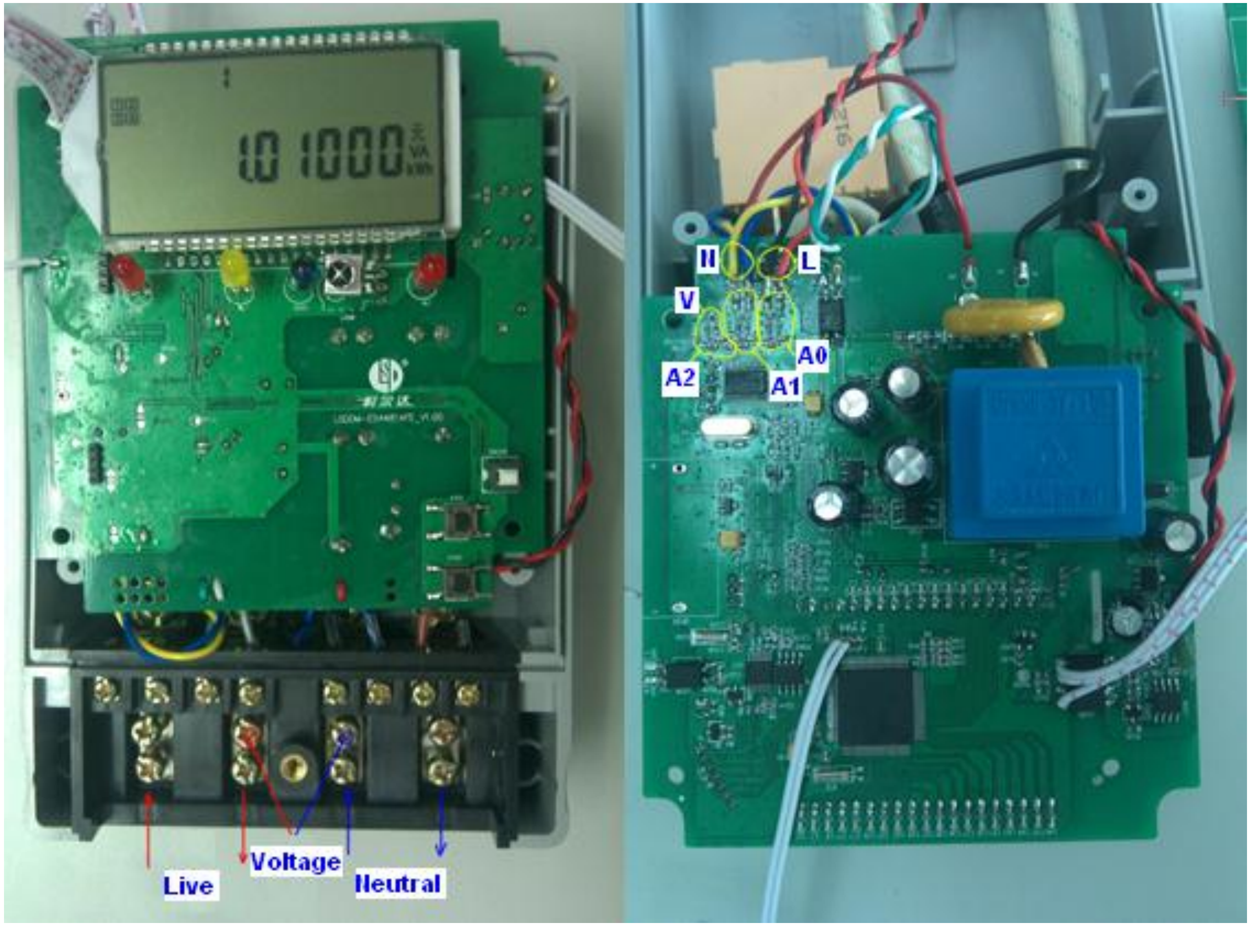
MSP430AFE25x pin out



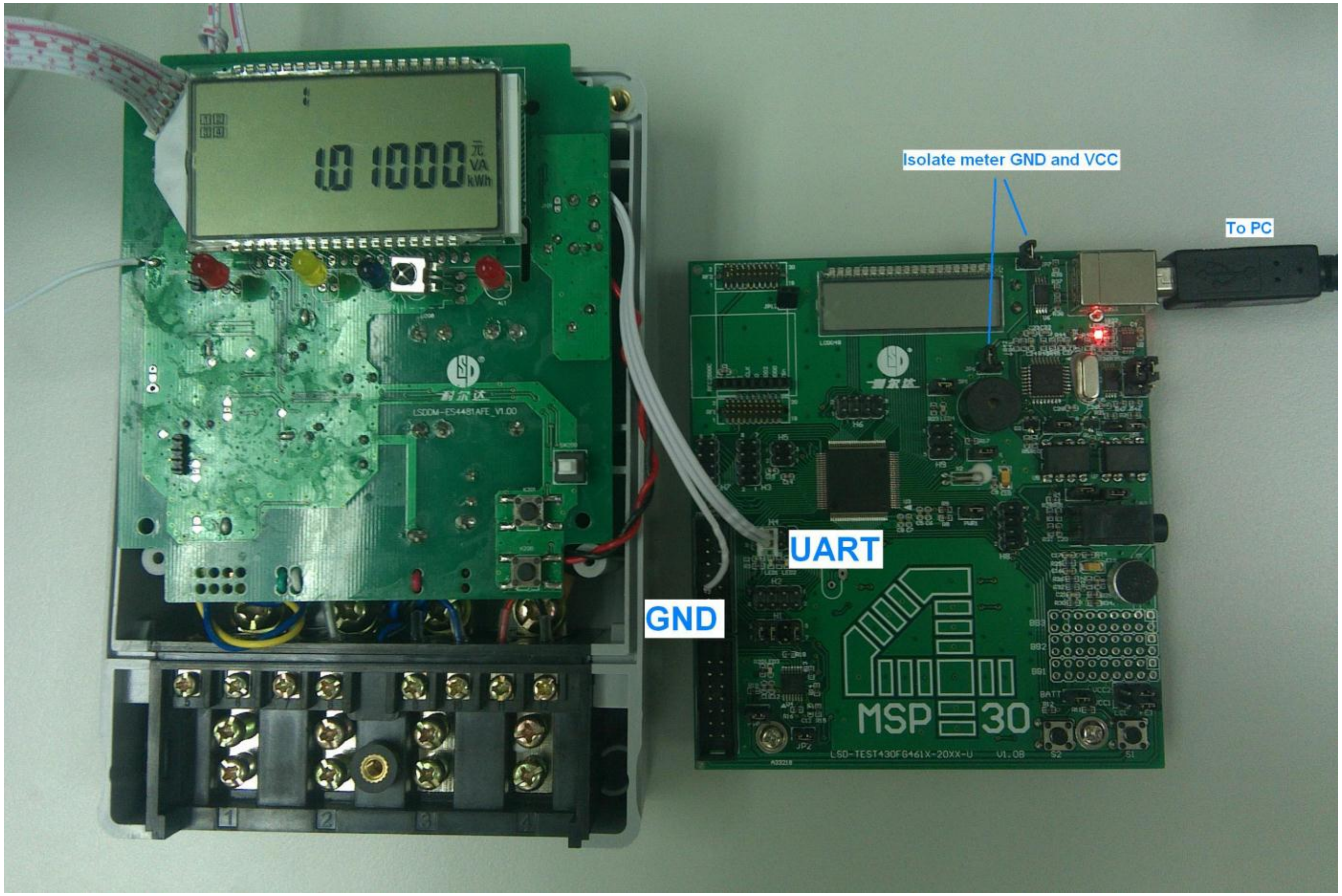
MSP430AFE25x demo set block diagram



MSP430AFE25x demo E-meter



MSP430AFE25x demo meter connection



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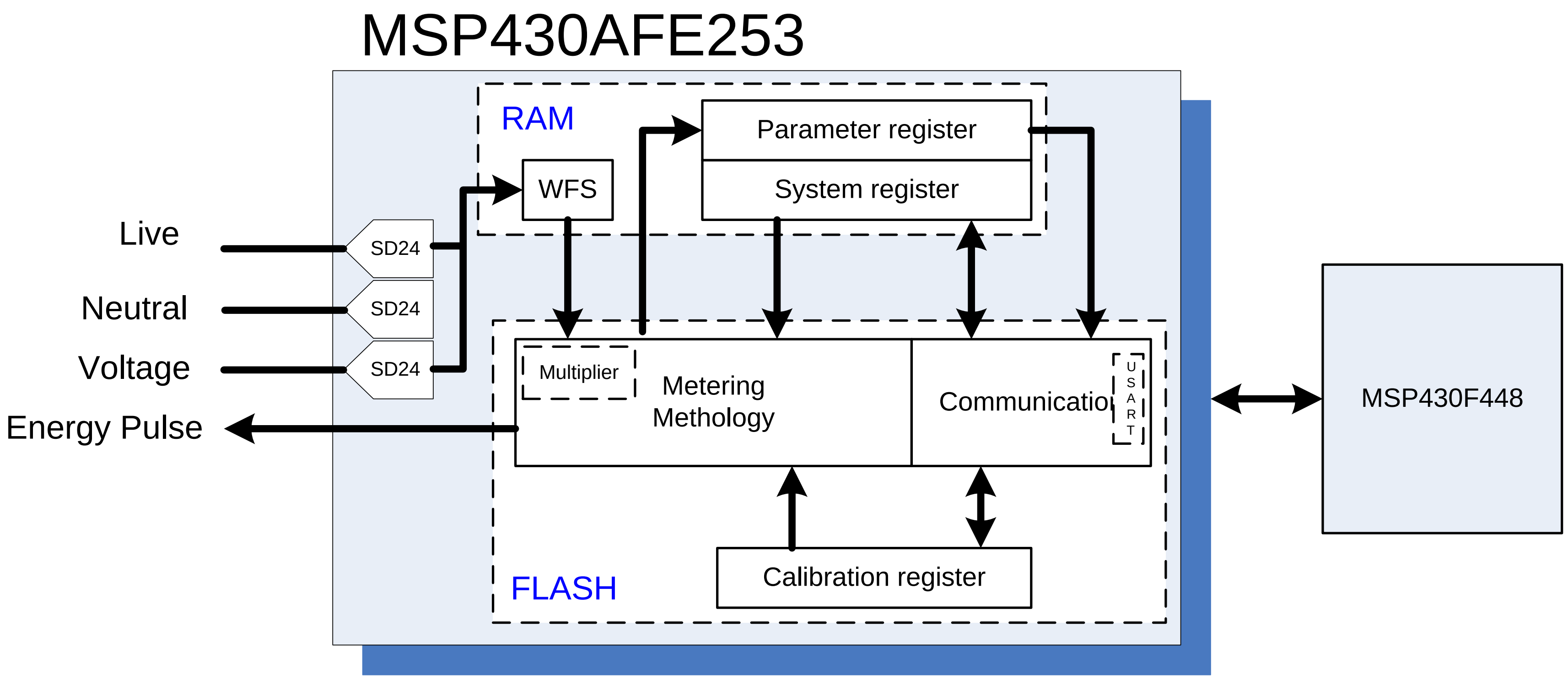
CSG Firmware Briefing

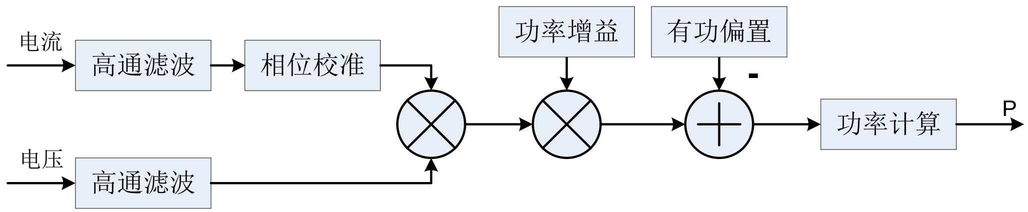
- Targeting CSG single phase E-meter specification defined by CEPRI
- Apply to all functions defined by GB/T 17215.321-2008
- Working range V：0.8Un-1.15Un。
- Working range I：5(60)A
- Frequency：50Hz±5%
- Accuracy：0.5S
- Power constant：1600imp/KWh
- Working temperature： -25℃— +70℃
- Start Current：≤0.004Ib

