Achieving Accuracy in Digital Meter Design

Introduction

This application note would mention the various factors contributing to the successful achievements of accuracy in a digital energy meter design.

These factors would cover both the hardware and software aspect in the implementation.

Target Device

Not Applicable.

Contents

1. Overview

With the increasing emphasis on revenue protection and increase of revenue by the utilities, an accurate and reliable power measurement has become significantly essential. With electromechanical meters, it could not meet these requirements and therefore, the adoption of electronic measurements is increasingly popular as it is more robust and accurate. The deregulation occurring in other countries also accelerated the adoption of the electronic measurements.

In order to be able to provide accurate energy measurement, the digital meter plays an important role. Hence, significant effort must be spent to ensure that the design of the digital meter complies with accuracy standards outlined by the governing authority in each country.

In the following sections, we would mention about the critical components required to achieve accuracy of a digital meter in two aspects: hardware and software aspect.

2. Hardware Consideration

The various factors of hardware design that would contribute to the system for the achievement of accuracy are listed as below: -

2.1 High Resolution by 10-bit Analog to Digital Converter [ADC] & its Reference Voltage stabilization

An analog to digital converter accepts an analog input a voltage or current and converts it to a digital value that can be understood by a microcomputer. The resolution of an ADC is determined by the reference input and number of bits. The resolution defines the smallest change in voltage that can be measured by the ADC.

For H8/38024 microcomputer, there is only analog voltage input available, and this is being fed into the reference voltage module within the device, which then provides the voltage to the comparator based on the AVCC input reference.

Therefore, with reduction in this AVCC value, say 3.3V, the resolution can be improved and it is calculated as follow:

$3.3/2^{10} = 0.00322$V [this derives to 0.097% of the total range]

However, the maximum voltage that can be measured is capped at 3.3V.

Similarly, as mentioned before, the resolution of an ADC is dependent on the reference voltage input. It plays a pivotal role in the success of achieving an accurate result. For a microcomputer, which uses the supply voltage as a reference, for example, a 3.3V system, this means the reference voltage is always 3.3V; hence measuring a 2.5V signal with an 10-bit ADC, would produce the following result:

$$(Vin \times 1024) / Vref = (2.5 \times 1024) / 3.3V = 776_{10} = 308_{H}$$

However, the value of 3.3V has a bearing on the accuracy of the result obtained. If the supply voltage is high by 1%, it has a value of 3.333V. This will yield a result as follow:

$$(Vin \times 1024) / Vref = (2.5 \times 1024) / 3.333 = 768_{10} = 300_{H}$$

Hence a 1% change in the supply voltage causes the conversion result to change by 8 count. The example cited shows that the stability of power supply input has an impact on the result obtained. Therefore it is mandatory to maintain a stable reference voltage to guarantee repeatability of values for the same input voltage, which does not fluctuate with temperature, loading and AC input variations. A good provision to achieve a stable reference voltage is to made use of a shunt regulator capable of delivering Fast Turn-On response, guaranteed thermal stability over applicable temperature ranges.

2.2 Gain Selection Network

The need for gain selection network is necessary because the output from the current transformer is very weak at low phase and neutral currents. As a result, this signal needs to be amplified to increase its resolution and also care is taken such that the signal amplitude lies within the linear region of the ADC to achieve higher accuracy. It is found that single gain amplification is insufficient over the entire range of current. Hence, a gain selection network with suitable fixed gains has been incorporated for this purpose, which can be selected by the microcomputer during range crossover.

2.3 Operational Amplifier Selection

In a digital meter design, operational amplifier used for example in the gain selection network mentioned in the previous paragraph, requires to be able to cater to the entire span between the negative and positive supply voltage as well as current. With the decreasing trend towards low power system, it is necessary to have the system make use of the entire voltage and current span to have usable dynamic range. This usable range has an influence on several parameters such as noise susceptibility, signal-to-noise (SNR) and dynamic range. In order to meet this requirement, a rail-to-rail type of operational amplifier is used.

Rail-to-rail operational amplifier can achieve a maximum output signal swing in systems with low single-supply voltages. Thus within a single gain selected, a wider range of input signal can be covered.

2.4 Passive Component Selection

Selection of passive component such as resistors and capacitors is conditioned such that these components exhibit least variation in the signal amplitude over the entire operating temperature range. Thus component with ±1% tolerance and 100ppm temperature coefficient is necessary.

2.5 Current Transformer Selection

In a digital meter design, when current transformer is employed, care must be taken during the selection of this current transformer. For a fixed frequency and fixed current position, the linearity error would vary with the current magnitude over the rated range of the current transformer.

As current transformer is made from magnetic materials and therefore, they may exhibit non-linear characteristic as well as may saturate when magnitude of current varies.

Therefore, it is important to select a current transformer with linear response over the entire operating range of the current.

As an additional note, current transformer also has inherent phase shift that changes the power factor of its output. Inductive and capacitive loads cause the measured ac power error to increase significantly and unacceptably as the mains power factor decreases. Hence this inherent problem can be overcome with digital compensation and automated calibration through software means.

2.6 PCB Design

In terms of the PCB design of the digital meter, it is a common practice to separate the analog signals from the digital signals to eliminate cross talks.

Methods range from providing separate ground plane for both analog and digital or dividing into analog region and digital region connected at a common point directly under the ADC. This common connection must be short and fat enough so that little voltage difference between the AGND and DGND pins of the ADC.

