Atmel AVR123: AT90PWM81/161 ADC Conversion Optimization Versus Temperature

8-bit Atmel Microcontrollers

Application Note

Features

- **Optimization of ADC conversion results versus temperature**
- **Applicable to the Atmel® AT90PWM81/161 when using the internal V_{REF} for the ADC**

1 Introduction

The AT90PWM81/161 features a 10-bit successive approximation ADC. The ADC is connected to a 15-channel analog multiplexer, which provides:

- 11 single-ended inputs which are referenced to 0V (GND)
- Two differential voltage input combinations, which come with a programmable gain stage, providing amplification steps of 14dB (5x), 20 dB (10x), 26 dB (20x), or 32dB (40x) on the differential input voltage before the A/D conversion. On the amplified channels, 8-bit resolution can be expected

This application note explains how to re-adjust the ADC conversion results over the temperature.

Rev. 8270B-AVR-01/12

2 Theory of operation – the ADC conversion

2.1 V_{REF} control

The reference voltage for the ADC (V_{REF}) indicates the conversion range for the ADC. It can be selected as either:

- AVCC,
- internal 2.56V reference,
- or the voltage present on the external AREF pin.

The internal reference V_{REF} of 2.56V is generated, after multiplication, from the Bandgap voltage.

2.2 V_{REF} calibration

This internal voltage reference is function of the temperature.

It is calibrated at factory @3V and ambient temperature within accuracy of ±1% of the 2.56V reference voltage. The result of this calibration is stored in the Signature Row. This Final Test “Amb.VREF” is loaded at address 0x1E (please also see the Atmel AT90PWM81/161 datasheet).

Still at factory, a reading of the V_{REF} level is achieved at 105°C. This value is also stored in the Signature Row. This Final Test “Hot VRef” is loaded at address 0x1F.

2.3 ADC conversion

For single ended conversions, the conversion result is:

Read ADC = $V_{IN} \times 1023 / V_{REF}$

where V_{IN} is the voltage on the selected input pin and V_{REF} the selected voltage reference.

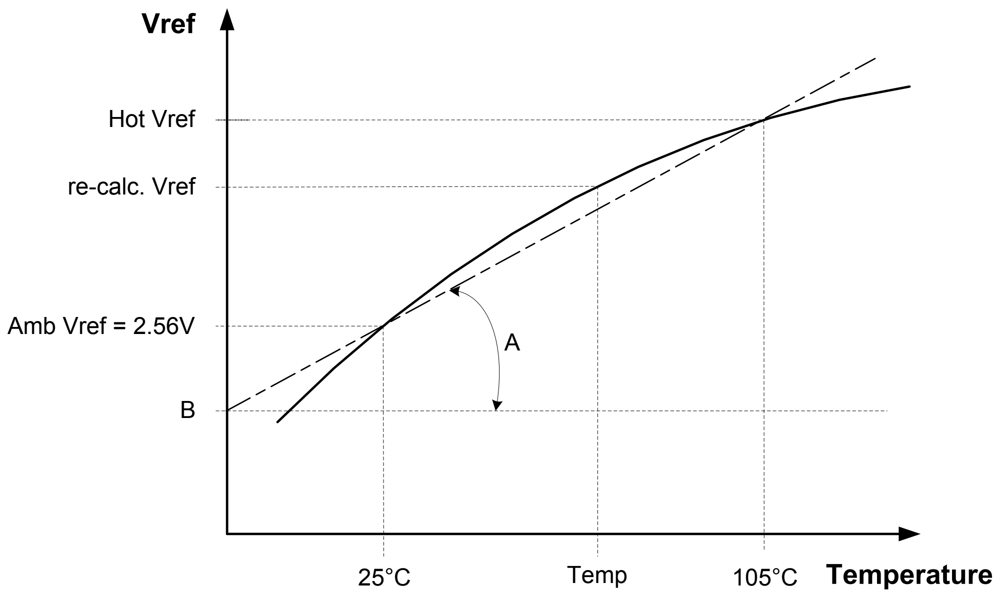
3 The compensation method

The Atmel AT90PWM81/161 microcontroller offers an embedded temperature sensor. This feature can be used for runtime compensation of temperature drift in the voltage reference.

3.1 V_{REF} versus temperature

In following example, we consider the default configuration of BGCRR Register which shifts the top of the V_{REF} curve to the highest possible temperature. In this configuration; the higher the temperature is, the higher the V_{REF}.

Figure 3-1. V_{REF} versus temperature.