CSG Firmware Data Flow

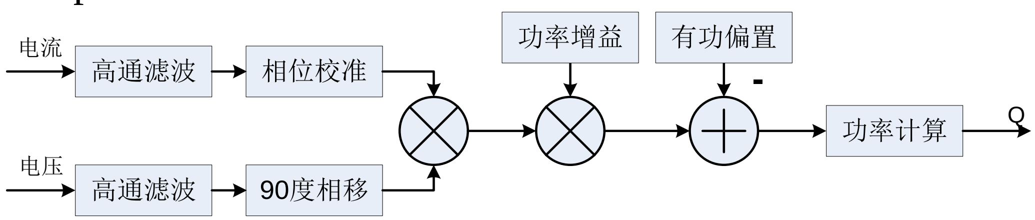


CSG Firmware – Metering Metrology

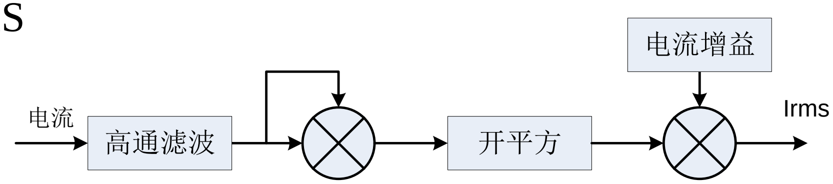
Active power



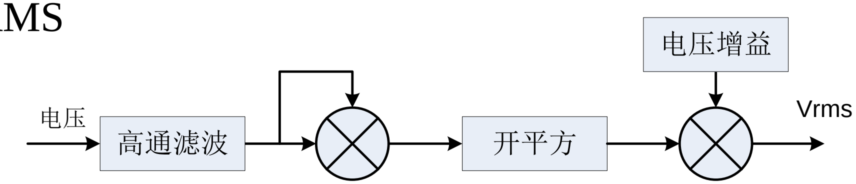
Reactive power



IRMS

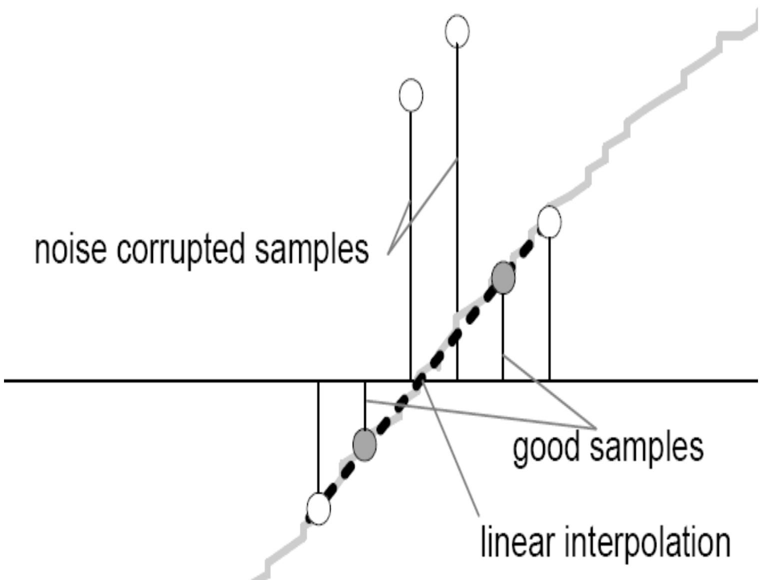


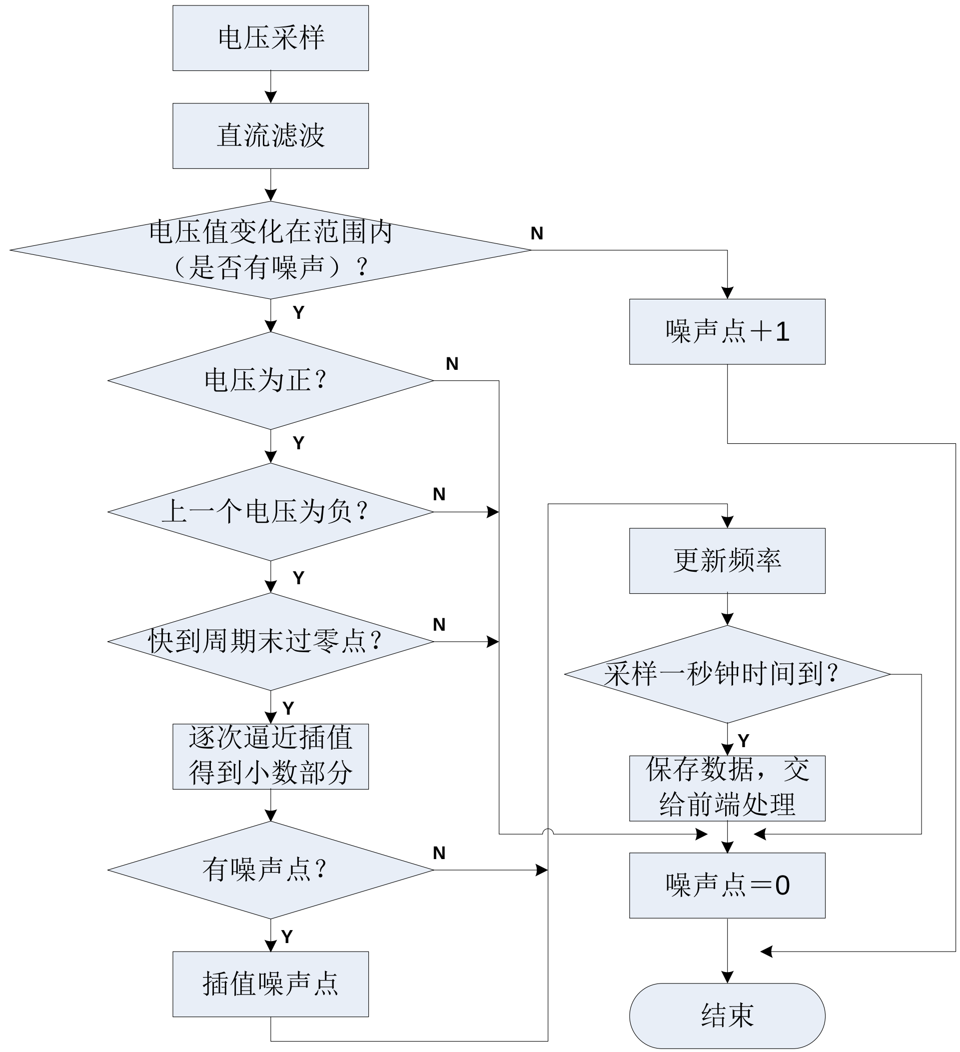
VRMS



CSG Firmware – Metering Metrology cont.

Frequency

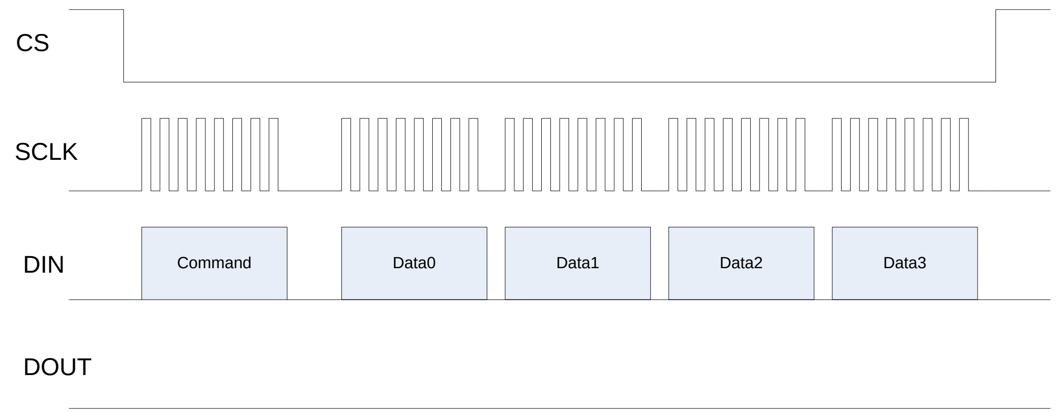




CSG Firmware – Communication

SPI or Uart selectable

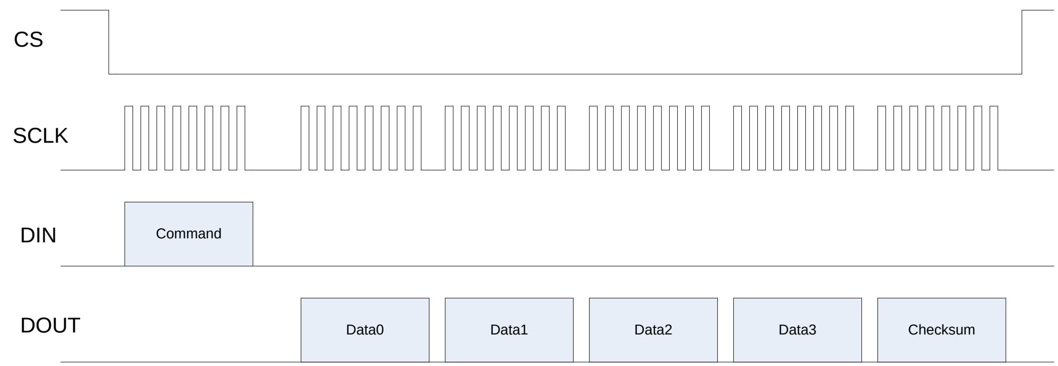
- Predefined when firmware is built
- Macro SPIUSED defined whether SPI or Uart used
  - SPIUSED defined, use SPI
  - SPIUSED not defined, use UART



Input packet

Command has below format

- Bit7、Bit6: 01 host read command
- Bit7、Bit6: 10 host write command
- Bit5...Bit0: register address



Output packet

CSG Firmware – System Register

System register – config CSG firmware functions

address	Name	R/W	Length(Byte)	Default	description
0x34	SYSCONF	R&W	2	0x0004	system config register
0x35	CSGCONF	R&W	2	0x1063	CSG function config register
0x36	POWER_CONST	R&W	2	0x0640	power constant
0x37	START_CURRENT	R&W	2	0x00DC	Start power threshold
0x38	IE	R&W	2	0x0001	CSG interrupt enable
0x39	IFG	R	2	0x0000	CSG interrupt flag
0x3A	STATUS	R	2	0x0000	CSG status
0x3B	CheckSum1	R	2	0x0000	checksum for calibration registers
0x3C	WREN	R&W	2	0x0000	write enable
0x3D	SRST	W	2	--	software rest
0x3E	USI_RX	R	2	0x0000	Last SPI received value
0x3F	USI_TX	R	2	0x0000	Last SPI transmitted value

CSG Firmware – ADC Gain setting

SYSCONF register

	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
SYSCONF	**RSV**	**RSV**	**RSV**	**RSV**	**RSV**	**RSV**	**RSV**	**GAINV**			**GAINI2**			**GAINI1**		
Default	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

SD24 Gain setting	**value**	**Gain**	**Input**	**unit**
GAINV/GAINI1/GAINI2	000	1	±500	mVp-p
	001	2	±250	mVp-p
	010	4	±125	mVp-p
	011	8	±62	mVp-p
	100	16	±31	mVp-p
	101	32	±15	mVp-p

CSG Firmware – CSG function register

CSGCONF register

