Application Report
SLAA203 - June 2004

Implementing An Electronic Watt-Hour Meter With The MSP430FE42x Devices

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ABSTRACT

This report shows how to implement an electronic watt-hour meter with the MSP430FE42x devices. It contains some guidelines and recommendations for the usage of the MSP430FE42x and shows a reference board including software demos.

Contents

List of Figures

List of Tables

1 Introduction

This report shows a hardware reference design and software routines for implementing an electronic electricity meter with the MSP430FE42x devices. It is intended to be used as a supplement to the ESP430CE1 user's guide that describes the ESP430CE1 module.

The MSP430FE42x with the ESP430CE1 embedded signal processing for single-phase energy metering with integrated analog front-end and temperature sensor has been specifically developed for energy metering applications. The ESP430CE1 does most of the work for the energy measurement automatically without needing resources of the main CPU. This keeps the main CPU free for other tasks like communication. The ESP430CE1 offers wide flexibility for current sensors, so that it is possible to use shunt, current transformers (including dc-tolerant CTs with high phase shift) or Rogowski coils without additional hardware. All parameters can be adjusted via software and the calibration parameters can be stored in the MSP430 flash memory and passed to the ESP430CE1 during the system initialization.

2 Hardware

The reference board schematic and system block diagrams are shown below in Appendix A and discussed in the following sections. The reference board can be used with either current transformers or shunts and can be configured for a variety of configurations. The following block diagrams show the different sensor connections and configurations. A similiar demo board is available for purchase from Softbaugh, part number DE427. Softbaugh can be contacted at www.softbaugh.com.

See the schematic in Appendix A for the V1, I1, and I2 channel connections for the reference board.

