AN-952 Low Cost A/D Conversion Using COP800

Literature Number: SNOA328
Low Cost A/D Conversion Using COP800

INTRODUCTION
Many microcontroller applications require a low cost analog to digital conversion. In most cases the controller applications do not need high accuracy and short conversion time. This appnote describes a simple method for performing analog to digital conversion by reducing external elements and costs.

PRINCIPLES OF A/D CONVERSION
The principle of the single slope conversion technique is to measure the time it takes for the RC network to charge up to the threshold level on the port pin, by using Timer T1 in the input capture mode. The cycle count obtained in Timer T1 can be converted into voltage, either by direct calculation or by using a suitable approximation. Figure 1 shows the block diagram for the simple A/D conversion which measures the temperature.

BASIC CIRCUIT IMPLEMENTATION
Usually most applications use a comparator to measure the time it takes for a RC network to charge up to the voltage level on the comparator input. To reduce cost, it is possible to switch both inputs as shown in Figure 2.

Port G3 is the Timer T1 input. Ports G2/G1 are general purpose I/O pins that can be configured using the I/O configurations (push-pull output/tristate). All Port G pins are Schmitt Trigger inputs. R Lim is required to reduce the discharge current.

GENERAL IMPLEMENTATION
The temperature is measured with a NTC which is linearized with a parallel resistor. Using a parallel resistor, a linearization in the range of 100 Kelvin can be reached. The value of the resistor can be calculated as follow:

\[ R_R = R_{tm} \left( \frac{B - 2T_m}{B + 2T_m} \right) \]

Where:
- \( R_{tm} \) is the value of the NTC at a medium temperature
- \( T_m \) is the medium temperature
- \( B \) is the NTC material constant

The linearization reduces the code, improves the accuracy and the tolerance of the NTC-R network (e.g. NTC = 100 kΩ ± 10%, \( R = 12 \) kΩ ± 1%, NTC//R ± 2%). Using that method the useful range does not cover the whole operating temperature range of the NTC.

GENERAL ACCURACY CONSIDERATIONS
Using a single slope A/D conversion the accuracy is dependent on the following parameters:
- Stability of the Clock frequency
- Time constant of the RC network
- Accuracy of the Schmitt Trigger level
- Non-linearity of the RC network

Figure 3. The maximum failure that appears when a sawtooth is generated without using a current source. In the current application the maximum failure would be more than 15% without using methods for reducing the non-linearities of RC-network/NTC-network.
The maximum error occurs when the gradient of the exponential function (RC) equals the gradient of the straight line (counter).

To reduce the error that is caused by the non-linearity of the RC-network a offset should be added to the calculated value. The offset reduce the failure to the middle.

Further, the accuracy can be improved by using a relative measurement method. The following diagram shows the method.

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Measurement:
- Timer Capture mode: $R_{CAL} \cdot C$ is measured
- Timer Capture mode: $R_{NTC}/R \cdot C$ is measured

Calculation:
- Build the vertical-component ($R_{TMIN} - R_{TMAX}$) of the triangle
- Calculate the slope
- Calculate the actual temperature

Using this method the accuracy is primarily dependent on the accuracy of $R_{TMIN}$ and $R_{TMAX}$ and independent of the stability of the system clock, the capacitor and the threshold of the Schmitt Trigger level. The variation of the capacitor only leads to variation of the resolution.

The following diagram shows the ideal resistance/temperature characteristic of a NTC which is linearized with a parallel resistor.
APPLICATION EXAMPLE

The following application example for temperature measurement demonstrates the procedure. The temperature is measured from 20° to 100° and is displayed on a Triplex LCD display.

<table>
<thead>
<tr>
<th>Component</th>
<th>Value and Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTC20</td>
<td>100 kΩ ± 10%</td>
</tr>
<tr>
<td>Rp</td>
<td>12 kΩ ± 1%</td>
</tr>
<tr>
<td>Tm</td>
<td>333 Kelvin → 60 Degrees</td>
</tr>
<tr>
<td>B</td>
<td>4800 Kelvin</td>
</tr>
<tr>
<td>NTC20/Rp</td>
<td>10.7 kΩ ± 2%</td>
</tr>
<tr>
<td>R_Cal</td>
<td>10.7 kΩ ± 1%</td>
</tr>
<tr>
<td>T_MIN</td>
<td>20 Degree</td>
</tr>
<tr>
<td>R_T_MIN</td>
<td>10.7 kΩ</td>
</tr>
<tr>
<td>T_MAX</td>
<td>100 Degree</td>
</tr>
<tr>
<td>RT_MAX</td>
<td>2.8 kΩ</td>
</tr>
<tr>
<td>C</td>
<td>1 µF</td>
</tr>
<tr>
<td>RC-Clock</td>
<td>2 MHz → 200 kHz instruction cycle, 5 µs</td>
</tr>
<tr>
<td>Timeconst.</td>
<td>R_CAL * C → 0.0107s</td>
</tr>
<tr>
<td>Resolution</td>
<td>2140 → 11 byte, depends which Cap. value is used</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 2 Degree</td>
</tr>
</tbody>
</table>