Notes:

1. Amb V_{REF} is not necessarily strictly equal to 2.56V depending on the calibration (±1% accuracy).
2. Amb V_{REF} is the calibrated value at Factory = 2.56V @25°C with a ±1% accuracy Hot V_{REF} is the Read value at Factory @105°C.
3. Amb V_{REF} and Hot V_{REF} are stored in Signature Row during Test operation at Factory and can be read by Software:
4. Final Test Amb V_{REF}: is loaded in two bytes at Address 0x3D (High Byte) 0x3C (Low Byte).
5. Final Test Hot V_{REF} (only for Read): is loaded in two bytes at Address 0x3F/0x3E.

These constants are the hexadecimal value of the voltage in mV: for instance 0x0A00 represents the Hexadecimal value of 2560mV.

3.2 Temperature measurement

This implementation uses the measurement achieved with the embedded temperature sensor of the AT90PWM81/161.

If the temperature sensor has been selected, the temperature measurement formula is:

Temp (°C) = ((([(ADCH << 8) | ADCL] - (273 + 25-TSOFFSET)) × TSGAIN)/128) + 25

TSGAIN and TSOFFSET are stored in the Signature Row during Test operation at Factory:

Temperature Sensor Offset:	TSOFFSET is loaded in High Byte of Address 0x05
Device Temperature Sensor Gain:	TSGAIN is loaded in High Byte of Address 0x07 (typical value is 0x80)

3.3 V_{REF} recalculation

Between 25°C and 105°C, V_{REF} curve versus temperature range can be extrapolated as a straight line (see Figure 3-1).

To improve overall V_{REF} accuracy, the recalculated V_{REF} can be calculated as following:

Re-calc. V_{REF} = (A × Temp) + B

The known points of the straight line are:

Amb V_{REF} = (A × (25°C)) + B = data stored in Signature Byte

Hot V_{REF} = (A × (105°C)) + B = data stored in Signature Byte

A and B variables can be extracted from these two equations.

3.4 ADC measurement compensation

The ADC measurement result can be compensated with following formula:

Compensated ADC = Read ADC × Re-calc. V_{REF} / 2.56

4 Hardware configuration

4.1 AT90PWM81/161

Five parts have been tested. Their Fuse configuration is:

Extended = FD

High = D9

Low = CC

4.2 STK521

XTAL:	8MHz
Monitoring of V_{REF}:	A_{REF} output / V_{SS}
UART software output:	PB0 connected to RS232 interface

4.3 Hyperterminal

UART Bitrate = 19200 bit/s

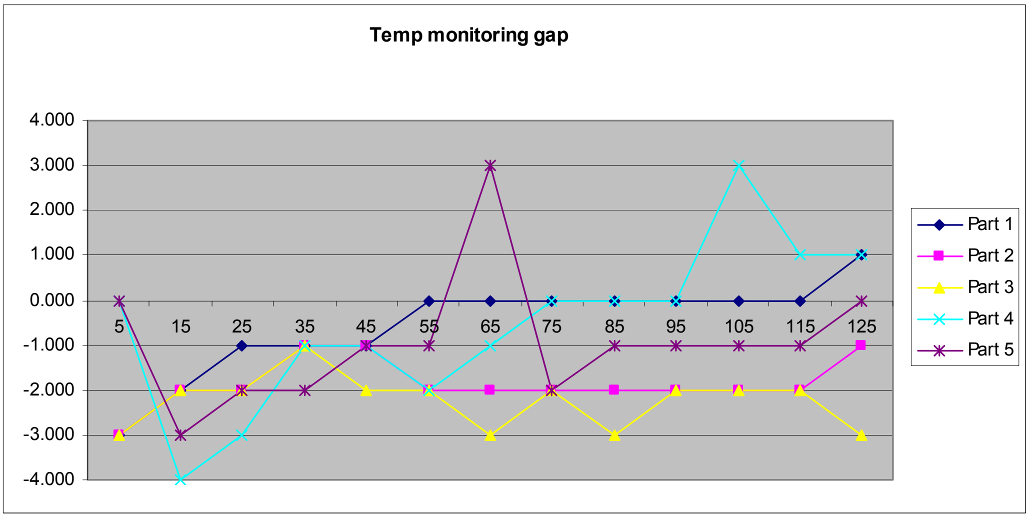
5 Software configuration

See Chapter 8: Code example (compiled with IAR).