2.1 Shunt as Current Sensor

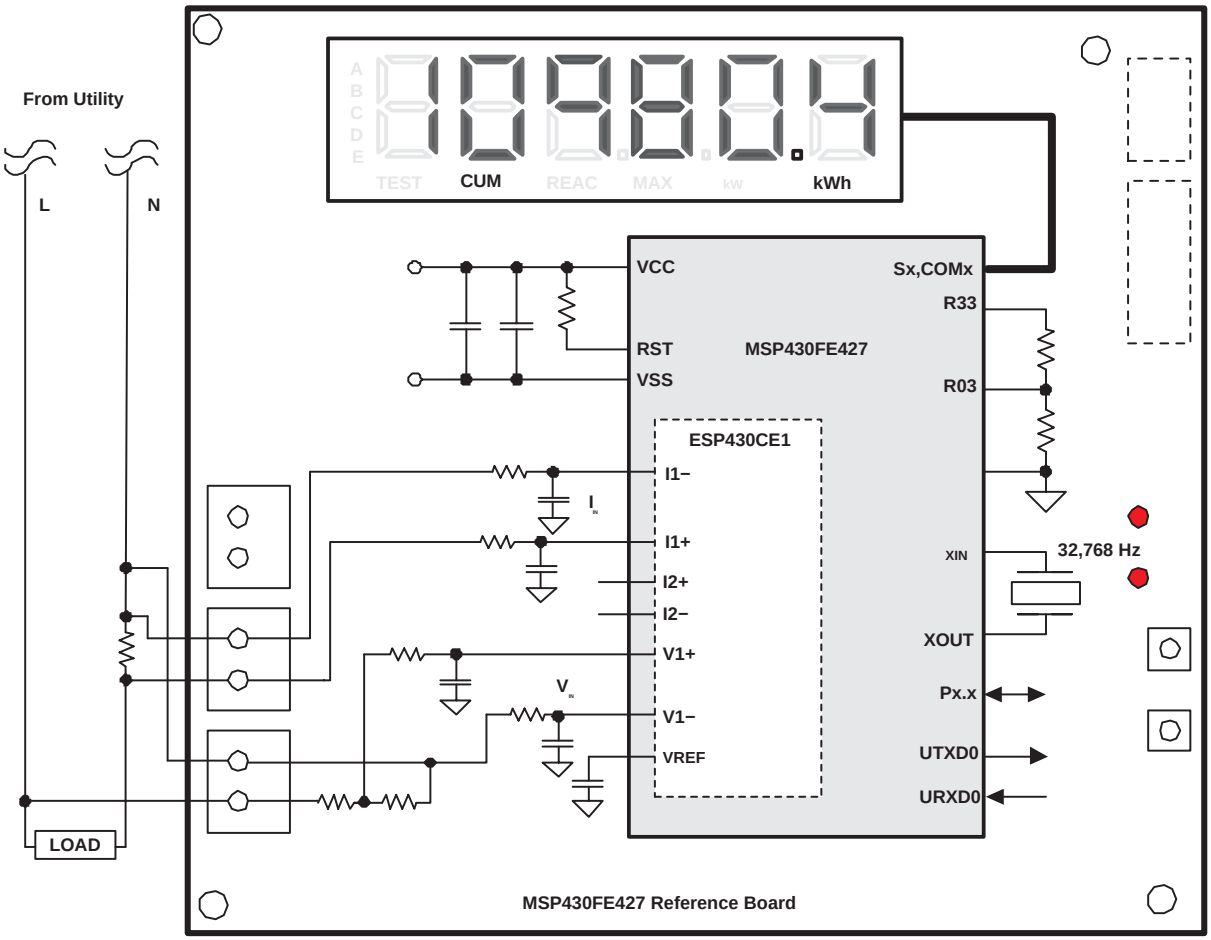


Figure 1. Block Diagram for the Connection of a Shunt for Single Phase, 2-Wire

2.2 CT as Current Sensor

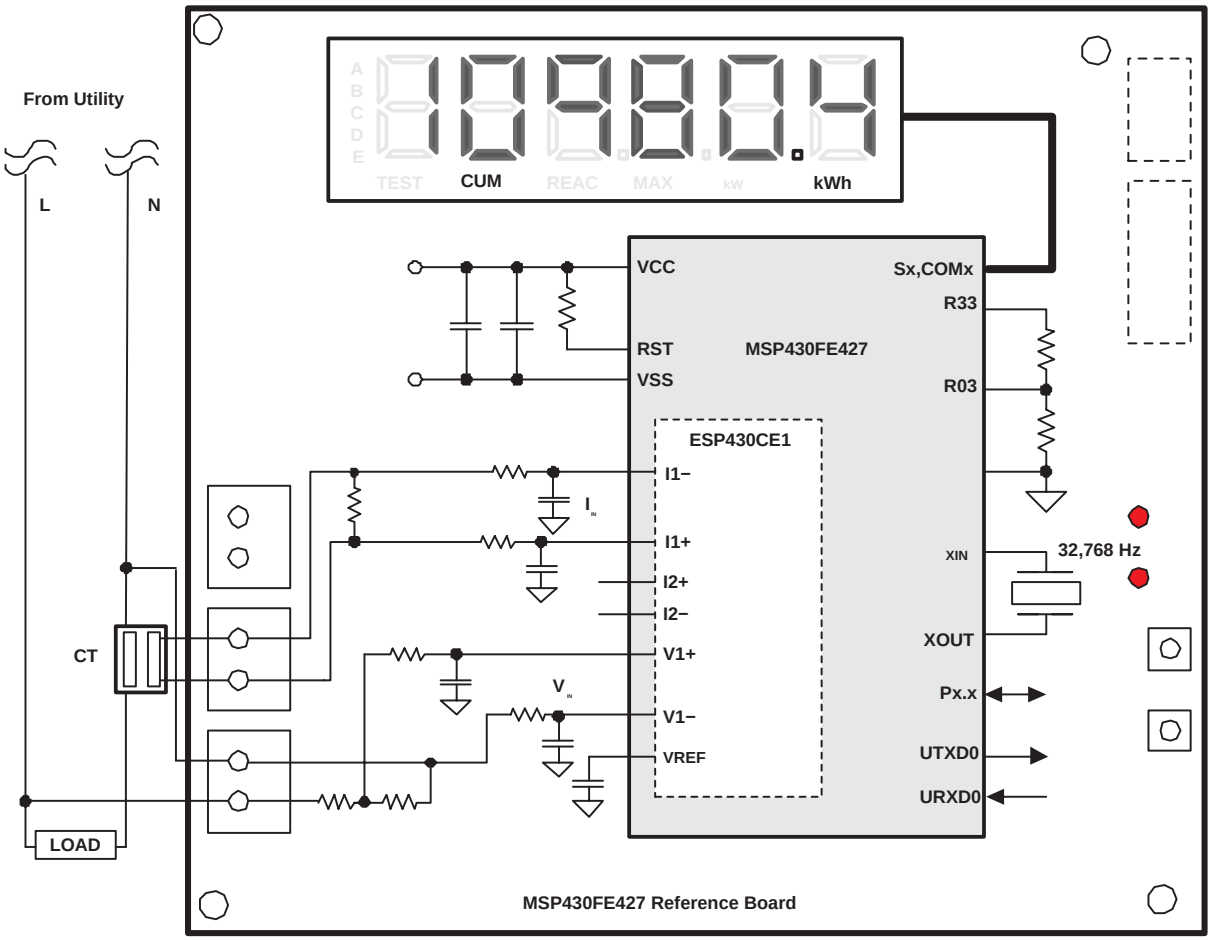


Figure 2. Block Diagram for the Connection of a CT for Single Phase, 2-Wire

2.3 CT and Shunt as Current Sensor for Tamper Detection

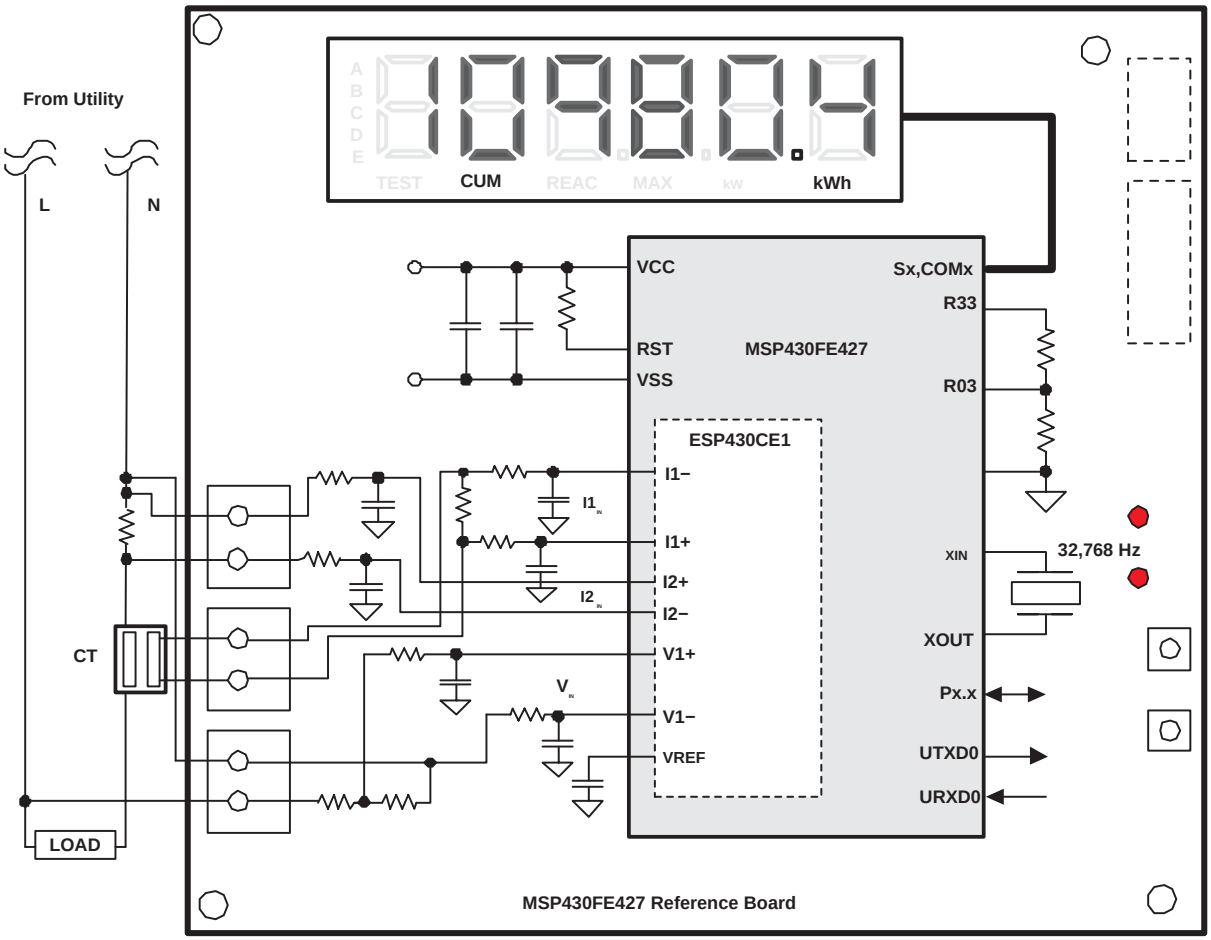


Figure 3. Block Diagram for the Connection of a Shunt and CT With Tamper Detection for Single Phase, 2-Wire

2.4 CT for the US 1-Phase 3-Wire E-Meter Solution

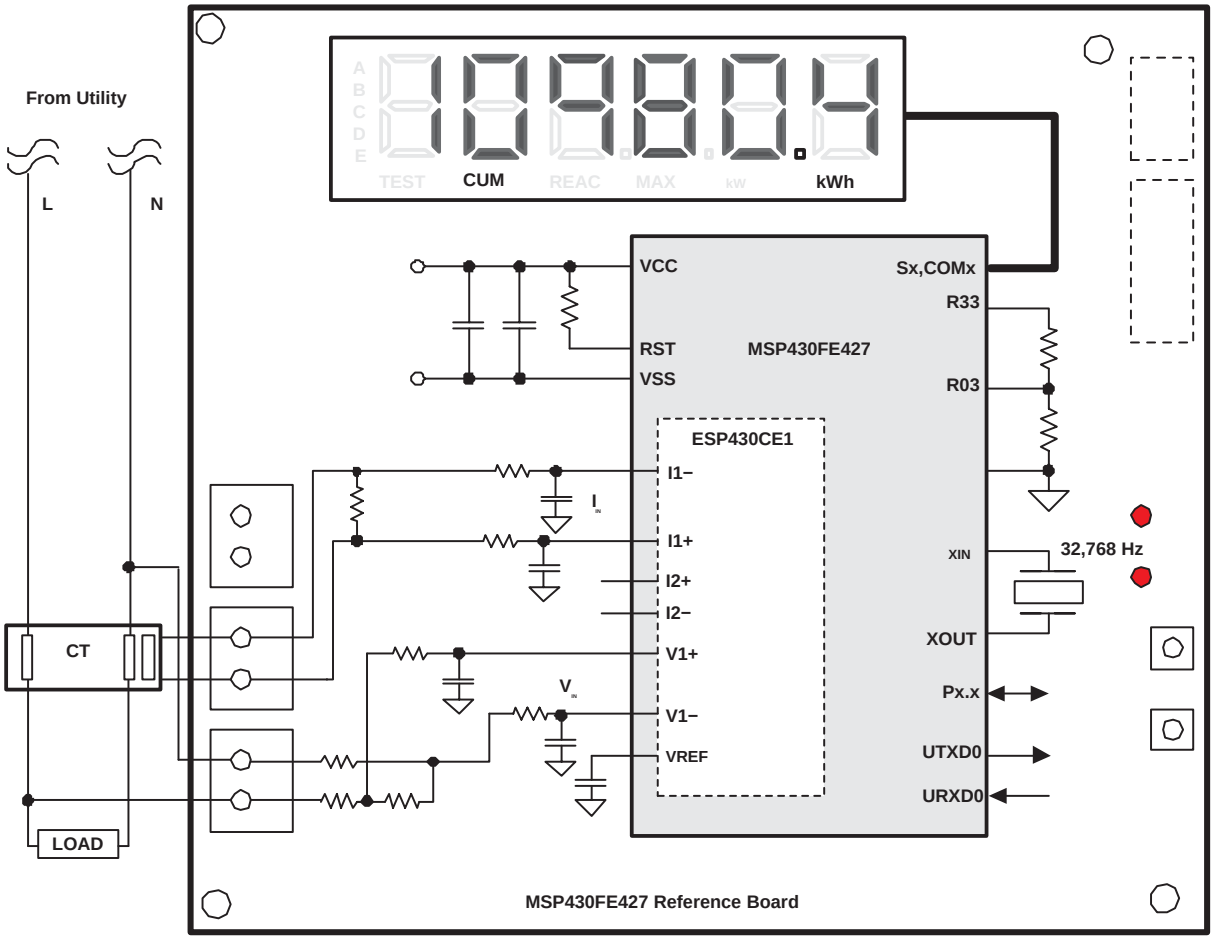


Figure 4. Block Diagram for the ANSI 1-Phase 3-Wire E−Meter Solution

2.5 Voltage Input Connections

The PCB is assembled with a voltage divider for an input voltage of 230 V (RMS). Also the protection circuit is designed for this input voltage.

The capacitor power supply is able to provide a current of ~4 mA. Care should be taken to not exceed this capacity. For example, a low-current LED was used on the reference design to help meet this requirement.

2.6 Current Input Connections

For the current path there is an SMD resistor footprint for the burden resistor of a current transformer (CT) but this resistor is not assembled.

NOTE: The burden resistor for a CT is **not** assembled. If a CT is connected, its burden resistor must be assembled. Otherwise, the MSP430 will be damaged.

2.7 Anti-Aliasing Filter

The recommended anti-aliasing filter is a 1-kΩ resistor in series to the ADC input and a 33-nF capacitor to the analog ground. To avoid external influences, it is recommended to have a filter in the positive and negative input channel of each used ADC input.

2.8 Unused ADC Inputs

Unused ADC inputs should be unconnected.

3 Calculation of the ESP430CE1 Meter Constants

The meter requires constants based on the voltage and current transformers / shunts. The following sections show how to calculate the ESP430CE1 meter constants.

3.1 Voltage Ratio

The voltage ratio, which calculates the real voltage from the ESP430CE1 voltage value, is calculated as follows:

V(inp.max) = VoltageGain x V (Line, Nom.) x sqrt(2) x R2 /(R1 + R2)

kV1 = Voltage (Line, nominal) x 2 x sqrt(2) / (2^{15} x (1- (Vref – V(inp.max) x 2)/Vref))

3.2 Current Ratio for Shunt

The current ratio for a shunt, which calculates the real current from the ESP430CE1 current value, is calculated as follows:

V(I, inp.max) = CurrentGain x Imax x R(Shunt) x sqrt(2)

kI1 = Current (Line, nominal) x 2 x sqrt(2) / (2^{15} x (1- (Vref – V(I, inp.max) x 2)/Vref))

3.3 Current Ratio for Current Transformer

The current ratio for a CT which calculates the real current from the ESP430CE1 current value, is calculated as follows:

V(I, inp.max) = CurrentGain x Imax / CTRatio x R(Burden) x sqrt(2)

kI1 = Current (Line, nominal) x 2 x sqrt(2) / (2^{15} x (1- (Vref – V(I, inp.max) x 2)/Vref))

3.4 Interrupt Level for Energy

The energy consumption interrupt level of the ESP430CE1 is calculated as follows:

InterruptLevel = Pulses/kWh x (1000 / 3600) x fADC / (kV1 x kI1 x 4096)

Pulses/kWh defines how many interrupts per consumed kWh should be generated.

4 Meter Calibration

Calibration of MSP430−based electricity meters with conventional calibration equipment using the same procedures as for Ferraris meters is possible, but not cost effective. The processing power of the MSP430 allows other methods shown below.

A basis calibration could be initiated with the UART c0 command. The execution of this command requires the input values which are defined in the parameter.h file:

- calVoltage
- calCurrent
- calPhi
- calCosPhi
- calFreq

The phase shift calibration between voltage and current should be done with an cos Phi of 0.5 as at this point the error of the phase shift resulting from the sensors does generate much higher errors and therefore a higher accuracy could be reach with less effort.

For the calibration of electricity meters it is necessary to separate the voltage and current path of the meters. This allows the calibration with low energy losses and a defined value for the voltage, current, and phase shift. Figure 5 shows the terminals of an electricity meter with the calibrating terminal switch open for the calibration.

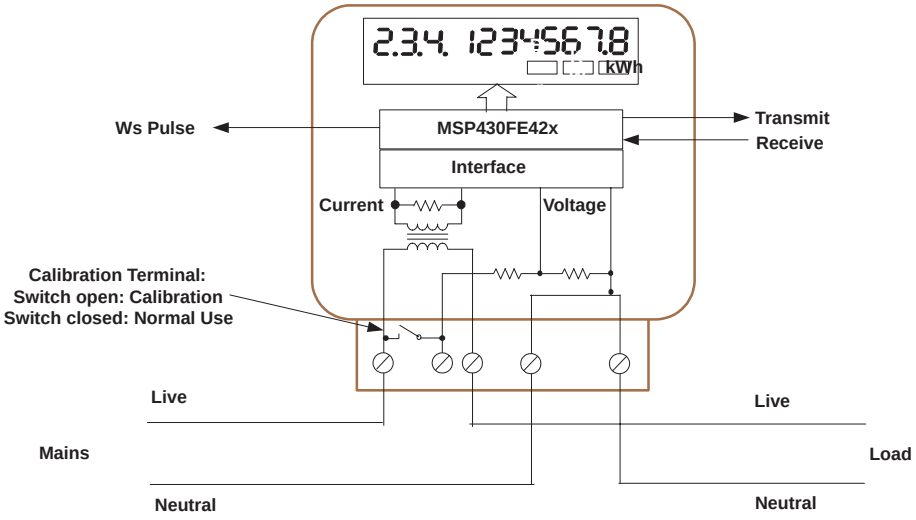


Figure 5. MSP430 Electronic Electricity Meter With External Terminals

4.1 Calibration With Continuous Measurement

The ESP430CE1 operation mode is set to electricity meter mode via the mailbox with the SetMode Command the CPU initializes the ESP430CE1 for normal measurement. The energy values written after each mains period to the value registers ActEnSPer1 (and ActEnSPer2 for two sensor systems) are converted by the CPU into a proportional, constant output frequency having only the information of the mean value of the measured energy. The Timer_A of the CPU may be used for the generation of an energy proportional output frequency.

