Evaluation Kit for SA5301A

EVKIT-SA5301A

ICDC

INTRODUCTION

The evaluation kit for the SA5301A energy metering device is intended to offer a simple and quick turn-around solution to evaluating and testing the features and performance of the device. It consists of the following parts as illustrated in Figure 1.

- This document
- RM5301ASAR reference design
- USB-to-SPI interface module
- SA5301A-Demo software
- external power supply and current transformers

This application note discusses the design and operation of all parts of the evaluation kit. The Gerber files for all required PCBs are included to facilitate simple reproduction of the evaluation kit.

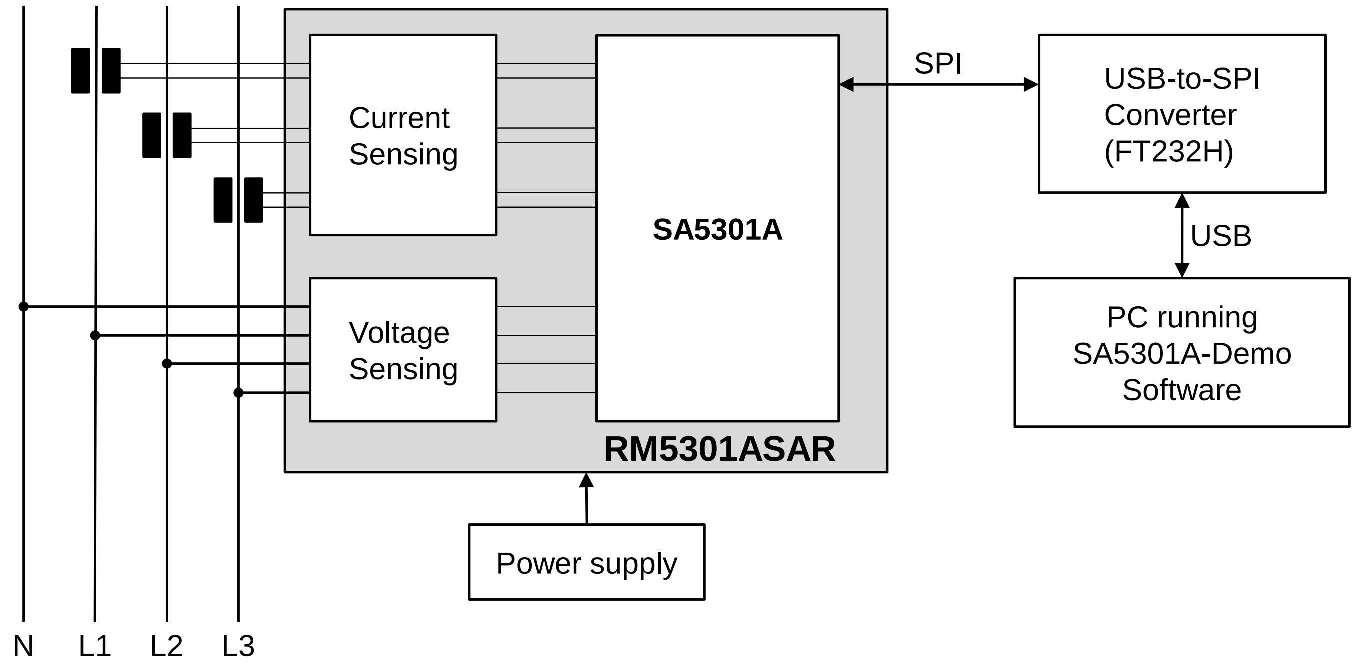

Figure 1: *SA5301A evaluation setup*

SA5301A INTEGRATED CIRCUIT

The SA5301A is a high accuracy three phase bidirectional energy/power metering integrated circuit. It has been designed to measure various additional quantities over and above active energy. This makes it an ideal device for use in multi-function three phase energy meters for residential or industrial purposes, as well as energy monitoring and control applications.

The SA5301A is capable of measuring active and reactive energy on a per channel basis to an accuracy of less than 0.1 % error over a 1000:1 current range. True RMS voltage and current, as well as mains frequency and phase angle, are also measured. Data is accessible via an integrated SPI serial interface. The device includes a fully programmable pulse output module to automatically generate active and reactive energy pulses. A multitude of programmable status and interrupt conditions can be configured to assist in monitoring various aspects pertaining to energy consumption. Four configurable output pins allow various status signals to be monitored directly.

The SA5301A includes a precision oscillator and voltage reference to ensure the circuitry maintains stable operation over a wide temperature and power supply range. Very few other external components are required.

Refer to the SA5301A data sheet for a complete description of the device features and operation.

RM5301ASAR REFERENCE DESIGN

Overview

The RM5301ASAR reference design illustrates the fundamentals required to design an energy meter around the SA5301A energy metering device and provides a platform for establishing a baseline performance benchmark. If the design principles discussed below are followed, it should not be challenging to replicate the performance figures of the reference design in the final meter solution.

The reference design is fully configurable for any 3 phase/4 wire energy metering application based on current transformers. For the purpose of this example, the module is being designed for a nominal voltage V_{NOM} of 220 V and a maximum current I_{MAX} of 60 A. The complete schematic of the reference module is shown in Figure 2. Table 1 contains the component list.

Power Supply

The SA5301A requires two power supplies, for the analog and digital circuits respectively. The analog supply must be in the range 5 V ±10 %, the digital circuits can operate on any supply in the range 2.5 V to 5.5 V, with 3.3 V being the suggested operating voltage. The digital supply voltage determines the signalling level of the digital input and output pins, so it is recommended to use the same supply that also powers the IO signals of the device that will be communicating with the SA5301A. If this is not possible, level shifters may be required, the SA5301A will not tolerate digital input signal voltage levels that exceed the digital power supply level.

The recommended solution for the analog supply is a separate and dedicated 5 V supply based on a simple low-cost 5 V regulator. A maximum supply current of 5 mA should be adequate. A separate analog supply is the optimum recipe for ensuring best performance. A digital supply that unifies the requirements of the SA5301A with the rest of the system is the best choice. Both supplies need to be adequately bypassed to their respective ground pins as close as possible to the SA5301A. A 10 µF tantalum electrolytic capacitor in parallel with a 10 nF ceramic capacitor is recommended. The analog and digital system grounds need to be connected together at one single point only, the use of a ferrite bead to accomplish this is recommended, it will assist in preventing the switching noise of the digital circuits from affecting the analog circuits of the SA5301A.

The RM5301ASAR reference design does not include power supplies and needs to be powered externally. For initial evaluation a single 5 V supply can be used to power the analog circuits, the digital circuits can be powered from the USB-to-SPI interface module if appropriate. The power supplies are connected to the module at JS5. The digital supply may also be connected on any of the SPI or digital IO pin headers. As soon as the power supply designs of the final energy meter are finalized, it is recommended to test them on the RM5301ASAR reference design, to ensure that required performance is achieved.

Power-up

The SA5301A has no specific power up sequence or power supply rise time requirements beyond those that are typically considered reasonable. Digital IO signals should not be driven beyond the power supply levels during power-up, as this could cause the SA5301A to enter a latch-up state from which it can only recover if all power is removed. The SA5301A will only start operating once the on-chip power-on reset circuit has detected at least 4 V on the analog supply and 2.2 V on the digital supply. Until that point the device remains in reset and all digital output signals are either driven to logic low (CA, CB, CC and CD) or will be floating (MISO). The device does not incorporate any pull-up or pull-down resistors on the SPI signals (CS, SCK, MOSI and MISO). These signals must always be at a valid digital signal level to prevent high power consumption or possibly latch-up, especially during power-up. The RM5301ASAR has optional pull-down resistors on these pins. The value is not critical, it should not be too small to prevent high power consumption during operation. A value above 100 kΩ and below 1 MΩ is recommended, depending on net capacitance.