6 Result of temperature measurement

The chart in Figure 6-1 confirms that, over the five tested parts, the difference of temperature measurement is + 4°C.

Figure 6-1. Temperature monitoring gap.

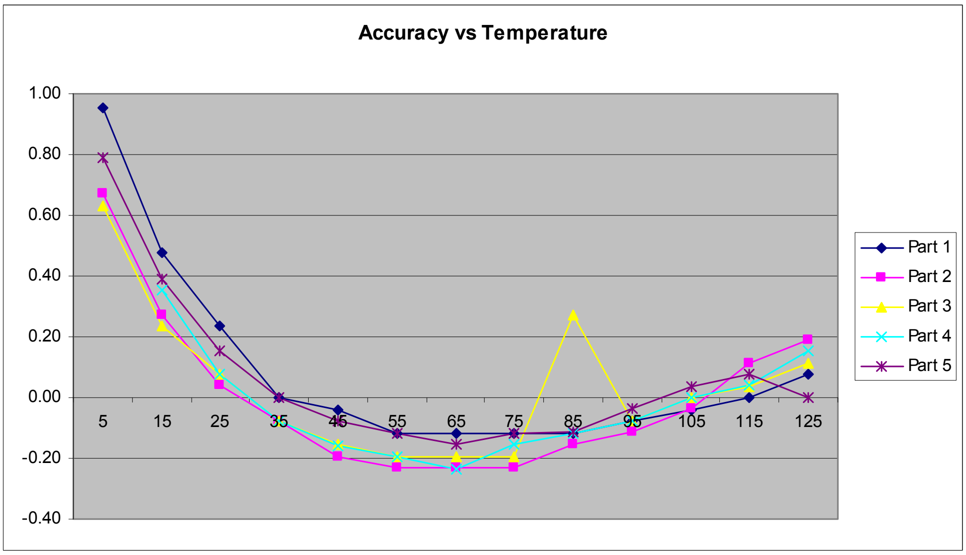


7 Results of V_{REF} recalculation

The chart in Figure 7-1 provides the accuracy (%) of the recalculated V_{REF} versus the real V_{REF} over the temperature range:

= (V_{REF} Recalculated – V_{REF} output monitoring) / V_{REF} output monitoring

Figure 7-1. Accuracy vs. temperature.



These typical results confirm that over a temperature range of [+5°C to +125°C]; the accuracy of the recalculation is better than 1%.