The calibration sequence is:

- The CPU sets the flags Curr_I1, Curr_I2 in control register 0 according to the measurement mode of the ESP430CE1.
- The parameter registers are initialized for the load point to be measured. This is made via the mailbox with the SET_PARAM Command.
- The ESP430CE1 mode is set to electricity meter mode via the mailbox with the mSet_Mode command
- The first result in addresses ActEnSPer1 (and ActEnSPer2 if current path 2 is enabled) is not used, due to the unknown start point inside the mains period.
- The next results in addresses ActEnSPer1 (and ActEnSPer2 if current path 2 is enabled) are valid and are used for calculations.
- The flag St_ZCld in status register 0 indicates, that with the next available samples (flag St_NEVal is set) new results for the last mains period are available in addresses ActEnSPer1 and ActEnSPer2.
- The CPU resets the flag St_NEVal with the Mailbox command mCLR_EVENT and processes the read results with the equations below.
- The last four steps are repeated if necessary (e.g. for a summing of the results of more than one mains period).

The above steps are repeated for the second calibration point.

Calibration of two current sensors should be done independently. The meter should be calibrated for one of the current sensors, while the current through the other is zero. A second calibration should then be run for the second current sensor, while the current through the first sensor is zero.

4.1.1 Formulas

Calibration is made for a single mains period (or during n_{per} mains periods) with the two currents I_{1HI} and I_{1LO}. The nominal energy results for the two calibration points are:

$$n_{HIcalc} = C_{Z1} \times I_{1HI} \times V_1 \times \cos\varphi_1 \times \frac{n_{per}}{f_{mains}} \times \frac{f_{ADC}}{4096} \quad [\text{steps}^2]$$

$$n_{LOcalc} = C_{Z1} \times I_{1LO} \times V_1 \times \cos\varphi_1 \times \frac{n_{per}}{f_{mains}} \times \frac{f_{ADC}}{4096} \quad [\text{steps}^2]$$

The resulting values for the slope and offset are:

Slope: $$\text{GainCorr1} = \frac{n_{HIcalc} - n_{LOcalc}}{n_{HImeas} - n_{LOmeas}} \times 2^{14}$$

Offset: $$\text{POffset1} = \frac{n_{HImeas} \times n_{LOcalc} - n_{LOmeas} \times n_{HIcalc}}{n_{HImeas} - n_{LOmeas}} \times \frac{f_{mains}}{n_{per}} \times \frac{4096}{f_{ADC}}$$

Where:			
	f_{mains}	Mains frequency	[Hz]
	f_{ADC}	ADC repetition frequency (4096 Hz normally)	[Hz]
	n_{per}	Number of mains periods used for calibration	[1]
	n_{HIcalc}	Calculated energy at the high current calibration point	[steps²]
	n_{HImeas}	Measured energy at the high current calibration point	[steps²]
	n_{LOcalc}	Calculated energy at the low current calibration point	[steps²]
	n_{LOmeas}	Measured energy at the low current calibration point	[steps²]

4.1.2 Calibration Example

The I_1 path of the electricity meter shown in figure 1 is calibrated with the following values:

V_1 = 230 V $_{1HI}$ = 20 A $_{1LO}$ = 1 A cosφ1 = 1 n_{per} = 1

f_{ADC} = 2048 Hz f_{mains} = 50 Hz

The nominal measurement results n_{HIcalc} and n_{LOcalc} are:

$$n_{HIcalc} = C_{Z1} \times I_{1HI} \times V_1 \times \cos\varphi_1 \times \frac{n_{per}}{f_{mains}} \times \frac{f_{ADC}}{4096} = 29{,}322.80806 \times 20 \times 230 \times 1 \times \frac{1}{50} \times \frac{2048}{4096}$$

$n_{HIcalc} = 1{,}348{,}849.171 = 14{,}94\text{F}1\text{h}$ [Steps²]

$$n_{LOcalc} = C_{Z1} \times I_{1LO} \times V_1 \times \cos\varphi_1 \times \frac{n_{per}}{f_{mains}} \times \frac{f_{ADC}}{4096} = 29{,}322.80806 \times 1 \times 230 \times 1 \times \frac{1}{50} \times \frac{2048}{4096}$$

$n_{LOcalc} = 67{,}442.458 = 1{,}0772\text{h}$

The measurement results for the two calibration points I_{1LO} and I_{1HI} are:

$n_{1Himeas}$ = 14,6040h −1 % error compared to $n_{1Hicalc}$ = 14,94F1h)

$n_{1Lomeas}$ = 1,0CB7h (+2 % error compared to $n_{1Localc}$ = 1,0772h)

With the above four results the rounded slope in address GainCorr1 becomes:

$$\text{GainCorr1} = \frac{n_{HIcalc} - n_{LOcalc}}{n_{HImeas} - n_{LOmeas}} \times 2^{14} = \frac{14{,}94\text{F}1\text{h} - 1{,}0772\text{h}}{14{,}6040\text{h} - 1{,}0\text{CB}7\text{h}} \times 2^{14} = 1.01171 \times 2^{14} = 40\text{C}0\text{h}$$

The offset in addresses POffset1 and POffset1+2 becomes:

$$\text{POffset1} = \frac{n_{HImeas} \times n_{LOcalc} - n_{LOmeas} \times n_{HIcalc}}{n_{HImeas} - n_{LOmeas}} \times \frac{f_{mains}}{n_{per}} \times \frac{4096}{f_{ADC}}$$

$$\text{POffset1} = \frac{14{,}6040\text{h} \times 1{,}0772\text{h} - 1{,}0\text{CB7h} \times 14{,}94\text{F1h}}{14{,}6040\text{h} - 1{,}0\text{CB7h}} \times \frac{50 \times 4096}{1 \times 2048} = -215{,}489 = \text{FFFC, B63Fh}$$

NOTE: the calculated value for (POffset1) is the offset for each product $N_{V1} \times N_{I1}$, thus the relatively high value.

If the measured calibration points are corrected with the calculated slope and offset:

$$n_{corr} = \left(n_{meas} \times (\text{GainCorr1})\right) \times 2^{-14} + (\text{POffset1}) \times \frac{n_{per}}{f_{mains}} \times \frac{f_{ADC}}{4096}$$

$$n_{HIcorr} = 14{,}6040\text{h} \times 40\text{C0h} \times 2^{-14} + \text{FFFC, B63Fh} \times \frac{1 \times 2048}{50 \times 4096} = 1{,}348{,}890 = 14{,}951\text{Ah}$$

$$n_{LOcorr} = 1{,}0\text{CB7h} \times 40\text{C0h} \times 2^{-14} + \text{FFFC, B63Fh} \times \frac{1 \times 2048}{50 \times 4096} = 67{,}441 = 1{,}0771\text{h}$$

The resulting error for both corrections is +3.1E−5 which is 31 ppm.

4.2 Calibration With a Host Computer

Figure 6 shows a possible calibration environment for electronic electricity meters. The host computer is connected to the meters via the USART0 communication port running in SPI or UART mode. All necessary calibration calculations are made by the host; the MSP430 in each meter only stores the received correction values in its information memory or an external EEPROM.

The host controls the calibration equipment containing a voltage generator, a current generator and a phase shifter via the host interface. The host reads out the accumulated results of the multiplying of voltage and current ADC steps (or counts the Ws pulses of each electricity meter) and compares the equivalent energy with the energy equivalent to the reference pulses coming from a reference meter, which is part of the calibration equipment. The host calculates the meter error out of the energy amounts for (e.g., 100% Inom) or two load points (e.g., 100% Inom and Imax). With these errors the slope and offset of the load characteristic can be calculated individually and sent to the MSP430s in each meter.

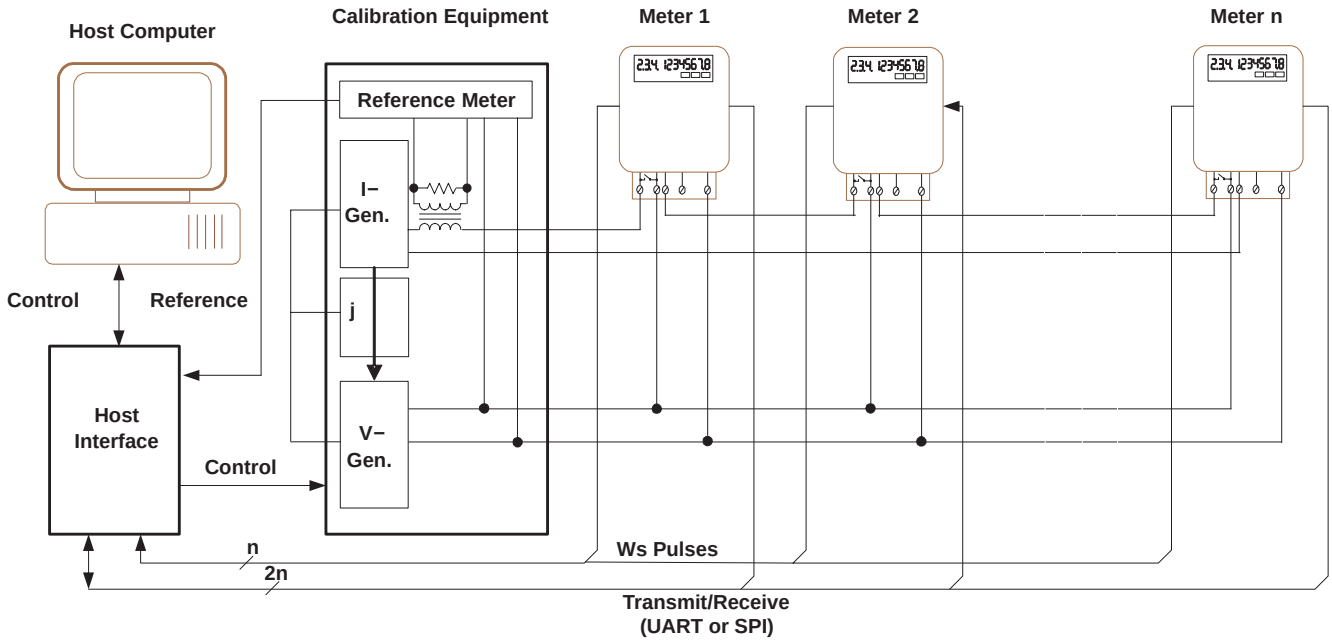


Figure 6. Electricity Meter Calibration With a Host Computer

The formulas for the calculation of the calibration values are shown in the ESP430CE1 module user's guide.

