Guidelines for kWh-Meter Design

The purpose of this application note is to provide guidelines for design of high-precision, solid state kWh-meters using Atmel's AT73C500 with AT73C501 or AT73C502 chipset. These guidelines also apply to any application where there are 16-bit analog-to-digital converters on the same circuit board with digital components, such as digital signal processors (DSPs) and microcontrollers.

The ATEK500 Evaluation Kit
Atmel's ATEK500 is an energy meter evaluation kit, designed to operate within one-percent accuracy limits as defined in the IEC61036 standard. The purpose of the kit is to give the customer a hands-on experience of the AT73C500 + AT73C501 chipset and not to perform as a commercial energy meter. Apart from functionality, accuracy and safety aspects, care has not been taken to design the kit to satisfy requirements one may set on a commercial meter for industrial or domestic use. The standard ATEK500 kit is, therefore, unsuitable for commercial production and it is not recommended to use the kit as a starting point for energy meter design.

Board Layout Considerations
One of the most important things to remember is to provide an environment that is as free of noise as possible. Noise propagates and may influence the analog signals before sampling, thus interfering with the input data for all energy calculation. If there is noise in the signal already before sampling, the error will accumulate during digital processing.

ATEK500 Printed Circuit Board
The Printed Circuit Board (PCB) layout of the ATEK500 is adequate for class 1 meters only. It is not recommended to use the layout of the ATEK500 PCB as a reference for meter design, at least not for meters aimed at higher accuracy than one percent.

Component Placement
Analog and digital components should be positioned on separate parts of the PCB. Analog components should be grouped together and positioned so that the trace line lengths are minimized, especially those going to the analog input pins. Also, the digital components should be grouped together, not surrounding or being surrounded by the analog components.

All bypass and decoupling capacitors must be located as close as possible to the device pins, the zero potential end of the capacitor being directly attached to the ground plane. If the same pin is to be decoupled by more than one capacitor, the one with the smallest value should be the one closest to the pin. SMD components are preferred.

Trace Lines
Position the components so that the digital signals are as far apart from analog signals as possible. For example, do not set the data bus or clock signals close to the analog inputs of the converter. Keep all traces short. Especially, the trace length of clock lines, data buses and analog input signals must be minimized.
It is recommended to fill empty regions between traces with copper, directly connected to the proper ground plane (ground planes explained below). The copper fill should be attached to the digital ground plane if enveloping digital signals or to the analog ground plane if surrounding analog signal traces. Do not leave copper fills unattached.

Component Types
Resistors used on the analog side should be of metal film type. Capacitors should be of type NPO/COG.

Power Supply and Ground
Supply lines must be robust in order to guarantee noiseless and stable voltage levels. It is recommended to power the device with separate supply lines for analog (VDA and VDDA) and digital (VCC).

Crystal Oscillator
Use a single crystal oscillator only. If an external microcontroller is to be included, try to operate it at the same frequency, using the same crystal. If different operating frequencies are required for the microcontroller and the DSP, try replacing the crystal oscillator with one higher than nominal and use a divider to step down the frequency. Place the crystal close to the ADC.

Signals between Boards
If digital signals leave the board, always use a buffer to drive them.

Grouping of A/D Converters
The VDA and VSA lines power analog converters 1, 3 and 5, while VDDA and VSSA lines are used to power converters 2, 4 and 6, as shown in Figure 1.
Typically, the supply lines would be combined, powering all six converters from the same analog power source.

Grounding
Ground pins VSA, VSSA and VGND of the device should all be connected to the analog ground plane. Physically, the analog ground plane should be located under the complete chip.

Supply Lines
Although not recommended, a single power supply may be used to power both the analog and digital parts of the device. Regardless of the number of power supply lines used, however, it is recommended to use low value series resistors (around 10 Ohms) between power supply of the meter and supply pins of the device. A better alternative is to use series inductors of some µH.