8 Code example

8.1 C Main function

```
//! //! Copyright (c) 2009 Atmel.
//!  This program uses a loop to:
//! - monitor the temperature sensor
//! - calculate the VREF which should be equal to the real internal VREF
/

//_____I N C L U D E S ___________________________________________________
#include "config.h"
#include "iopwm81.h"
#include "my_print.h"

//_____D E C L A T A T I O N S ______________________________________________

#define HIGHBYTE(v) ((unsigned char) (((unsigned int) (v)) >> 8));
#define LOWBYTE(v) ((unsigned char) (v));

int main(void)
{
unsigned char gain, offset, temp, vref_amb_low, vref_hot_low,vref_amb_high,
vref_hot_high,result;
unsigned int vref_recalc, vref_amb, vref_hot, n;
char g, i;
float a, b;

  PORTB= 0x00;
  DDRB=0xC7;
  ADCSRA |= 0x80;/* ADEN=1 */
  ADMUX |=0x80; /*Vref=2.56V */
  ADMUX &= ~0x2F;
  ADMUX |=0x0C; /* MUX to Temp sensor */
  ADCSRB =0x80; /* ADC High speed + free running*/
  ADCSRA |=0x04; /* prescaler /16 */
  ADCSRA |= (1<<ADSC); /* first conversion  */
```

```
while (SPMEN==1);

asm("LDI R17,$00");/* Beginning of LPM sequence to read the Temp. sensor OFFSET in Signature Row */
asm("LDI R16,$05");
asm("MOV R31,R17");/*  */
asm("MOV R30,R16");/* ;move address to z pointer (R31=ZH R30=ZL)*/
SPMCSR=0x21;
asm("LPM");/* ;Store program memory*/
asm("MOV R16, R0");/* ;Store return value (1byte->R16 register)*/
asm("OUT 0x1B, R16");/* ;Store return value (1byte->R16 register)*/
while (SPMEN==1);
offset=GPIOR2;  /* return of Temp. sensor OFFSET in Signature Row */


asm("LDI R17,$00") ;/*Beginning of LPM sequence to read the Temp. sensor GAIN in Signature Row */
asm("LDI R16,$07");
asm("MOV R31,R17");/*  */
asm("MOV R30,R16");/* ;move adress to z pointer (R31=ZH R30=ZL)*/
SPMCSR=0x21;
asm("LPM");/* ;Store program memory*/
asm("MOV R16, R0");/* ;Store return value (1byte->R16 register)*/
asm("OUT 0x1A, R16");/* ;Store return value (1byte->R16 register)*/
while (SPMEN==1);
gain=GPIOR1; /* return of Temp. sensor GAIN in Signature Row */

asm("LDI R17,$00");/*Beginning of LPM sequence to read the Vref. Amb.(low Byte) in Signature Row  */
asm("LDI R16,$3C");
asm("MOV R31,R17");/*  */
asm("MOV R30,R16");/* ;move adress to z pointer (R31=ZH R30=ZL)*/
SPMCSR=0x21;
asm("LPM");/* ;Store program memory*/
asm("MOV R16, R0");/* ;Store return value (1byte->R16 register)*/
asm("OUT 0x1A, R16");/* ;Store return value (1byte->R16 register)*/
```

```
while (SPMEN==1);
vref_amb_low=GPIOR1; /* return of Vref. Amb. Low Byte in Signature Row */

asm("LDI R17,$00") ;/*Beginning of LPM sequence to read the Vref. Amb.(High Byte) in Signature Row   */
asm("LDI R16,$3D");
asm("MOV R31,R17");/*  */
asm("MOV R30,R16");/* ;move adress to z pointer (R31=ZH R30=ZL)*/
SPMCSR=0x21;
asm("LPM");/* ;Store program memory*/
asm("MOV R16, R0");/* ;Store return value (1byte->R16 register)*/
asm("OUT 0x1A, R16");/* ;Store return value (1byte->R16 register)*/
while (SPMEN==1);
vref_amb_high=GPIOR1; /* return of Vref. Amb. High Byte in Signature Row */

asm("LDI R17,$00");/*Beginning of LPM sequence to read the Vref. Hot(low Byte) in Signature Row   */
asm("LDI R16,$3E");
asm("MOV R31,R17");/*  */
asm("MOV R30,R16");/* ;move adress to z pointer (R31=ZH R30=ZL)*/
SPMCSR=0x21;
asm("LPM");/* ;Store program memory*/
asm("MOV R16, R0");/* ;Store return value (1byte->R16 register)*/
asm("OUT 0x1A, R16");/* ;Store return value (1byte->R16 register)*/
while (SPMEN==1);
vref_hot_low=GPIOR1; /* return of Vref. Hot Low Byte in Signature Row */

asm("LDI R17,$00");/*Beginning of LPM sequence to read the Vref. Hot(High Byte) in Signature Row  */
asm("LDI R16,$3F");
asm("MOV R31,R17");/*  */
asm("MOV R30,R16");/* ;move adress to z pointer (R31=ZH R30=ZL)*/
SPMCSR=0x21;
asm("LPM");/* ;Store program memory*/
asm("MOV R16, R0");/* ;Store return value (1byte->R16 register)*/
asm("OUT 0x1A, R16");/* ;Store return value (1byte->R16 register)*/
while (SPMEN==1);
```

```
  vref_hot_high=GPIOR1; /* return of Vref. Hot High Byte in Signature Row */

  vref_hot= (vref_hot_high * 256) + vref_hot_low;
  vref_amb = (vref_amb_high * 256) + vref_amb_low;
  a=(vref_hot - vref_amb)*100;
  a = a / 0x50;
  b= vref_amb - ((a * 0x19)/100);

  while(1)
   {
   while (ADIF == 0);
   ADCSRA |=0x10;  /* reset ADIF */
   temp =ADCL;
   result =(ADCH<<8);
   result = result | temp;
   result = result - (273+25-offset);
   temp = gain / 128;
   result = result * temp;
   temp = result +25;

   putchar(0x54); putchar(0x3D);print_hex(temp);/* T=... temperature measurement in
hex format*/

   for(i=1;i<100;i++); putchar(0x0D); for(i=1;i<100;i++); putchar(0x0A);

   vref_recalc = (((a * temp)/100) + b); /* Vref. recalculated versus the temperature
measurement */

   putchar(0x41);putchar(0x3D);
   print_hex(vref_amb_high);
   print_hex(vref_amb_low);
   for(i=1;i<100;i++);  putchar(0x0D);  for(i=1;i<100;i++);  putchar(0x0A); /* A=... Vref
Amb. in hex format*/

   putchar(0x48);putchar(0x3D);
   print_hex(vref_hot_high);
   print_hex(vref_hot_low);
```

```
    for(i=1;i<100;i++); putchar(0x0D); for(i=1;i<100;i++); putchar(0x0A); /* H=... Vref Hot. in hex format*/


    putchar(0x52);putchar(0x3D); /* R=... Vref recalculated in hex format*/
    temp=HIGHBYTE(vref_recalc);
    print_hex (temp);
    temp=LOWBYTE(vref_recalc);
    print_hex (temp);
    for(i=1;i<100;i++); putchar(0x0D); for(i=1;i<100;i++); putchar(0x0A); /* R=... Vref Recalculated in hex format*/
    for(n=1;n<10000;n++)
      {
      for(i=1;i<100;i++);/* Delay to improve display in Hyperterminal */
      }
    ADMUX |=0x0C;
    ADCSRA |= (1<<ADSC); /* Starts a new conversion on Temp. sensor */
    }
}
```