4.3 Self Calibration

Another calibration method uses the processing capability of each MSP430 in each meter. The main advantage of this calibration method is the simplicity: no wiring for the information transfer is necessary (see Figure 7). The error correction equations – used by the electricity meter under test − are the same ones as shown in the *Calibration With Continuous Measurement* section.

- The meters to be calibrated are put into the calibration mode via a hidden switch, the UART, a key or an input pulse, etc.
- The host switches on the calibration equipment and transmits a defined amount of energy − measured with the reference meter − to the electricity meters being calibrated.
- The electricity meters measure the transmitted energy and calculate the energy value WEM1 for the 100% Inom current.
- After this transmission of energy the calibration equipment is switched off (I = 0, U = 0). This allows the electricity meters to calculate or measure the ADC offsets if necessary.
- The host switches on the calibration equipment again and transmits a defined amount of energy (e.g. 5% Inom, 100% Vnom, cosφ = 1) to the electricity meters. After this transmission of energy the calibration equipment is switched off (I = 0, V = 0).
- The electricity meters measure the transmitted energy and calculate the energy value WEM0 for the 5% Inom current.
- With the two faulty energy values WEM1 and WEM0 found for the 100% and 5% Inom loading conditions the electricity meters calculate their individual offsets and slopes.

- A simple visual final test is possible after the calibration:
  - The electricity meters reset their display to zero
  - The calibration equipment transmits a precisely defined energy profile (different percentages of *Inom*, *Vnom* and two values of cosφ) to the electricity meters.
  - A visual check is made if the meters display the known amount of energy.
  - The MSP430 indicates in the LCD if the calculated slopes and offsets are within worst case limits.

EXAMPLE: the energy profiloe for the final check consists of

- 10,000 *Ws* (100% *Inom*, 100% *Vnom*, cosφ = 1)
- 5,000 *Ws* (100% *Inom*, 100% *Vnom*, cosφ = 0.5)

The calibrated electricity meters must display the number 15,900 *Ws* ± accuracy, otherwise the calibration failed.

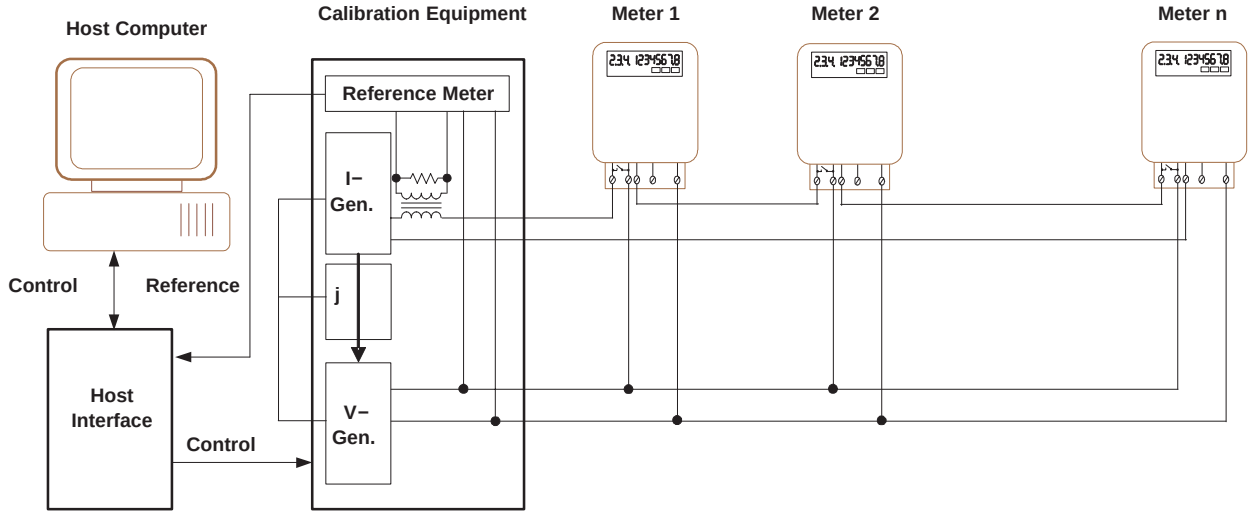


Figure 7. Self-Calibration for Electricity Meters

5 Capacitor Power Supply

Figure 8 shows a capacitor power supply for a single output voltage *Vcc* = +3 V. If the output current is not sufficient, an NPN output buffer may be used.

The design equations for the power supplies below are given in SLAA024, section *3.8.3.2 Capacitor Power Supplies*. This chapter also describes other kinds of power supplies with their design equations.

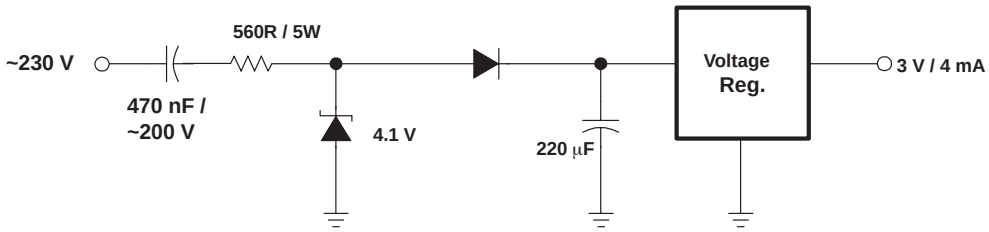


Figure 8. Capacitor Supply

5.1 Power Line Voltage On/Off Detection

Because the ESP430CE1 voltage drop detection is combined with the line cycle counter, the voltage drop detection of the ESP430CE1 does not function if the voltage drops to 0 V. To detect this condition, the VRMS voltage can be observed in dedicated time intervals or an external circuit may be used to detect when the power line is off. If an external circuit is used, the ESP430CE1 module can be switched off to conserve power.

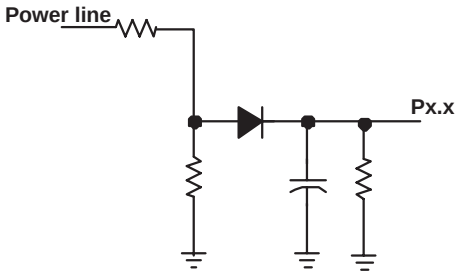


Figure 9. Power Detection

6 Layout Recommendations

6.1 Grounding

Good circuit-board layout is important for high resolution ADC systems. Following are some basic layout guidelines.

1. Use of a separate analog and digital ground plane wherever possible:
2. Thick traces from the battery to the DV_{SS}, AV_{SS}, DV_{CC}, and AV_{CC} terminals.
3. The decoupling capacitor at the AV_{SS} terminal is a star point for all analog ground connections. The decoupling capacitor at the DV_{SS} terminal is a star point for all digital ground connections.
4. The connections of the capacitor Cb are the star point of the complete system. This is due to the low impedance of this capacitor.
5. The AV_{SS} and DV_{SS} terminals must be connected together externally.
6. The AV_{CC} and DV_{CC} terminals must be connected together externally.
7. Battery and storage capacitor Cb should be close together. Two capacitors are connected across the digital (Cd) and the analog (Ca) supply terminals.
8. The coil L could be used to keep disturbances introduced from the digital supply away from the analog supply voltage. It is also possible to use a resistor for this. The coil brings additional advantage in filtering high frequency signals.
9. If a metal case is used around the printed circuit board containing the MSP430 then it should be connected to the ground potential (0 V) of the board.

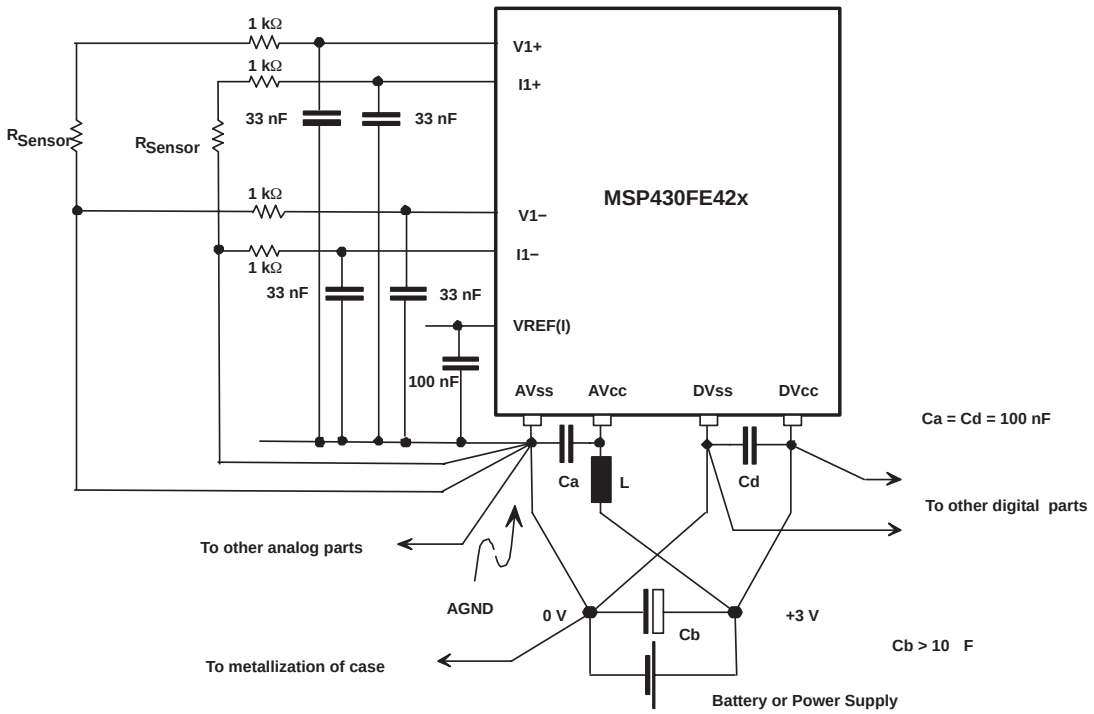


Figure 10. Analog-to-Digital Converter Grounding

6.2 EMI Sensitivity

Figure 11 shows a simplified way a routing that is not optimal: the gray areas receive EMI from external sources. For a minimum influence coming from external sources, these areas must be as small as possible.