SOFF
1: switch off apparent power measurement. Apparent power always read 0
0: switch on apparent power measurement

QOFF
1: switch off reactive power measurement. Apparent power always read 0
0: switch on reactive power measurement

CSEL
energy pulse selection
00: energy pulse generate from large current channel
01: energy pulse generate from channel 1
10: energy pulse generate from channel 2

EMOD
negative energy accumulate mode
00: accumulate negative energy ,
01: do not accumulate negative energy, if P<0,P=0
10: accumulate absolute value for negative energy, if P<0,P=-P

DCFILTER
DC filter selection
00: IIR filter on V channel, no filter for I channel
01: IIR filter for both V and I channel
10: average filter on V channel, no filter for I channel
11: average filter for both V and I channel

FPEN
1: fast energy pulse enable
0: fast energy pulse disable

FPF
Fast pulse ratio
When FPEN is set, FPF decide the ratio between fast energy pulse and normal energy pulse
00:×1 01:×2 10:×4 11:×8

QPEN
1: enable reactive energy pulse
0: disable reactive energy pulse

PPEN
1: enable active energy pulse
0: enable active energy pulse

CSG Firmware – Interrupt

IE and IFG register

IE		WFS	ZX	QEO	PEO	QF	PF	NEWLOG
default	0	0	0	0	0	0	0	1
IFG		**WFS**	**ZX**	**QEO**	**PEO**	**QF**	**PF**	**NEWLOG**
default	0	0	0	0	0	0	0	0

Event

- **WFS** waveform sample event is trigged every time SD24 sample ready.
- **ZX** Cross Zero event is trigged on the leading zero cross point on Voltage.
- **QEO** reactive energy pulse overflow event is trigged every 65536 reactive energy pulses.
- **PEO** active energy pulse overflow event is trigged every 65536 active energy pulses.
- **QF** reactive energy pulse event is trigged every reactive energy pulse
- **PF** active energy pulse event is trigged every active energy pulse
- **NEWLOG** parameter register update event is trigged when parameter registers are updated by CSG firmware. It indicate the right time to read out parameter registers