In addition, care must also be taken to ensure that this common connection does not encourage ground currents circulating between the analog and digital regions else it would defeat the purpose of having separate grounds.

3. Software Consideration

The various factors of software design that would contribute to the system for the achievement of accuracy are listed as below: -

3.1 Gain Switching

With reference to the gain switching network implemented and mentioned in the section 2.2 of the hardware consideration, similarly software control must be in place to control the switching of this gain network according to the ADC values.

If the value read by ADC is very small, then the software controls the switching such that the amplifier is set to a higher gain and if the value read by ADC is very big, the software controls the switching such that the amplifier is set to a lower gain. With this mechanism, the entire range of current is being covered and accuracy is achieved.

When switching from high gain to low gain, current needs to be increased and due to this, there is a possibility that the operational amplifier would saturate, hence it is important to switch the gain quickly. However, when switching from low gain to high gain value, a tolerance period should be added to prevent the toggle switching of gain index due to certain period of inaccuracy. This would be taken care by the software.

3.2 Sampling Rate

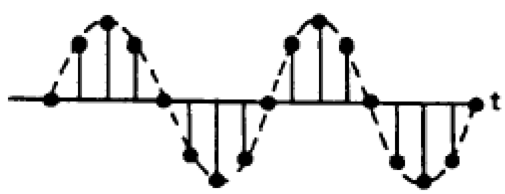
For a digital meter design, sampling of the AC voltage and current signals is performed either simultaneously or in a staggered manner by the ADC of a microcomputer. Sampling rate is the time at which the analog-to-digital converter (ADC) is sampling the AC signals.

The continuous analog data must be sampled at discrete intervals which must be carefully chosen to ensure that an accurate representation of the original analog signal. It is obvious that the more samples taken (at higher sampling rate), the more accurate the digital representation. However, if the fewer samples are taken (at lower sampling rate), a point is reached where critical information about the signal is actually lost. This would lead us to the Nyquist's theorem:

- An analog signal with a bandwidth of fa must be sampled at a rate fs ≥ 2fa in order to avoid the loss of information.
- If fs < 2fa, then a phenomena called aliasing will occur in the analog signal bandwidth illustrated in below figure, Eg. 4.

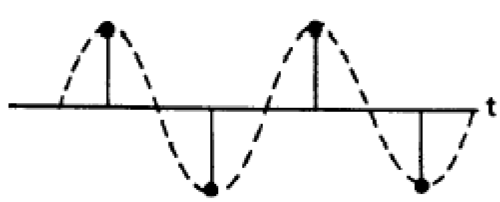
The following figures illustrates the Nyquist theorem:

Eg. 1 fs = 8fa

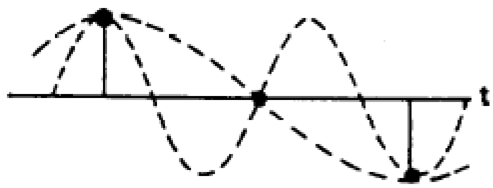


Eg. 2 fs = 4fa

Eg. 3 fs = 2fa



Eg. 4 fs = 1.3fa



In order to avoid loss of data, this sampling rate must be carefully derived such that it provides sufficient data for calculating of parameters collected such as voltage & current parameters.

As an illustration, samples per cycle are chosen as 32 and the sampling rate derived below would provide a good digital representation of the analog signal targeted.

Number of samples per cycle	=	32
Frequency of analog signal, fa	=	50Hz
At 50Hz, the sampling rate, ts	=	(1/50) / 32
	=	20 /32
	=	625usec
Hence, the sampling frequency, fs	=	(1/625usec)
	=	1600Hz

3.3 Calibration

Calibration is inevitable because in a real world design, a digital meter is never ideal such that it achieves good accuracy.

After the calculation of energy is obtained, this energy is multiplied with a calibration coefficient in order to bring the calculated energy to accurate value. To obtain this coefficient, energy is applied to a standard meter and the same energy is also applied to the meter under calibration. The energy read from the meters is compared to the nominal energy.

Taking an illustration for the calibration of the gain coefficient in the energy calibration, if the energy read from the meter under calibration is X watts and the energy read by the standard meter is Y watts, if the percentage error between the 'X' and 'Y' readings is more than ±0.5%, the meter is calibrated by changing the coefficient in the meter under calibration.

Calibration coefficient is calculated based on the formula below:

Calibration coefficient = Y/X

This value is multiplied with the calculated energy to achieve accuracy.

With the necessary calibration performed, the digital meter shall be able to perform the energy measurement accurately hence this has further strengthen the migration from electromechanical meter to perform electronic measurement.

4. References

1. *H8/38024, H8/38024S, H8/38024F-ZTAT Group Hardware Manual*, Revision 4, 26 May 2003, Renesas Technology Corporation.
2. *Analog-to-Digital Converters*, 1 May 2001, Embedded.com
3. *Application of Rail-to-Rail Operational Amplifier*, December 1999, Texas Instruments
4. *Fundamentals of Sampled Data Systems*, Analog Devices
5. *Current –Transformer Phase Shift Compensation and Calibration*, February 2001, Texas Instruments

Revision Record

Rev.	Date	Description	
		Page	Summary
1.00	Mar.15.04	—	First edition issued

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