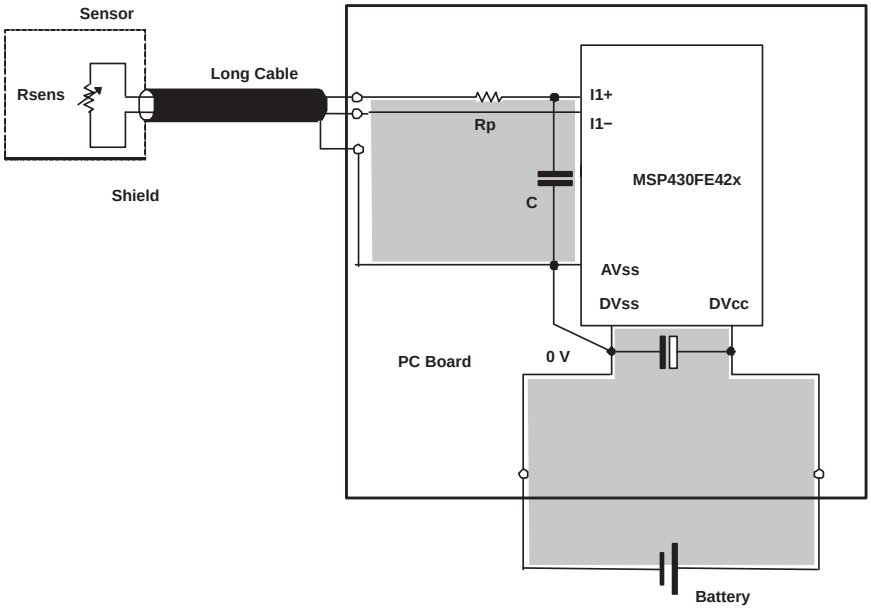


Figure 11. Routing that is Sensitive to External EMIT

Figure 12 shows an optimized routing. The areas that receive noise have a minimum loop area.

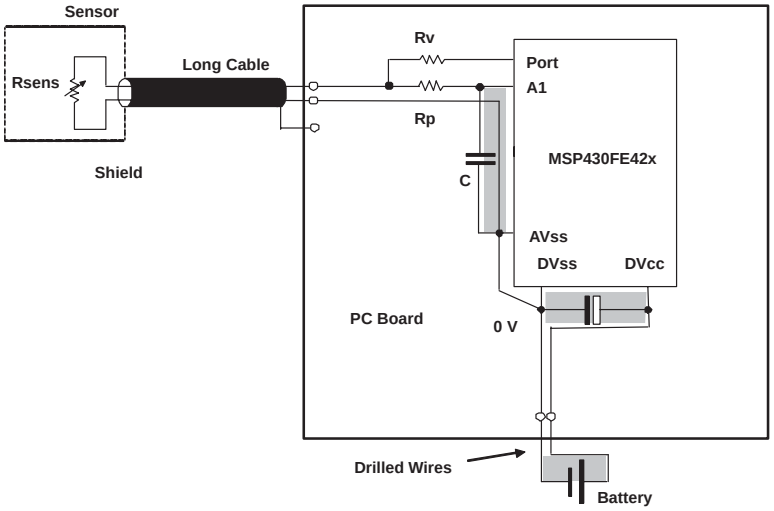


Figure 12. Routing for Minimum EMI Sensitivity

7 Demo Software

7.1 Analog Front-End Initialization

While the ESP430CE1 is off, the MSP430 CPU has access to the SD16 module. During this time, the MSP430 CPU should do the initialization of the analog front-end. This consists of setting the gain, oversampling ration, and clock source for the SD16 as shown in the code below:

```
//*********************************************************************
/**
 * Analog front-end initialization routine.
 *
 * Configures the sigma-delta ADC module as analog front-end for
 * a tamper-resistant meter using a current transformer and a
 * shunt as current sensors (see configuration of channel 0 and 1).
 */
void init_analog_front_end(void)
{
/**
 * First it makes sure that the Embedded Signal Processing is
 * disabled, otherwise it wouldn't be possible to modify the
 * SD16 registers.
 */
 ESPCTL &= ~ESPEN;
```

```
/**
 * Then the general configurations of the analog front-end are done
 * that apply to all channels: clock selection (SMCLK) and divider
 * settings (depending on SMCLK frequency) and reference voltage
 * selections.
 */

 SD16CTL= SD16SSEL_1 // Clock selection: SMCLK
// SD16CTL = 0x800 + SD16SSEL_1 // Clock selection: SMCLK + (Amp: )
#if (MCLK_FREQ == 2)
     | SD16DIV_1  // divide by 2 => ADC clock: 1.094MHz
#endif
#if (MCLK_FREQ == 4)
     | SD16DIV_2  // divide by 4 => ADC clock: 1.094MHz
#endif
#if (MCLK_FREQ == 8)
     | SD16DIV_3  // divide by 8 => ADC clock: 1.094MHz
#endif
     | SD16REFON; // Use internal reference
 SD16CCTL0 = SD16INCH_0; // I1
 SD16CCTL1 = SD16INCH_0; // I2
 SD16CCTL2 = SD16INCH_0; // V
 SD16CONF0 |= 0x70;  // 2.Silicon
 SD16CONF1 |= 0x68;  // Delay of ADC clock = 40ns 2.Silicon

// -------------------------------------------------------------------
/**
 * - Selection of ADC gain:
 *  - VIN,MAX(GAIN = 1) = 0.5V > VCT(Peak)
 *  - VIN,MAX(GAIN = 2) = 0.25V < VCT(Peak)
 *  - VIN,MAX(GAIN = 16) = 0.031V > VShunt(Peak)
 *  - VIN,MAX(GAIN = 32) = 0.015V < VShunt(Peak)
 */
 // -----------------------------------------------------------
 // Configure analog front-end channel 2 - Current 1
 SD16INCTL0= I1_Gain; // Set gain for channel 0 (I1)
 SD16CCTL0 |= SD16OSR_256; // Set oversampling ratio to 256 (default)
 // -----------------------------------------------------------
 // Configure analog front-end channel 1 - Current 2
 SD16INCTL1= I2_Gain; // Set gain for channel 1 (I2)
```

```
 SD16CCTL1 |= SD16OSR_256; // Set oversampling ratio to 256 (default)
 // -----------------------------------------------------------
 // Configure analog front-end channel 2 - Voltage
 SD16INCTL2= V_Gain; // Set gain for channel 2 (V)
 SD16CCTL2 |= SD16OSR_256; // Set oversampling ratio to 256 (default)
/**
 * \note
 * Please note, that the oversampling ratio should be identical
 * for all channels. Default is 256.
 */
} // End of init_analog_front_end()
```

7.2 E-Meter Initialization

The ESP430CE1 must be configured before use. A configuration example is shown in the following subroutine:

```
//=====================================================================
/**
 * Initializes ESP430CE1.
 *
 */
void init_esp_parameter(unsigned char flashvars)
{
 volatile unsigned int timeout;
 // /\ Prevent variable from being "optimized".
 // copy predevined init values to RAM
 if (flashvars) s_parameters = s_parameters_flash;

/**
 * Makes sure that the Embedded Signal Processing
 * is enabled,
 */
 ESPCTL |= ESPEN;
 MBCTL = 0;

/**
 * that it is not in measurement or calibration mode,
 */
 if ((RET0 & 0x8000) != 0)
 {
  // Set Embedded Signal Processing into "Idle" mode
  MBOUT1= modeIDLE; // ESP_IDLE;
  MBOUT0= mSET_MODE;
  timeout= 0xffff;
  while (((RET0 & 0x8000) != 0) && (timeout-- > 0)) ;
 }
/**
 * and that it is ready to receive messages by requesting the
 * firmware version.
 */
 MBOUT0= mSWVERSION;
 timeout= 0xffff;
 do
```

```
 {
  while (((MBCTL & IN0IFG) == 0) && (timeout-- > 0)) ;
  if (timeout == 0) { display_error(); return; }
 } while (MBIN0 != mSWRDY);
 firmware_version= MBIN1; // Save firmware version.

/**
 * Then the parameters are initialized.
 *
 * Control 0: make settings for :
 * - Use current channel I2 - tamper-detection
 * - Count absolute active energy
 *  (negative energy is considered as tampering)
 * - Switch DC removal alorithm on for I1
 * - Switch DC removal alorithm on for I2
 */
 set_parameter(mSET_CTRL0, defSET_CTRL0);
/**
 * \Set Number of Measurement:
 *  e.g. 4096 * 50Hz. => int after 1sec
 */
 set_parameter(mSET_INTRPTLEVL_LO, s_parameters.pSET_INTRPTLEVL.w[0]);
 set_parameter(mSET_INTRPTLEVL_HI, s_parameters.pSET_INTRPTLEVL.w[1]);
/**
 * Nominal Mains Frequency:
 *  e.g. 50Hz.
 */
 set_parameter(mSET_NOMFREQ, defSET_NOMFREQ);

/**
 * Phase Error Correction:
 * Sets phase error for current 1/2 at nominal mains frequency for
 * current transformer according to its specification
 * The phase error of the shunt is zero.
 */
 set_parameter(mSET_PHASECORR1, (int)s_parameters.pSET_PHASECORR1);
 set_parameter(mSET_PHASECORR2, (int)s_parameters.pSET_PHASECORR2);

/** Adjustment parameters for the two currents:
 * Current Transformer:
```

```
 *
 * There are two possibilties to adjust the two current
 * values:
 */
 set_parameter(mSET_ADAPTI1, defSET_ADAPTI1); // = 1 * POW_2_14 = 16384
 set_parameter(mSET_ADAPTI2, defSET_ADAPTI2); // = 1 * POW_2_14 = 16384
/** Adjustment parameters Gain settings: */
 set_parameter(mSET_GAINCORR1, s_parameters.pSET_GAINCORR1);
 set_parameter(mSET_GAINCORR2, s_parameters.pSET_GAINCORR2);
/** Adjustment parameters Offset settings: */
 set_parameter(mSET_V1OFFSET, s_parameters.pSET_V1OFFSET);
 set_parameter(mSET_I1OFFSET, s_parameters.pSET_I1OFFSET);
 set_parameter(mSET_I2OFFSET, s_parameters.pSET_I2OFFSET);
// set_parameter(mSET_POFFSET1_LO, s_parameters.pSET_POFFSET1_LO);
// set_parameter(mSET_POFFSET1_HI, s_parameters.pSET_POFFSET1_LO);
/** Adjustment parameters start up currents: */
#if withStartCurrent == 1
 set_parameter(mSET_STARTCURR_INT, s_parameters.pSET_STARTCURR_INT);
 set_parameter(mSET_STARTCURR_FRAC, s_parameters.pSET_STARTCURR_FRAC);
#else
 set_parameter(mSET_STARTCURR_INT, 0);
 set_parameter(mSET_STARTCURR_FRAC, 0);
#endif
/** Adjustment parameters for DC Removal Periods: */
 set_parameter(mSET_DCREMPER, defSET_DCREMPER);

} // End of init_esp_parameter()} // End of init_esp_parameter()
```

7.3 Demo 1 Software

Demo 1 is as a simple demo that initializes the ESP430CE1 for energy measurement and outputs the data on the display. The LED is also pulsed. This demo can be use with IAR Kickstart development tool.