CSG Firmware – Status

Status register

Status

- UNBAL 1: current unbalance between neutral and live
- 0: current balance between neutral and live
- The threshold of unbalance is:
- If absolute active power is larger than 2000W, 6.25% error between neutral and live
- If absolute active power is less than 2000W, 25% error between neutral and live
- M_REV 1: current reversed (either live or neutral)
- 0: current not reversed
- CH2_USED 1: Channel 2 used to generate energy pulse
- 0: Channel 1 used to generate energy pulse
- I2_REV 1: Channel 2 reversed
- 0: Channel 2 not reversed
- I2_OR 1: Channel 2 over range
- 0: Channel 2 in range
- I1_REV 1: Channel 12 reversed
- 0: Channel 12 not reversed
- I1_OR 1: Channel 1 over range
- 0: Channel 1 in range
- V_OR 1: Channel V over range
- 0: Channel V in range
- EOF 1: Active energy pulse counter reach 65536 and reset
- 0: Active energy pulse counter does not reach 65536
- I2POS 1: Channel 2 on positive half
- 0: Channel 2 on negative half
- I1POS 1: Channel 1 on positive half
- 0: Channel 1 on negative half
- VPOS 1: Channel V on positive half
- 0: Channel V on negative half

CSG Firmware – Write Protection

WREN register

- System registers addressed from 0x34 to 0x38 and all calibration registers are writing protected and can not be modified without write enable.
- Write 0x00ca to WREN register enable writing to calibration registers.
- Writing 0xc500 to WREN register enable writing to system registers address from 0x34 to 0x38. Write 0xc5ca to WREN registers enable all register writing.
- Write other value than 0x00ca, 0xc500, 0xc5ca will disable all register writing enable.
- Write to calibration registers or system registers address from 0x34 to 0x38 will clear corresponding write enable afterward.

CSG Firmware – other CSG system register

POWER_CONST register

- POWER_CONST register contain the number of energy pulse for 1KWH energy.
- If PowerConstant=1600, then 1 energy pulse denote 1000kw*3600s/1600=2250WS energy

START_CURRENT register

- START_CURRENT register contain the threshold below which CSG firmware will stop accumulate energy.
- It's in 10mW step and default value is 220 denote 2.2W.

CheckSum1 register

- CheckSum1 register contend the check sum of all calibration registers address from 0x00 to 0x0C.
- CheckSum1 is updated by CSG firmware every time calibration registers modified by host.

SRST register

- Write 0x0099 to SRST register will reset MSP430AFE2xx CSG firmware

SPI buffer

- USI_RX and USI_TX registers store last received data and transmitted date from SPI respectively.

CSG Firmware – Parameter Register

Parameter register – store measurement results

address	Name	R/W	Length(Byte)	Default	discription
0x20	P1_ACT	R	4	0x0000	Channel1 active power
0x21	P2_ACT	R	4	0x0000	Channel2 active power
0x22	P1_REACT	R	4	0x0000	Channel1 reactive power
0x23	P2_REACT	R	4	0x0000	Channel2 reactive power
0x24	P1_APP	R	4	0x0000	Channel1 apparent power
0x25	P2_APP	R	4	0x0000	Channel2 apparent power
0x26	VRMS	R	2	0x0000	VRMS
0x27	FREQ	R	2	0x0000	Line Frequency
0x28	I1RMS	R	2	0x0000	Channel1 IRMS
0x29	I2RMS	R	2	0x0000	Channel2 IRMS
0x2A	PF1	R	2	0x0000	Channel1 power factor
0x2B	PF2	R	2	0x0000	Channel2 power factor
0x2C	EP_ACT	R	2	0x0000	active energy pulse counter
0x2D	EP_RACT	R	2	0x0000	reactive energy pulse counter
0x2E	EP_NEG_ACT	R	2	0x0000	negtive active energy pulse counter
0x2F	EP_NEG_RACT	R	2	0x0000	negtivereactive energy pulse counter

CSG Firmware – Calibration Register

Calibration register – used to calibration measurement result

address	Name	R/W	Length(Byte)	Default	description
0x00	I1RMS_OFFSET	R&W	2	0	Channel1 IRMS offset
0x01	I2RMS_OFFSET	R&W	2	0	Channel2 IRMS offset
0x02	I1RMS_GAIN	R&W	2	last written	Channel1 IRMS slope
0x03	I2RMS_GAIN	R&W	2	last written	Channel2 IRMS slope
0x04	P1_GAIN	R&W	2	last written	Channel1 active power slope
0x05	P2_GAIN	R&W	2	last written	Channel2 active power slope
0x06	P1_PHASE	R&W	2	0	Channel1 phase shift
0x07	P2_PHASE	R&W	2	0	Channel2 phase shift
0x08	P1_OFFSET	R&W	2	0	Channel1 active power offset
0x09	P2_OFFSET	R&W	2	0	Channel2 active power offset
0x0A	Q1_OFFSET	R&W	2	0	Channel1 reactive power offset
0x0B	Q2_OFFSET	R&W	2	0	Channel2 reactive power offset
0x0C	VRMS_FACTOR	R&W	2	0	Voltage RMS slope

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Calibration

- **Mandatory for every meter**
- **Corrects inherent errors**
  - Digital Phase Correction (Current channels)
  - Offset Correction (Current, Voltage)
  - Gain Correction (Current, Voltage)
  - Power Offset
- **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
- **Two calibration methods are possible**
  - Measurement of energy for a defined number of periods of the mains (ESP430 Calibration Mode is used for example)
  - Continuous measurement mode: Energy accumulation for a single period of mains or fixed measurements (Ex: 4096) is compared using a calibration equipment

Calibration cont.

Why need calibration

- Metering metrology based on ideal model
- Discretion error of components, sensor and IC
- Parasitic capacitive on PCB will induce extra phase delay on Mains

What kind of calibration needed

- Power
  - Slope
  - Phase delay
  - Offset
- RMS
  - Slope
  - Offset (optional)

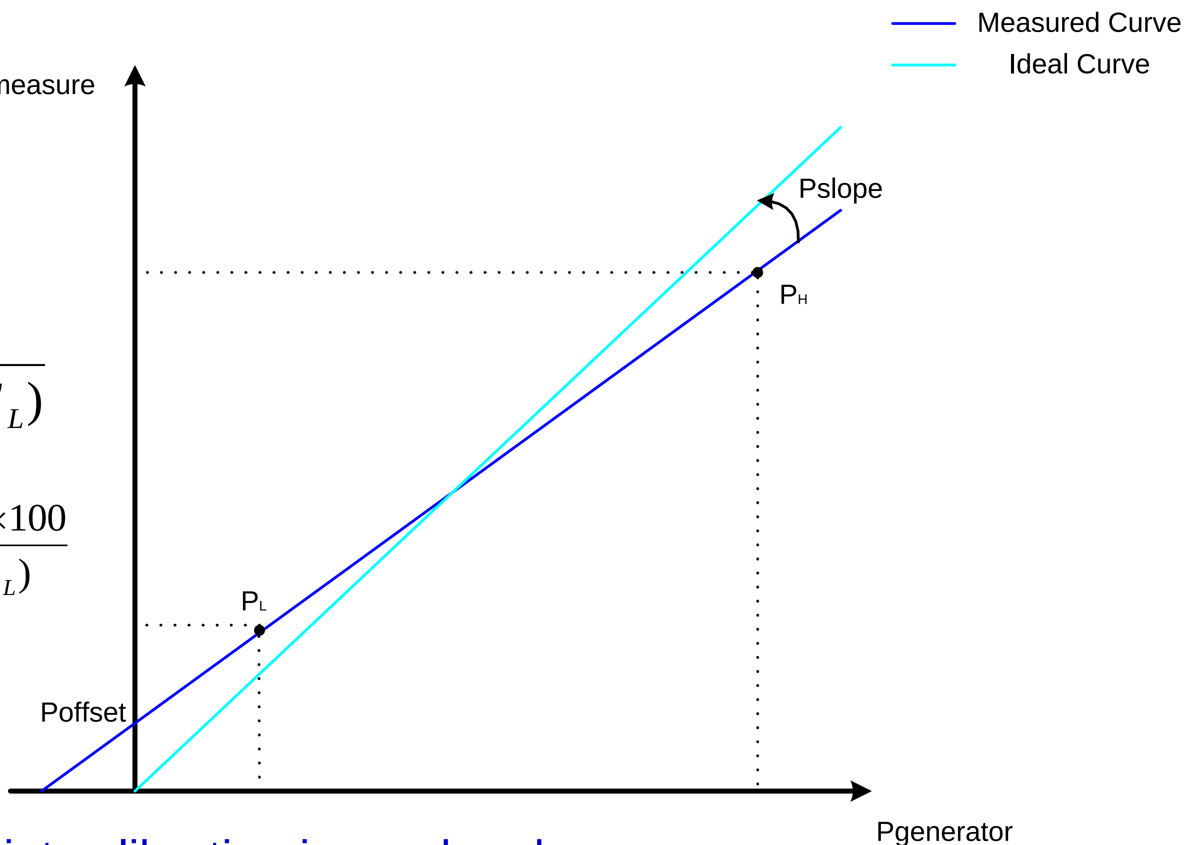
Calibration approaches

- Single point calibration
- Two points calibration

Meter Calibration -- Slope and Offset

$$Pslope_{n+1} = \frac{Pslope_n \times (N_{H2L} - 1)}{N_{H2L} \times (1+E_H) - (1+E_L)}$$

$$Px\_OFFSET_{n+1} = \frac{(E_H - E_L) \times N_{H2L} \times P_{GEN} \times 100}{N_{H2L} \times (1+E_H) - (1+E_L)}$$