Bandgap and Oscillator

The SA5301A on-chip bandgap voltage reference and oscillator require some external components. Their selection and location can be critical to stable operation of the device. The bandgap requires external capacitance to be added to the reference voltage pin VREF in order to filter transients and noise. A recommended 10 µF tantalum electrolytic capacitor in parallel with a 10 nF ceramic capacitor is required. Capacitors with fairly low ESR should be selected. The oscillator requires an external resistor to be connected to the ORES pin. The value of this resistance directly determines the oscillator frequency and temperature stability. A value of 100 kΩ should be used under most circumstances, which will set the optimum oscillator frequency of 1.786 MHz nominal. A metal film resistor is required to reduce noise, carbon film resistors must be avoided.

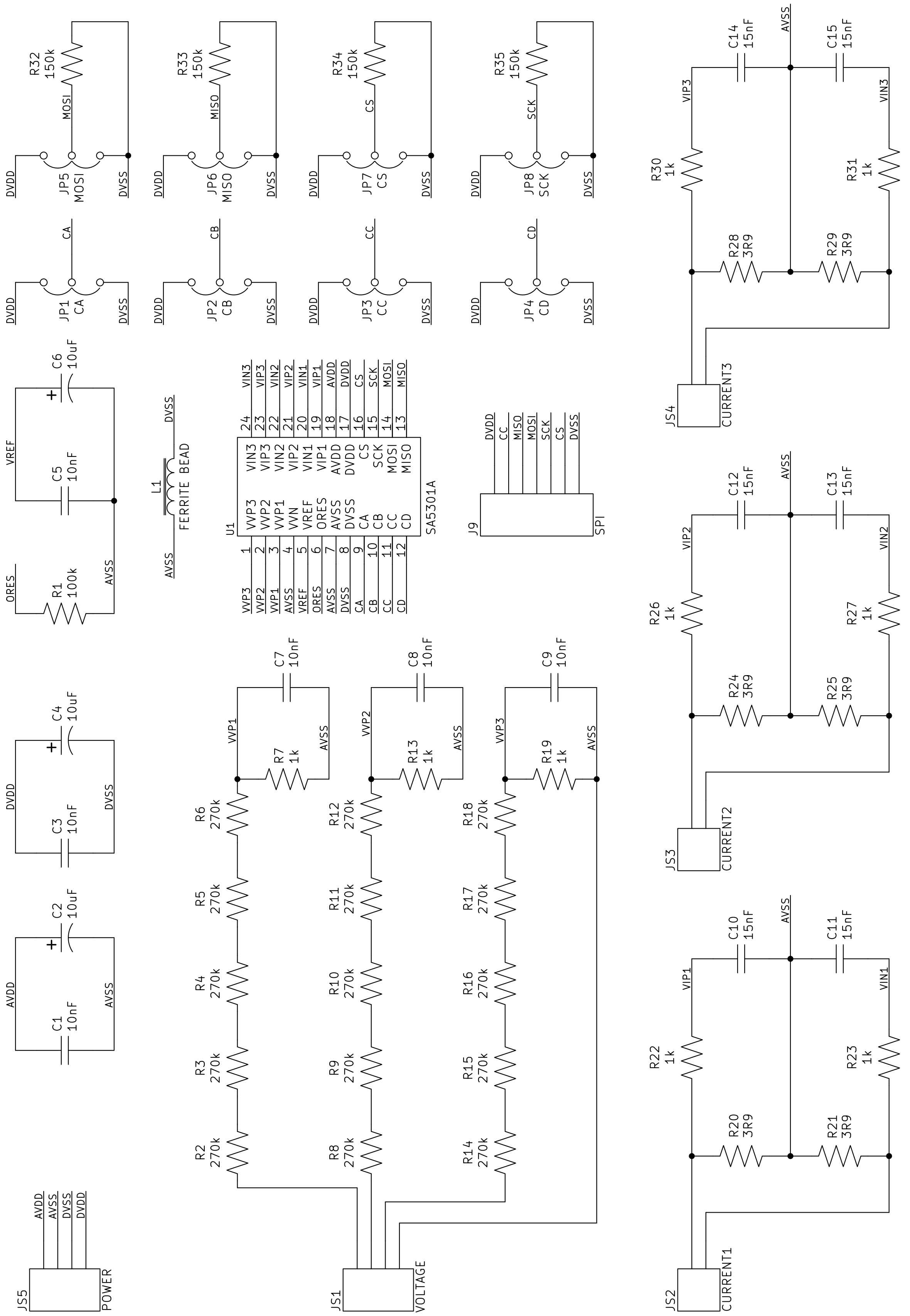

Figure 2: *RM5301ASAR reference module schematic*

Table 1: Component list for RM5301ASAR

Symbol	Description	Package
U1	Energy meter, SA5301ASAR	SOIC24
C1, C3, C5, C7, C8, C9	Capacitor, ceramic X7R, 10 nF, ±10 %, 50 V	SM0805
C2, C4, C6	Capacitor, tantalum, 10 µF, ±10 %, 16 V, ESR 2.5 Ω	SMT B
C10, C11, C12, C13, C14, C15	Capacitor, ceramic X7R, 15 nF, ±10 % 50 V	SM0805
R1	Resistor, metal film, 100 kΩ, 1 %, 1/10 W	SM0805
R2, R3, R4, R5, R6	Resistor, metal film, 270 kΩ, 1 %, 1/4 W	Axial leaded
R8, R9, R10, R11, R12	Resistor, metal film, 270 kΩ, 1 %, 1/4 W	Axial leaded
R14, R15, R16, R17, R18	Resistor, metal film, 270 kΩ, 1 %, 1/4 W	Axial leaded
R7, R13, R19	Resistor, metal film, 1 kΩ, 1 %, 1/10 W	SM0805
R20, R21, R24, R25, R28, R29	Resistor, metal film, 3.9 Ω, 1 %, 1/4 W	Axial leaded
R22, R23, R26, R27, R30, R31	Resistor, metal film, 1 kΩ, 1 %, 1/10 W	SM0805
R32, R33, R34, R35	Resistor, metal film, 150 kΩ, 1 %, 1/10 W	SM0805
L1	Ferrite bead	Axial leaded
JS1, JS5	Terminal block, 4 way	Pitch 5.08 mm
JS2, JS3, JS4	Terminal block, 2 way	Pitch 5.08 mm
JP1, JP2, JP3, JP4	Single inline pins, 3 way	Pitch 2.54 mm
JP5, JP6, JP7, JP8	Single inline pins, 3 way	Pitch 2.54 mm
J9	Single inline pins, 7 way	Pitch 2.54 mm

The temperature coefficient of the ORES resistor is critical to ensure good temperature stability of the SA5301A measurement circuits, although it is more the relative temperature coefficient to other resistors in the design that is relevant, rather than the absolute temperature coefficient. The use of metal film resistors from the same series and from the same manufacturer throughout the design should be sufficient to achieve adequate temperature stability for most applications. Refer to the Design Considerations / Temperature Compensation section in the SA5301A data sheet for a detailed explanation on how the external resistors influence the temperature behaviour of the SA5301A. No external capacitance must be added to the ORES pin as this will introduce jitter on the oscillator frequency and degrade device performance.

The VREF capacitors and the ORES resistor should be placed as close to the respective device pins as possible. If they are placed on the opposite side of the PCB as the SA5301A, fairly large vias should be used to reduce stray resistance effects.

Current Sensing Networks

The SA5301A requires three current sensing networks, one for each measurement channel. The main parts of the current sensing networks are incorporated on the RM5301ASAR module, but the current transformers are external to the module and should be connected at JS2, JS3 and JS4 for channels 1-3 respectively. The SA5301A requires the use of current transformers to provide electrical isolation to the line voltages when sensing the currents. Any good quality current transformer can be used. For the purposes of this example design, the TZ76V current transformer from Taehwatrans is used. They have a winding ratio of 1:2500 and a measured phase shift of approximately 0.09°.