The files and contents of the Demo 1 software are:

File	Contents and Function
Main.c	Control of system Initialization and call of the functions for the display update once requested in the interrupt service routines: − Init FLL and System Clock − Init Basic Timer and Real time Clock − Init LCD − Init analog front end − Init ESP430CE1 Parameters − Start Measurement
FET4xx_RTCwLCD.s43	Basic routines for LCD and Real Time Clock with Basic Timer interrupt service routine.
Display.c	High level routines for LCD
FLL.c	Routines to setup FLL and clock system
PortFunc.c	Interrupt service routine for Port1
TimerA.c	Initialization routine and interrupt service routine for Timer_A. The Timer_A is used to generate a pulse without flicker.
EMeter.c	EMeter.c contains the initialization routine for the analog front end, the ESP430CE1, and the interrupt service routine for the ESP430CE1.
FE427_Measure_v3.ewp FE427_Measure_v3.eww	Project Files for IAR Workbench Version 3
FE427_Measure.ewp FE427_Measure.eww	Project Files for IAR Workbench Version 2
FE427_Measure.hzp FE427_Measure.hzs	Project Files for Rowley CrossStudio

The Demo software flow is shown in Figure 13.

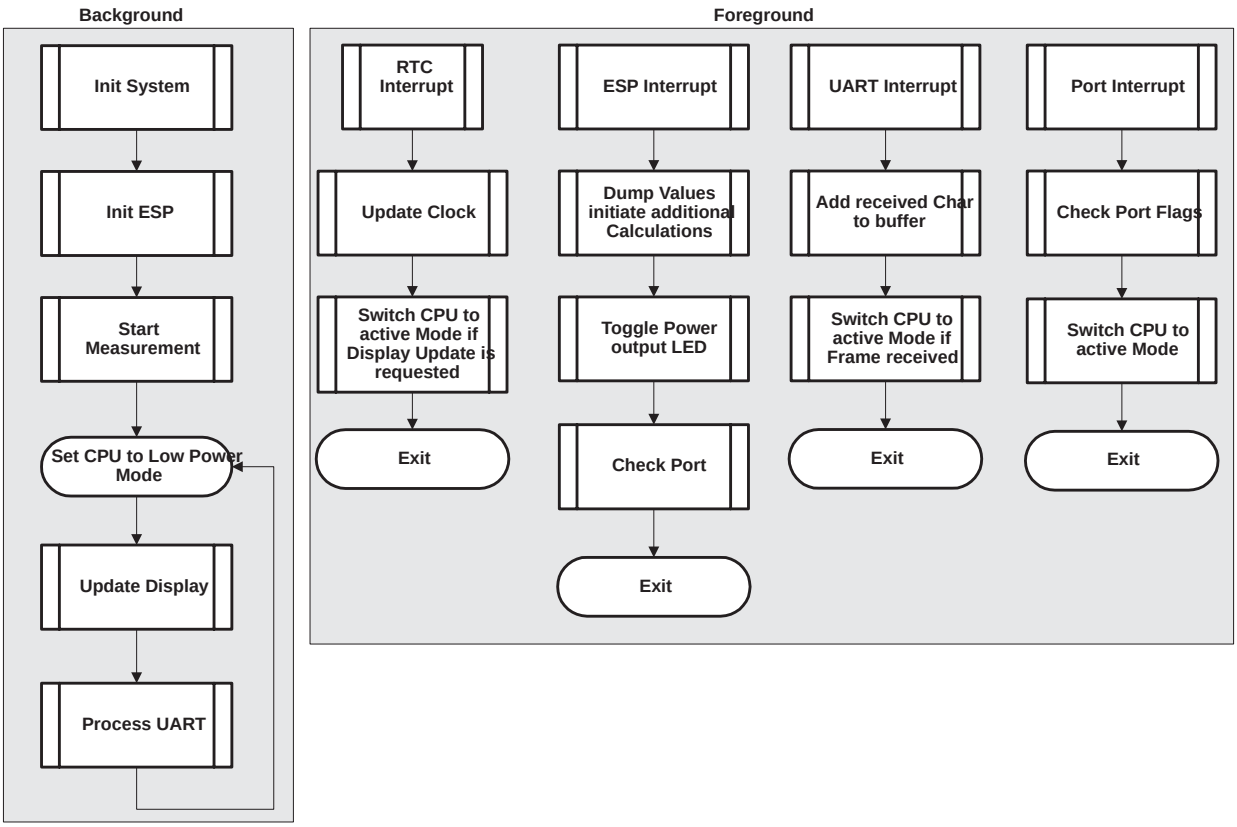


Figure 13. Software Flow

7.4 Energy Pulse Generation

A pulse can be output to indicate a specific energy level. Three methods can be used for the generation of the energy pulse output signal.

7.4.1 Direct Output With Interrupt Level

The first method is the direct interrupt source of the ESP430 module with the Interrupt level set to a specific energy level. The implementation is simple, does not need any additional hardware or software resources but, as the energy is the accumulation of a sine wave; this signal could have some jitter.

This method is active if the following are defined:

```
//#define TIMERA_PULSE_OUTPUT
//#define WITH_AVERAGING
```

7.4.2 Timer_A Output

The second method uses the Timer_A as a constant time basis to directly remove the jitter of the interrupt level method. This method is sufficient for pulse frequencies up to ~30 Hz. Here, the following setting could be used in the parameter.h file.

```
#define  TimerAClock           TASSEL_1    /* ACLK = 32kHz
#define  TACLOCK               32768ul
#define  CLOCKSPERPERIOD      (TACLOCK/defSET_NOMFREQ)
```

This is active if the following is defined:

```
#define TIMERA_PULSE_OUTPUT
//#define WITH_AVERAGING
```

7.4.3 Timer_A Pulse Output With Averaging

The third method uses an averaging over a certain time period and generates a pulse clock rate with the Timer_A only.

This is active if the following are defined:

```
#define TIMERA_PULSE_OUTPUT
#define WITH_AVERAGING
```

7.5 Controls

The two buttons are used for following functions:

- S_A: Switch the ESP430CE1 off and set the MSP430 into low power mode. The real time clock continues to run.
- S_B: Toggle through the display modes

7.5.1 Parameter.h file

All configuration settings are done within the parameter.h file including the settings for the:

- Pulse output level
- Voltage and current ratio
- Configuration settings for the ESP430CE1

The #define for withDisplay allows scaling the code for different functions and sizes. The code uses floating point functions for the UART output and the calibration. Including one of these two parts will increase the code size.

The shunt definition, `*define shunt,` selects the between using a shunt or a CT for the I1 input.

For an easier calculation of the main parameter defined the parameter.h file, the Excel sheet FE427_Settings.xls could be used. After entering the required information into the white fields, the parameters are calculated and displayed. Pushing the *Save Parameter to File* button, the parameters are saved into the file ‘Test_Parameter.h’.

This file with the calculated parameters will be included into the source instead of the default values in the ‘Parameter.h’ if the ‘#define Test’ line is uncommented in the ‘Parameter.h’ file.

7.6 Demo 2

Demo 2 is setup as a complex application including UART communication and some auto-calibration routines that store the parameters back into the flash memory. For the energy calculation, the energy values reported from the ESP430CE1 are used instead of the interrupt level function. The initialization of the ESP430CE1, the data output on the display, and the LED usage is included as in the Demo 1. This demo is too large to be used with IAR Kickstart.

Demo 2 contains all the files in Demo 1 plus:

File	Contents and Function
UART.c	Interrupt handler for UART receive
Comms_UART.c	UART communication routines: − Init UART − UART Send Functions − UART Receive Function: Process_UART (This routine processes a received UART Command).
SendData.c	Conversion routines for the data which should be sent by the UART
Calibration.c	Some simple calibration functions which could be used to do a basic calibration. These functions are executed by commands sent via the UART.

7.6.1 UART Communication

The baud rate is 57600 / 8 N 1

Each command should be terminated with a ‘CR’.

The ’h’ command displays the help list in the terminal window, as shown below.

```
MSP430FE427 Firmware Version: 0114

UART commands:
 SHxx: set hour
 SMxx: set minutes
 SSxx: set seconds
 SDxx: set day
 SOxx: set month
 SYxx: set year

 Dx: set Display mode
 D1: Off
 D2: Time
 D3: Date
 D4: Voltage (V)
 D5: Current (A)
 D6: Peak Voltage (V)
 D7: Peak Current (A)
 D8: Frequency (Hz)
 D9: CosPhi
 DA: Temp
 DB: Power (kW)
 DC: Energy (kWh)

 H : show help test
 Tx: set test dump mode
 R : reset system
 Mx: execute calibration measurement over x*50 cycles
 I : init

 C0: auto calibration of U / I / P / Phase Shift
 C1: calibration of Interrupt Level
 C2: calibration of Phase correction 1
 C3: calibration of Phase correction 2
 C4: calibration of V1 Offset
 C5: calibration of I1 Offset
 C6: calibration of I2 Offset
 C9: save settings to flash
 CA: calibration of V Ratio
```

```
CB: calibration of I Ratio
CC: calibration of Energy Ratio
+ : inc values for calibration
– : dec values for calibration
```

7.6.2 Calibration

A basic calibration can be done with the UART command ‘C0’.

The execution of this command requires the input values defined in the parameter.h file:

- calVoltage
- calCurrent
- calPhi
- calCosPhi
- calFreq

With the UART command ‘C9’ the calculated values are stored into the flash.

7.6.3 Parameter.h file

All configuration settings are done within the parameter.h file including the default settings for:

- Pulse output level
- Voltage and current ratio
- Configuration settings for the ESP430CE1

The #defines for withUARTComm, withCalibration, withDisplay allow scaling the code for different function and sizes. The code uses floating point functions for these functions and including one them will increase the code size.

Commenting or uncommenting of the following line in the parameter.h file configures the software to use a Shunt or CT on the I1 input:

```
#define shunt
```

To do a precalculation of the parameters, the following formulas can be used:

- defVRatio = kV1 / 1000 (for kV1 see the *Voltage Ratio* section)
- defIRatio = kI1 / 1000 (for kI1 see the *Current Ratio For Shunt* section)
- defEnergieRatio = (defVRatio x defIRatio)

See the Excel sheet which is included with the source code.