For example, if single point calibration is used and
EH =0.5%
original P1_GAINn = 10000,
then the new P1_GAINn+1 =10000/(1+0.5%)=9950

Meter Calibration – Phase Shift

Actual power:

$$P = V \times I \times \cos\theta$$

Measured power:

$$P^{'} = V \times I \times \cos(\theta + \phi)$$

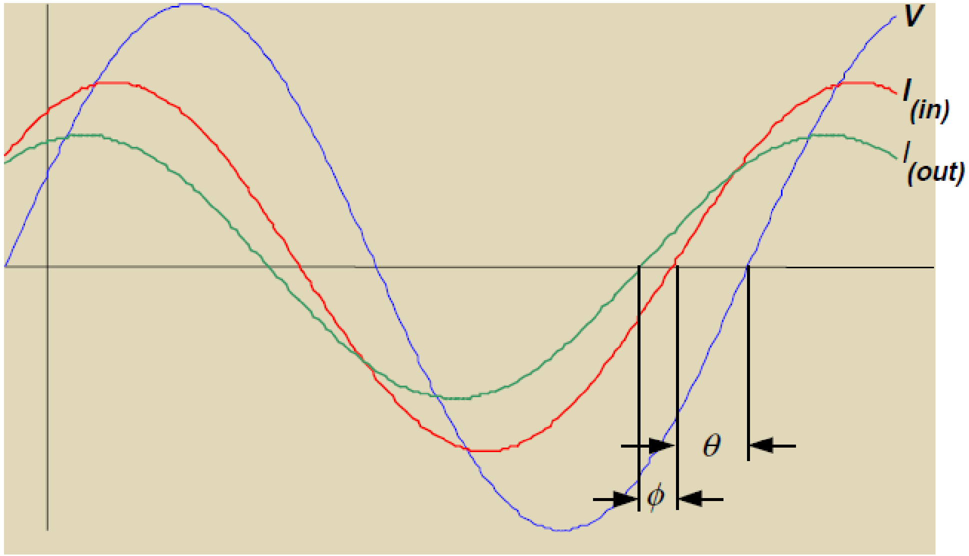
Error caused by phase shift:

$$E = 1 - \frac{P^{'}}{P} = 1 - \frac{\cos(\theta + \phi)}{\cos\theta}$$

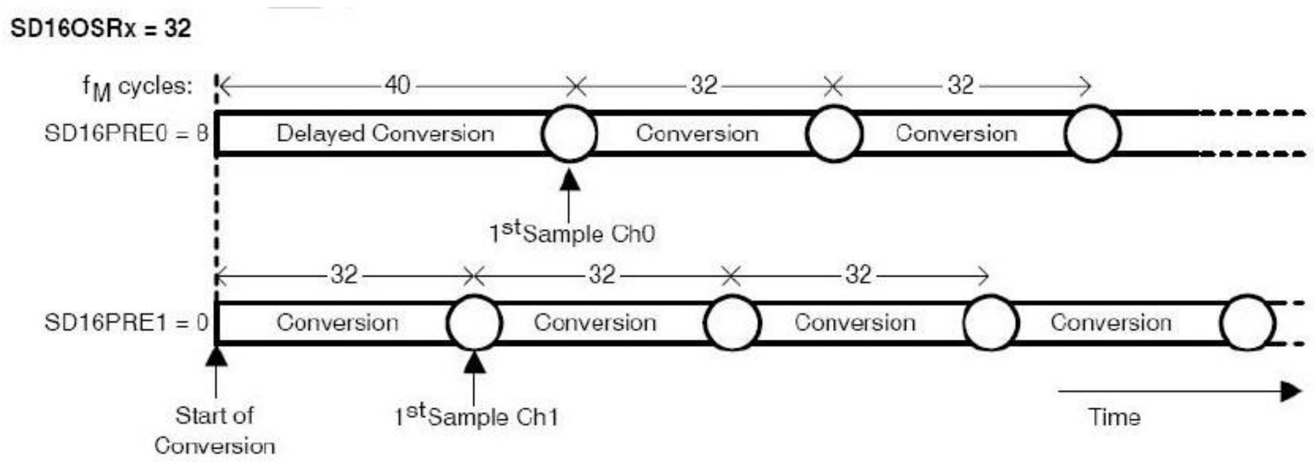
While calibration:

$$\theta = \frac{\pi}{3} \qquad E = 1 - 2\cos(\frac{\pi}{3} + \phi)$$

$$\phi = \arccos\frac{1-E}{2} - \frac{\pi}{3}$$



Meter Calibration – Phase Shift



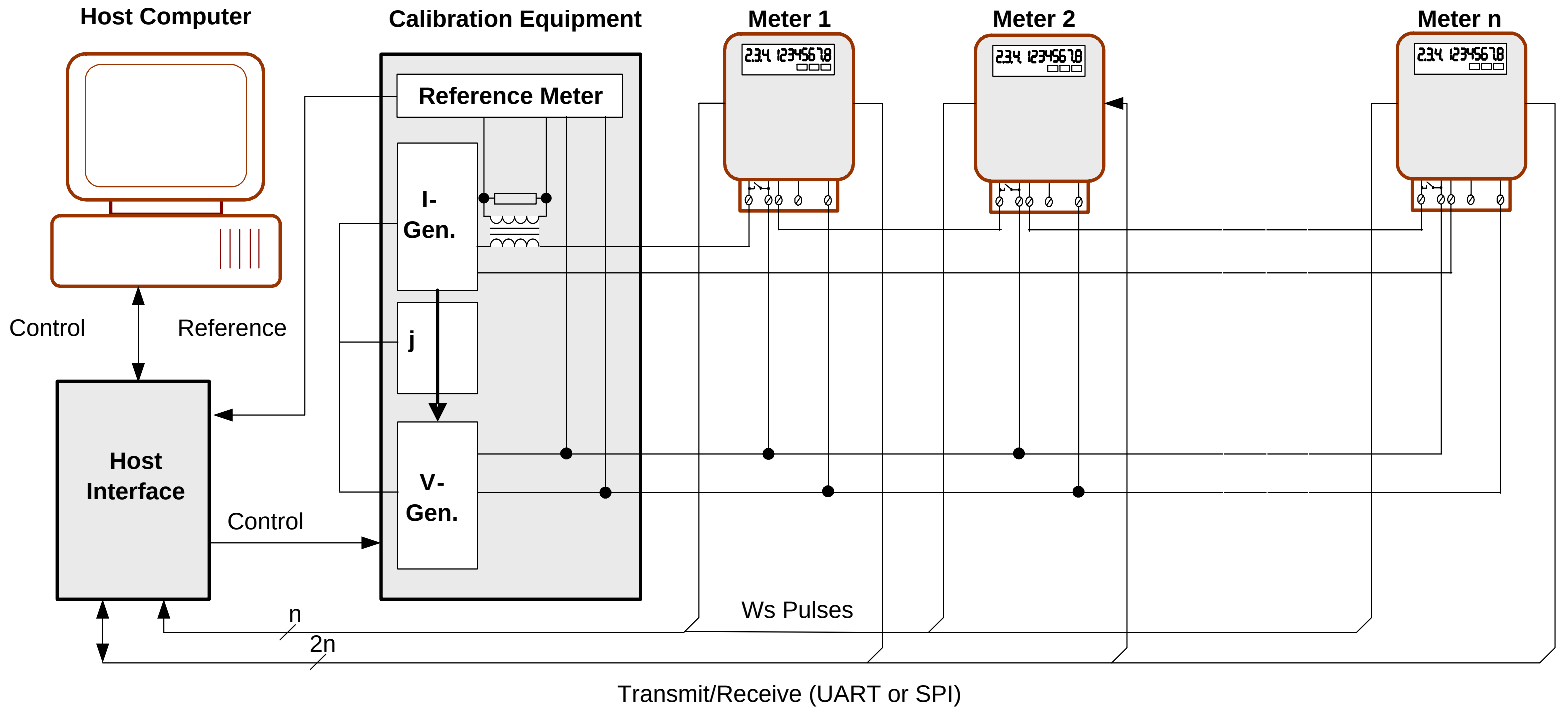
$$\phi = n \times \frac{2\pi \times f_{in}}{OSR \times f_s} = n \times \frac{2\pi \times f_{in}}{f_M}$$

$$Px\_PHASE_{n+1} = Px\_PHASE_n + \frac{256 \times 4096}{2 \times \pi \times 50} \times (\arccos \frac{1-E}{2} - \frac{\pi}{3})$$