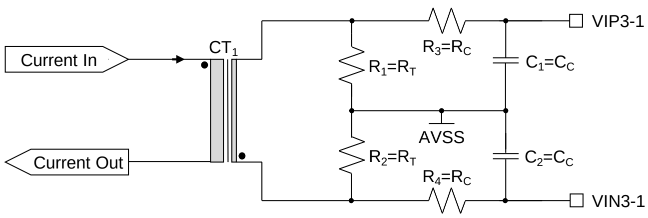

***Figure 3:** Current sensing network*

Figure 3 illustrates the current sensing network for one measurement channel. The resistor values should be selected to provide the SA5301A with a 200 mV_{RMS} differential input signal at maximum rated mains current, I_{MAX}. The resistors R_1 and R_2 together form the termination resistor for the current transformer. The reference level is connected in the centre of the termination resistor to achieve a purely differential input signal. The ground reference level of the current sensing network should be the analog system ground of the meter, which is connected to AVSS of the SA5301A.

$$R_T = R_1 = R_2 = \frac{200\,\mathrm{mV}}{2 I_{MAX}/N}$$

where

I_{MAX} is the maximum rated mains current of the meter and

N is the turns ratio of the current transformer.

For an I_{MAX} of 60 A with a turns ratio of 1:2500 the termination resistors are calculated as 4.16 Ω. Typically the next smaller resistor value is selected, 3.9 Ω in this case, to ensure that the analog circuits of the SA5301A do not saturate at maximum current. The added advantage of this strategy is that the meter will be linear beyond the maximum rated mains current. A slightly larger resistor value may also be selected, there is always some voltage drop that occurs due the interaction of the output resistance of the current sensing network and the input resistance of the SA5301A current sense inputs which will extend the linear operating range of the meter.

For optimal performance the SA5301A requires anti-alias filters on the current signal inputs. These filters are realized by means of the capacitors C_1 and C_2 together with the resistors R_3 and R_4. The typical cut-off frequency of these filters should be between 10 kHz and 20 kHz. The resistor values of R_3 and R_4 must be equal and large enough to ensure reasonably sized capacitors. Additionally, the resistor value should not be too large to limit significant interaction with the modulator input impedance. For most scenarios an optimum input network is achieved by setting R_3 and R_4 to 1 kΩ and C_1 and C_2 to 15 nF. The anti-alias filter cut-off frequency, f_{CC}, is then 10.6 kHz. The total phase shift of the current sensing network, ϕ_C, can be calculated as the sum of the phase shift of the anti-alias filter and the phase shift of the current transformer. in this case the total phase shift is −0.18°.

$$f_{\mathrm{CC}} = \frac{1}{2\pi R_{\mathrm{C}} C_{\mathrm{C}}}$$

$$\phi_{\mathrm{C}} = -\arctan\left(2\pi R_{\mathrm{C}} C_{\mathrm{C}} \times f_{\mathrm{MAINS}}\right) + \phi_{\mathrm{CT}}$$

where
f_{MAINS} is the mains frequency of the meter and
ϕ_{CT} is the phase shift of the current transformer.
Upon completion of the current sensing network design, it is important to determine the actual input voltage level at maximum rated mains current. This value will be required for the set up of the SA5301A-Demo software. It is calculated as 180.3 mV_{RMS} using

$$X_{\mathrm{CC}} = \frac{1}{2\pi f_{\mathrm{MAINS}} C_{\mathrm{C}}}$$

$$Z_{\mathrm{A}} = X_{\mathrm{CC}} || \left(\frac{ZID_{\mathrm{I}}}{2}\right)$$

$$Z_{\mathrm{B}} = \left(Z_{\mathrm{A}} + R_{\mathrm{C}}\right) || R_{\mathrm{T}}$$

$$I_{\mathrm{IN}} = 2 \times \frac{I_{\mathrm{MAX}}}{N} \times Z_{\mathrm{B}} \times \frac{Z_{\mathrm{A}}}{R_{\mathrm{C}} + Z_{\mathrm{A}}}$$

where
X_{CC} is the impedance of the anti-alias filter capacitor at the mains frequency f_{MAINS} and
ZID_{I} is the differential input impedance of the current signal inputs on the SA5301A, typically about 60 kΩ.
The value of 180.3 mV_{RMS} leaves more than 10 % headroom on the current inputs until saturation occurs. If this is not required, the value of the termination resistors can be increased.

All resistors used in the current sensing networks must be metal film resistors to reduce noise. Very often the extremely low value surface mount resistors required for the current transformer termination have significantly poorer temperature coefficients than the larger value counterparts. The use of larger axial resistors typically overcomes this problem. The overall temperature coefficient of the current input network should be verified to ensure it meets the requirements for the overall meter.

Voltage Sensing Networks

The complete voltage sensing networks are included on the RM5301ASAR module. A 3 phase/4 wire energy metering circuit requires all three line voltages as well as the neutral voltage to be connected. These are connected at JS1. The neutral voltage is connected to the analog system ground and the VVN pin of the SA5301A. The three line voltages are reduced to the required input signal level by means of voltage dividers.

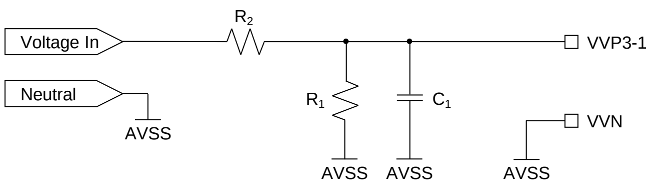

Figure 4: *Voltage sensing network*

Figure 4 shows the voltage sensing network for one measurement channel. This circuit attenuates the mains voltage signal to the level required by the SA5301A. The attenuation ratio should be designed so that the input signal to the SA5301A is 200 mV_{RMS} at the maximum mains voltage (V_{MAX}) that the meter must be able to operate at. For this design V_{MAX} is assumed to be 20 % larger than V_{NOM}.

The resistor R_1 defines the output resistance of the voltage sensing network. It should not be too small, else the capacitor value for the anti-alias filter will be quite large. However, if it is too large, inaccuracies will occur in the interaction with the input impedance of the SA5301A voltage signal input. An optimum input network is achieved by setting R_1 to 1 kΩ. R_2 is typically split into multiple similarly sized resistors, 5 in this case, in order to limit the power dissipation and voltage across each resistor.

$$R_2 = \left(\frac{V_{\mathrm{MAX}}}{200\,\mathrm{mV}} \times R_1\right) - R_1$$

where
V_{MAX} is the maximum mains voltage the meter needs to operate at, 1.2 V_{NOM} in this case.
Using R_1 = 1 kΩ, R_2 can be calculated as 1.319 MΩ. Splitting this into 5 equally sized resistors and choosing the nearest larger value (270 kΩ) results in R_2 = 1.35 MΩ.

For optimal performance the SA5301A requires an anti-alias filter on the voltage signal inputs. Referring to Figure 4, the capacitor C_1 is used to both implement the anti-alias filter and compensate for any phase shift caused by the current transformer on the current sensing network. Even though the SA5301A contains a phase shift error compensation feature, it is still recommended to compensate the phase angle difference between the voltage and current networks externally. Fine tuning the compensation can then be done using the SA5301A phase shift compensation feature. The cut-off frequency of the anti-alias filter is adjusted so that the phase shift of the voltage sensing network is identical to the sum of the phase shifts of the current transformer and the current sensing network anti-alias filter.

The value of the voltage sensing network capacitor and the anti-alias filter cut-off frequency may be determined using:

$$\phi_{\mathrm{V}} = \phi_{\mathrm{C}}$$

$$C_1 = \frac{|\tan \phi_{\mathrm{V}}|}{2\pi R_1 \times f_{\mathrm{MAINS}}}$$

$$f_{\mathrm{CV}} = \frac{1}{2\pi R_1 C_1}$$

where

f_{MAINS} is the mains frequency of the meter and

ϕ_{C} is the phase shift of the current sensing network.

The effect of the current transformer phase shift is an increase in cut-off frequency of the the anti-alias filter on the voltage sensing network. A cut-off frequency up to 25 kHz is usually acceptable due to the smaller dynamic range of the mains voltage signal. Using the measured phase shift of 0.09° for the TZ76V current transformer, C_1 is calculated as 10 nF, resulting in a cut-off frequency of 15.9 kHz. If the calculated capacitor value is not exact, as happens to be the case in this example, the nearest capacitor value should be chosen. Fine tuning the phase shift is then done using the on-chip phase calibration of the SA5301A. No anti-alias filter should be used on the VVN input pin, it will cause cross-coupling between voltage channels if the mains voltages are unbalanced.