8 References

1. *MSP430FE42x Data Sheet* (SLAS396)
2. *ESP430CE1 Module User’s Guide* (SLAU134)
3. *MSP430x4xx Family User’s Guide* (SLAU056)
4. *MSP430 Family Application Report Book* (SLAA024)

Appendix A Reference Board Schematic and Layout

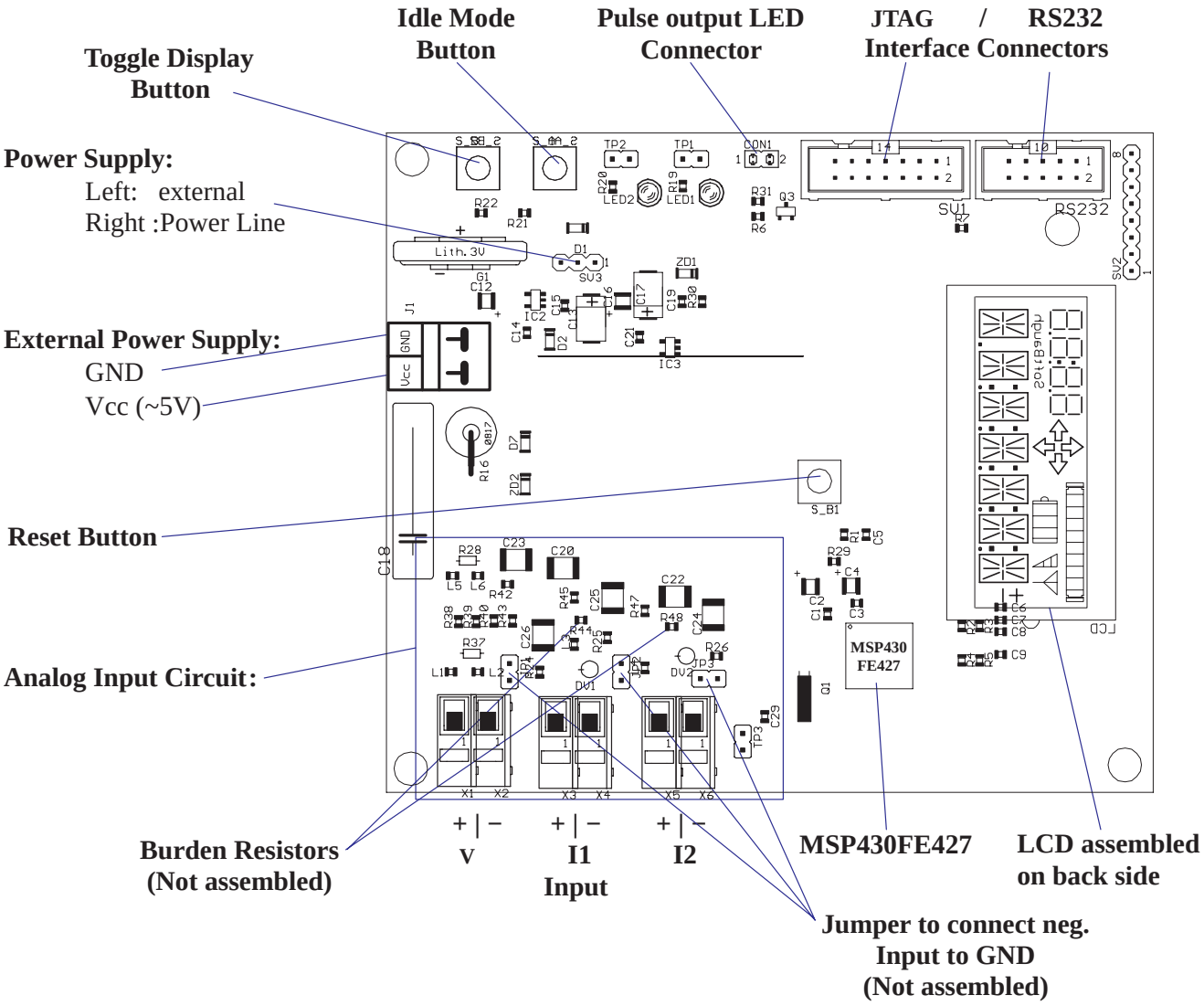


Figure A−1. Components on the Reference Board

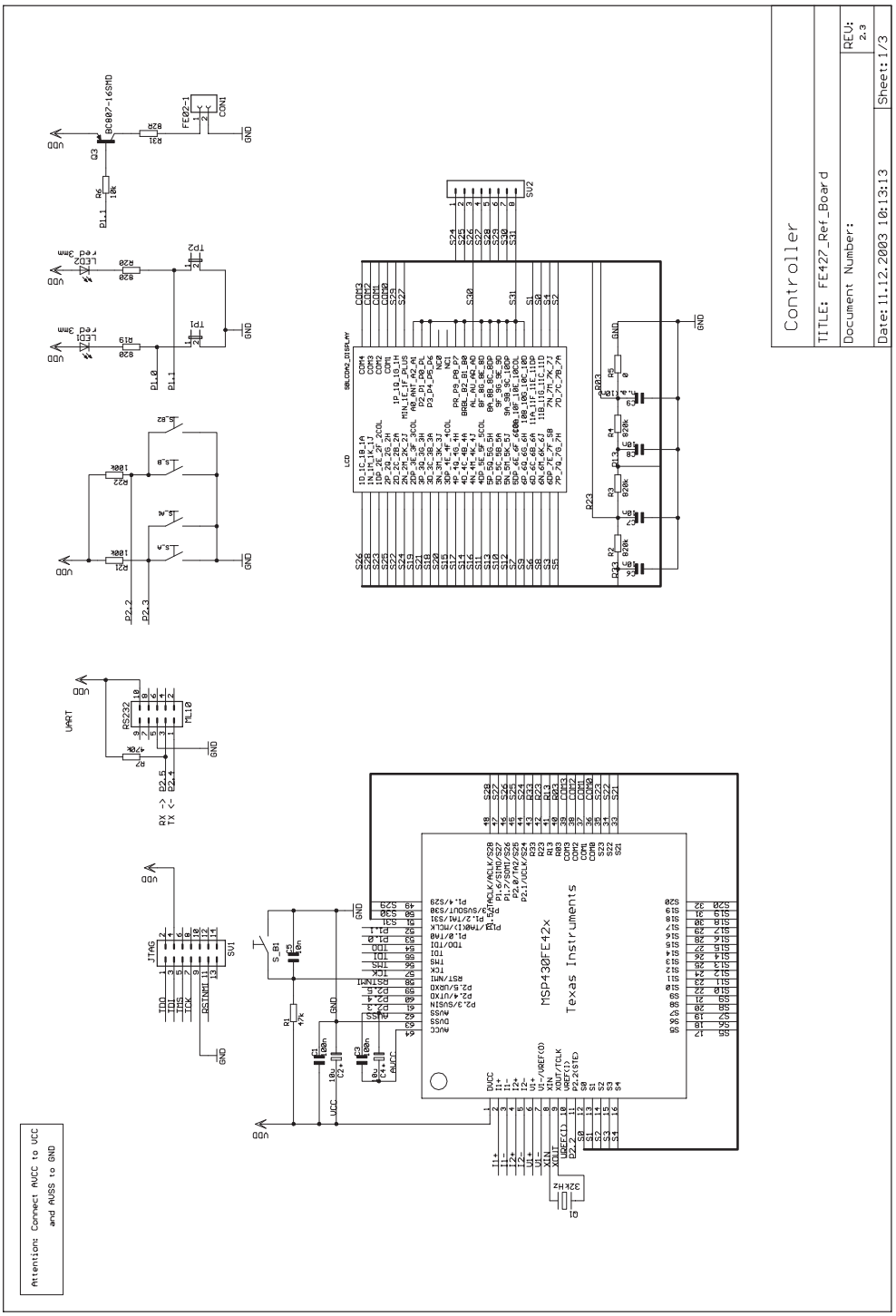
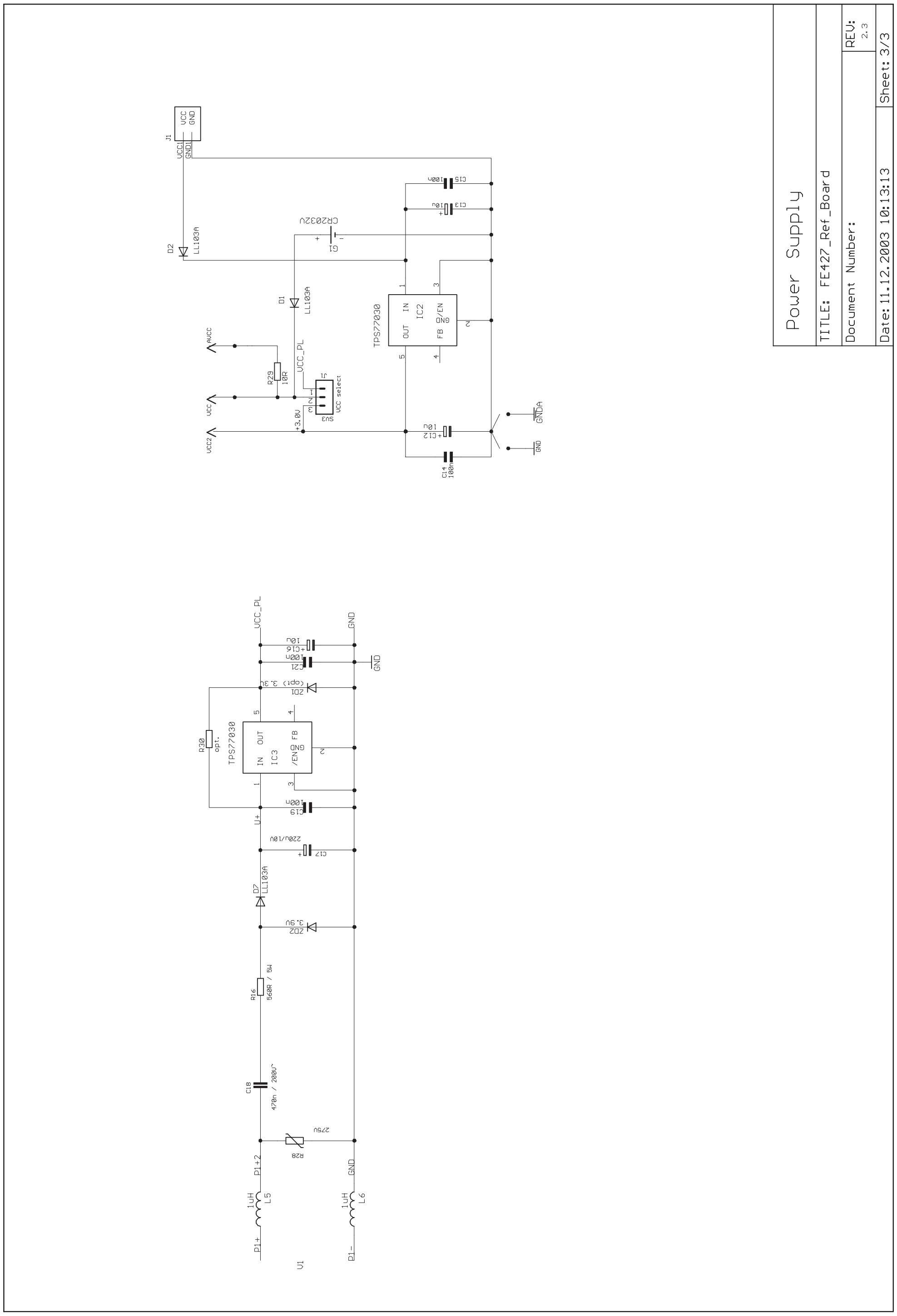
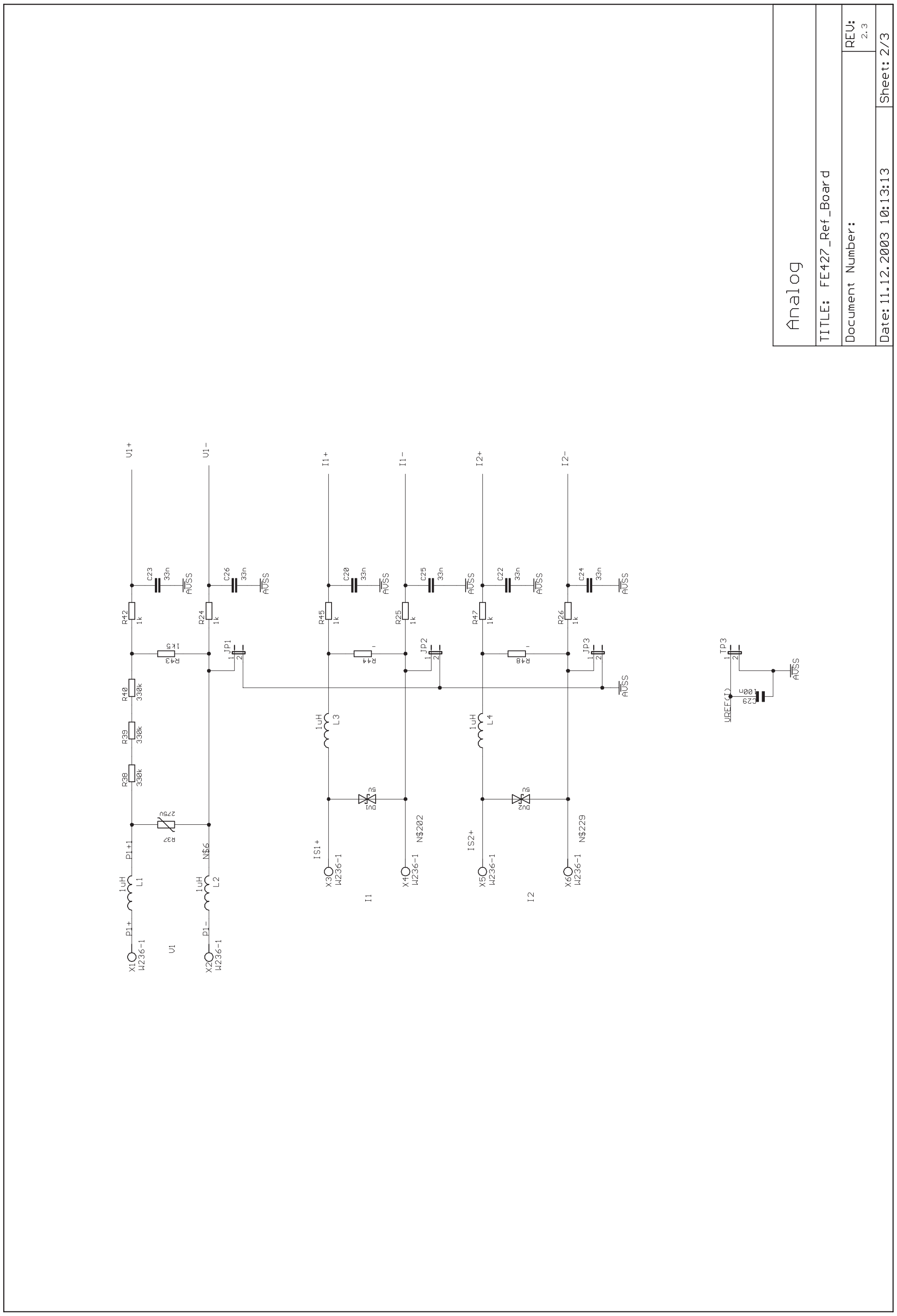