For example, if calculated
E =0.3%
original P1_PHASEn = 6,
then the new P1_PHASEn+1 =10+6=16

Automatic Calibration setup for MP

- 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

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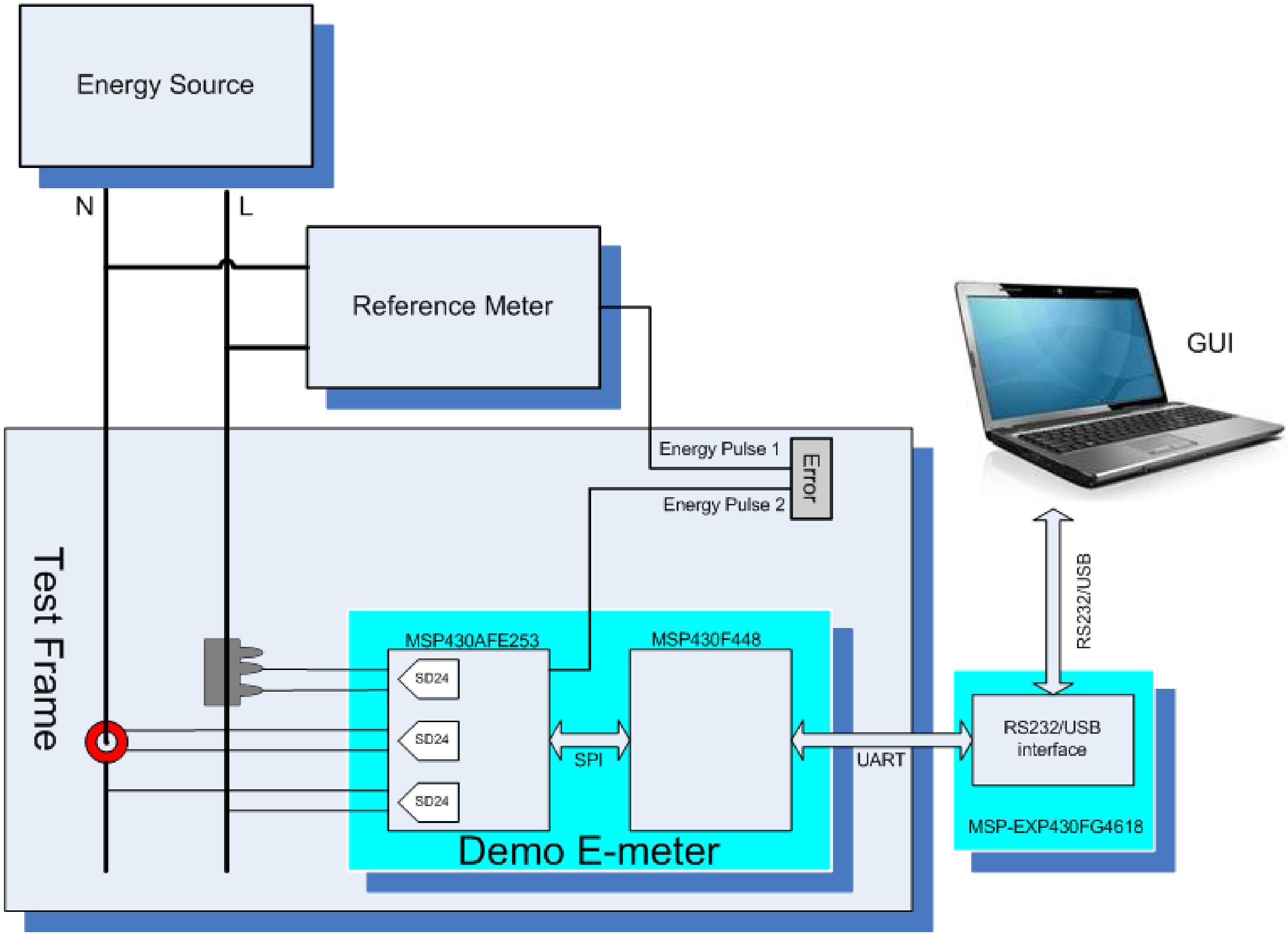
MSP430AFE25x demo set test system block diagram



Software Installation

Software needed:

1. MSP430AFE253 firmware in **Emeter_TI_AFE253_SoftM_SG550_101124_V0.98(4481).zip**
2. MSP430F4481 host firmware in **Emeter_TI_F4481_Host_101124_V0.98(4481).zip**
3. Windows GUI calibrator.exe package in **gui.zip**

All these files can be found in **AFE test packet.zip**.

Software installation:

1. Program MSP430AFE253 firmware to MSP430AFE253.
2. Program MSP430F4481 firmware to MSP430F4481.
3. Empty MSP430F4619 flash with a simple LPM3 code, which release control of comm port in FG4619 board.

```
void main(void)
{
  volatile unsigned int i;

  WDTCTL = WDTPW+WDTHOLD;                 // Stop watchdog timer
  FLL_CTL0 |= DCOPLUS + XCAP18PF;                 // Configure load caps

  LPM3;
}
```

4. Copy calibrator.exe package and upzip it to your laptop.

TEXAS INSTRUMENTS

Hardware Installation

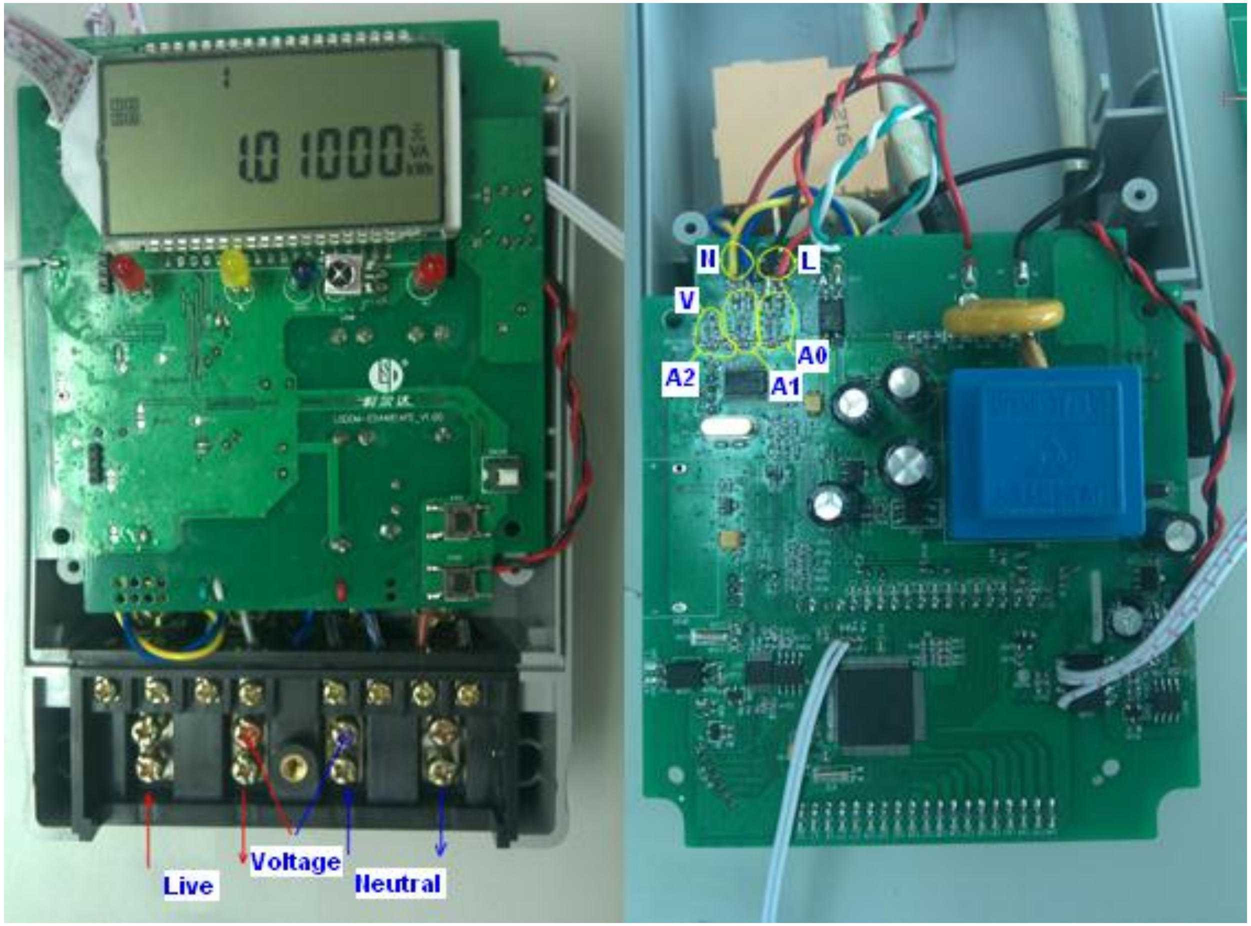
Hardware needed:

1. Single phase demo meter
2. MSP-EXP430FG4618 demo board
3. Laptop
4. E-meter test facility

Hardware installation:

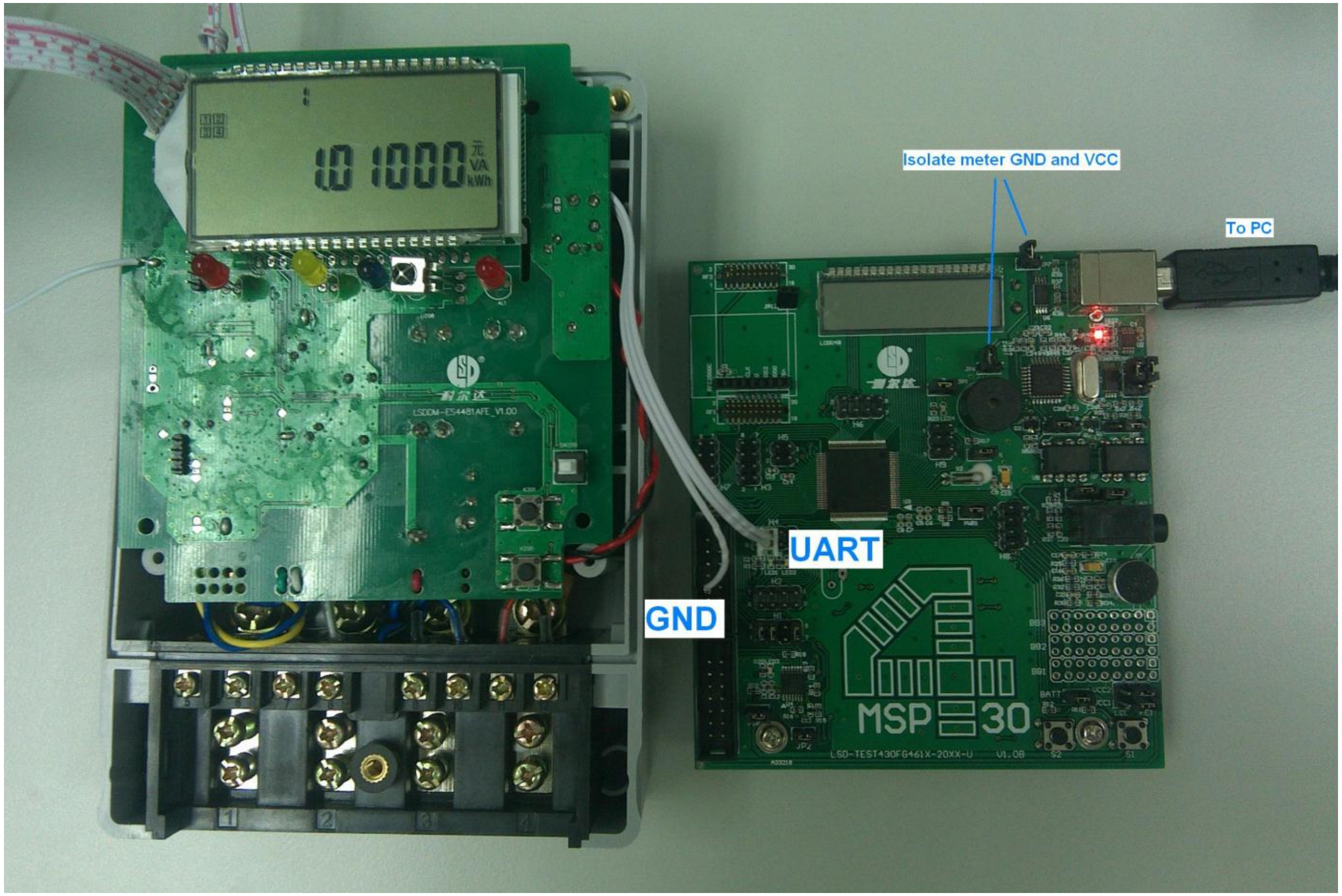
1. Install MSP430AFE253 demo meter to test panel.
2. Connect MSP430F448 Usart1 to MSP430FG4619 board UCA0(H4 p5&p6)
3. Connect MSP430FG4619 board to PC

MSP430AFE25x demo E-meter



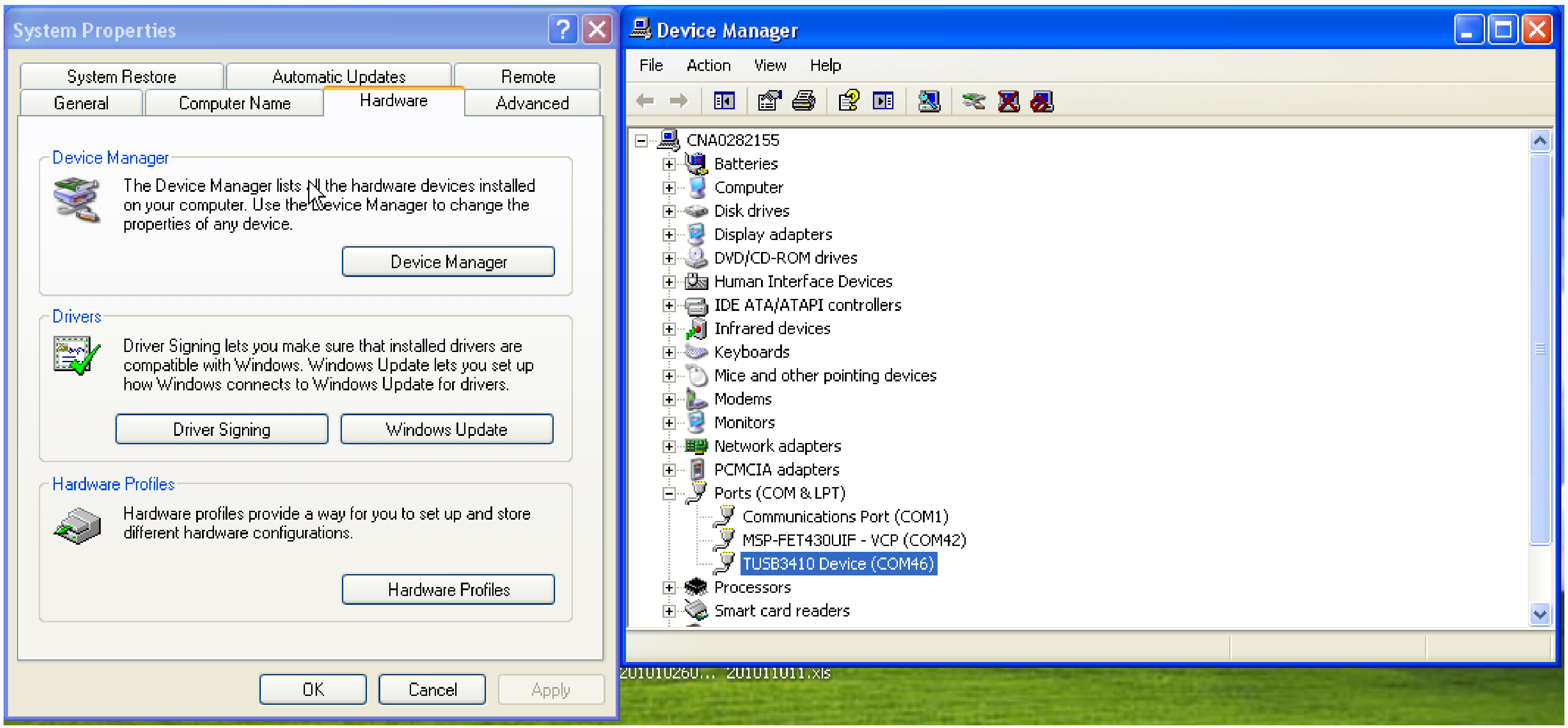
MSP430AFE25x demo E-meter Connection to test panel

MSP430AFE25x demo meter connection to PC



Software – Com port distribution

Check device manager of windows and find the serial port number which MSP-EXP439FG4618 occupies



Software – Com port distribution cont.