The final input voltage signal level at nominal mains voltage needs to be determined, once again to set up the software later. It is calculated as 159.7 $\mathrm{mV_{RMS}}$ using

$$X_{\mathrm{C1}} = \frac{1}{2\pi f_{\mathrm{MAINS}} C_1}$$

$$Z_{\mathrm{C}} = R_1 || X_{\mathrm{C1}} || ZI_{\mathrm{V}}$$

$$V_{\mathrm{IN}} = V_{\mathrm{NOM}} \times \frac{Z_{\mathrm{C}}}{R_2 + Z_{\mathrm{C}}}$$

where

X_{C1} is the impedance of the anti-alias filter capacitor at the mains frequency f_{MAINS} and

ZI_{V} is the input impedance of the voltage signal inputs on the SA5301A, typically about 60 kΩ.

Notice how the value of 159.7 $\mathrm{mV_{RMS}}$ is significantly lower than the nominal input value of 200 $\mathrm{mV_{RMS}}$ to account for the requirement of V_{MAX} being 20 % larger than V_{NOM}

All resistors used in the voltage sensing networks must be metal film resistors to reduce noise. The high value resistors used on the voltage divider dissipate significantly more power than the other resistors used throughout the design. To avoid significant heating of those resistors and the associated temperature variations, it is suggested to use larger resistors. The RM5301ASAR reference design will use 1/4 W axial resistors. Once again it is strongly suggested to verify the overall temperature coefficient of the voltage input network to ensure it meets the requirements for the design.

Current Transformer Phase Shift

The phase shift specification given in the typical current transformer data sheets is often not accurate enough to perform the above calculations. It can also be dependent on the value of the termination resistor, so it is best to rather characterize the phase shift by means of a measurement. The recommended procedure is to:

- Perform all the above calculations except those relating to the calculations of the capacitor values.
- Assemble an RM5301ASAR reference design module with the calculated resistor values. Omit the capacitors on the voltage and current sensing networks or set them all to an equal value. In the latter case a value of 10 nF is suggested for a typical design.
- Using the active pulse output from the SA5301A or the active energy output generated from a micro-controller interfacing to the SPI bus of the SA5301A, measure the active energy error on an individual channel separately at V_{NOM} and 10 % I_{MAX} with zero phase shift.
- Adjust the meter constant in the calibration setup until the measured active error is zero.
- Repeat the error measurement at the same voltage and current, this time with 60° inductive phase shift (0.5 LAG), without changing the meter constant. If the current transformers had zero phase shift this second measurement would be close to zero error, but due to the phase shift a negative error will be measured.
- Determine the current transformer phase shift using the definition for the measurement error in this case which is

  $$\%\mathrm{Error} = \left(\frac{\cos(\theta + \phi_{\mathrm{CT}})}{\cos\theta} - 1\right) \times 100$$

  where

  θ is the phase angle at which the second measurement is performed and assuming the measurement error for the first measurement is zero.

  Therefore

  $$\phi_{\mathrm{CT}} = \arccos\left(\left(\frac{\%\mathrm{Error}}{100} + 1\right) \times \cos\theta\right) - \theta$$

  and a typical error of around −0.272 % means the current transformer has a phase shift of around 0.09°.

- Repeat this procedure on the remaining two channels and average the results for a more accurate estimate of the current transformer phase shift.
- Complete the circuit design calculations with the newly measured current transformer phase shift.

Digital IO Headers

The SPI interface signals as well as the 4 programmable outputs of the SA5301A are accessible on 8 separate headers, JP1 to JP8. Each of these includes the digital supply and ground signals as well for convenience. The SPI signals are also grouped together on the SPI header, J9. Power supply lines are included and the digital power supply may be supplied through this header. One of the programmable outputs (CC) is also included, although the SA5301A-Demo software do not use this output.

PCB Design

There are no critical considerations for designing the PCB layout for an SA5301A application, but the following principles should be incorporated to ensure optimal performance. The Gerber files of the RM5301ASAR module that form part of the SA5301A evaluation kit provide an example. They may be used for direct manufacturing of an RM5301ASAR reference module. Refer to the component list in Table 1 for an index of components that are required. Note that this component list assumes the parameters of the design as discussed.

- Ground planes connected to the analog system ground should be used around and below the SA5301A and all the analog signals and components. The planes should be isolated from other ground planes used for other components to limit noise injection. Multiple vias should be placed to tie the top and bottom ground planes together. The use of a multi-layer PCB is not required, the pin layout of the SA5301A has been designed to enable efficient routing of all required signals on two layers.
- The wires and PCB traces from the current transformers to their termination resistors should form a closed loop of minimal area to prevent interference. The CT wires should be twisted, the PCB traces placed close together and surrounded by the ground plane. The PCB traces should be constrained to one routing layer if possible.
- The anti-alias filters of the voltage and current sensing networks, the CT termination resistors, the ORES resistor and the VREF and supply bypass capacitors should be as close as possible to the SA5301A.
- The current sensing networks are differential signal networks, care should be taken to keep their PCB layouts as symmetrical as possible.
- All external resistors associated with the SA5301A should be placed in the same region of the PCB. This ensures that they are subjected to similar temperature and improves temperature stability.

USB-TO-SPI INTERFACE MODULE

Overview

In order to demonstrate the features and capabilities of the SA5301A energy metering device the SA5301A-Demo software needs to be able to access the SPI port of the device. To facilitate this a USB-to-SPI interface module is required. The software has been designed to operate with almost any interface module based on the FT232H / FT2232H / FT4232H family of devices from FTDI. It is possible to either use one of the many available evaluation boards containing one of these FTDI interface devices or manufacture the custom interface module described below. The latter has the advantage of providing electrical isolation between the SA5301A and the PC to improve safety and allowing a wider range of digital supply voltages to be supported due to the inherent level shifting that takes place through the digital isolator. The FTDI device is accessed in bit-bang mode, any 4 of the 8 data port signals may be connected to the SPI pins of the SA5301A. The sequence of connections is subsequently setup in the SA5301A-Demo software to enable correct signalling. Various setup scenarios using off-the-shelf modules are discussed below, refer to the relevant FTDI device and module data sheets for additional information.

Using An FTDI Evaluation Module

This section focuses on the use of one of the following three evaluation modules, which are all readily available from most electronic component distributors.

- UM232H, an evaluation module for FT232H
- FT2232H Mini-Module, an evaluation module for FT2232H
- FT4232H Mini-Module, an evaluation module for FT4232H

For ease of setup the evaluation module itself will be configured as bus-powered, drawing its power directly from the USB bus. This is achieved by making the following connections

- The 5 V USB power needs to be connected to the input of the on-chip regulator on the USB interface device. On the UM232H, connect J1-2 and J1-3 together. On either of the mini-modules connect CN3-1 and CN3-3 together.
- The 3.3 V output of the on-chip regulator needs to be connected the IO supply pins of the interface device. On the UM232H, connect J2-2 and J2-3 together. On either of the mini-modules connect CN2-5 and CN2-11 together.

A self-powered USB configuration is possible if desired, refer to the data sheet of the relevant module for the setup configuration.

In order to enable the SPI communication to take place any 4 of the 8 bits of the data bus (DBUS) on the FTDI interface device need to be connected to the SPI pins of the SA5301A. Note that the control bus signals (CBUS) (FT232H and FT2232H only) cannot be used. The FT2232H and FT4232H have multiple channels, only one of them can be used at once, so ensure to connect all SPI signals to the data bus bits of only one channel.

The FTDI devices operate from a 3.3 V digital IO power supply. Although the digital IO pins of these devices are 5 V tolerant, it is not advised to use different digital supply voltages on the SA5301A and the FTDI device. Doing so will typically violate some signal level requirements and potentially introduce communication errors. This restricts the digital supply on the SA5301A to 3.3 V.