Figure A−2. Schematics


Power Supply
TITLE: FE427_Ref_Board
Document Number:
REV: 2.3
Date: 11.12.2003 10:13:13
Sheet: 3/3


Analog
TITLE: FE427_Ref_Board
Document Number:
REV: 2.3
Date: 11.12.2003 10:13:13
Sheet: 2/3

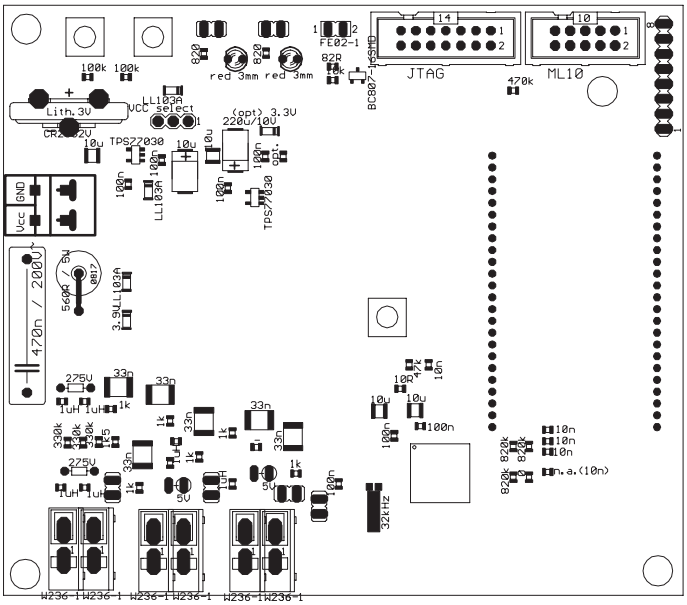


Figure A−3. Components on Top Side

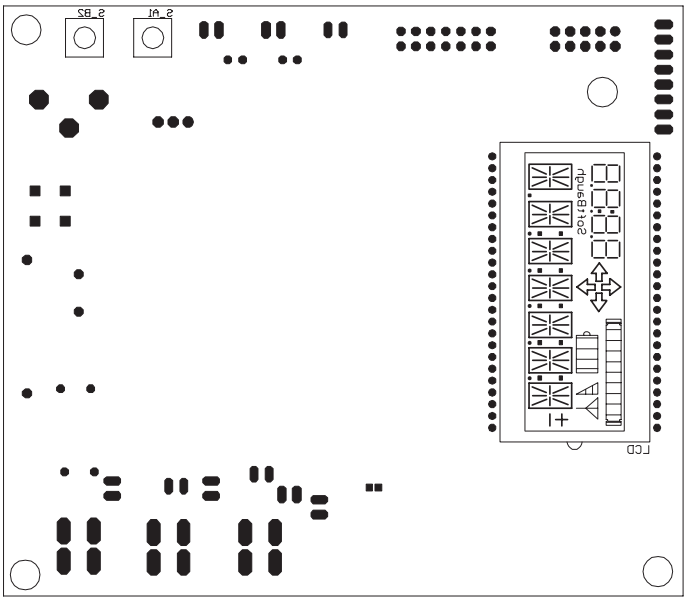


Figure A−4. Components on Bottom Side

Table A−1. Bill of Materials

QTY	PARTS	VALUE	DEVICE	MANUFACTURER
4	C1, C3, C19, C21	100 nF	CSMD0805	
1	C13	10 µF	ELKO	multicomp (10 µF/ 35 V)
3	C14, C15, C29	100 nF	C	
1	C17	220 µF/10 V	ELKO	
1	C18	470 nF / 200 V~	C−EU225−062X268	Phicomp
4	C2, C4, C12, C16	10 µF	ELKO_1210	10 µF/10 V
6	C20, C22, C23, C24, C25, C26	33 nF	C−EUC4532	AVX
1	C27	22 µF/25 V	CPOL−EUD/7343−31R	AVX Typ: TAJ
4	C5, C6, C7, C8	10 nF	CSMD0805	
1	C9	N.A. (10 nF)	CSMD0805	
2	D2, D3	LL103A	BAS32	
2	D7, D10	LL103A	D	
2	DV1, DV2	5 V	D_SUPPRESS	
1	G1	CR2032V	CR2032V	Varta
2	IC2, IC3	TPS77030	TPS77001	Texas Instruments
1	J1	SUP_CON	SUP_CON	
6	L1, L2, L3, L4, L5, L6	1 µH	L−US08050805	
1	LCD	SBLCDA2_DISPLAY	SBLCDA2_DISPLAY	Softbaugh
2	LED1, LED2	Red 3 mm	LED3MM	Multicomp (Low Power)
1	LED3	SFH486	LED5MM	Infinion
1	MSP1		FE427_CHIP	Texas Instruments
1	Q1	32 kHz	QUARZ32K	
1	Q3	BC807−16SMD	BC807−16SMD	Philips (5Ap)
1	R1	47 kΩ	R_0805	
1	R16	560R / 5 W	R−EU_0817/7V	
2	R19, R20	820	R_0805	
3	R2, R3, R4	820 kΩ	R_0805	
2	R21, R22	100 kΩ	R_0805	
1	R23	0R	R_0805	
6	R24, R25, R26, R42, R45, R47	1 kΩ	R_0805	
2	R28, R37	275 V	VARISTOR−2,5	EPCOS
1	R29	10R	R_0805	
1	R30	opt.	R_0805	
1	R31	82R	R_0805	
3	R38, R39, R40	330 kΩ	R_0805	
1	R43	1k5	R_0805	
2	R44, R48	–	R_0805	
1	R5	0	R_0805	
1	R6	10 kΩ	R_0805	
1	R7	470 kΩ	R_0805	
1	RS232	ML10	ML10	
5	S_A, S_A1, S_B, S_B1, S_B2	Switch	Switch	
1	SV1	JTAG	ML14	
1	SV2		MA08−1	

QTY	PARTS	VALUE	DEVICE	MANUFACTURER
1	SV3	VCC select	MA03−1@2	
3	TP1, TP2, TP3		JP1E	Connector row
6	X1, X2, X3, X4, X5, X6	W236−1	W236−1	Wago 256
1	ZD1	(opt) 3.3 V	D	
1	ZD2	3.9 V	D	

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