A Low-end Approach to Tamper-proof Energy Metering with the AVR465

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TRADITIONALLY, ELECTRICAL ENERGY HAS BEEN MEASURED USING ELECTROMECHANICAL METERS, ALSO KNOWN AS FERRARIS METERS OR, MORE DESCRIPTIVELY, TURNING-WHEEL METERS. GRADUALLY, AND AT AN INCREASING RATE, MECHANICAL METERS ARE NOW BEING PHASED OUT BY ELECTRONIC. CONTEMPORARY DESIGNS INCLUDE THE USE OF HIGH-RESOLUTION A/D CONVERTERS, 16- OR 32-BIT DSPS, µCS.

ATMEL NOW CHALLENGES THIS SETTING BY INTRODUCING A CONCEPT WHERE A SINGLE LOW-END, COST-EFFECTIVE, 8-BIT AVR MICROCONTROLLER HANDLES ALL MEASUREMENT TASKS REQUIRED IN A SINGLE-PHASE METER. THE DESIGN PRESENTED IS A TAMPER-PROOF METER, AIMED TO PARTICIPATE IN THE MOVEMENT AGAINST ENERGY THEFT BUT IT IS EASILY MODIFIED TO FIT OTHER ENERGY METERING DEMANDS, AS WELL.

Introduction

Energy or power metering is about collecting data on energy consumption for billing purposes; the electricity utility provides customers with energy and customers pay for the amount of energy consumed. The energy meter measures energy and stores billing data for the utility provider to collect, either manually or electronically.

Traditionally, energy meters have been mechanical but are rapidly being replaced by electrical due to many reasons. Foremost, the price of electronic meters has come closer to that of mechanical but other factors are also playing increasingly more important roles. Electronic meters are fast and easy to calibrate, calibration can be automated, measurement results don't degrade over time and it is easy to add more sophisticated functions like remote reading to an already electronic design. In selected areas the most important issue, however, is that electronic meters can resist tamper attempts and continue to measure reliably in situations where the mechanical meter could not.

It has been estimated that some utility companies are loosing more than 40% of their revenue due to defective or illegal connections, defective or dead meters and meter tampering. The major cause for revenue loss is tampering, i.e. illicit interference with the meter and wiring in an attempt to withdraw more energy than the customer is paying for. Mechanical meters are highly subjected by tampering but most pilfering schemes can be detected, signalled and even overcome by electronic meters. Replacing mechanical meters with electronic gives many benefits, including an immediate improvement in revenue yield.

Application note AVR465 describes how to use the AVR microcontroller to build a tamper-resistant meter. Besides meeting all the demands on tamper prevention it gives all the benefits one can ask for in a modern energy meter. Also, the design is easily customized to fit special needs, such as remote reading and demand recording. It is easy to replace the default ATmega88 with the pin-compatible ATmega168 and gain twice the Flash memory for program enhancements whereas migrating to, say an ATmega169 gives the benefit of an integrated LCD driver.

Tamper-proof metering is a special case of single-phase metering, the difference being that tamper-proof metering requires current to be measured in live and neutral wires, whereas traditional single-phase metering relies on only one current transducer. Application note AVR465 is easily modified (reduced, actually) to fit traditional single-phase metering by simply removing the second current transducer, related measurement algorithms and tamper logic. The reduced code roughly fits a 4kB AVR microcontroller such as the ATmega48, cutting the overall cost of the meter. Current transformers are typically expensive and easily mount up to a quarter or even half of overall component cost. As a result, the bill of materials of a single-phase meter can be nearly half of that of the presented tamper-proof design.

Key Features and Benefits

Albeit many mechanical meters are yet to be replaced, there are many solutions for electronic metering. The three most used solutions are based on ASICs, ASSPs and microcontrollers. Very few companies use ASICs anymore, leaving the struggle between ASSPs and microcontrollers.

Cost

Meter manufacturers naturally want to drive the overall cost of the meter as low as possible. As a discrete component, the ATmega88 used in this application is less expensive than most ASSP devices and rival microcontrollers. Considering the integrated peripherals of the ATmega88, the price benefit increases, as there is no need to include external devices such as an EEPROM for calibration data storage.

In addition, many ASSP designs include a microcontroller.

Flash Memory

Because of the competition, many manufacturers want to offer a meter with unique features or personalized settings. Also, since many meters are based on the same technology and the use of similar components, manufacturers want to offer something personalized, a meter with unique functions. In addition, it should be easy to make modifications to the design, when required.

The integrated Flash memory of the AVR makes all the above possible at no extra cost. The firmware is easily customized to fit any needs of the manufacturer and it can be updated at any time, even in the field. This is a huge benefit over ASSP designs, which are fully static and therefore make the design easy to copy by rival meter manufacturers. The AVR enables the firmware to be securely locked inside the microcontroller, making it impossible to copy the design but yet allowing the firmware to be updated at any time using a bootloader. Nonvolatile memory can also be used in more advanced meters for demand recording and logging measurement data.