Externally Powered Configuration

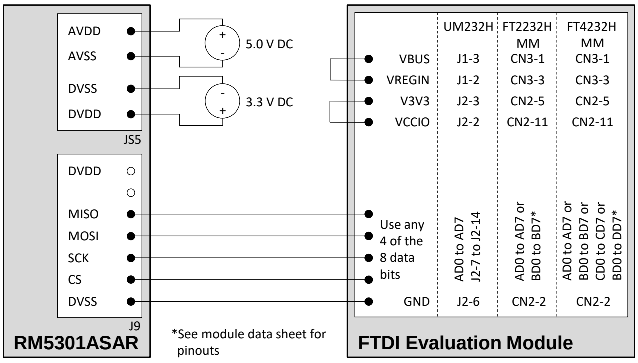

Figure 5: *Evaluation setup using FTDI module with external power supplies*

In this configuration the RM5301ASAR is powered from two external supplies. Refer to Figure 5.

- Connect an external 5 V supply to the analog supply and ground of the RM5301ASAR. This supplies 5 V to the analog circuits of the SA5301A.
- Connect an external 3.3 V supply to the digital supply and ground of the RM5301ASAR. This supplies 3.3 V to the digital circuits of the SA5301A.
- Connect the ground of the USB module (J2-6 on the UM232H and CN2-2, 4 or 6 on the mini modules) to the digital ground of the RM5301ASAR to create a common ground.

Hybrid External and USB Powered Configuration

In this configuration the digital supply to the SA5301A is supplied from the USB bus. A separate analog supply is required. Refer to Figure 6.

- Connect an external 5 V supply to the analog supply and ground of the RM5301ASAR. This supplies 5 V to the analog circuits of the SA5301A.
- Connect the output of the FTDI device on-chip regulator to the positive digital supply of the RM5301ASAR. This supplies 3.3 V to the digital circuits of the SA5301A. The regulator output is accessible on J2-3 (UM232H) and CN2-1, 2 or 5 (mini-modules).
- Connect the USB interface module ground to the digital ground of the RM5301ASAR. The module ground is accessible on J2-6 (UM232H) and CN2-2, 4 or 6 (mini-modules).

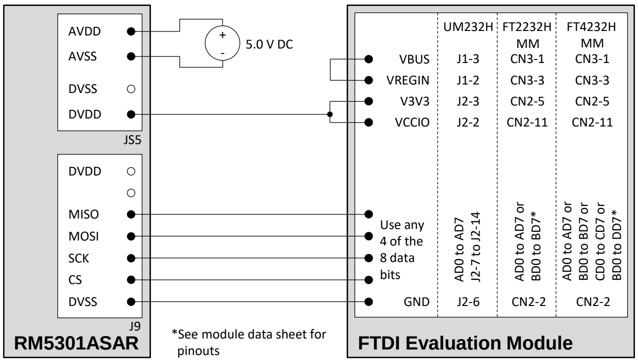

Figure 6: *Evaluation setup using FTDI module with analog power supply only*

USB-Only Powered Configuration

In this configuration the entire demonstration setup is powered entirely from the USB port (Figure 7). This method is illustrated for the sake of simplicity only since no external power supply is required. The USB bus power is typically rather noisy and could affect the performance of the SA5301A analog circuits. The use of this configuration should be restricted to functional tests only, the performance of the SA5301A might be affected.

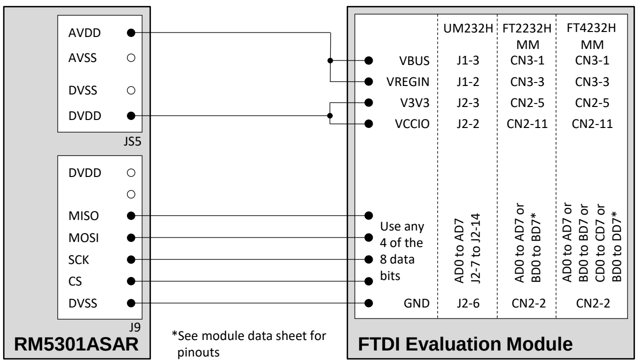

Figure 7: *Evaluation setup using FTDI module with USB supply only*

- Connect the 5 V USB bus power to the positive analog supply of the RM5301ASAR. This supplies 5 V to the analog circuits of the SA5301A. Use J1-3 (UM232H) or CN3-1 (mini-modules) to access the USB power output.
- Connect the output of the FTDI device on-chip regulator to the positive digital supply of the RM5301ASAR. This supplies 3.3 V to the digital circuits of the SA5301A. The regulator output is accessible on J2-3 (UM232H) and CN2-1, 2 or 5 (mini-modules).

- Connect the USB interface module ground to the digital ground of the RM5301ASAR. The module ground is accessible on J2-6 (UM232H) and CN2-2, 4 or 6 (mini-modules).

Isolated USB-to-SPI Interface Module

The use of a custom designed USB-to-SPI interface module is possible too. Using this module has the advantage of providing electrical isolation between the RM5301ASAR module and the PC. This enhances the safety of the demonstration setup for both the equipment and the user. Additionally the digital isolator that is used allows level shifting between the IO voltages of the FTDI device and the SA5301A to take place. The SA5301A can therefore be evaluated at digital supply voltages other than 3.3 V.

The custom module is based on the FT232H device and ADuM141 digital isolator. The schematic and component list are given in Figure 9 and Table 2 respectively. The Gerber files are part of the SA5301A evaluation kit and facilitate easy manufacturing of the interface module. The external EEPROM (U2) on the module is optional, the SA5301A-Demo software will work even if it is not fitted. The EEPROM allows the identification settings of the interface module to be customized. Take note that the Vendor ID and Product ID must not be changed or else the FTDI software driver will no longer recognize the interface module.

To use this module simply connect the SPI header on the RM5301ASAR (J9) to the SPI header on the isolated interface module (J2) with a straight pin-to-pin cable. Refer to Figure 8. The RM5301ASAR needs to be supplied with the two power supplies for analog and digital power.

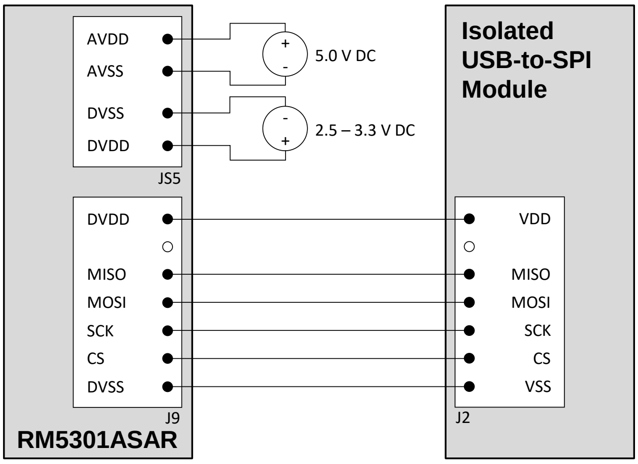

Figure 8: *Evaluation setup using the isolated USB-to-SPI interface module*

Table 2: *Component list for isolated USB-to-SPI interface module*

Symbol	Description	Package
U1	USB interface, FT232HL	LQFP48
U2	SPI EEPROM, 93LC56BT-E/OT	SOT23
U3	Digital isolator, ADUM141E0BRWZ	SOIC16N
C1, C4	Capacitor, ceramic X7R, ±10 %, 10 nF 50 V	SM0603
C2, C5, C8, C11	Capacitor, ceramic X7R, 100 nF, ±10 %, 50 V	SM0603
C13, C14, C15, C16	Capacitor, ceramic X7R, 100 nF, ±10 %, 50 V	SM0603
C3, C12	Capacitor, electrolytic, 4.7 µF, ±20 %, 35 V, 105 °C	“B” 4x5.8 mm
C6, C7	Capacitor, ceramic COG, 27 pF, ±5 %, 50 V	SM0603