This temperature measurement example shows a low cost technique ideally suited for cost sensitive applications which do not need high accuracy.

Figure 6 shows the complete circuit of the demo board using the Triplex LCD method and the low cost A/D conversion technique.

The Triplex LCD drive technique is documented in a separate application note.

FIGURE 6. Circuit Diagram

Pressing key 1, key 2 the temperature is displayed in Degree/Fahrenheit.
Pressing key 3, key 4 Up/Down counter is displayed.

TL/DD/12075–6

TL/DD/12075–7
Figure 7 shows the flow chart of the program.

FIGURE 7. Flow Chart
The following code is required to implement the function. It does not include the code for the Triplex LCD drive.

```
RAM = 17 Byte;
ROM = 450 Byte; Optimization is possible about 50 byte if the B-pointer consistent is used!

***********************************************************************
A/D-CONVERSION  

***********************************************************************

.SECT REGPAGE,REG  
COUNT1: .DSB 1  
COUNT2: .DSB 1  

.SECT BASEPAGE,BASE  
ZL: .DSB 1 ;TEMPORARY  
YL: .DSB 1 ;TEMPORARY  

.SECT RAMPAGE,RAM  
CALIBLO: .DSB 1 ;CALIBRATION-VALUE  
CALIBHI: .DSB 1  
NTCLO: .DSB 1 ;NTC-VALUE  
NTCHI: .DSB 1  
TEMP: .DSB 2 ;TEMP.-VALUE  
KORRL: .DSB 2  
COMPL: .DSB 1  
COMP: .DSB 1  
CONTROL: .DSB 1 ;STATUS REGISTER  

***********************************************************************
**START MAIN PROGRAM**  

```

MAIN: LD #006F ;INIT SPACER_POINTER
      JSR DISCH ;DISCHARGE C (A/D-CONVERSION)
      JSR CALIB ;INIT CAPTURE MODE FOR UREF. MEASUREMENT
POLL: IFBIT 3, PORTGP ;POLL - MODE (TIO - PORT)
       JP CAL
       JP POLL

CALIB: LD B,#CALIBLO  
       JSR CAPTH ;STOP TIMER, STORE CAPTURE VALUE
       JSR CALCR ;SLOPE IS CALCULATED
       NEW: JSR DISCH ;DISCHARGE C (A/D-CONVERSION)
       JSR NTC ;INIT CAPTURE MODE FOR UNTC MEASUREMENT
POLL1: IFBIT 3, PORTGP ;POLL-MODE
       JP CAL1
       JP POLL1

CAL1: LD B,#NTCLO  
       JSR CAPTH ;STOP TIMER, STORE CAPTURE VALUE
       JSR CALCN ;TEMPERATURE IS CALCULATED
       JSR DISCH ;DISCHARGE C (A/D-CONVERSION)
       JSR DCHECK ;REDUCE THE DISPLAY FLICKERING
       JMP NEW

.ENDSECT

***********************************************************************
TL/DD/12075-9
; SECT CODE1.ROM
; THIS ROUTINE IS REQUIRED TO REDUCE THE NOISE ON THE LINE AND THE
; DISPLAY FLICKERING.
; SECT CODE1.ROM
DCHECK:
  LD A,CONTROL ;COMPARE TWO VALUES, IF EQUAL THEN
  XOR A,#300 ;DISPLAY IT, OTHERWISE THE OLD VALUE
  X A,CONTROL
  IFBIT 7,CONTROL
  JSR SAVE ;TEMP. SAVE
  JSR COMP ;COMPARE
  RET

; HANDLER FOR CAPTURE MODE
CAPTH: RBIT TPND,PSW ;RESET TIMER PENDING
  LD A,#0FF
  SC
  SUBC A,TAULO
  X A,[B+]
  LD A,#0FF
  SUBC A,TAUHI
  X A,[B+]
  RET