Integrated Peripherals

The AVR microcontroller includes many peripheral

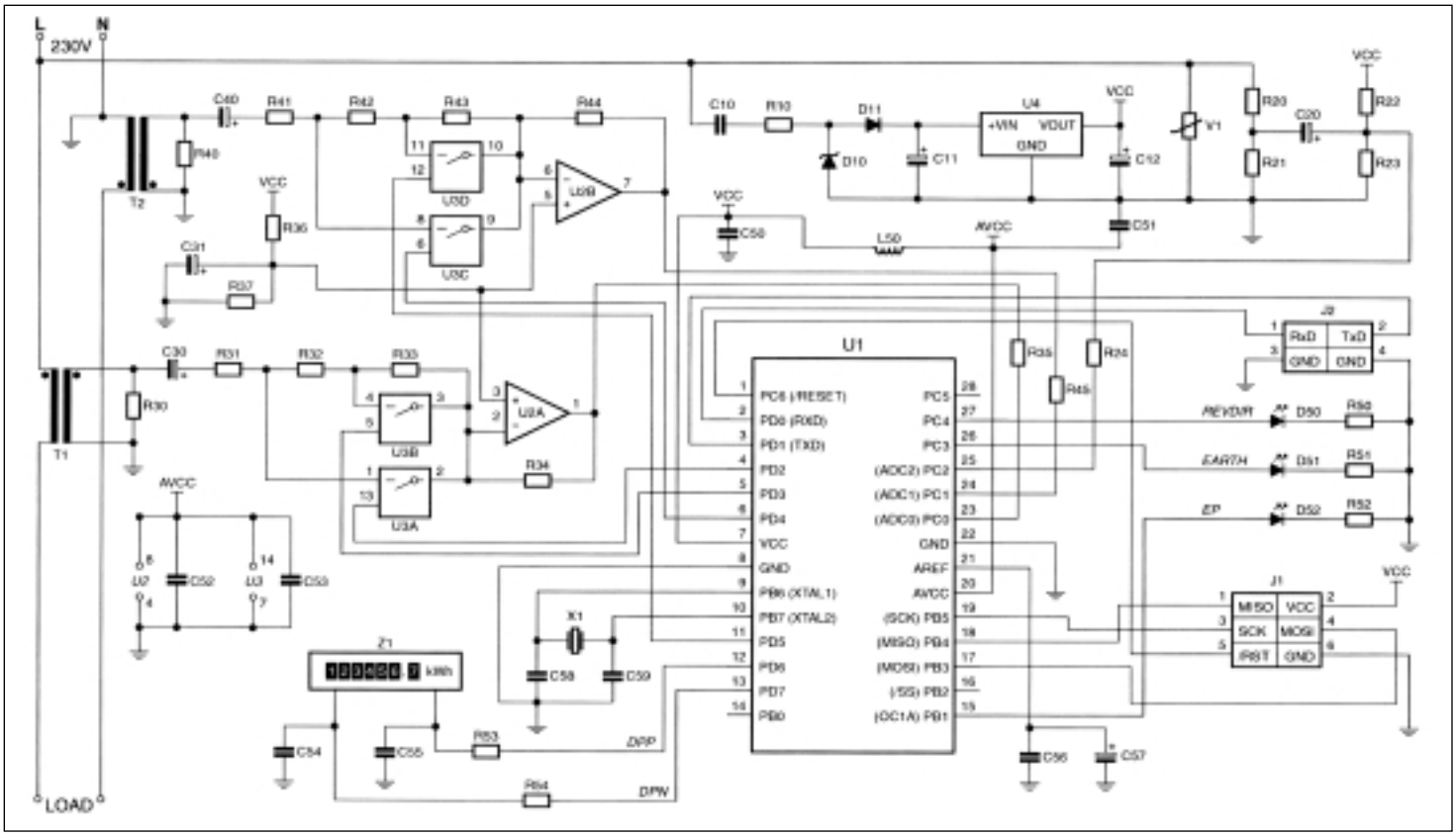

Figure.1: AVR465 Schematic

functions not available in any ASSP and not many rival microcontrollers. The USART interface enables easy remote reading and calibration via the PC serial port, but also comes in handy if the meter is to be equipped with an optical interface. ASSP designs typically do not include serial interfaces at all. Also inherent to the ATmega88, SPI and TWI enable fast and efficient communication with external components, for example. In addition, the fully programmable I/O ports of AVR microcontrollers allow easy control of other external components, such as LEDs.

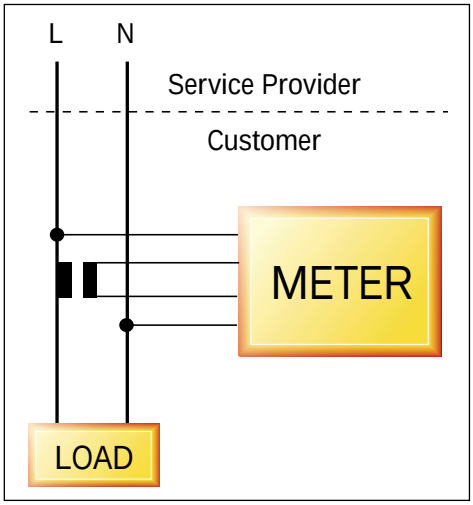

Figure 2: Single-phase Metering

Ease of Migration

The meter design is easily customized, not only because of the integrated Flash memory but also because the firmware readily migrates to other AVR microcontrollers. For example, in a matter of seconds the firmware is migrated to ATmega168, effectively doubling the Flash size without changing the pin configuration. Similarly, the design can be stripped down to fit the 4kB Flash of an ATmega48, effectively reducing the component cost. Additional features, such as an LCD driver are readily added by migrating to ATmega169, for example.