Symbol	Description	Package
C9, C10	Capacitor, ceramic X5R, 1 µF, ±10 %, 16 V	SM0603
R1, R5	Resistor, metal film, 2 kΩ, 1 %, 1/16 W	SM0603
R2	Resistor, metal film, 12 kΩ, 1 %, 1/16 W	SM0603
R3, R4	Resistor, metal film, 10 kΩ, 1 %, 1/16 W	SM0603
L1, L2, L3	Ferrite	SM0603
X1	Crystal, 12 MHz, ±20 ppm	HC-49S
LED1	LED, green	3 mm
J1	Micro USB 2.0 RA, Molex 105017-0001	SMT
J2	Single inline pins, 7 way	Pitch 2.54 mm

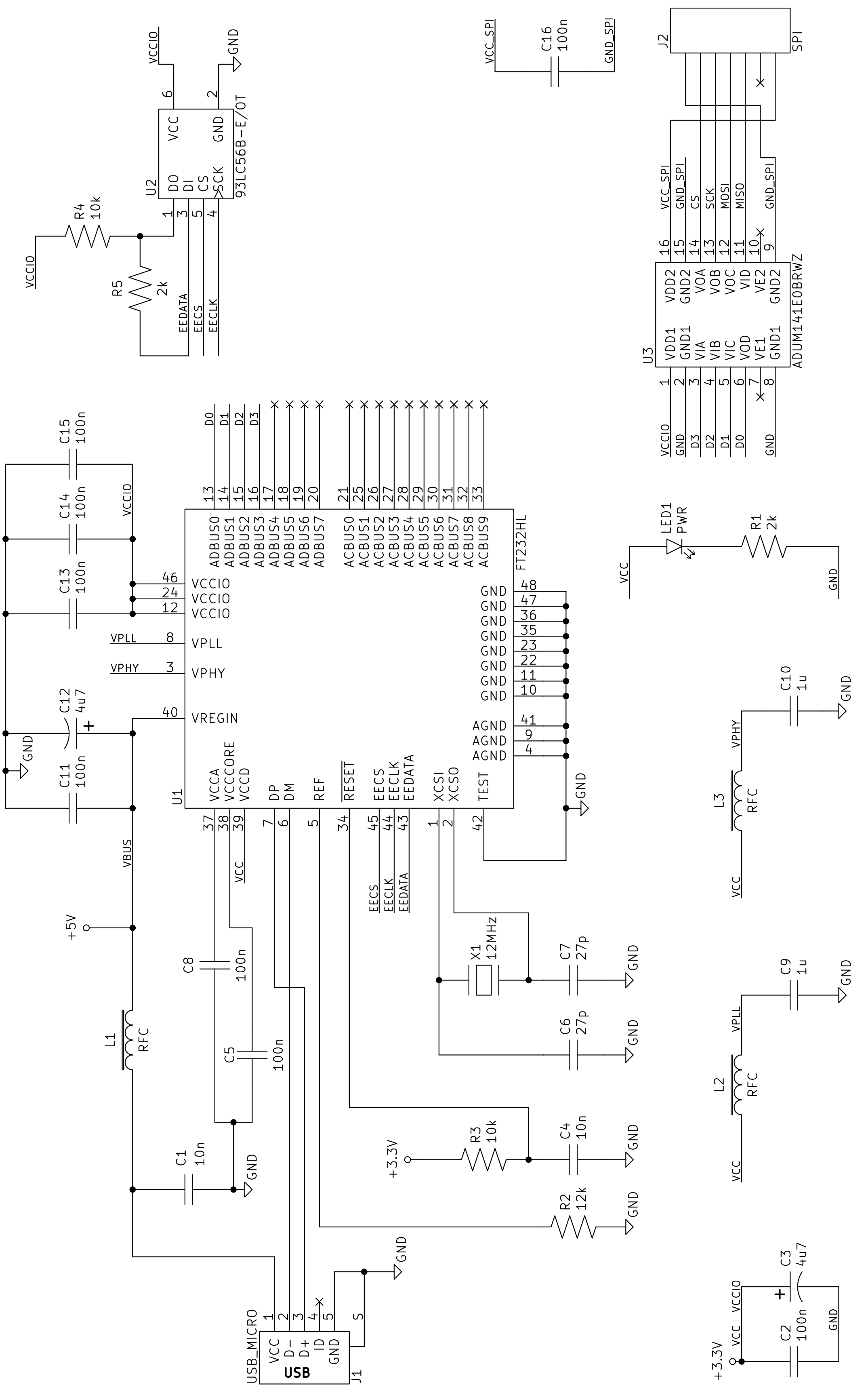

Figure 9: Isolated USB-to-SPI interface module schematic

SA5301A-DEMO SOFTWARE

Overview

The SA5301A-Demo software can interface to the SA5301A device via any USB interface module based on the FT232H / FT2232H / FT4232H device family. It allows writeable registers to be configured and the information in the readable registers to be accessed and displayed in a useful format.

Disclaimer

The demo software is intended for demonstration and evaluation purposes of the SA5301A integrated circuit. No guarantee can be made regarding the correctness of the data displayed under all circumstances, so the software may not be used in any form of formal energy metering or monitoring application. SA5301A-Demo is available in binary form only, the source code has not been made available. The disclaimer needs to be accepted before the software will run.

System Requirements

SA5301A-Demo requires a PC running at least Windows 7 (32-bit or 64-bit) with an available USB 2.0 port. The critical signal timing is handled by the FTDI interface chip, but the data rate between the FTDI chip and the software is important if accurate timing is to be maintained. A multi-core processor with a few 100 MB available memory should suffice, it might be advantageous to close other running applications if timing lag is being experienced. In order to communicate with the the FTDI device, the D2XX driver from FTDI needs to be installed. It can be downloaded and installed from ftdichip.com.