; CALIBRATION SUBROUTINE, UREF IS MEASURED
CALB:
  RBIT 3,PORTGD
  RBIT 3,PORTGC ;TRISTATE TIO
  LD PORTCD,#0
  LD PORTCC,#0 ;TRISTATE PORT C
  TICAP HIGH ;INIT CAPTURE MODE, HIGH SENSITIVE (MACRO)
  LD B,#CALIBLO
  SBIT 0,PORTCD ;CONFIRGURE C0 TO OUTPUT HIGH
  SBIT 0,PORTCC ;CHARGE CAP.
  SBIT TRUN, CNTRL ;START TIMER CAPTURE MODE
  RET

; NTC SUBROUTINE, UNTC IS MEASURED
NTC:
  RBIT 3,PORTGD
  RBIT 3,PORTGC ;TRISTATE TIO
  LD PORTCD,#0
  LD PORTCC,#0 ;TRISTATE PORT C
  TICAP HIGH ;INIT CAPTURE MODE, HIGH SENSITIVE (MACRO)
  LD B,#NTCLO
  SBIT 1,PORTCD ;CONFIRGURE C1 TO OUTPUT HIGH
  SBIT 1,PORTCC ;CHARGE CAP.
  SBIT TRUN, CNTRL ;START TIMER CAPTURE MODE
  RET
; DISCHARGE ROUTINE
DISCH:
   LD PORTCD,#000
   LD PORTCC,#000
   RBIT TIO,PORTGD ; DISCHARGE CAP.
   SBIT TIO,PORTGC
   LD COUNT1,#H(500) ; DISCHARGE TIME
   LD COUNT2,#L(500)
   JSR C1 ; DELAY ROUTINE FOR DISCHARGE TIME
   RET

; THIS SUBROUTINE CALCULATES THE SLOPE
; THE FOLLOWING CALCULATIONS ARE DONE
; KORR=CALIB/11KOHM (RCALIB.=11KOHM)
; KORR=KORR*2.8KOHM (T=100 DEGREE, RNTC=2.8KOHM)
; CALIB=KORR-KORR
; DIV=CALIB/30 (TEMPRANGE=80 DEGREE,100-20), SLOPE IS CALCULATED
; CALCR:
; KORR=CALIB/11KOHM
   LD ZL,#L(110)
   LD ZL+1,#H(110)
   LD A,CALIBLO
   X A,YL
   LD A,CALIBHI
   X A,YL+1
   JSR DIVBIN16 ; SUBROUTINE BINARY DIVIDE 16 BIT BY 16 BIT
   LD A,YL
   X A,KORRL

; KORR=KORR*28
   LD A,KORRL
   X A,ZL
   LD A,#28
   X A,YL
   JSR MULB16 ; SUBROUTINE MULTIPLY TWO 8 BIT VALUES
   LD A,YL
   X A,KORRL
   LD A,YL+1
   X A,KORRL+1

; KORR=CALIB-KORR
   LD B,#CALIBLO
   LD A,[B+]
   SC
   SUBC A,KORRL
   X A,KORRL
   LD A,[B]
This subroutine calculates the temperature.

The following calculations are done:

1. Subtract the temperature offset from the raw temperature.
2. Divide the result by 16.
3. If the result is higher than 54 degrees, then:
   a. Add the correction offset.
   b. The final result is used.

Subroutine binary divide 16 bit by 16 bit.

Conversion from HEX to BCD.
HEX TO BCD CONVERSION

LD A,ZL

IFGT A,#100 ;IF TEMPERATURE IS MORE THAN 100 DEGREE THEN
JP ERR ;ERROR

JSR BINBCD ;SUBROUTINE BINARY TO BCD CONVERSION;
LD A,BCDLO
X A,TEMP
LD A,BCDLO+1
X A,TEMP+1
RET

ERR: LD A,#00E ;ERROR MESSAGE IS DISPLAYED
X A,TEMP
CLR A
X A,TEMP+1
RET

COMP: LD A,COMPL ;IF THE LAST BOTH MEASUREMENTS ARE EQUAL
SC ;THEN DISPLAY
SUBC A,TEMP
IFEQ A,#0
JP DISPLAY ;OTHERWISE DISPLAY THE OLD VALUE
RET

DISPLAY: LD A,TEMP
X A,PF+2
LD A,TEMP+1
X A,PF+3
JSR LADDR ;UPDATE THE DISPLAY
JSR DEL ;DELAY TIME
RET

SAVE: LD A,TEMP ;TEMPORARY SAVE
X A,COMPL
LD A,TEMP+1
X A,COMPH
RET
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