8.2 C Software UART function

```
#include "my_print.h"
void print_hex(unsigned char n)
{
   unsigned char i;
    i=n>>4;
   if(i>9) putchar(i-0x0A+'A');
   else putchar(i+'0');
   i=n&0x0F;
   if(i>9) putchar(i-0x0A+'A');
   else putchar(i+'0');
}

void print_int(unsigned int n)
{
   print_hex(n>>8);
    print_hex(n);
```

8.3 Assembler Soft_uart.s90

```
// include the register definitions for the used AT90PWM81/161
mcu
#include "iopwm81.h"


PUBLIC putchar
PUBLIC soft_uart_init

;***** Pin definitions


TxD EQU     0                 ;Transmit pin is PDx

;***** Global register variables

#define  bitcnt r16                 ;bit counter
#define     temp   r17              ;temporary storage register

#define  Txbyte r18                 ;Data to be transmitted


RSEG CODE:CODE:NOROOT(1)


;***************************************************************************
;*
;* "putchar"
;*
;* This subroutine transmits the byte stored in the "Txbyte" register
;* The number of stop bits used is set with the sb constant
;*
;* Number of words         :14 including return
;* Number of cycles        :Depens on bit rate
;* Low registers used      :None
;* High registers used     :2 (bitcnt,Txbyte)
;* Pointers used           :None
;*
;***************************************************************************
sb EQU 1          ;Number of stop bits (1, 2, ...)

putchar:
      cli
      ;ldi  bitcnt, (9+sb)    ;1+8+sb (sb is # of stop bits)
      mov   r18, r16
      ldi   r16, (9+sb) ;1+8+sb (sb is # of stop bits)
            com   Txbyte            ;Inverte everything
            sec               ;Start bit

putchar0:   brcc  putchar1    ;If carry set
            cbi   PORTB,TxD   ;    send a '0'
            rjmp  putchar2    ;else

putchar1:   sbi   PORTB,TxD   ;    send a '1'
            nop

putchar2:   rcall UART_delay  ;One bit delay
```

```
                rcall UART_delay

                lsr   Txbyte            ;Get next bit
                dec   bitcnt            ;If not all bit sent
                brne  putchar0    ;   send next
                                  ;else
                sei
                ret               ;   return


;***************************************************************
;*
;* "UART_delay"
;*
;* This delay subroutine generates the required delay between the bits
when
;* transmitting and receiving bytes. The total execution time is set
by the
;* constant "b":
;*
;*     3•b + 7 cycles (including rcall and ret)
;*
;* Number of words          :4 including return
;* Low registers used       :None
;* High registers used      :1 (temp)
;* Pointers used            :None
;*
;***************************************************************

b EQU 63

UART_delay:
   ;ldi      temp,b
   nop
   nop
   ldi      r17,b
UART_delay1:      dec   temp
            brne  UART_delay1

            ret

;***** Program Execution Starts Here

;***** Test program

soft_uart_init:
            sbi   PORTB,TxD   ;Init port pins
            sbi   DDRB,TxD
      ret


forever:
            ldi   r18,0x55    ;'U'
            rcall putchar
            rjmp  forever

END
```

9 Application note revision history

Please note that the page numbers are referring to this document. The revision reference in this section is to the document revision.

9.1 Rev. 8270B – 01/12

1. AT90PWM161 is added.

9.2 Rev. 8270A – 09/10

1. Initial version.

10 Table of contents

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