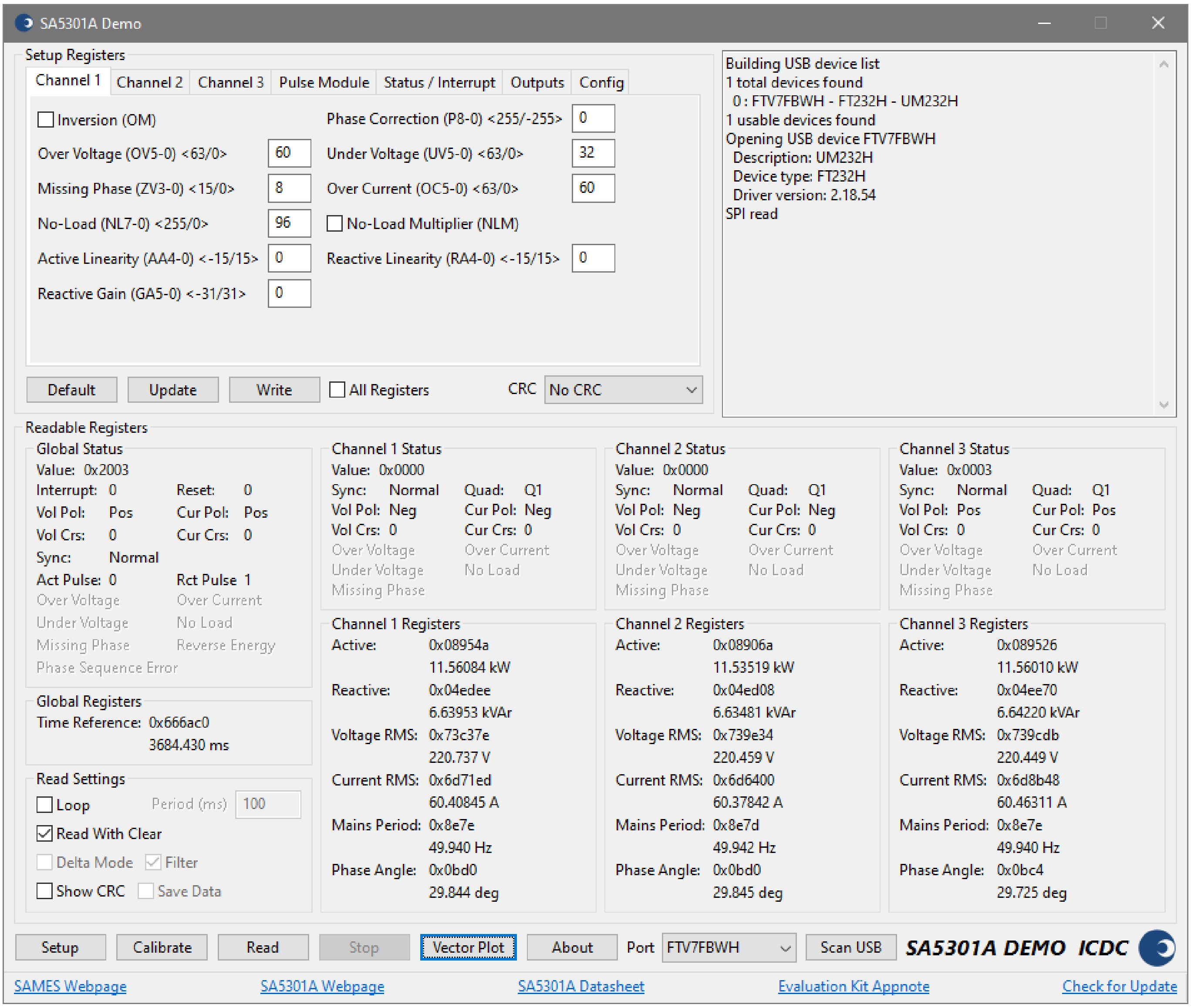

Figure 10: *SA5301A-Demo, Main window*

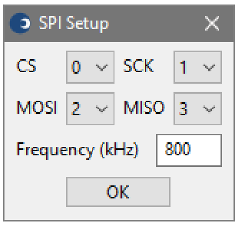

***Figure 11:** SA5301A-Demo, SPI Setup window*

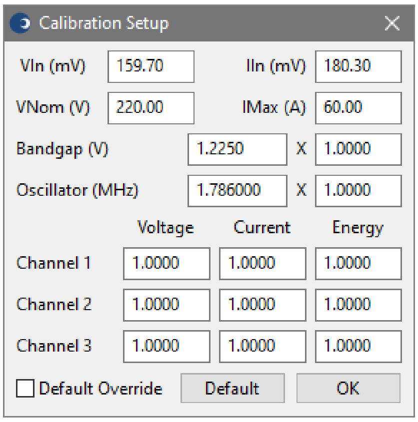

***Figure 12:** SA5301A-Demo, Calibration Setup window*

Setup Procedure

The following procedure should be followed to set up the SA5301A evaluation kit. Refer to Figure 10.

- Set up an RM5301ASAR module or alternate PCB containing an SA5301A energy metering device. Ensure the module is powered up, and that a measurable 3 phase mains network with an appropriate load is connected.
- Connect a compatible USB-to-SPI interface module as described in the previous section to the SPI port of the SA5301A.
- Connect the interface module to a PC with the latest versions of the FTDI D2XX drivers and SA5301A-Demo installed.
- Run SA5301A-Demo, read and accept the disclaimer.
- Click “Scan USB”, this will scan for all compatible FTDI devices connected to the PCs USB ports. The list of connected devices will be displayed in the log window. The USB-to-SPI interface module should be listed.
- Connect to the USB-to-SPI interface module by selecting its identifier in the “Port” selector. If a FT2232H or FT4232H mini module is being used, multiple device identifiers will be listed for the module, the selection must match the data port to which the SPI signals were connected.
- Click “Setup” to bring up the SPI Setup window, Figure 11. Here it is required to set the bus port pins that have been connected to the various SPI interface pins of the SA5301A. Set each of the four signals to the relevant bus bit used on the FTDI interface device. The SPI clock frequency can also be changed, the default is 800 kHz. It can be set to any lower value. As per the SA5301A data sheet, values exceeding half the on-chip oscillator frequency will violate timing constraints and cause faulty communication.
- Click “Calibrate” to bring up the Calibration Setup window, Figure 12. There are 4 initial setup requirements that need to be done. Set the VNom and IMax values to the V_{NOM} and I_{MAX} values used during the RM5301ASAR module design. Also the VIn and IIn values need to be set to the input voltages at V_{NOM} and I_{MAX} that were calculated during the module design. All other values can be left at default for now.
- The software is now set up and ready. It should be possible to read the SA5301A registers by clicking “Read”, if everything is set up correctly. This can be verified by observing the time reference register which should be changing at the correct rate between repeated reads.
- If an energy load is connected to the SA5301A the other readable registers should function as well.

Debugging Connection Issues

If the above procedure is followed correctly and all connections and power supplies are correct, the SPI reading should function. If not it is best to double check everything and repeat the setup procedure. Should the PC at any time loose connection to the USB-to-SPI interface module, the module USB scan and selection procedure needs to be repeated. If the module can be accessed, but no data or corrupt data is being received, the most likely cause is a missing power supply to the SA5301A or an incorrect data bit setup. If the time register reads correctly and seems to increment at the correct rate, it can be assumed that the setup is correct and will function as desired.

Reading SA5301A Registers

The SPI interface read thread that triggers whenever “Read” is clicked reads all readable registers of the SA5301A and displays the results in the the “Readable Registers” section of the software, see Figure 10. The “Global Status” and “Channel Status” subsections display the information contained in the global and channel status registers respectively. The timing reference register is the only global readable register and its value is displayed in the “Global Registers” subsection. The “Channel Registers” subsections display the register contents of the individual channels of the SA5301A. The first value displayed for any register is always the actual register value that was read, in hexadecimal notation. The second value is a processed value that uses the various formulas in the SA5301A data sheet to derive usable parameters from those raw register values. In some cases, clicking on this processed value brings up a pop-up menu to select an alternative calculated quantity. If the displayed quantity is changed, the SPI read must be rerun to obtain a value.

Register Read Options
Some options regarding the mode in which registers are read can be changed in the “Read Settings” subsection.

- ***Loop**:* In this mode the registers are read continuously. The read period can be set up using the “Period” value. Values from 10 ms upwards are sensible, smaller values will result in poor timing, especially on less powerful PCs. The registers will be read and displayed continuously until the “Stop” button is clicked.
- ***Read With Clear**:* This uses the ’read-with-clear’ SPI command to read the registers, rather than the standard ’read’ command. Those registers supporting this feature will now operate in delta mode, where the value obtained is the change in value since the last read. The calculated register quantities will change accordingly. This mode is only available if loop reading is enabled.
- ***Delta Mode**:* This is essentially identical to the “Read With Clear” setting, except that the delta mode is implemented in software rather than using the read-with-clear feature of the SA5301A. This mode is only available if loop reading is enabled. Only one of the delta modes can be activated at a time.
- ***Filter**:* A simple 8-point moving average filter is applied to the calculated register values before being displayed. This is useful to reduce measurement noise, especially at very low mains currents. This setting has no effect unless loop mode is activated. Also the raw hexadecimal register data is not filtered, neither is the data for the global and bank status registers.
- ***Save Data**:* For further analysis or debugging purposes, the data that has been read from the SA5301A in loop read mode can be saved to a file. If this setting is enabled a file name is requested once the register reading thread is terminated and the register data will be written to that file. The file format is text based, one line per register read with each line containing 25 values separated by single spaces. The sequence of values is:
  - Counter in 6-character decimal, increments by one for every read
  - Elapsed time since reading started in milliseconds, 9-character decimal
  - Global status register in 16-bit hexadecimal
  - Time reference register in 24-bit hexadecimal
  - Bank status register channel 1 in 16-bit hexadecimal
  - Active energy register channel 1 in 24-bit hexadecimal
  - Reactive energy register channel 1 in 24-bit hexadecimal
  - Voltage RMS register channel 1 in 24-bit hexadecimal
  - Current RMS register channel 1 in 24-bit hexadecimal
  - Mains period register channel 1 in 16-bit hexadecimal
  - Phase angle register channel 1 in 16-bit hexadecimal
  - Bank status register channel 2 in 16-bit hexadecimal
  - Active energy register channel 2 in 24-bit hexadecimal
  - Reactive energy register channel 2 in 24-bit hexadecimal
  - Voltage RMS register channel 2 in 24-bit hexadecimal
  - Current RMS register channel 2 in 24-bit hexadecimal
  - Mains period register channel 2 in 16-bit hexadecimal
  - Phase angle register channel 2 in 16-bit hexadecimal
  - Bank status register channel 3 in 16-bit hexadecimal
  - Active energy register channel 3 in 24-bit hexadecimal
  - Reactive energy register channel 3 in 24-bit hexadecimal
  - Voltage RMS register channel 3 in 24-bit hexadecimal
  - Current RMS register channel 3 in 24-bit hexadecimal
  - Mains period register channel 3 in 16-bit hexadecimal
  - Phase angle register channel 3 in 16-bit hexadecimal

  The file contains the raw register data, as read from the device, without any further processing. Up to 300 000 register reads can be saved.