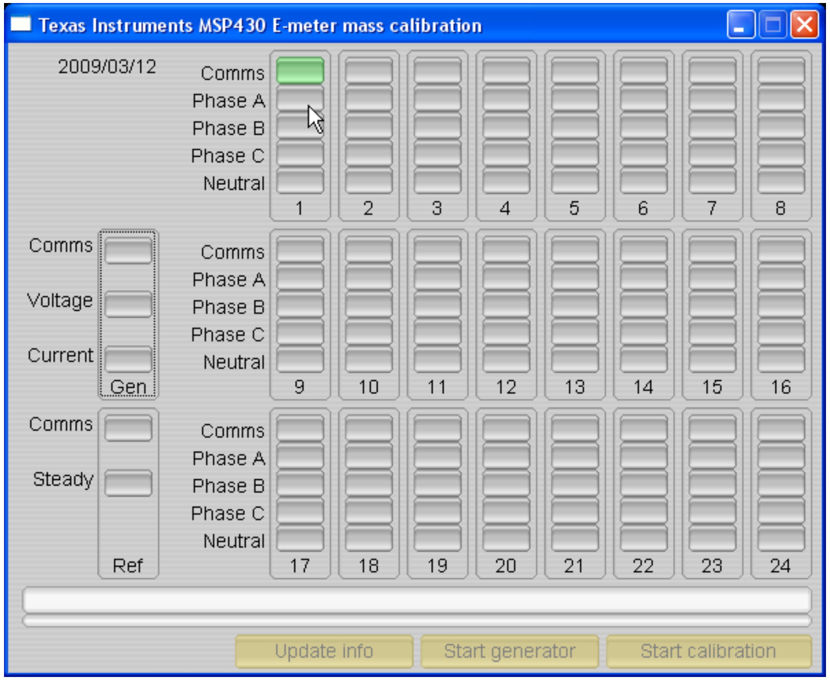
Modify the port number setting in calibration-config.xml (included in GUI packet) and give the correct port number. File calibration-config.xml is used by Calibrator.exe as configuration file.

emeter-background.c | emeter-1ph-bare-bones-afe.h | emeter-foreground.c | emeter-communication.c | msp430afe253.h | calibration-config.xml

```
        <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="\\.\com46" speed="9600"/>
  </meter>
  <reference-meter>
    <port name="com2" speed="9600"/>
    <type id="kaipu-p300lc"/>
    <log requests="on" responses="on"/>
  </reference-meter>
  <generator>
    <port name="com2" speed="9600"/>
    <type id="kaipu-p300lc"/>
    <log requests="on" responses="on"/>
  </generator>
  <idle voltage="230" current="5.0" phase="0" frequency="50.0"/>
  <test-pattern>
```

Software – GUI calibrator.exe

Power up demo meter and Run Calibrator.exe



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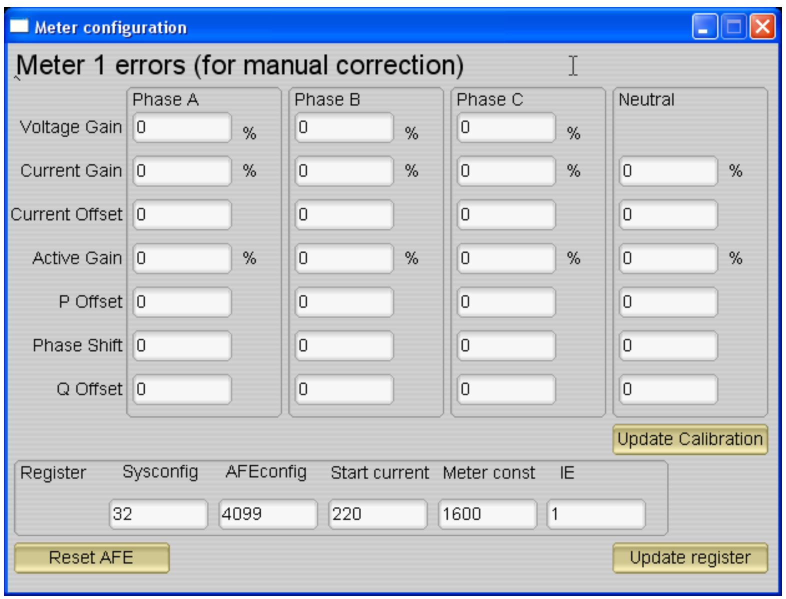
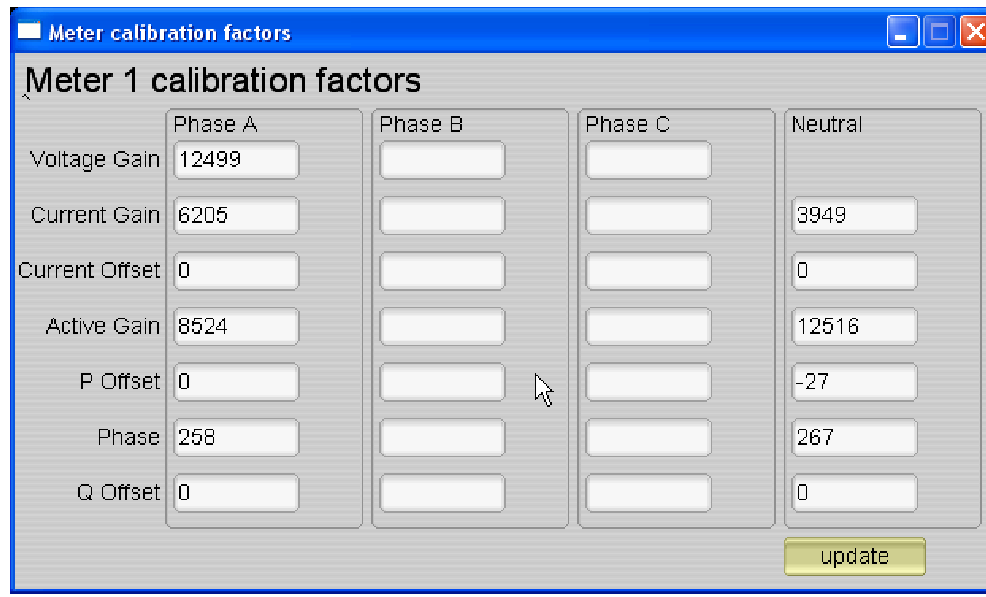
Software – Calibration with Calibrator.exe

Check Calibration factors and calibrate meter in Meter configuration window

- Power (two points)
- Phase shift
- IRMS (single point)
- VRMS (single point)





Software – Manual Calibration

Calibrate meter by change MSP430AFE253 firmware

- Power (two points)
- Phase shift
- IRMS (single point)
- VRMS (single point)

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Performance

			Imax	300	100	50	20	10	5	2	1
Active power	Shunt	1	+0.014	0.023	-0.012	+0.014	+0.011	-0.001	+0.014	-0.059	-0.096
		0.5L	-0.014	-0.006	-0.003	+0.003	-0.003	-0.076	-0.020	+0.002	
		0.5C	+0.035	-0.006	+0.000	+0.006	+0.006	+0.034	-0.021		
	CT	1	+0.035	0.029	+0.003	+0.029	+0.041	+0.036	+0.029	+0.026	+0.008
		0.5L	-0.056	-0.041	+0.007	+0.077	+0.133	+0.143	+0.133	+0.123	
		0.5C	+0.133	0.124	+0.010	-0.032	-0.065	-0.076	-0.079		
Reactive Power	Shunt	1	+0.019	0.035	+0.024	+0.011	+0.017	-0.028	-0.022	-0.072	-0.125
		0.5L	+0.048	0.038	-0.011	+0.003	+0.035	-0.046	-0.054	-0.116	
		0.5C	+0.001	-0.006	+0.046	+0.006	-0.023	+0.037	+0.038		

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- Thank You!