Target Applications

Application note AVR465 describes a tamper-proof single-phase meter, but it also serves well as a starting point for other types of energy meter designs.

Tamper-proof Single-phase Meters

Tamper-proof meters rely on two current transducers, where traditional single-phase meters rely on one. The idea is to measure current flowing to the load (through the live wire) and current returning from the same (through the neutral wire). The meter then assesses the validity of the measurements and uses the assumption to overcome attempts of tampering.

Traditional Single-phase Meters

Tamper-proof meters are required in selected regions where revenue loss due to pilfering is significant. Traditional single-phase meters do not need two current transducers and, more to the point, regional demands may even forbid meter connections to cut the neutral wire due to safety regulations.

The design presented in application note AVR465 is readily reduced to a traditional single-phase meter. Measurement circuitry and measurement algorithms related to the neutral wire are easily removed, effectively reducing the bill of materials at the same time. Reductions in board space, component cost and firmware size are typically between 25% and 50%.

Advanced Single-phase Meters

An advanced meter typically does something else than just measures and records energy consumption. Additional features such as remote reading, demand recording and displaying measurement results on an LCD are typically considered. Remote reading is readily implemented using Atmel's SmartRF™ solutions, for example. Demand recording and profiling requires little more than a modification to the firmware and some spare Flash or EEPROM, both of which are already included on-chip. LCD support is also an option in some AVR microcontrollers.

Single-phase, Three-wire Meters

Single-phase energy service in the US is distributed using three wires; two for live voltage and one as grounded neutral. Similarly as in the AVR465 design, two transducers are required for measuring current in both live wires. Minor changes to the hardware and a

few changes to the firmware effectively transform the AVR465 design into a single-phase, three-wire meter.

Polyphase Meters

Most polyphase energy service is three-phase. The design presented in AVR465 serves as a starting point in a polyphase meter design where each phase is monitored by a separate microcontroller.

Development Tools

Firmware development, downloading the code to the microcontroller, reading measurement results and calibrating the meter can all be done using Atmel's AVR Starter Kit, STK500. For program development and debugging purposes and for easier access to on-chip EEPROM during calibration Atmel recommends using AVR development tool JTAGICE mkII.

Related Products

As part of an attempt to minimize the theft of energy, many utility companies consider using more than just a stand-alone meter for billing and monitoring. Although an energy meter built around the principles illustrated in AVR465 does function properly under listed tamper conditions people involved in energy theft sometimes use brutal methods, including partial or full destruction of the meter. Some meter manufacturers may therefore consider enhancements to the basic design, such as remote reading or prepayment systems.

In addition, the meter manufacturer may want to provide a wide product range, with meter options altered either during production (as population alternatives), or after (as plug-ins). Market volumes for ehanced meters may not be as large as those for plain, but the manufacturer probably wants the option to exist in the basic meter design. Hence, additional circuitry needs to be designed already at an early stage.

Remote Metering

Remote metering is typically not a default option, but something provided for selected customers. The preferred customer base may include suspicious clients or those located very close to others, such as in a high-rise building. In the latter case, tens or hundreds of meters may use RF to send billing data to a common collector unit, which then transmits the data package to the service provider using telephone modem, cable TV, internet connection, or similar.

Atmel has a broad range of communication products that fit remote reading demands, such as Wireless LAN, BlueTooth, SmartRF, and similar devices.

Prepayment Metering

Prepayment metering means the meter is equipped with an interface to a token or a chip, which contains validation data that either allows or prohibits energy withdrawal. If no validation is found the meter will cut power line connections, for example when all money tokens have been used. Prepayment meters are often used in temporary connections.

Atmel has a selection of SmartCard products that fit prepayment demands.

The ATmega88 Microcontroller

ATmega88 is a fresh addition to the well-established 8-bit AVR Flash micontroller family. The mega88 (and pin-compatible ATmega48 and ATmega168) AVR Flash microcontrollers expand the AVR's reach into the low pin count, medium memory size market. Designed with low-power consumption in mind, this sub-family introduces many of the high-end AVR features into the low price point market. Features such as Self-Programmable Flash, Data EEPROM, and On-Chip Debug (OCD) are rarely seen on low cost devices in this range, but Atmel's high-density non-volatile memory process technology allows the integration of such advanced features at minimum cost.

Further information can be obtained from Atmel's Web site at www.atmel.com. Contact: Kim Meyer, AVR Applications Group, Finland. Tel: +358 (0) 9 4520 820, email: kmeyer@atmel.com.