SPI CRC
The built-in SPI CRC feature on the SA5301A can be activated, either with or without clearing the CRC register every time it is read. Use the “CRC” selector to set which mode is desired. If enabled, a CRC check is appended to every SPI transaction. Setting the “Show CRC” option will display the result of every CRC evaluation in the log window, with this setting off only CRC errors will be display. When CRC without clear is enabled, the software needs to remain in synchronization with the device. If this is synchronization is lost CRC errors will result. Simply resetting the CRC selection should resolve this issue. Always make sure a device is connected to the software and can be successfully accessed before changing the CRC selection.

Data Calibration
Some aspects of the calibration feature have already been discussed in the setup section. The following is a brief description of the additional calibration features that can be used to correctly calculate the measured quantities from the SPI register data. Refer to Figure 12.

- ***Bandgap, Oscillator**:* The formulas for certain calculations require the bandgap voltage and/or the oscillator frequency of the SA5301A. One method of calibration is to supply the algorithms with the actual bandgap voltage and oscillator frequency of the device being measured. The input fields allow the bandgap voltage and oscillator frequency to be adjusted and scaled by a factor. The bandgap voltage can be measured on the VREF pin of the device. The oscillator frequency is best measured by determining the pulse width of the output pulses from the pulse generation module. For a default pulse module setup the pulse width is 128 clock cycles wide.
- ***Calibration Factors**:* 9 independent calibration factors can be set, one each for voltage, current and energy on each channel. The VRMS calculation uses the voltage calibration factor, the IRMS calculation uses the current calibration factor and the active and reactive energy calculations use all three.

- ***Default**:* Clicking this button will reset all calibration and setup data back to the initial default values.
- ***Default Override**:* Setting this option will ignore all entered calibration and setup data and use the software default values without resetting the data back to default values. SA5301A-Demo saves all setup, configuration and calibration data when closed and reloads the settings when it is run again.

Voltage/Current Vector Plot

The RMS voltage, current and phase angle data can be visually displayed in a vector plot. Click the "Vector Plot" button to activate the plot and perform an SPI read to obtain and display data. The plot is also updated continuously in loop read mode. This plot assumes that the phase angle between voltages is 120°. The voltage and current scales of this plot may be manually adjusted or can be set to auto-scale mode. The solid circle represents 100 % of the scale magnitude.

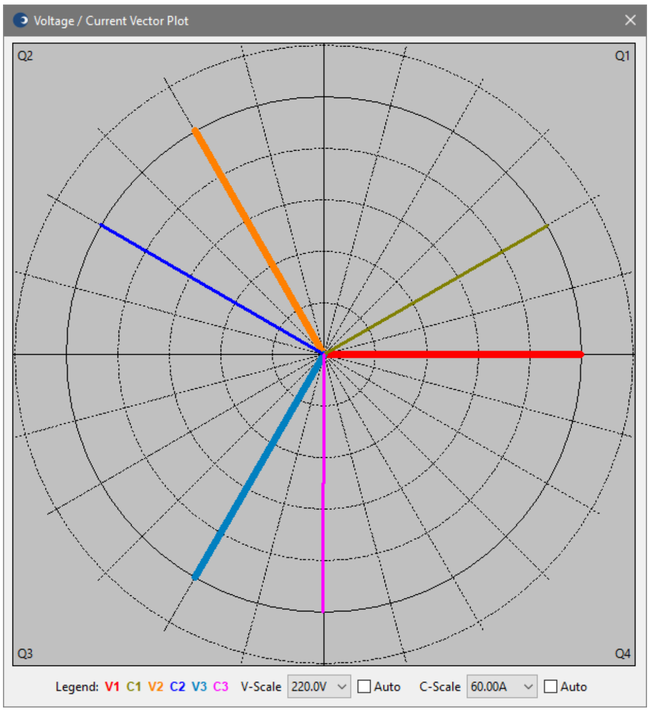

Figure 13: *SA5301A-Demo, Voltage/Current Vector Plot window*

Writing SA5301A Registers

The SA5301A-Demo software also allows the writeable registers on the SA5301A to be configured. This is done in the "Writeable Registers" section, see Figure 10. The tab pages can be used to find the various writeable registers and adjust the bits accordingly. Each setting has the name of the register bit or bits that is affects in brackets. Refer to the SA5301A data sheet for a complete description of what each setting entails.

The values within angled brackets, if present, represent the range of values that can be entered.

- ***Channel 1, Channel 2, Channel 3**:* On these tabs the bank registers for each of the three channels respectively can be set up. These are the channel settings register, the phase shift correction register, the voltage status parameters register, the current status parameters register and the channel performance tuning register.
- ***Pulse Module**:* All settings relevant to the pulse output module can be changed on this tab. Registers affected are the active and reactive pulse output divider registers, the pulse output calibration registers for the three channels and the pulse output setup register.
- ***Status/Interrupt**:* This tab allows all the bits of the status and interrupt setup register to be modified.
- ***Outputs**:* This tab is used to change the contents of the configurable outputs setup register.
- ***Config**:* Here the settings that control the SPI transaction by means of an SPI config transaction can be adjusted.

Any changes made to the settings in all tabs are not written to the device until one of the following buttons is clicked.

- ***Update**:* Only those registers that are affected by any settings that have been changed since the last write will be updated.
- ***Write**:* All writeable registers will be updated with the current settings.
- ***Default**:* All writeable registers will be updated with the default settings. The settings in all tabs are also changed back to the device defaults.

Register data may be written while the readable registers are being accessed in loop read mode. In this case the write transactions will be appended to one of the read transactions.

The settings on the "Config" tab affect the format of the SPI transactions. The software will remain in synchronization with the device and adjust the SPI reading routines to take these settings into account. Data errors will result if these settings are out of sync. If corrupt data is being displayed as a result of these settings having been changed, cycle the power on the SA5301A and restart the software. Changes on the "Config" tab will not be updated to the SA5301A if a loop read is in progress, since this would require the read transaction to be altered as well. A notice to this effect is displayed in the log window.

Also note that the writeable registers on the SA5301A cannot be read, there is no way for the software to retrieve the information currently stored in the registers. The values reflected by the settings on the tabs will not correspond to the values in the device registers, unless any changes made are written to the device.

ICDC

NOTES

DISCLAIMER

Any sales or technical questions may be sent to our support e-mail address:
support@sames.co.za

For the latest updates on data sheets, please visit our web site:
www.sames.co.za

INTEGRATED CIRCUIT DESIGN CENTRE (PTY) LTD
a division of
SOUTH AFRICAN MICRO-ELECTRONIC SYSTEMS (PTY) LTD

Tel: 012 333 6021
Tel Int: 00 27 12 333 6021

PO BOX 15888
LYNN EAST 0039
REPUBLIC OF SOUTH AFRICA

UNIT 4, PERSEQUOR CLOSE
49 DE HAVILLAND CRESCENT
PERSEQUOR TECHNOPARK
LYNNWOOD, PRETORIA
REPUBLIC OF SOUTH AFRICA