Ground Planes
The meter PCB should include individual ground planes for analog and digital. Ground planes must be on the same copper layer and at least some millimeters apart. The ground planes must not overlap at any point and the gap between the planes should not be crossed by any trace. The ground planes must not surround each other and must be connected at a single point only. The location of the connection point does influence the performance of the meter and it is, therefore, recommended to have several vias or jumpers for alternate connection. Good connection points are near the power supply or near the ADC.
Switching Power Supplies
In the case of switching power supplies or DC to DC converters, the switching frequency should be locked to the same frequency used by the ADC.

Analog Front End
Interfacing the A/D converter to the power grid is more than just providing resistor ladders for voltage downscaling and transformers for sensing current.

Current Transformers
Cheap current transformers (CT) may introduce errors to the signal, such as line delays of fundamental and higher order frequency components (harmonics). Also, the current transformer may increase the distortion of the input by adding more harmonics to the signal. Using accurate signal interfacing components guarantees high accuracy input data and improved overall accuracy of calculations. Signal conditioning components, especially the CTs, of the ATEK500 are designed for class 1 accuracy only.

Typical Wiring
If there are DC levels of interest to be expected in the input signal, the connections to analog inputs at the ADC must be referenced to AGND. Generally, only AC signals are of interest, in which case the signals should be connected to the ADC using bypass capacitors, as shown in Figure 2.

The typical front end connection above interfaces the ADC to the main signals via resistor dividers, current transformers and some input protection components. Component values shown are for maximum ratings of 270 volts and 80 amperes.

At the current input stage, the zener diode (ZD1) is for input protection and can be of type BAT-85, or equivalent. In the voltage-input stage, the varistor (VDR) is used to protect the circuit from voltage peaks.

Figure 2. Typical Analog Front End with Recommended Component Values
The A/D Converter

The A/D converter chip can be of type AT73C501 (single-ended) or type AT73C502 (differential-ended). In order to guarantee high accuracy of the meter, it is important to give the A/D converters an environment that accommodates for reliable conversion.

Positioning

Make sure the whole ADC is positioned over the analog ground plane. Trace lengths can be minimized and kept apart from noisy, digital signals if the ADC is properly located and rotated on the PCB.

Stabilizing Capacitors

Use capacitors to decouple each power supply pin of the ADC to the proper ground plane. Recommended capacitor sizes are 100 nF and 1 µF. The smallest capacitor should be of SMD type and be positioned as close as possible to the power supply pins of the device.

Also stabilize VREF with respect to analog ground, as shown in Figure 3. It is recommended to use parallel coupled capacitors of size 10 µF and 100 nF, plastic and ceramic.

Use capacitors to stabilize AGND with respect to analog ground, as shown above. Capacitors of size 10 µF and 100 nF are recommended.

Figure 3. Recommended Conditioning of AGND and VREF

Temperature

Being accurate at ambient temperature is one thing, but the meter must also maintain its accuracy as the temperature changes. One source of error is the gain drift induced by a change in temperature.

The full-scale output of the ADC is fixed to the voltage reference level. When using internal reference, the bandgap voltage will typically change with some 0.01% per degree change in temperature. Theoretically, it is possible to compensate for this change, given the temperature of the meter is known. A simpler way to give stability over temperature is to use an external voltage reference with low drift.

External Voltage Reference

A class 1 meter does not require external voltage reference. For an IEC60687 standard meter of class 0.5, a voltage reference of 50 ppm accuracy is recommended.

For meters of class 0.2, a voltage reference of 25 ppm is recommended. The initial accuracy of the reference is not of importance, since gain errors are easy to correct by means of calibration.

External interference

Energy meters, especially in industrial environments are subject to electromagnetic (EM) interference from a various number of sources. EM signals may be induced into the meter and in the analog signal path. Already a low level of induced EM interference may distort the measurement results severely. Care should always be taken to maximize the amount of EM that the meter can withstand. The meter case should be shielded on the inside and, in some cases, it may be necessary to additionally screen the actual chipset or the meter PCB.